The Current Role of Geological Mapping in Geosciences

Edited by

Stanisław R. Ostaficzuk

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IV. Earth and Environmental Sciences – Vol. 56

The Current Role of Geological Mapping in Geosciences

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edited by

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From the Editor:

The unavoidable innovation of Geological Cartography - The goals, concepts, and problems of modern geological mapping

Geological Cartography is the most important tool for exploration and presentation of geological knowledge. Geological maps with their related databases are getting more comprehensive, complex and sophisticated with the help of electronic information technologies. In follows of the current trends, the environmental issues are getting more and more important in understanding of the interaction between the Man and the Nature, and that is the key to securing global sustainability for the next generations.

A group of concerned geologists gathered together at the Advanced Research Workshop (ARW) on Innovative Geological Cartography in the Kazimierz Dolny, Poland in November 2003. It was an opportunity for direct exchanging of opinions on the future and role of geology in the modern society, presentation of current works, ideas and achievements in adapting modern cartographic technologies into geology for better servicing the needs of Man. The ad hoc collected and immediately published in the bimonthly *Technika Poszukiwań* were extended abstracts, picture presentations and some elaborative papers comprising almost complete selection of the ARW topics, i.e.:

1 - The problem of standards in modern geological cartography;
2 - The new technologies and methodologies, and results of their application;
3 - The decline of geology due to inadequate dealing with challenges of contemporary world.

The whole issue was supplemented with *The Summary, Conclusions and Recommendations of the ARW*, edited with great effort by the Recommendations Committee editors, and dedicated as the important document with the logo of NATO for Science to all, who are concerned (attached *in-extenso* next to this Introduction).

The current book is composed with most of the re-edited ARW papers, reviewed by Dr Earl Brabb[*)], and supplemented with new contributions by, both, former participants of the ARW and other authors, who present their views and/or excerpts of their geological mapping achievements with the aid of electronic technologies. For that reason, a new title was given: *"The Current Role of Geological Mapping in Geosciences"*. The whole presented material naturally falls into two groups of different topics. At the front are grouped papers dedicated to the problems of standardization in geological mapping, the decline of basic "conservative" geology, and the concepts of restoring the position of geosciences in modern economies. The following group of papers reports and presents advanced geological mapping activities in various countries. While having on mind the recent-most decisions undertaken by International Stratigraphic Committee, the Editor has decided not to remove from the book so well known words we are still accustomed to - the Tertiary and Quaternary. They were not deleted due to sympathy to authors, however, it must be clearly stated here, that their use was quite informal.

The would-be Readers of this book are kindly advised to pay special attention to vigorous polemics with some Authors initiated by Earl Brabb in his reviews. Besides, as from his regular paper-contribution appears clearly, that *"nihi novum sub Sole"*. In the USA, in Europe alike, geological bureaucrats had and still have much impact on the fate of geology in the current world. They undoubtedly have contributed to the widening gap between the current information technologies (IT), and the geological mapping, which should be the main user of IT. The last paper, by David Soller & Thomas Berg, was added to the ARW materials with the hope to having the creative pain of geoscientists eased in their attempts for making various databases reliable and accessible. What is especially interesting is the unbelievable great number of institutions and organizations dealing with geological mapping in the USA. And, the USA is still waiting for having her country completely covered with detail geological map.

Another truth appeared from the presented collection of papers. Different scientific background and cultural environments may cause difficulties in professional communication. All contributors represent high professional skill, and high position within the Geoscience. All are active practitioners, supervise or make geological maps personally, but a merit of their contribution to the book was to some extent lost in the translation, what made the Reviewer confused.

The Editor would like to take this opportunity for expressing his gratitude to the NATO Science Committee, without of which support neither the ARW on modern geological mapping could be held in Poland, nor its results could be published. Another words of gratitude are thus directed to the *Kluwer Academic Publishers* (now Springer), for their help in final shaping and issuing this book.

Specially, editor is indebted to dr Alison Lusty, who has English-adjusted, re-formatted and corrected most of the texts in this book, battling with strange idioms, professional jargon and unifying variety of international English languages.

And the last message to the readers - the *Kluwer Academic Publishers* kindly agreed to supplement this book with a true folded sheet of innovative map belonging to the paper by Bertolini et al. and for those who may meet difficulties in understanding grey pictures the Publisher added a CD with text full colour pictures.

Stanisław Ostaficzuk
Division of Structural Analyses and Geological Cartography,
Minerals and Energy Economy Research Centre
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[*)] Dr. Earl Brabb is a scientific pioneer in the development of Geographic Information Systems for the preparation of geological hazard maps. His maps of San Mateo County near San Francisco, California have been used to greatly restrict development in hazardous areas, reducing the potential number of houses from 500,000 to only 2,500. His analyses of economic costs associated with landslides in the United States, his encouragement of geologists who have produced similar information for other countries, and his reports on innovative techniques for making landslide maps have given him widespread recognition in the international community.

He is the only American geologist to receive the prestigious Sergey Soloviev Medal from the European Geophysical Society, and a Distinguished Service Citation and Medal from the Italian National Research Council. He is co-editor of a book on the geographic and economic extent of landslides in the world and the author of a chapter on the extent of the landslide problem in the United States. His career was recognized at a Special Symposium of the Association of Engineering Geologists in San Jose, California, in September 2000.

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Summary of Conclusions and Recommendations

Kazimierz Dolny, Nov. 26, 2003

PREAMBLE

In November 2003, 29 geological mapping experts from four continents (see the attached list) met for three days in Kazimierz Dolny, Poland at the NATO ARW I.G.C. Workshop. The objectives of the workshop were to discuss innovative techniques for geological cartography and to make recommendations pertinent to constructing modern geological maps and information systems, maintaining key databases, and delivering relevant geological information to the widest possible range of users.

Five recommendations to NATO and governments are made to better ensure that society is provided with the geological information it requires and that nations have appropriate funding and support needed to make crucial water and resource decisions, ensure adequate environmental protection, and deal with earth hazards, such as earthquakes and landslides.

1) Products to Serve the Widest Possible Range of Users

Products of geological research and surveying need to be designed to provide services to meet the needs of not only earth scientists but also other potential users, in fields such as the environment, sustainable development, resources, education, public health and national security.

While conventional geological maps will remain an important geological product, there is an increasing need for user-defined, web-accessible geoscience information services.

Recommendation: Digital geological information systems that conform to international standards should be developed to deliver both standard and customized products and services.

2) Need for Standards

Digital geological datasets must be compatible with each other and also with other national and international map data to facilitate continuity and consistency across boundaries and to facilitate sharing and preservation of information.

Recommendation A: Geological agencies must define, agree, and adopt common standards. The International Union of Geological Sciences, Commission on the Management and Application of Geoscience Information (CGI) –

http://www.bgs.ac.uk/cgi_web

was endorsed by participants as an appropriate mechanism to encourage development of appropriate standards.

Recommendation B: Geological information delivery requires that high quality topographic and other base-map information be freely available to users.

3) Technology and Expertise Transfer

Different institutions and countries are at different stages in the progression from previous geologic mapping methods to new digital mapping and associated data management, analysis, and delivery systems.

Recommendation: There is an urgent need to accelerate transfer of technology and expertise among nations through workshops, staff exchanges, and inter-agency sharing of resources.

4) Geology for Public Health, Safety, and National Security

Geological knowledge provides key information to support analysis and mitigation of natural hazards such as landslides, earthquakes, and groundwater contamination. It also provides information about resources that are strategically important to all nations.

Recommendation: Geological information must be delivered with appropriate quality and accuracy statements. Information providers should work to establish and promulgate appropriate mechanisms for delivery of information that conveys the degree of confidence placed on the data provided.

5) Geological Information at Risk

Government geological survey agencies must establish a balance between new data acquisition and management of the existing information resource. It is a fact that large quantities of invaluable geological data representing billions of dollars of past investment are not being managed adequately or according to modern standards.
Recommendation: Measures must be taken to reduce the risk of valuable and unique information from becoming inaccessible or lost.

(Prof. Stanisław Ostaficzuk)
for:
The Editorial Committee for:
the Summary of Conclusions and Recommendations,
the NATO Advanced Research Workshop
on Innovative Geological Mapping

/-/ Richard Berg, USA,
/-/ John Broome, Canada,
/-/ Jean-Paul Cadet, France,
/-/ Ian Jackson, UK,
/-/ Peter T. Lyttle U.S.A.
/-/ Stanisław Ostaficzuk, Poland,
/-/ Werner Stackebrandt, Germany,
/-/ Harvey Thorleifson, USA and Canada

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Enclosure to The Summary of Conclusions and Recommendations

List of 29 geological mapping Experts from 29 countries Participants of the NATO ARW - The Innovative Geological Cartography - 24-26.11.2003, Kazimierz Dolny, November 2003

1 Kristine Asch, Germany Bundesanstalt für Geowissenschaften und Rohstoffe;
Project Manager, IUGS Geologic Map of Europe

2 Richard Berg, USA, Illinois State Geological Survey;
Director, Geological Mapping Program

3 Giovanni Bertolini, Italy Regione Emilia-Romagna Administration;
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4 David Bridge, UK, British Geological Survey;
Head of Urban Geoscience Programme;

5 John Broome, Canada, Earth Sciences Sector, Natural Resources Canada (Canadian Federal Government);

6 Jean-Paul Cadet, **Professor**, **France**, Commission for the Geological Map of the World (CCGM).
Professor of geology at Pierre and Marie Curie University, Paris. President of CGMW. Councillor, International Union of Geological Sciences (IUGS). Commission of the Geological Map of the World

7 Valery Gubin, Belarus, Faculty of Geography, Belarus State University;
Professor, Head of Department of Dynamic Geology,

8 Zygmunt Heliasz, Poland, Minerals and Energy Economy Res. Institute, Polish Academy of Sciences;
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9 Christof Heubeck, Professor, Germany, Freie Universität Berlin;

10 Ian Jackson, UK, British Geological Survey, Director of Information Services, and Management, BGS. Secretary General, Commission for the Management and Application of Geoscience Information.

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Head of Laboratory of Neogeodynamics, Institute of Geological Sciences

13 Pawel Karnkowski, Poland, State Petroleum Bureau Geonafta & Faculty of Geology, Warsaw University; Reader

14 Jaan Kivisilla, Estonia, Geological Survey of Estonia; Research Director

15 Andrei Kovkhuto, Belarus, Institute of Geological sciences of National Academy of Belarus, & Belarus State University, Faculty of Geography, Laboratory of Neogeodynamics, Institute of Geological Sciences

16 Jaroslav Lexa, Slovakia, Head, Department of Metallogeny, Geological Survey of Slovak Republic;

17 Alexander Lobasov, Ukraina, State Informational Geological Bureau Geoinform; Head of Department;

18 Peter T. Lyttle U.S.A. Geological Survey; U.S. Geological Survey, Program Coordinator for the National Cooperative Geologic Mapping Program and Landslide Hazards Program

19 Zbigniew Małolepszy, Poland, University of Silesia, Faculty of Earth Sciences; Department of Fundamental Geology, Geothermal Projects Director

20 Snjezana Mihalic, Croatia, Faculty of Mining, Geology and Petroleum Engineering;

21 Anatoliy M. Nikishin, Professor, Russia, Geological Faculty, Moscow State University, Head of Department

22 Stanisław Ostaficzuk, Professor, Poland, University of Silesia, Faculty of earth Sciences; Head, Department of Fundamental Geology, & Chairman, Ministers's of Environment Commission on Cartographic Elaborations

23 Dugkeun Park, South Korea, National Institute for Disaster Prevention, Ministry of Government Administration & Home Affairs;

24 Zbigniew Perski, Poland, University of Silesia, Faculty of Earth Sciences; Department of Fundamental Geology, Remote Sensing Projects Director

25 Ech-Charki R'JIMATI, **Maroc**; (The personal representative of hon. Mohamed SADIQUI, Directeur de la Geologie Ministere de l'Energie et des Mines); Engineer Geologist, Chief of the Regional Center of Geology of Dakhla.

26 Salius Sliaupa, Lithuania, Institute of Geology and Geography

27 Werner Stackebrandt, Germany, Geological Survey of Brandenburg; Director General,

28 Alexandr V. Tevelev, Russia, Geological Faculty; Moscow State University, Head of Laboratory

29 Harvey Thorleifson, Professor, USA/Canada, Minnesota Geological Survey, Director & President of Geological Association of Canada.

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THE NEW DIGITAL GEOLOGICAL MAP OF EUROPE AND STANDARDISATION: CONSISTENCY AS THE LAST REFUGE OF THE UNIMAGINATIVE?!

Kristine Asch
Federal Institute for Geosciences and Natural Resources, Stilleweg 2, 30655 Hannover, Germany

Abstract: A geological map is without doubt the visual language of geologists (Rudwikc1976). Given a geological map of anywhere in the world, a geologist will be able to share a basic understanding of the disposition of the rocks that the map author depicted. Further, with a little time to interpret the maps and their legends, most geologists could make sense of two maps of adjacent countries, even though the linework and classification systems may not always be the same. Unfortunately computers, Geographical Information Systems (GIS) and digital databases do not possess such powers of interpretation and deduction. They do not comprehend that polygon X on one map is probably the approximate equivalent of polygon Y on the other. Although systems using fuzzy logic are currently being investigated, most GIS and databases require data to be logically structured and relationships between features and attributes to be explicit and not merely tacit. Using the example of the 1:5 Million International Geological Map of Europe and Adjacent Areas (IGME 5000) project, this paper will explore some of the reasons for the inconsistency in geological maps and classification systems, illustrate why this poses serious problems for those who wish to construct and use geological GIS across regions and countries and introduces a few evolving initiatives on digital geological standards.

Keywords: IGME 5000, consistency, map compilation, IT, geodata exchange

MAPS, GEOLOGISTS AND THE ADVENT OF INFORMATION TECHNOLOGY

Generations of earth scientists ('Geognosten' and other geoscientists) have summarised the results of their fieldwork and research in map form (Asch 2003). The geological map has been the means for 'geo-logists' to record, store and disseminate their knowledge and the results of their investigation of the rocks and unconsolidated deposits of the Earth's surface. For several hundred years geological maps have been, and still are, "the visual language of geologists" (after Rudwick 1976). They represent the

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 1–8.

"… knowledge simply of what is where on the Earth's surface …" (Maltman 1998).

Geological maps have always provided for their users basic knowledge about the distribution of natural resources such as ore, water, oil or building stone. They may, albeit indirectly, warn about the danger of natural hazards or supply information about suitable sites for landfill, house building or tourism. They thus provide the basis for environmental planning and protection and support public policy decisions. Geological maps are the basis for understanding the Earth and its processes.

In the last quarter of the 20th century, the era of Information Technology (IT) arrived and changed the world of geosciences totally and irrevocably. Loudon (2000:A2) points out: "IT influences the way in which scientists investigate the real world, how they are organised, how they communicate, what they know and what they think. We are just at the dawn of that era".

Many factors that constrained our predecessors no longer exist. Modern computing systems (for example databases, GIS and Internet tools) allow us to store, retrieve and present far more information and knowledge about an area than we could ever display on a two-dimensional (2-D) piece of paper. The key point is that we can now separate the storage and recording of information from the means of disseminating it; we are no longer forced to try and serve all purposes with the same 'general-purpose document'. Using IT we can select the area, change the scale and topographic base, choose the theme, amend the colours and line styles. We can distribute the knowledge in an infinitely variable number of ways, delivering it on paper, on CD-ROM or across the Web, and choose a variety of resolutions, qualities and levels of complexity. Increasingly, geologists are now using modelling software to create 3- and 4-D models, allowing users, through a variety of visualisation methods, an insight into the original scientist's interpretation of the Earth below our feet.

In many respects the IGME 5000 project is bridging the domains of the traditional paper map and the digital era.

GIS AND PAPER MAP: THE IGME 5000 PROJECT

IGME 5000 is a major European geological GIS map project (Figure 1) which is being managed and implemented by the Federal Institute for Geosciences and Natural Resources (BGR) under the umbrella of the Commission for the Geological Map of the World (CGMW). It follows a long tradition of the BGR and its predecessors in producing international geoscientific maps of Europe.

IGME 5000 is a collaborative European project; its aims are to develop a GIS, underpinned by a geological database, and a printed map providing up-to-date and consistent geological information.

The main theme of the project is the pre-Quaternary geology of the on-shore and, for the first time at this scale, the off-shore areas of Europe (Asch 2003). As a geological GIS of the whole of Europe, the IGME 5000 displays the geology of all European countries and thus needed to adopt a system that could be applicable and consistent across the whole of Europe. 48 different national geological survey organisations across Europe are actively involved and needed, from the beginning, to be supplied with common standards and guidelines.

With the laudable exception of the IUGS standards which mainly tackle geological terms, rock classifications and the time scale, it became apparent that certified and widely used international geological standards were indeed scarcely available. Thus, project standard procedures, data structures and dictionaries were developed in order to gather, integrate and constrain the necessary spatial and attribute information from the many participants' organisations. This was a structured but pragmatic process, which included not only novel developments but also the adaptation of suitable existing standards and conventions, such as the IUGS International Stratigraphic Chart (Remane et al., 2000) and the Streckeisen classifications of igneous rocks (Streckeisen, 1976, 1978).

SOME RECURRING PROBLEMS

Organising the co-operation of so many participating nations and compiling their input proved to be a considerable information management task. Without doubt the major challenge was coping with the inconsistency of approach by the participants: different interpretations, variable data input, generalisation and drawing quality techniques.

It seems that almost every geological survey organisation in Europe has created its own conventions (and sometimes several conventions) to produce traditional paper maps, and now their digital representation within a GIS (a fact subsequently reinforced by a FOREGS (Forum of European Geological Surveys Directors) census of 29 Geological Surveys; Jackson and Asch 2002).

Significant discrepancies (Asch 2001) were found in the following areas: - geological classification, such as lithology and chronostratigraphy-mapped units (emphasis, number, …); - topographic base (co-ordinate system, ellipsoid, drainage system, projection); - draft map scale; - level of detail and completeness (especially offshore); - - colours, symbols - data structures and hierarchies.

Figure 1. Draft of the IGME 5000 GIS, reduced 10x in scale (Asch, 2004).

Not unexpectedly, these differences gave rise to inconsistencies at the political boundaries—the well-known ‘national boundary faults’ (Figure 2), not to mention highlighting the substantial differences between the mapping of onshore and offshore areas.

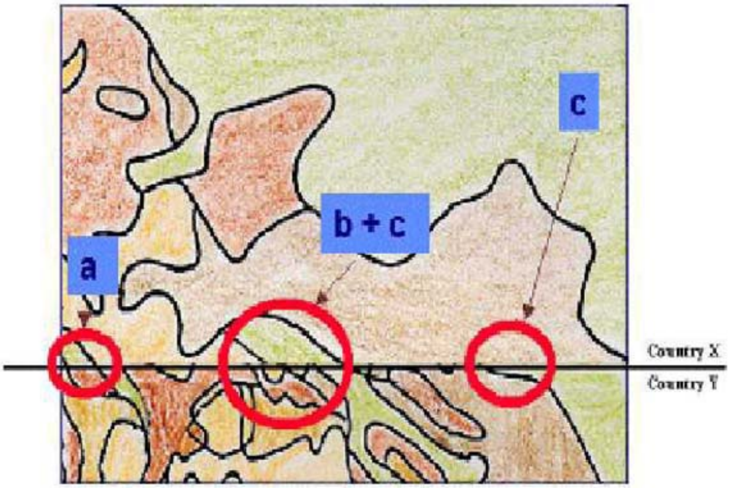

Figure 2. An example of inconsistency at national boundaries from the IGME 5000 project. The differences are notable particularly with regard to geological classification, mapped units and level of detail (from Asch; 2004: 94). **Key:** Harmonisation of:
(a) terms (e.g. for age or lithology), (b) grade of detail, (c) ‘sheet boundary faults’ and drawing style.

There may be numerous reasons for the inconsistencies described above, inconsistencies that are repeated within the mapping of most national territories. The amount of data available in areas will vary; different classification schemes have been used; the mapping may be of different ages; and advances in the scientific techniques and new data will have occurred. But perhaps the underlying and most fundamental reason is that geology is a deductive science, and a geological map is the result of the interpretation of often sparse and variable data by individual geologists, each with their own idiosyncratic approaches.

ARE STANDARDS IMPORTANT?

Does it matter if we have these inconsistencies? After all, given a little time, geologists can usually establish the intended equivalence, or otherwise, between the ‘apparently different’ rock types on adjacent maps? Given time, they may be able to, but the total effort taken to research and solve these discrepancies in an ad hoc manner must consume an enormous amount of time. These variations and the adjustments made to correct them will inevitably also lead to misunderstandings between geologists and make it more difficult to recognise relationships and associations between geological sequences. This will result in obstruction of the progress of cross-border scientific understanding.

Further on, those without the benefit of geological training will not be able to appreciate or resolve the inconsistencies, a fact which seriously limits the worth of geological maps and databases outside the geological profession. In addition, when the maps are used as the basis for applied products, e.g. geohazard or mineral maps, the differences may lead to potentially serious inconsistencies in future risk or resource prediction. In this context should be also considered the need to provide coherent geoscience information for pan-regional or pan-national initiatives, e.g. the European Water Framework Directive (European Union 2000) or Mineral Waste directive initiative (Clifford and Fernandez Fuentes 2002).

Last, but not least, while geologists may be able to deal with uncertain relationships, computers, GIS and database systems find it extremely difficult, if not impossible. Such systems demand a much more rigorous approach to geometry, data structure and attribution. Thus, the potential benefits of IT, i.e. interoperability, data integration and the ability to share and supply harmonious information for scientific research to address pan-national geological problems across frontiers, are entirely dependent on the continuity and consistency that standards would bring.

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REVIEW BY EARL BRABB

This paper rightfully calls attention to the discrepancies between geologic maps made by different authors and the work to digitise this information. The discrepancies include geological classification, mapped units, topographic base, scale of the original map, level of detail and completeness, colours and symbols, and data structure and hierarchies. The report also emphasises that "a geological map is the result of the interpretation of often sparse and variable data by individual geologists, each with their own idiosyncratic approaches".

Armed with this knowledge, the author indicates that "GIS and database systems find it extremely difficult, if not impossible" to deal with these discrepancies. However, GIS and database systems are machines and applications, not people. Most of younger geologists, in the USA at least, are trained in both geologic mapping and GIS/database systems. These young geologists are capable of resolving all the discrepancies, regardless of scale and individual approach, given sufficient time and resources. If discussions with the original authors about the discrepancies are not possible, fieldwork can be done to find the best solution. Even better, if the geologic maps with discrepancies are digitised and put on a digital raster base at a scale of 1:20 000 or larger, the fieldwork can be done even more efficiently. The real problem is that the information technology people and their bosses are the ones with all the money and they do not want to give any of it to the geologist.

WHY SHOULD WE WORRY ABOUT STANDARDS FOR DIGITAL GEOLOGICAL MAPS?

Earl E. Brabb
Rocklin, California, USA

Abstract: Geological mapping seems to be terminally ill, except in Lithuania and Estonia (this volume) and perhaps a few other countries. The addition of earth materials information to geological maps and greater cooperation with agencies and partnerships that are not traditional users of geological information may preserve geological mapping long enough to worry about standards.

Keywords: Mapping, EM data, USGS, trends, applicability & demand

INTRODUCTION

There may be no need to worry about standards for digital geological maps unless geological mapping can be revived. Today, it seems to be terminally ill. No maps, no need for standards. Geological mapping in the US Geological Survey (USGS) has changed dramatically since 1963. Then, approximately 150 general-purpose geological maps at 1:24 000 scale were published, whereas only about 10 maps were published each year between 1999 and 2001. The character of the mapping has also changed from collection of new outcrop information in sufficient detail for representation at 1:24 000 scale to the synthesis of old geological information in a digital format suitable for publication at 1:100 000 or smaller scales. This change was forced by the realization that a very long period of time would be required to map the United States at 1:24 000 scale, and that political and financial support for the work were dwindling. McDonald (2002, p. 119) has estimated that preparing detailed geological maps of Ohio would take about 100 years with present resources. A similar estimate to map Utah was provided by Kennelly and Willis (2002, p. 87).

The near-demise of 1:24 000-scale mapping is unfortunate, because Kockelman (1975, 1976, 1979, 1980) determined that city, county, and regional planning agencies and decision makers in the San Francisco Bay region were nearly unanimous in wanting geological maps at 1:24 000 scale

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 9–22.

or larger. Compromise may be possible if the limitations are clear on the map products. We have successfully enlarged geology derived from a 1:100 000-scale digital map over a 1:24 000 raster base and they fit quite well. Besides, geologists may overestimate the level of detail needed. I remember preparing a slope map with six categories in response to a county request, only to discover that all they wanted was a line to separate hilly land from flat land. When they saw a line on a map separating up to 15% slope from slope higher than 15%, they were quite content.

The problem of declining resources for geological mapping, however, is quite serious. The USGS in Menlo Park is one-quarter the size it was in 1980, and the California Geologic Survey and the Washington State Survey have just undergone cuts of 40%. The USGS has terminated its mapping program in the San Francisco Bay region, will terminate the program in the Los Angeles region in 2005, and has abandoned plans to move into the fast-growing Sacramento area. Moreover, many of the geologists who could do geological mapping have been transferred to other programs with more direct relevance to public needs. I can count only about 20 geologists in the entire country who are still preparing geological maps for the USGS, in contrast to hundreds 40 years ago. Kennelly and Willis (2002) point out that geological surveys are missing opportunities to secure funding for geological mapping because they have focused too narrowly on traditional users instead of considering a different market for geological maps. The 'top-down' approach with Federal funds is not working in an environment where some members of Congress have actually tried to eliminate the Geological Survey. Kennelly and Willis recommend a 'bottom-up' approach to promote interagency cooperation and partnerships.

Implementation Teams (I-Teams) formed with representatives of State agencies (transportation, agriculture, public safety, governor's planning council, school trust land administration, and geological surveys, among others); Federal agencies (Forest Service, Park Service, Bureau of Land Management, military, and others); local governments (city and county units, water districts, lay-enforcement agencies, and others); academia (university geology and geography departments, and others); and private interests (gas and electric utilities, pipeline companies, communication companies, and others). How all these diverse groups would meet and interact stimulates the imagination, but apparently all or most of them are already members of coordinated State geographical information system (GIS) agencies.

PREPARATION OF EARTH MATERIALS (EM) MAPS

Some geological information exists for most areas of most developed countries. The problem is how to update the old geological maps and add sufficient earth materials (abbreviated hereafter as EM) information emphasizing physical properties, so that the maps will be more useful for modern societal needs. Fortunately, Ellen and Wentworth (1995) and Wentworth et al. (1985) have provided prototypes for EM maps of hillside areas, and Helley et al. (1979) and Knudsen et al. (2000) have provided prototypes for geological and EM maps of flatland areas. Standards used by these authors are relatively simple to use in the field and provide a means of dealing with large areas in minimum time and with relatively little expense. Both prototypes, however, require reasonably good geological maps and good maps of Quaternary deposits on which to build the EM framework.

Ellen and Wentworth (1995) provide information on bedrock composition, hardness, fracture spacing, bedding thickness, bedding-plane parting, expression on aerial photographs, permeability, weathering, texture of surficial mantle, texture, expansivity, and stratigraphic thickness for nearly 360 material units in the San Francisco Bay region, an area nearly as large as Sicily. The information for these units was gathered largely by systematic observations in the field and partly from published and unpublished unit descriptions. Physical properties are provided both for the dominant character of the materials and the range, allowing statistical treatment of the data. Rock hardness is estimated from the response of the rock to a geological hammer swung with moderate force. Estimates of permeability are provided in Meinzer and metric units, along with general comments about the quality of aquifers and limitations on percolation in soils for septic tanks. About 1000 free-swell tests were made to determine which material units might damage roads, houses, or concrete foundations and slabs.

Most of the EM units coincide with geological units, partly because the time allotted for the project was not sufficient to change many of the geological boundaries, and partly because the criteria for separating the geological units are in most places the same as those for EM units. Faults and large landslides are preserved on the EM maps because these areas are likely to be modified by shearing. A second set of maps shows where slopes may provide constraints on land use. The maps are published at 1:125 000 scale.

Another map and table by Wentworth et al. (1985) provide even more information on the engineering character of hillside materials at 1:62 500 scale. The applications for engineering purposes include expansivity, cut-slope stability, permeability, excavatability, character of material as fill, texture of the surficial mantle, and physical properties of bedrock.

USES FOR GEOLOGICAL MAPS WITH EM DATA

Forty years ago, we envisioned, that our geological maps would be used mainly by petroleum and mining companies, to narrow their search for areas of interest. During the late 1960s, environmental concerns and regional planning became more and more important. Today, we need to reassess the priorities for geological mapping and EM information to determine how they can be used to attract funding and greater support. The following list is not complete, but will indicate some topics of current concern.

The location and protection of water resources is probably the highest priority for earth scientists today. Geologists and hydrologists must work together to locate and protect water resources because they bring different perspectives for solving water problems. Unfortunately, the word water separates geologists from hydrologists in many agencies, including the USGS. USGS geologists and hydrologists are in separate offices with separate funding sources. Crossing these boundaries is difficult. The article by Berg (2004, this volume), however, shows how geologists and hydrologists can employ some innovative techniques and maps to indicate aquifer sensitivity. This information can be used to protect ground-water resources and direct the siting of waste-disposal facilities, industrial plants, and other potentially polluting operations to areas where the potential for aquifer contamination is low. Conversely, EM maps could also indicate where ground-water recharge would be most effective.

The origin and distribution of natural contaminants, such as arsenic and asbestos, can also be derived from geological and EM maps. Collecting representative samples of rocks, sediment, and water and analyzing them for chemical composition should be a routine procedure for any area.

The lack of a means to map and characterize the regolith (soil, as defined in engineering geology) is an important problem related to landslide and water distribution. One reason is the difficulty in determining the thickness of the regolith. Reports by Dietrich et al. (1993) and Montgomery and Dietrich (1994) discuss some ways of determining regolith depth and subsurface topography in relation to debris flows. Few geological maps have dealt with the regolith in any meaningful way, although a few maps in New England (see e.g. Hatch and Warren 1982) show bedrock that has been examined with a gray overprint. Nilsen (1972) mapped obvious areas of colluvium when he prepared a landslide inventory for part of the San Francisco Bay region, and Schlocker (1974) differentiates slope wash and ravine fill.

Determining the location of sand, gravel, and clay resources is another potential use of EM maps. California leads the United States with nearly $1 billion in annual production of these resources (*California Geology* September/October 2000). As more and more flatland areas are covered with houses and commercial developments, builders must go further and further at greater expense for building materials. Even some rural areas are not easily exploited because of concerns about traffic, dust, and noise. EM maps may help cities and counties decide which areas should be set aside for sand, gravel, and clay extraction.

EM maps may indicate that material excavated from hills is highly expansive and probably unsuitable for fill to create a building pad (Wentworth et al. 1985), and that the bedrock itself has swelling clays that will disrupt house foundations. EM maps in flatland areas may reveal areas of potential settlement where artificial fill has been placed on top of soft clay and silt with a high water content. Site-specific studies are needed to confirm or deny the general evaluations.

Depth to bedrock in flatland areas underlain by surficial deposits and the presence or absence of soft clays have been established by the Applied Technology Council (1978) and the Uniform Building Code (1985, 1988) as important parameters for determining the design and construction of earthquake-resistant buildings. Hensolt and Brabb (1990) prepared maps from boreholes in a county south of San Francisco showing depth to bedrock and where the different requirements of the Uniform Building Code are likely to prevail.

MAPS DERIVED FROM GEOLOGICAL AND EM MAPS AND OTHER DIGITAL DATA

Geological and EM maps have significant application in preparing derivative maps showing where landslide and earthquake damage may occur in the future. Landslide distribution is related to rock strength and amount of slope, so an inventory of where landslides have occurred in the past in combination with a geological map or EM map derived from the hardness of rock units and a slope map can be used to determine landslide susceptibility. Brabb et al. (1972) prepared such a map for a county near San Francisco. The map, was used by the county to restrict development in landslide-prone areas and to require geological reports before any building is permitted (Brabb 1995, p. 300). If additional information is available in digital form about factors that might influence the distribution of landslides, that information can also be used. This information would include vegetation (see e.g. Beuchel and Wagner 1996), fracture spacing and orientation, direction and amount of bedding dip (see e.g. Brabb 1983; Briggs 1974), land-use practices (see e.g. Napier et al. 1992), slope (see e.g. Mark et al. 1988), and subsurface water content.

Debris flows are highly sensitive to slope, so a slope model derived from a digital elevation model (DEM) may be used by itself to determine where debris flows may occur if no other information is available. Brabb et al. (1999) prepared such a map for the conterminous United States. Mark (1992) used rainfall data, slope, rock hardness, and a debris-flow inventory following heavy rainfall in 1982 to determine where debris flows might impact a county near San Francisco under different rainfall conditions. Keefer et al. (1987) used information on rainfall needed to trigger debris flow in the San Francisco Bay region in order to construct a warning system based on 6-hour rainfall forecasts.

Several effects of earthquakes can be predicted from geological and EM maps. A map of surficial deposits and liquefaction potential for a county south of San Francisco was prepared by Dupré (1975) and tested by the 1979 Loma Prieta earthquake (M = 7.1). Almost all the liquefaction took place in the areas shown on the map as having the highest potential. Subsequent mapping has been focused on preparing even better maps for the entire San Francisco Bay region (Knudsen et al. 2000). Quantitative liquefaction hazard maps for Oakland, California were prepared by Holzer et al. (2003).

The literature on ground response is extensive, beginning nearly 100 years ago when Lawson et al. (1908) described the different responses of the ground from shaking and liquefaction during the 1906 earthquake near San Francisco. Borcherdt (1975) provided a state-of-the-art update. Many reports using geological and EM maps have been prepared since that date. For example, Wieczorek et al. (1985) prepared a map showing where earthquake-triggered landslides might occur in a county near San Francisco. A slope map, direct shear tests of rock units, and a geological map were used in the model. A dynamic analysis developed by Newmark (1965) for dam failures was also used in the model and showed that about 30% of the county is highly susceptible to earthquake-induced landslides. An even more remarkable map of the same county was prepared by Perkins (1987) to show cumulative damage potential for wood-frame, tilt-up concrete, and concrete and steel buildings from earthquake ground shaking. Rock strength inferred from a geological map and the location of active faults were among the factors used in the analysis. The California Geological Survey is preparing seismic hazard maps at 1:24 000 scale for the Los Angeles and San Francisco regions.

The cost of investigating the possible effects of earthquakes, landslides, and other geological hazards before land is developed is possible in a user-friendly format. An interactive web site developed by Brabb et al. (2000) and Roberts and Brabb (2000) for rural areas south of San Francisco encourages the public to get landslide information on the Web. The first task is to locate the land for development on a series of maps at increasing scale and detail. After the property is located, a computer determines if it includes deep-seated landslides as mapped by Brabb et al. (1972) and as adopted in zoning regulations by San Mateo County in 1975. If so, the cost escalates to what an engineering geologist (like the co-authors of the report) might charge to determine whether a building can economically be put on the land. The hazards covered by this technique could be expanded beyond deep-seated landslides, but the use and effectiveness of the method in the initial report have not apparently been tested.

The ease and expense involved in grading hills for roads and building pads can be determined in a general sense from geological and EM maps in combination with slope maps prepared from DEMs. The hardness of the rocks will determine the kind of construction equipment needed, and the slope map will indicate the volume of material that needs to be removed (Ellen and Wentworth 1995, Figure 6). Softness of the rocks may result in lower excavation costs, but higher costs for slope stabilization to prevent landslides. Site-specific studies are needed to supplement the general evaluations

An exciting new development in predicting the consequences of debris flows after wildfires have denuded slopes has been provided by Cannon et al. (2003). Two types of maps have been produced, one dealing with the chance of debris-flow production and the other an estimate of debris-flow peak discharge at a basin outlet. The probability maps use a logistic multiple-regression model as a function of burned extent, soil properties, basin gradients, and storm rainfall. The peak discharge maps are based on application of a multiple regression model that uses basin gradient, burned extent, and storm rainfall. The maps have been used to identify basins most prone to debris flows, and have provided critical information for the preliminary design of mitigation measures and for the planning of excavation timing and routes.

A shaded-relief map of the United States at 1:3.5 million scale prepared by Thelin and Pike (1991) was dubbed ‘an instant classic’ by geographers. The map sold out quickly and has been reprinted three times. It is the all-time best-selling USGS map; thousands hang in venues from elementary school classrooms to company boardrooms. It is available on the Web (http://tapestry.usgs.gov/two/relief.html) and is for sale from the USGS. An even more spectacular and beautiful map was prepared by Vigil et al. (2000), which combined a colored geological map with the shaded relief. This map was nicknamed ‘The Tapestry of Time’, and it was placed second in a Government-wide Communications Award competition in 2000. The ‘Tapestry’ is also on the Web (http://tapestry.usgs.gov/Default.html); it has logged millions of hits and recently spawned a 550-piece jigsaw puzzle. Still another outgrowth of the original map is an 8-million-scale shaded-relief and geological map of the whole of North America (Barton et al. 2003). This map is also on the Web (http://geopubs.wr.usgs.gov/Imap/i2781). These maps, experimental 'skunk works' projects in the preparation phase, have called public attention to USGS work in an unprecedented way.

In summary, geological and EM maps in digital form may be used in conjunction with other digital databases to produce new maps not possible from a geological map alone. Such derivative maps include the location and protection of water resources, areas suitable for septic tanks, location of natural contaminants, location of sand, gravel and clay resources, ease and expense of grading for building sites on hilly terrain, location of swelling-clay deposits, and locations where the effects of earthquakes and landslides may be most severe. These varied applications provide clues as to which agencies, institutions, or businesses may provide funding for the work.

MODELS FOR 3-D VISUALIZATION

Nearly half of the authors in this volume have provided beautiful three-dimensional (3-D) images that helped them to explain their research. Such images also have the potential to explain geological problems to a skeptical public. Images from satellites and DEMs converted into slope maps, such as the spectacular images provided by Ostaficzuk (2004, this volume), are practically self-explanatory with only a little help from captions.

Abstracts about preparing 3-D models of crustal structure in the San Francisco Bay region were provided by Brocher et al. (1997) and Jachens et al. (1997) with the purpose of understanding the propagation of seismic waves during local earthquakes. The models use outcrop geology, well logs, and seismic profiles to infer the shape and location of the top of basement rocks. Jachens et al. (2001) provided a 3-D visualization of the Silicon Valley area south of San Francisco.

STANDARDS

Some Europeans (Snjezana Mihalic excepted - this issue) do not seem to be aware that significant amounts of information about techniques for digitizing and manipulating geological databases to standards have been put on the Web in the past decade. Under the leadership of David Soller of the USGS, yearly conferences on these topics have been held in the United States since 1977. The 2002 Conference, held in Salt Lake City, was attended by 101 technical experts from 43 Federal and State agencies in the United States, Canada, and Albania (!!), and universities and private companies. The meetings foster informal discussion and exchange of information (Soller 2004, this volume).

A Data Model Design Team (DMDT) with Federal, State, and university representatives from the United States and Canada (Boisvert et al. 2002) has been drafting a geological map data model for consideration as a standard
(see http://geology.usgs.gov/dm/steering/teams/design/charter.shtml).

After reviewing a model proposed by Johnson et al. (1999), the team decided to determine how geological map databases might be queried, and to document requirements for database contents. About 760 questions received from the user community were classified into 30 types along with descriptions, classifications, and relationships. Documentation for four variants is posted on the DMDT web site. Boisvert et al. (2002, p. 45) indicate that the team is currently working on the next-generation data model incorporating geological unit (chronostratigraphic, lithostratigraphic, etc.), geological structure (contact, fault, etc.), EM (rock, mineral, etc.), geological relation (stratigraphic, spatial, etc.), geological process (deposition, erosion, etc.), geological classification scheme (geological time scale, lexicon, etc.), and geological property (genesis, fabric, etc.).

Many of the standards and techniques required to determine the statistical reliability, completeness, and variation in geological and EM maps are already in place. Most geologists, for example, use the Wentworth size scale to distinguish boulders, cobbles, pebbles, sand, silt, and clay. Ellen and Wentworth (1995) provided additional terms to describe proportions of components in materials units and their defining percentages, such as the percent of shale in a sandstone materials unit. They also developed a rock-hardness scale, and scales of bedding thickness, fracture spacing, and fragment size. They estimated expansivity by testing representative samples for free swell, and they correlated the results with the International Building Code Expansion Index Test. They developed their standards to provide a relatively quick and inexpensive way of determining the physical properties of nearly 360 rock units in a 7000-mile area.

Many more standards are available with far more detail to describe rocks and surficial deposits. Those prepared by the International Organization for Standardization (ISO) are, probably, the most widely distributed. The one on the classification of rock (ISO_14689-1) has 16 categories for the identification of rock and 106 categories for the description of rock material, depending on how the descriptions are subdivided. An annex for describing the type of rock has 93 choices, designed to provide an engineer with limited rock knowledge with a matrix to pigeonhole a rock.

My basic problem with the ISO and many other rock and geological map standards is that they seem designed primarily for individuals working in an office to write a report, not for the person in the field struggling with selecting from an overwhelming amount of information at an outcrop.

Preparing a geological map is a subjective, physically exhausting, and hazardous task. Differences between authors who have different perspectives at map boundaries is common, not the exception. These differences need new analysis from geologists in the field, not arbitrary standards. Holding a check-list with alpha-numeric terms in the hand, while studying an outcrop is simply not practical. The brief list of standards provided by Ellen and Wentworth (14 categories) should provide a trained geologist with nearly all the information needed to characterize and add the physical parameters of an EM unit to geological maps in order to make them more useful

The advantages of using digital cartography, satellite images, DEMs, geophysics, and geohydrology to prepare 2-D and 3-D models to explain our science to new audiences, as indicated by the many examples in this volume, are so obvious that even standards will not impede progress in this field. Conversion of geological information into digital form, and the creation of EM maps and derivative maps to illustrate our geological information in stunning 3-D models that decision makers and the public can understand, will hopefully translate into increased funding and support for these activities. Geological maps, along with better techniques for dating the rocks and surficial deposits, are still needed in order to understand processes of change within, on, and above the Earth, and to provide the framework for making informed decisions about wise use of the surface of the Earth.

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GEOLOGICAL MAP OF THE FUTURE: DIGITAL, INTERACTIVE, AND THREE-DIMENSIONAL

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Extended abstract: Geological survey agencies are developing methods for government geological mapping in the post-paper map era. Surficial and bedrock maps are being digitized and reconciled, while multiple generations of legends are being made accessible in a categorized format. Regional three-dimensional (3-D) geological models that integrate soils and geology, surficial and bedrock geology, as well as onshore and offshore, are increasingly in demand as the information, technology, and protocols to build them progress. Applications such as regional groundwater modeling require digitizing, reconciliation and assembly of a digital elevation model, bathymetry, offshore geology, soils, surficial geology, public domain drillhole and geophysical data, bedrock maps and existing stratigraphic models typically expressed as structure contours. New stratigraphic modeling, particularly required for surficial unconsolidated deposits in many regions, requires information from cored holes logged by geologists, as well as geophysical surveys. These high-quality results are extrapolated laterally using drillhole data, commonly large quantities of water-well data of varying resolution and reliability. Much effort is required to adequately georeference the drillhole data, and to parse large numbers of unique lithological descriptions. Stratigraphic modeling methods ideally use all data and an approach that permits judgement in the acceptance or rejection of data, while interpolation and extrapolation are guided by genetic insights. Models are best captured as a grid of predicted stratigraphy profiles that convey expert opinion on interpolation and extrapolation from the data points. Reconciliation of mapping with that of neighbouring

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 23–24.

jurisdictions is a key step, as is balancing subjective definition of strata with more objective geostatistical approaches to characterizing the heterogeneous physical properties of the strata. Progress is readily achievable in undeformed strata, while deformed strata present far greater challenges. Increasingly, databases of observations and measurements are being retained alongside the interpreted model, and models are being assigned varying confidence levels, such that the result is seen not as an end but as a means for prioritizing new mapping. Current activity is broadening our reliance not only from paper maps to digital models, but also from plan view maps to drillhole databases, to 3-D models, to dynamic models such as groundwater flow models. Pressing user requirements demand that geological survey work advances rapidly along this progression.

Keywords: Innovative geological mapping, user demands, digitalization, interactive, 3-D

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REVIEW BY EARL BRABB

This is an excellent abstract that summarizes well many of the applications and problems in using digital geological information to solve societal problems. An expansion of the abstract to provide examples of both the accomplishments and problems, would be welcomed by the international geological community.

THE ROLE OF ENGINEERING GEOLOGY IN STANDARDIZATION OF INNOVATIVE GEOLOGICAL MAPPING

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Abstract: The ever-growing development of national digital geological cartographic systems emphasizes the need for standardization of geological mapping. A synthesis of the two existing approaches, which are of interest as starting points in the tremendous process of standardization of innovative geological mapping, is presented. A recent example of the US Geological Survey standardized geological information system for the production of stratigraphic maps is emphasized. A general conceptual model of the database content and structure is presented in brief, considering the main concepts related to standardization of geological mapping procedures and geological terminology. A second issue concerns traditional engineering geological mapping. Its importance lies in the abundance of engineering geological standards and recommendations, which could be directly applied to custom-oriented geological mapping. Therefore, the goal of analyses of engineering geological mapping is to extract the main issues of engineering geological mapping related to standardization of modern geological cartography. The main contribution of this paper is to address the extensions of digital geological cartographic databases with engineering geological data which are required for the production of a wide spectrum of geological custom-oriented maps from the same geological information system.

Keywords: Digital geological cartography, geological information system, engineering geology, custom-oriented maps, standards

INTRODUCTION

The main innovation in geological cartography, as well as in cartography in general, lies in the application of information technology to the field of digital cartography and geographical information systems (GIS) (Bonham-Carter 1997). The special type of cartography that is developing in the frame of GIS could be named *cartography from databases*, in which geocoded (i.e. spatial) data are stored. Cartography from databases requires the establishment of geological information systems, which are the digital equivalent of the real-world mapping processes. Consequently, the following two basic components of geological cartographic information systems

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should be established: (1) digital mapping procedures; and (2) archives of digital geological data. The process of digitalization stresses the necessity of standardization, because databases and GIS do not tolerate inconsistency in the sense of diverse terminology and mapping practices (Asch 2003).

In recent years, the geological surveying at most national institutes has been progressively characterized by replacement of traditional mapping methods with new digital applications (Laxton and Becken 1996; Brodaric et al. 1998). The National Geologic Map Database (NGMDB) (Soller et al. 1998; Soller & Berg 1999) is an example of the development of standardized digital map production systems at the US Geological Survey (USGS). In the frame of the NGMDB, digital mapping procedures are developed on the basis of real-world geological mapping procedures, i.e. processes of interpretation, interpolation and extrapolation of sampled data. The treating of geological maps as a representation of selected geological objects located in space and time, represented by symbols and described for some specific purpose, enables production of all types of geological maps from the same system, independently of the scale or content of a map (Johnson et al. 1999). In the early stages of the development of this system, as a primary objective a definition of the data content and structure (so-called *grammar for geologic map information*) for production of conventional geological (i.e. stratigraphic) maps is established. The incorporation of *vocabulary* with standardized geological terminology is also foreseen. Moreover, a map legend definition based on a standardized classification scheme (litho-stratigraphic, biostratigraphic, chrono-stratigraphic and geochronologic; Anon. 1983) is included in the model as a tool for map creation or retrieval.

The degree of innovation and range of applications is impressive, but the use of digital methods, and GIS in particular, has raised several fundamental questions and issues in the geological community. New possibilities for map creation and the long-term application of such a system were factors leading to the necessity of reconcilement of the strategic role of a national geological survey with commercial imperatives (Jackson 1998). In response, most of the national geological surveys have changed the focus of their activities, from initial conventional thematic mapping to client-driven research and the improved management and dissemination of their unique knowledge bases. Moreover, modern data storage and communication technology have created an opportunity to rethink the manner in which geological information is archived and presented (Richard 1999). Consequently, custom-oriented geological maps are progressively becoming the most important group of GIS cartographic products produced by geological surveys (Jackson 2000).

Most of the geological maps that genuinely meet society's requirements relating to resource assessment, economic development, environmental issues and social benefit used to be produced in the frame of the disciplines of applied geology (i.e. geological engineering; Bates and Jackson 1987), hydrogeology and in particular engineering geology. Engineering geology, is defined in the statutes of the International Association for Engineering Geology and the environment (IAEG) as the science devoted to the investigation, study and solution of the engineering and environmental problems which may arise as a result of the interaction between geology and the works and activities of man, as well as to the prediction of geological hazards and the development of measures for their prevention or remediation. Consequently, engineering geological maps are the most exploited type of geological maps today (Griffiths 2002).

The ever-growing demand for production of digital engineering geological maps from geological databases has revealed the need for revision of traditional mapping principles and methods for their incorporation into digital mapping production systems. The production of digital engineering geological maps from cartographic databases presupposes numerous extensions of the geological database. Accordingly, this paper deals with an analysis of some of the issues of the conceptual framework for the creation of digital engineering geological maps from the geological information system. The main objective is to stress the necessary extension of content and structure of geological cartographic databases aimed at the production of standardized custom-oriented maps. As a starting point, a methodological approach to standardization of the NGMDB was chosen, as summarized in the next section. The traditional and internationally accepted principles, definition and classification of engineering geological maps, issued by the IAEG Commission for engineering geological maps, are dealt with in the third section. By application of the main concepts of engineering geological mapping to the standardized NGMDB approach, the general content and structure of a complex geological information system is outlined in the fourth section.

STANDARDIZATION OF GEOLOGICAL MAPPING: NGMDB APPROACH

The NGMDB is a long-term project of the USGS related to the development of an information system for the production of geological maps. The main innovation of this project is in the establishment of various standards and guidelines for geological map production and their incorporation into the structure and content (i.e. in the data model) of a cartographic database. The project is planned to be developed in several phases. The first phase is aimed at providing the structure for the organization, storage and use of all stratigraphic maps, and ensuring possibilities for data model extensions. The fundamentals of a conceptual data model are presented in the first subsection as a background for the development of tools for data model standardization (second subsection). The purpose of a standard data model is to provide a consistent framework for long-term archiving of existing ‘knowledge’ collected through geological interpretations and data (Richard 1999). Levels of consistency ensured by the NGMDB data model are listed in the third subsection.

Fundamentals of the NGMDB Data Model

A geological cartographic database is treated as a digital equivalent of a geological map library. To ensure the production of all types of geological maps from the same system, all geological maps are treated in the same way, i.e. as a representation of selected geological objects located in space and time, symbolized and described for some specific purpose. Because of this, the core of the geological map data model is an archive of digital geological objects, from which different geological maps can be created. Geological objects are all geological features which are presented on geological maps, such as particular rock properties, e.g. rock type, geological structures, field sites etc. In the archive, three groups of data are stored for every geological object: geographical description (named spatial object data); descriptive data; and source reference. The digital archive of geological features is connected to a geological map legend facility. The legend can be viewed as a filter which selects specified geological features from the archive and symbolizes them for presentation on a map. Thus, the process of creating a new (or derivative) map from existing data within the archive becomes a natural process of defining the new map’s legend and then applying it to the archive.

Tools for Data Model Standardization

The standard geological map data model defines formally the two independent components: grammar and vocabulary of geological maps. Database grammar defines the standardized database content and structure for organization, storage and use of geological map data in a computer. The database vocabulary is a collection of standardized geological terminology stored in the attribute tables and archived in the database.

NGMDB grammar defines five portions of the data model: *Metadata, Singular geologic object archive, Compound geologic object archive, Spatial object archive* and *Legend*. The function of these portions is separate storing of map information. In the process of entering the data from an existing map into an archive, legend information (map object descriptions and symbolizations) would be archived in the Legend portion, and geological objects in the Singular or Compound geologic object archive. The Singular geologic object archive is dedicated to geological data that have been directly observed at a single point location, such as bedding orientation, sample description etc. The Compound geologic object archive typically consists of data derived on the basis of interpretation, grouping and classification of many observations at multiple locations, e.g. rock units. Compound objects also include descriptions of stratigraphic mapping units. Spatial portions of each object, its size, shape and location, are stored separately from descriptive data, i.e. in the Spatial object archive. The original source of each archived object (whether descriptive or spatial), as well as legend descriptive information about individual maps, is stored in the Metadata portion.

The content of each portion is also defined in the framework of data model grammar (Johnson et al. 1999). For the purpose of this paper, the contents of the Singular and Compound object archives are relevant. The Singular object archive is used to store descriptive information related to individual spatial objects of stratigraphic geological maps: rock compositions, geological ages, structural measurements and fossils. For a compound type of geological object, the following units and their descriptions are included: rock unit (composition, geochronological and stratigraphic age); geological structure (type and orientation data); and metamorphic unit. The Compound object archive is also composed of a number of look-up tables for describing the lithology, type of geological structure and stratigraphic age.

The NGMDB vocabulary consists of a series of word lists and look-up tables in which standardized terminology for describing database attributes should be stored. Most of the standardized vocabulary is placed in the Compound object archive, to ensure description of either the singular or the compound geological objects. In order to analyse maps based on composition or stratigraphic age, the list of relevant geological terms is required to be finite and defined. Moreover, the terms in these lists are hierarchically defined (e.g. rock type ‘slate’ from level two belongs to ‘metamorphic rock’ from level one). This hierarchy is useful for generalization of geological features. The most important standardized hierarchically organized items are mapping units. In the NGMDB example, standard ranks of lithostratigraphic classification units are defined, as well as their relative relationships.

Consistency of Digital Geological Maps

The main innovation of this system lies in the possibilities of storing and producing a wide range of standardized, as well as derived, geological maps from the same system. The precondition for the long-term validity of such a large system is digital geological map consistency. In the NGMDB data model the following standardization tools are developed to ensure this:

- geological object characteristics' consistency is ensured by a standardized set of attributes defined in word lists;
- map scale consistency is ensured by hierarchically organized attribute values and possibilities for variation in geometrical shape representation of any geological object;
- map purpose consistency is ensured by the possibility of reclassification of the original map data and of the separate archiving of more legend map information for the same set of geological object data, together with metadata;
- data precision consistency is ensured by separate archiving of geological object description based on the degree of subjectivity included into their interpretation.

Although the NGMDB was primarily developed for the storage and creation of lithostratigraphic maps, the listed consistency levels are also important for other geological maps. Based on the provided digital geological map consistency, it is possible to expand the data model with engineering properties, which is planned as a future extension in the NGMDB project.

ENGINEERING GEOLOGICAL MAPS

Engineering geological maps are the most exploited type of geological maps today, because most of the custom-oriented maps result from an engineering geological study. Traditionally, engineering geological maps (accompanied by reports) were the medium for storage and dissemination of the results of engineering geological research. The wide range of subjects of engineering geological investigation caused great variability of engineering geological maps (Anon. 1972). Generally, the main purpose of engineering geological maps is the presentation of engineering geological conditions, because they determine terms of design, construction and exploitation of engineering constructions. Engineering geological maps can be differentiated according to the extent and content of presented information. Engineering geological maps created as a result of regional studies encompassing large areas (several square miles to several thousands of square miles) in order to provide information for land-use planning. However, site investigation maps (i.e. engineering geological plans) concentrate on the presentation of geological information that affects the design and construction of a particular project at a specific location. Moreover, the different phases of design require different degrees of engineering geological condition knowledge, as well as a different degree of content completeness and data precision (Johnson and DeGraff 1988).

Because of its long tradition of engineering geological mapping, the Commission C-1 ‘Engineering geology maps’ was established in the frame of the International Association of Engineering Geology (IAEG). This Commission published a guide to the preparation of engineering geological maps (Anon. 1976), which is largely accepted by most engineering geologists as the world standard (Culshaw 1998). In the following subsections a summarized overview of the IAEG Commission’s recommendations on related issues is given. Criteria and methods of engineering geological interpretation and zoning, as well as the data types necessary for map production and engineering geological zonation, are summarized in the first subsection; types of engineering geological maps, their format and contents are described in brief in the second subsection.

Criteria and Methods of Engineering Geological Zonation

The main objective of engineering geological interpretation of sampled data is evaluation of engineering geological units, followed by their representation as engineering geological zones.

Engineering geological maps depict engineering geological units determined on the basis of four basic components of the geoenvironment: rocks, groundwater, relief and geodynamic processes. The types of geoenvironmental data necessary for the interpretation of engineering geological zones are listed in Table 1.

Engineering geological mapping units are the zoning units which cover a particular map sheet continuously. Engineering geological zones are individual areas on the map, which are approximately homogeneous in terms of interpreted engineering geological data. There are two categories of engineering geological mapping units: engineering geological condition units and engineering geological valuation units (Hrašna 1998). The criteria for the interpretation of these two unit categories are listed in Table 2.

Table 1. Data types for engineering geological maps (Anon. 1976)

Component	Data types
Rock	Rock/soil[1] characteristics: spatial distribution, stratigraphic and structural arrangement, age, genesis, lithology, physical state and their physical and mechanical properties
Groundwater	Hydrogeological conditions (e.g. notes on groundwater basins); hydrogeological properties of rock/soils (aquifers, aquitards etc.); and superficial hydrogeological objects (e.g. springs, rivers, lakes)
Relief	Surface topography and important elements of the landscape, for example steep scarp, gentle dip slope etc.
Geodynamic processes/ phenomena	Erosion and deposition, aeolian phenomena, permafrost, landslides, formation of karstic conditions, suffosion, subsidence, volume changes in soil, data on seismic phenomena includi suffosion ng active faults, current regional tectonic movements, volcanic activity

[1]Engineers differentiate between ‘rock’, which is a solid rock material, and ‘soil’, which is a loose aggregate.

The detail and degree of homogeneity of each engineering geological mapping unit will depend on the type of engineering geological map (according to map scale and purpose).

Table 2. Categories of engineering geological units, i.e. engineering geological zones (modified according to Hrašna 1998)

Unit/zone category	Criteria
Engineering geological conditions	Homogenous properties of one or more of the four geoenvironmental components (rock/soil, groundwater, relief, geodynamic phenomena)
Engineering geological valuation	Homogenous in terms of the engineering geological suitability, optimization or hazard of engineering geological condition

The basic engineering geological condition units are derived on the basis of rock/soil characteristics. There are four ranks of basic engineering geological condition units, which are named as follows (Anon. 1976): (1) lithological suite; (2) lithological complex; (3) lithological type; and (4) engineering geological type. There is a strong relation between the first three ranks of engineering geological units and the ranks of lithostratigraphic units: a lithological suite is equivalent to a lithostratigraphic suite; a lithological complex is equivalent to a lithostratigraphic formation; and a lithological type is equivalent to a lithostratigraphic bed or member. The engineering geological type (large-scale mapping unit) is the only engineering geological rank, having no lithostratigraphic equivalent. The engineering geological type has the highest degree of physical homogeneity. It should be uniform in lithological character and physical state. To satisfy the criteria for the physical–mechanical properties of homogeneity, an engineering geological type should consist of one lithological type, uniform structural geology features and a narrow range of weathering states.

The other types of engineering geological condition units are derived on the basis of different combinations of two or more geoenvironmental components (rock/soil, groundwater, relief and geodynamic phenomena). Irrespective of the chosen combination, the ranks of taxonomic natural territorial units derived in this way are: regions, areas, zones and districts.

Engineering geological valuation units depict reinterpretation of engineering geological condition units with respect to rational use or protection of the environment (Hrašna 1998). On these maps, properties of geoenvironmental components are treated as geofactors, because they influence land use and engineering activities. Geofactors that through their character and quality facilitate or in some way positively affect the exploitation of an area (mineral resources, water resources, suitable foundation conditions etc.) are called *geopotentials* (geological potentials). Geofactors that limit or in a negative way affect human activities (landslides, unsuitable foundation conditions etc.) are called *geobarriers*. Zones of engineering geological valuation can be interpreted in terms of their suitability, optimization or hazard, and they are usually named by the simple terms ‘high’, ‘medium’ or ‘low’, followed by a detailed description according to the purpose of the map.

Types of Engineering Geological Maps

Engineering geological maps may be classified according to purpose, content and scale (Anon. 1976).

As far as purpose is concerned, they may be of special purpose or multipurpose. Special-purpose maps provide information either for one specific purpose or for one particular aspect of engineering geology. Multipurpose maps provide information for a variety of planning and engineering purposes covering many aspects of engineering geology. According to content, engineering geological maps may be analytical or comprehensive. Analytical maps evaluate individual components of the geological environment (e.g. a map of weathering grades). Comprehensive maps give engineering geological conditions depicting all the principal components of the engineering geological environment. All map combinations are possible, as it is shown in Table 3.

The categories of engineering geological units are related to the map type. The basic engineering geological cartographic units (lithological suite, lithological complex, lithological type and engineering geological type) are used on analytical maps derived on the basis of rock/soil characteristics. However, engineering geological units, regions, areas, zones and districts, are used either on analytical maps, which evaluate hydrogeological, geomorphological and geodynamical conditions, or on comprehensive engineering geological maps. Engineering geological valuation units can be applied on all types of engineering geological maps, because they are derived by reinterpretation of all engineering geological condition units.

Table 3. Examples of different types of engineering geological maps

Content/purpose	Special purpose	Multipurpose
Analytical	Assessment of individual component of engineering geological condition from the viewpoint of a single specific purpose, e.g. landslide hazard evaluation in the context of urban development	Assessment of individual component of engineering geological condition for many purposes, e.g. landslide hazard evaluation for general purposes
Comprehensive	Assessment of all geoenvironmental components for one specific purpose, e.g. evaluation of rock/soil characterstics, hydrogeological and geomorphological conditions and geodynamic phenomena in the context of urban development	Assessment of all geoenvironmental components for many purposes, e.g. evaluation of rock/soil characteristics, hydrogeological and geomorphological conditions and geodynamic phenomena for general purposes

According to scale, engineering geological maps may be: detailed scale (>1:5000); large scale (1:5000–1:10 000); medium scale (1:10 000–1:100 000); or small scale (<1:100 000) (UNESCO guidebook, Anon. 1976).

There is a strong relationship between the map scale and rank of basic engineering geological condition units. Lithological suites are only used on small-scale maps. One lithological suite comprises several lithological complexes. The lithological complex is used as a mapping unit on medium-scale and some small-scale maps. A lithological complex comprises a set of genetically related lithological types. These units are used on large-scale and, where possible, on medium-scale maps. A lithological type is entirely homogeneous in composition, texture and structure, but it is usually not uniform in physical state. Engineering geological types can be characterized by statistically determined values derived from individual determinations of physical and mechanical properties and are generally shown only on detailed-scale maps.

The fully completed contents of engineering geological maps encompass: title; cartographic picture (engineering geological map in a strict sense); legend; symbols; cross-section; scale; table of geotechnical properties; survey details and date. Lengthy descriptive material should not form a part of the map but should rather be presented separately. The end products have to be readily intelligible to map users. Mapping units should be defined and described according to map purpose, using terminology adjusted to non-geologists (planners, engineers, decision makers and the general public). The format of engineering geological maps is not specified, but it is very important to adjust it to the map content, so that it can be completely and clearly presented (Dearman 1991).

STANDARDIZATION OF GEOLOGICAL INFORMATION SYSTEMS: ENGINEERING GEOLOGICAL APPROACH

The standardization of the geological information system for production of engineering geological maps should be based on requirements for engineering geological mapping (first subsection) and for standardized digital archives of engineering geological data (second subsection). These requirements are derived from traditional engineering geological mapping practice. In order to illustrate the general idea of a conceptual data model of a cartographic information system for the production of custom-oriented maps, engineering geological requirements are incorporated into the NGMDB data model and presented in brief in the third subsection.

Digital Engineering Geological Mapping Requirement Analysis

The main specificity of digital engineering geological maps with respect to other types of digital geological maps lies in the fact that their primary use is for analyses and cartography is only a secondary use. Engineering geological mapping analyses use the digital representation of geological map data to combine the data with other data in order to solve engineering geological problems. The digital mapping procedure during cartographic analyses would consist of the production of a wide range of maps, starting with the creation of the original engineering geological map and followed by reinterpretation of mapping units in relation to map purpose.

Irrespective of mapping purposes, the original engineering geological map should always start with the creation of a basic engineering geological condition unit (Figure 1). Using GIS terminology, the first step would be the creation of polygonal mapping units based on the rock/soil characteristics. In the case of detailed mapping, the relevant rock/soil characteristics would be the rock/soil type, geological–structural properties (discontinuities) and degree of weathering. The overlaying of thematic GIS layers depicting lithology, structural geology and weathering would result in a digital map with engineering geological type units. In the case of large-, medium- and small-scale mapping, the relevant rock/soil characteristics are those depicted by lithostratigraphic units.

The simple transformation of lithostratigraphic units into basic engineering geological condition units is allowed on scales smaller than 1:5000. The overlaying of basic engineering geological condition units (in relation to rock/soil material) with thematic GIS layers of hydrogeological and geomorphological condition and geodynamic phenomena is the process of the creation of engineering geological condition based on interpretation of all of the geoenvironmental components. The so-derived mapping units are named regions, areas, zones or districts (depending on map scale), followed by a description of all four components for every mapping unit. For the cartographic use of engineering geological maps, the main aim is to make a digital representation of engineering geological condition units for the publication of one or more maps, usually on paper.

Engineering geological condition units are also input parameters for the derivation of engineering geological valuation units. The reinterpretation of engineering geological conditions as geofactors (geopotentials or geobarriers) in relation to some specific purpose is the process of the creation of maps of geological suitability, optimization or hazard. GIS analyses for the production of engineering geological valuation maps comprise spatial queries, cartographic modelling and spatial analysis (Bonham-Carter 1997).

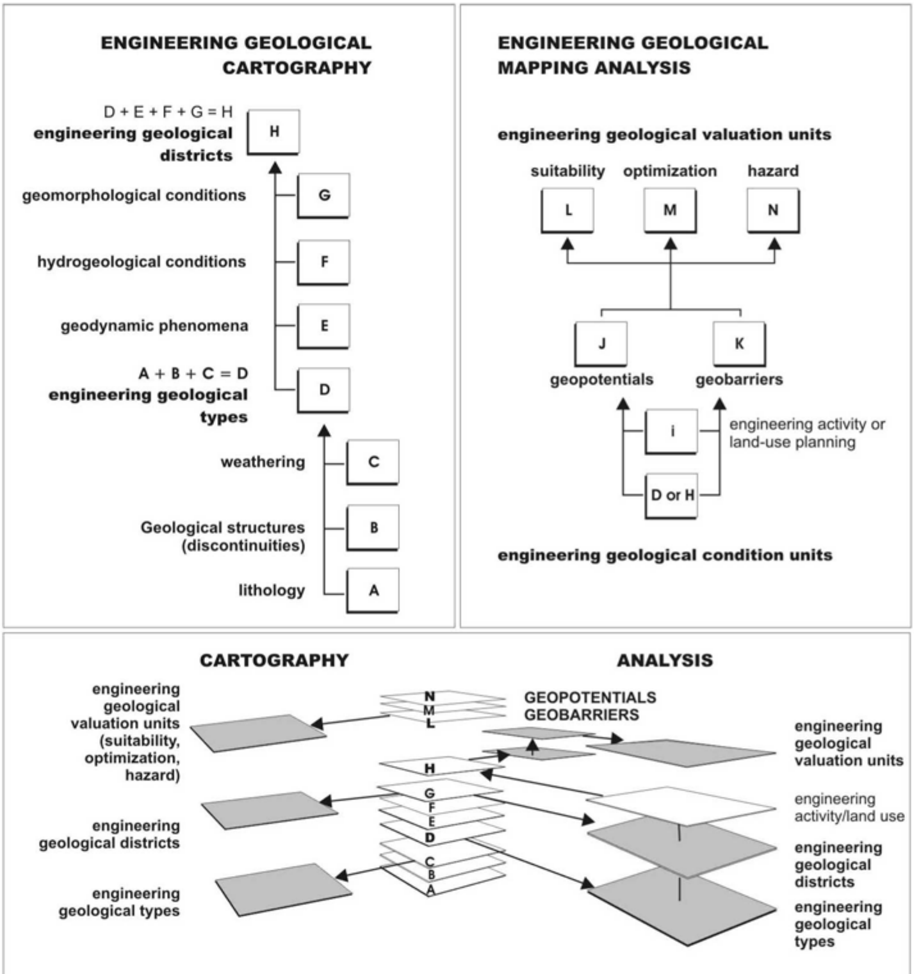

Figure 1. Engineering geological mapping analysis: schematic representation of creation of mapping units.

Spatial query is a complementary activity to data visualization. GIS provides tools for two types of interactive query. The first type gives answers about the characteristics of selected locations, and the second type about the locations (spatial distribution) of particular characteristics. Cartographic or map modelling is the process of combining the two or more maps together in order to understand and interpret the spatial phenomena that are simply not apparent when individual spatial data types are considered in isolation. Integration models are symbolic mathematical models, using arithmetic and logical operations. Spatial data analysis is best described as the process of extracting meaning from data. It consists of spatial queries and cartographic modelling combined with statistical computations. The objective is to seek out patterns and associations on maps that help to characterize, understand and predict spatial phenomena (well-known examples are landslide hazard analyses). Throughout GIS analyses, derivative maps are continuously produced from original maps, thereby most of them belong to intermediate steps.

Digital engineering geological mapping requirements could be summarized to the following statements:

- the geological information system should enable cartography and analyses;
- the cartographic database should have the possibility for archiving original maps as well as derivative maps;
- the procedures of creation of the original or derivative maps should also be retained through archiving of the mapping units derived by reinterpretations;
- to ensure consistency of mapping procedures, standardized terms for the map and mapping units should be established.

Requirements for Standardized Digital Archives of Engineering Geological Data

A geological database for the production of engineering geological maps needs to enable at least the storing of the data on engineering properties of rock/soils and geodynamical phenomena. Data on the hydrogeological and geomorphological condition can be archived in external databases.

The list of engineering geological properties of rocks/soils is well defined in the internationally accepted guidelines 'Rock and soil description and classification for engineering geological mapping' issued by the IAEG Commission C-1 (International Association of Engineering Geology 1981). The considerable overlap between the geological and engineering geological rock descriptions is a result of the following engineering geological principle for rock/soil classification: 'physical or engineering geological properties of rock in its present state are dependent on the combined effects of mode of origin, subsequent diagenetic, metamorphic and tectonic history, and on weathering processes' (International Association of Engineering Geology 1976). Subsequently, the core of engineering geological description consists of geological rock characteristics (rock name, colour, texture and structure) extended with some engineering properties. Because of the great difference in the physical–mechanical properties, engineers distinguish between: solid rock material (engineering rock) and loose aggregates (engineering soil); and rock/soil material (or specimen) and rock/soil mass (or outcrop, sized in metres). Consequently, the engineering geological description also includes: state of weathering of soil/rock material/mass; rock/soil strength parameters;

and rock/soil mass discontinuities. All of these issues are well defined in the frame of nationally accepted standards (e.g. British Standards, Anon. 1981). Recently, international unification has been achieved through European norms named EUROCODE 7 (Anon. 1996a, b). Recommendations of the international association are the equivalent of international standards. A typical example is the text ‘Suggested methods for the quantitative description of discontinuities in rock masses’ published by the International Society for Rock Mechanics (ISRM 1978).

Geodynamic phenomena result from endogenetic and exogenetic processes operating in the Earth’s crust and at the surface. The most important endodynamic processes are seismic and volcanic activity; exodynamic ones include erosion and landsliding. Because of their harmful impact on people and human activities, they are called geohazards. Although they have less catastrophic effects than do seismic and volcanic activity, the most widespread geohazards are landslides. This is the reason why a number of guidelines for mapping landslides have been published and internationally accepted. The International Geotechnical Societies’ UNESCO Working Party for World Landslide Inventory issued a ‘Multilingual landslide glossary’ (Anon. 1993) containing the definitive and finite list of landslide-related terms. Terms related to hazard, risk and vulnerability were for the first time extensively elaborated in Varnes (1984) and more recently in Fell (1993).

A precondition for standardized digital archives of engineering geological data is the storing of the Earth’s material physical–mechanical properties and Earth process characteristics, described according to the terminology recommended in internationally accepted standards or in the documents of expert working parties which are accepted as equivalents of standard.

Extension of NADM Data Model with Engineering Geological Map Data

The extensions of the NADM data model aimed at the production of engineering geological maps encompass the completion of both of the digital geological map components, grammar and vocabulary.

Grammar extensions related to database content mainly pertain to the addition of new types of geological objects, singular and compound (Table 4). Listed extension is limited to the creation of a basic engineering geological condition unit, because the incorporation of other types of geoenvironmental components (groundwater, relief, geodynamic processes) into a database requires more complex elaboration.

One of the main requirements is the provision of further subdivision of the smallest available lithostratigraphic unit (bed or member) into physically and mechanically uniform units, i.e. engineering geological types. To ensure this subdivision, the mechanisms for modifying a lithological rock unit with discontinuity pattern (structural domain) and weathering grade are necessary.

Table 4. Extension of NADM data model with engineering geological map data groups

Data model portion	Geological (NGMDB) map content	Engineering geological map content extensions
Singular geologic object archive	Rock compositions, geological ages, structural measurements and fossils	Discontinuity properties, strength characteristics, state of weathering
Compound geologic object archive	Rock unit (composition, absolute and relative geological age); geological structure (type and orientation data); and metamorphic unit	Lithological unit (rock and soil unit), structural–geological (structural domain) unit, weathering unit

Vocabulary extensions are related to the installation of a series of word lists and look-up tables in which standardized terminology for describing engineering geological attributes should be stored. Standardized vocabulary for discontinuities should be taken from the ISRM suggested method for quantitative description of discontinuities (ISRM 1978). Vocabularies for a standardized soil/rock strength characteristics and weathering state description also already exist in the engineering geological, rock mechanical and soil mechanical standards.

CONCLUSIONS

In recent times, the geological community has constantly recognized the need for the production of geological maps which are dedicated to non-geologist users of geological data (planners, engineers, decision makers and the general public). Simultaneously, after a decade of successful development of national GIS custodial geological databases, a need is appearing for the international standardization of geological information systems. From a compilation of these two trends of innovative geological mapping, the logical conclusion is that a geological information system is needed, suitable for the production of a wide range of geological maps, with an emphasis on custom-oriented mapping.

The standardization of custom-oriented mapping is already partially carried out in the frame of traditional engineering geological mapping. Despite technological differences in the production of historical analogue maps and innovative digital maps, the basic cartographic principles remain the same. The USGS National Geologic Map Database for production of geological maps is a geological information system that confirms the possibilities for standardization of mapping practice. One of the conclusions of this paper is that standardized engineering geological mapping practice, as well as engineering geological data, could provide most of the materials for standardization of innovative geological mapping.

Furthermore, using the example of extension of the NGMDB data model with engineering geological data, it is shown that the standardization of innovative geological mapping should encompass more than conventional stratigraphic mapping. With a standardized creation of *the virtual geological world* stored in databases, the possibilities for derivation of cartographic outputs are unlimited.

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REVIEW BY EARL BRABB

An article like this fills me with despair. Not because the author is not doing an excellent job of educating us about the issues of standards for geologic maps, but because geologic mapping is disappearing as a profession. Who will people like Mihalic talk to in the future?

To provide some background, the Geologic Division of the U. S. Geological Survey (USGS) had about 2,000 people in 1980, perhaps 500 of whom did geologic mapping. Even earlier, in 1965 when I was in Washington, D. C. concerned with expanding the USGS geologic mapping program, the principal tasks of the Geologic Division were to prepare geologic maps and to make mineral assessments. At that time, we estimated that less than one-third of the USA had adequate geological maps at scales of 1:62,500 or larger, and that even those maps were rapidly becoming obsolete. Our National Program was to complete an adequate geologic map of the country, aided by various state geological surveys, university professors and students.

Since 1980, the USGS Geologic Division in Menlo Park has been cut 75%, mostly through retirements, Reduction in Force (RIF), and transfer of people to other centers and other tasks that do not involve geologic mapping. Of the people who are left, I cannot count more than 5 who are still doing geologic mapping. Moreover, support for geologic mapping, such as the examination of fossils to help the mapping geologists determine the ages of rocks has been cut 90%. Oil and mining companies which used to hire 15,000 geologists every year have instead been firing large numbers of geologists and paleontologists, shutting down their domestic USA exploration programs, and selling their oil fields and production facilities. The Houston, Texas paleontology laboratory for Chevron Oil Company, for example, used to have 52 paleontologists - today they are all gone. Universities, in response, have closed geological field camps and have stopped offering geologic mapping in their curriculum.

Geologic mapping for engineering applications has fared no better. In the 1970's, the USGS had three engineering geology mapping projects in the San Francisco Bay region - today there are none anywhere on the West Coast and perhaps not in the USA. The California Geological Survey (CGS) had active engineering geology mapping programs in both the Los Angeles and San Francisco Bay regions in the 1970's - today there none and the CGS has just been downsized drastically by firing their entire library and publications staff and by encouraging others to take early retirement. Huge deficits forecast for 2005 probably means that both the USGS and CGS will be cut again.

As a result, people with computer skills and geologic training are likely in the future to be talking to each other and not to geologists who are preparing geologic maps.

There is a more fundamental problem, however, with the standards proposed by Mihalic and others. Natural processes generally prevent the preparation of geologic or engineering maps with the standards advanced in this paper, even if everyone had huge amounts of time available to learn and follow the rules. In the San Francisco Bay region, where I spent much of my 45-year career preparing geologic maps, the rocks consist mainly of complexly folded and faulted sandstone and shale ranging in age from Late Cretaceous to Pliocene. Probably less than 5% of these rocks are exposed, so that making a geologic map involves much subjectivity in interpreting the areas between outcrops. To insist that the lines on a geologic map must enclose units with homogeneous properties is an exercise in futility that will most likely eliminate the small amount of geologic mapping that is still being done.

AUTHOR'S RESPONSE

It seems to me, that Dr Brabb's main objection to the paper refers to the interpretation of homogeneity of geological units. Indeed, Dr Brabb views the delineation of geological units with homogeneous properties as professionally incorrect. I accept that; from geological perspective there is no homogeneity in properties of natural material (even on a microscopic scale). However, geologists are continuously producing maps with zones (i.e. map units), which are homogeneous according to just one or more properties. The principle that the question of homogeneity is exclusively related to map scale is widely accepted as being very important in engineering geology. The main challenge of engineering geology as a scientific discipline is to divide the inhomogeneous natural environment into homogenous zones with a narrow range of properties, which could then have a significant input into an engineering application. Furthermore, the choice of criteria for engineering geological maps differs according to the complexity of geological settings and engineering application. Consequently, I would agree with Dr Brabb that the question of homogeneity should be very carefully considered.

Dr Brabb described the trend of decrease in production of geological maps (i.e. geological mapping), and I appreciate his elaboration. He also mentioned the trend of decrease in numbers of engineering geological mapping projects. I assume that this is referring to regional engineering geological mapping, which is producing maps not exceeding 1:25.000 scale. In contrast to this, the production of large-scale engineering geological maps, at a scale of 1:5.000 and above, in the frame of site investigation could not decrease, because the need for geological information, which could be applied in geotechnics is constant. Arguably, if engineering geology is considered as a filter between traditional geology (stratigraphy) and geotechnics, and engineering geological maps as tools of translation or interpretation of lithostratigraphical and structural-geological units for non-geologists, **there is an evidence that geological mapping is not disappearing**. In my view, the relationships between engineering geological mapping and lithostratigraphical mapping are two-fold: (a) lithostratigraphical maps are valuable starting point for engineering geological mapping; (b) engineering geological investigation (boreholes, trenches etc.) could be an important source of new geological data about the thickness of surficial deposits, structural-geological features and geological boundaries which are not exposed on the surface.

One of the more recent issues in geological mapping are geological databases and in particular archiving and producing geological maps based on them. The main idea of my article is that if geologists want to store engineering properties of rocks into geological databases, more than lithostratigraphical standards should be considered, because of question of homogeneity. The original idea of archiving engineering properties into geological databases I accepted from USGS's NGMDB project (National Geologic Map Data Base; http://geology.usgs.gov/dm/). The principles of homogeneity of geological and engineering geological mapping units I accepted from IAEG (International Association for Engineering Geology and the Environment)**.** The theoretical compilation of these two concepts was mine.

I could agree that the proposal in my article may be considered impractical at present, because of the vast amount of data about engineering properties, which could not be stored into real database due to limitations in their storage capacity. However, I could not agree with Dr Brabb's view that my paper is written against geological mapping in general. I appreciate traditional geological mapping methods, because basic geological knowledge and consequently a geological map as its representation remains starting point for all branches of geology.

I would also like to use this opportunity to thank Dr Brabb for his review of my paper. This is the first time I have faced a sharp critique of my work and I am determined to use it as a motivation to deepen my knowledge in the field of geological mapping.

CAN GEOLOGICAL SURVEYS HAVE THEIR OWN STANDARDS?
OME PERSONAL REMARKS FROM INSIDE THE GEOLOGICAL SURVEY OF BRANDENBURG, GERMANY

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Abstract: Can geological surveys have their own standards? This question can very briefly be answered with *no*. More than ever before, the harmonization of standards is an absolute must. However, this raises some problems which have to be solved in order to reach closer collaboration and progress within geosciences.

Keywords: Cartographic standards, quick database access, geodata transfer, new technologies

HISTORICAL ASPECTS

The Geological Surveys of Germany were founded due to the requirement to obtain geological information for the growth of industry and for the general sustainable development of the German ***Länder*** (federal states). It was obvious right from the early days of the Geological Surveys that, as a result of their geoscientific competence, they achieved good synergy and were able to respond to changing social demands. Rules (standards or norms) were established as a result of the demand to present geological results in a comprehensible and comparable manner. Improvements of results followed the methodological and regional progress (Meinhold 2003).

Good examples, such as the mapping rules of Prussia, set standards not only for the other German states but also throughout Europe. The experience of the Prussian Geological Survey was the reason they were assigned editorial control for the Geological Map of Europe by the International Geological Congress in 1881 (Asch 2003).

A substantial reorganization of the Geological Surveys of Germany took place after the Second World War. The political division of Germany led to the formation of federal structures in the western part and a central

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 45–50.

geological institute in the eastern part. After reunification in the early 1990s, federal structures including geological surveys were also established in the east, although the Central Geological Institute of Berlin did develop standards and common mapping rules (Hänel & Homilius 1998).

In general, the new geological surveys adopted existing methods and rules. In addition, they organized their own geological duties and responsibilities according to the demands of their territories. It may well be possible to transfer some experiences of this process from the federally organized Germany to the now-accreting Europe.

DO WE HAVE USEFUL DATA?

As a result of the long tradition of the Geological Surveys in Germany and their obligation to collect geological information, there exists an incredible accumulation of geological data. As in other geological surveys, a comprehensive geological database (e.g. in Brandenburg) provides excellent conditions for geological investigations. However, this has both positive and negative consequences.

Short-term access to the Geological Survey data is required in order for the database to be useful to society. The data collections have to be in a suitable and up-to-date condition. For the Geological Survey of Brandenburg this requirement means that the documentation of boreholes and reports (for at least 170 000 boreholes and 20 000 reports) needs to be reorganized, and scores of older geological maps and other information have to be transformed into digital form, compatible and accessible for other users. However, personnel as well as technical resources are extremely limited for this important challenge.

THINK GLOBALLY, ACT LOCALLY

Geological processes need to be understood within a regional framework. An example is the geological surface map of Brandenburg. This map, showing the quaternary sequence of Brandenburg, can only be understood by correlation with quaternary sequences of the same age in a wider area of the northern European glaciations. Such an example demonstrates that progress is possible by detailed investigations at a local scale and integration of the results into wider regions, in a cross-national setting.

With respect to deep-seated geological horizons this requirement for a wide-ranging correlation is much more important because of the lack of surface data and the reduced possibilities for geological analyses. The international geological maps of recent decades, published by the International Union of Geological Sciences_(IUGS) and others, are good examples of the importance of international correlation. The integration of detailed geological results from different countries into international programmes constitutes the need for correlation and standardization over regional and state boundaries.

As a result of the cooperation between the state surveys of Brandenburg and Saxony and the National Geological Survey of Germany and the Republic of Poland, the geological map 'CC 4750 Cottbus' at 1:200 000 scale was recently published. This map is part of a Germany-wide map series, for which the close cooperation between the German federal states and their neighbours was essential. The transfer of knowledge and data over state boundaries more than ever requires rules and standards enabling this transfer. The southeastern part of this map shows the so-called push moraine of the 'Muskauer Faltenbogen' (Stackebrandt 2003).

The compilation of geological information in wide-ranging information systems and databases does not mean that detailed investigation can be avoided, as demonstrated in Figure 1a and b. These figures show detailed results on the morphology of the 'Muskauer Faltenbogen' push moraine in southeastern Brandenburg, which was generated by glaci-tectonic processes and overprinted by anthropogenic activity. By the evaluation of data achieved by airborne laser scanning, detailed structures could be pointed out in spite of the intense forestation of the area.

Figure 1a shows a digital surface model (especially the surface of forestation) of the intensively investigated area. Figure 1b shows nearly the same area as a digital terrain model (DTM) after reprocessing. The high-resolution DTM is a useful method for geologically detailed analysis of underground processes close to the surface.

The close relationship between inner structure and shape of the push moraine, as well as the effects of the historic underground lignite mining on the morphology, can clearly be established. Subsequent treatment and thematic colouring are useful tools for a better visualization of the structures (see Figure 2, a coloured part of Figure 1, showing glaci-tectonic folding and faulting as well as sink holes above mining structures). The results of the studies on the western flank of the 'Muskauer Faltenbogen' push moraine are published in Brandenburgische Geowissenschaftliche Beiträge, issue 1/2 (2003) see inter alia Stackebrandt 2003.

Finally, it can be stated that detailed geological analyses will be necessary also in the future. The results should to be integrated in standardized form into wide-ranging maps and information management systems. These could then be evaluated in different ways and be accessible to the public according to users' requirements.

Figure 1a. DSM (digital surface model) in a forested zone of the push moraine of the 'Muskauer Faltenbogen'

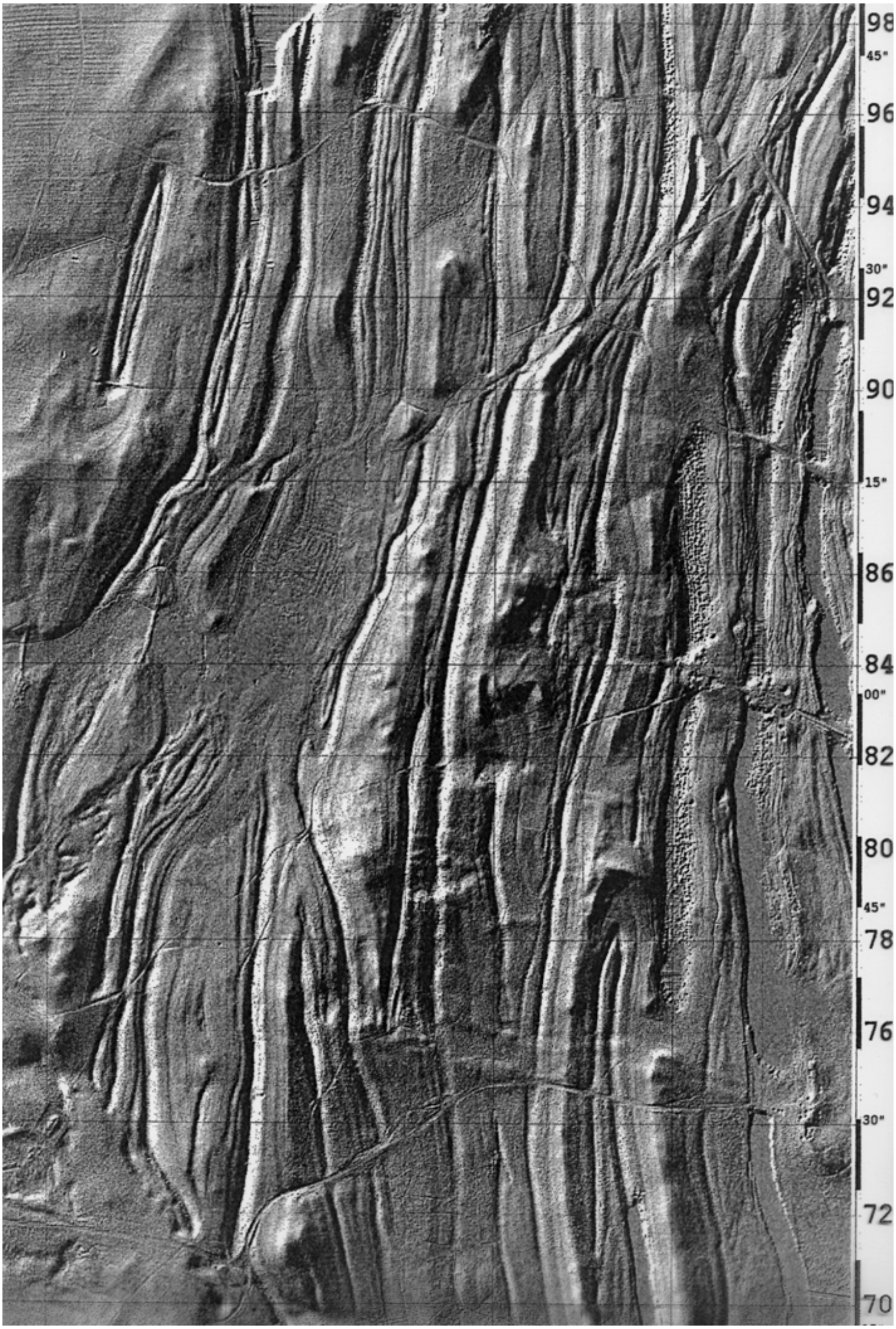

Figure 1b. For Comparison with (a): the DTM image of a forested zone of the push moraine of the 'Muskauer Faltenbogen'

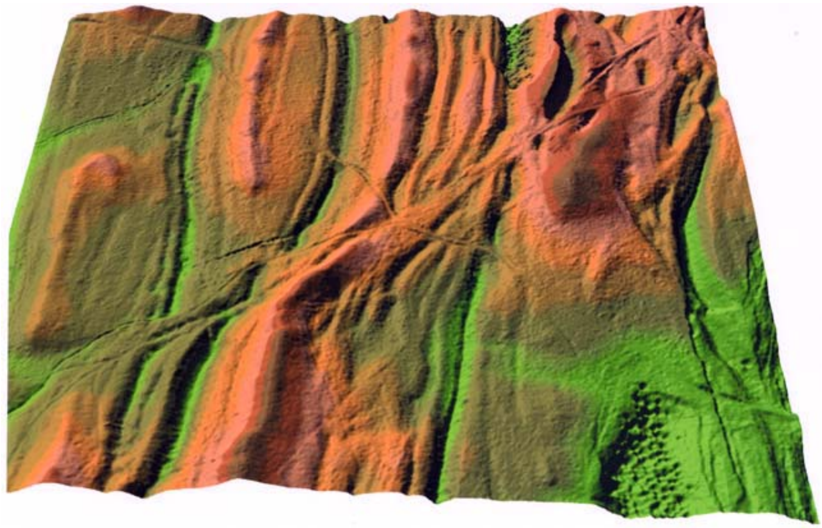

Figure 2. Detail from Figure 1 with digitally 'uncovered' glaci-genic folding and faulting ansink structures of the former underground lignite mining.

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REVIEW BY EARL BRABB

A digital elevation model (DEM) and its derived product, a digital terrain model (DTM), are among the most useful new digital tools for geologists looking for faults and assessing the amount of slope needed to trigger landslides. Two models for a DTM are provided in this paper dealing with a glaciated terrain in northeastern Germany. One image shows a 'digital surface model (especially the surface of forestation)', whereas the other image of the same area is a 'DTM after processing'. After processing for what? The difference between the two images is startling. Is the grid cell size of the DEM the same in both models? Has an arbitrary elevation for the crown of trees been subtracted from the first model? The reader would have also been helped immensely by an overlay on Figure 2 indicating the approximate area where coal has been extracted underground.

THE FUTURE OF GEOSCIENCE IN THE 21ST CENTURY: ART, SCIENCE, OR RESOURCE?

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Abstract: Geoscience was driven by a need to support discovery of raw materials and energy, and a need to understand Earth processes in order to support engineering and hazard reduction. As geoscience matured, it became sophisticated, specialized, and controversial. Unfortunately, geoscientists increasingly looked inward rather than outward and became increasingly isolated from society and regionalized. Since the 1990s, geoscience has been at a crossroads, struggling with diminishing funding reflecting the inability of society to recognize its value. This is unfortunate since geology is relevant to modern life in many ways. A wealth of geoscience knowledge is available, but the geoscience community has done a poor job of communicating its relevance to modern society; thus future vitality and relevance are dependent on developing systems and products that meet the needs of the 21st century. Achieving this goal will require a profound change in the culture of the geoscience community, combined with rapid adoption of appropriate standards, information management systems, and outreach initiatives.

Keywords: Geoscience, geological mapping, funding, communication with society, modern life demands, systems and products

THE PROBLEM

Most geoscientists labor in their own isolated and esoteric world. Traditional outputs have been artistic colored maps and reports written in language understandable only by fellow geoscientists. Unfortunately, these traditional products are seeing declining use and relevance in a world overflowing with accurate, up-to-the-moment, dynamically delivered information.

In the early days, geoscience was driven by societal needs: a need to support discovery of raw materials and energy, and a need to understand the fundamentals of Earth processes in order to support engineering and hazard reduction. Geology answered relatively simple questions and its relevance and value were apparent to most. As geoscience understanding matured, it became more sophisticated, complex, specialized, and controversial.

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 51–58.

Geoscience often involved complex three- and four-dimensional (3- and 4-D) problems that could only be solved with 2-D data. The complexity and ambiguity was explained in increasingly complex language. Differences in scientific opinion often correlated to regional differences in terminology. While fellow scientists appreciated the subtleties of geological language and theory, they were seen as simply confusing and inconsistent to outsiders.

Unfortunately, rather than moving to resolve these issues, geoscientists responded by increasingly looking inward rather than outward and became increasingly isolated from society and regionalized in their outlook. Geologists are typically creative and intelligent, and revel in their arcane world but make little attempt to explain to others. This has served only to increase their isolation from society.

Since the 1990s, geoscience agencies throughout the world have been struggling with gradually diminishing funding, reflecting the inability of society to recognize their value. This is unfortunate since geology is relevant to modern life in many ways.

MOVING FORWARD …

The Earth Sciences Sector (ESS):
(http://www.nrcan.gc.ca/ess/index_e.php)
in which the Geological Survey of Canada is situated, is taking an aggressive and controversial approach to address this issue. In an effort to reverse the trend of gradually diminishing funding, the ESS has completely redesigned its programs so that they explicitly address the issues of Canadians as defined by the Canadian Federal Government. In the new issues-driven ESS, geoscience is conducted neither to satisfy scientific curiosity nor to complete mapping coverage; it is conducted to address specified societal needs. Seventeen programs have been implemented, including programs that address 'natural hazards', 'climate change', 'northern development', 'metals in the environment', and 'groundwater'.

Just doing relevant work is, however, not enough. Appropriate outputs and services must be created and Canadians must be able to easily discover and quickly access the information they need in an understandable form. Traditional published geological maps and reports do not meet this need. All too often, existing geoscience knowledge is not used because users are not aware that it exists, it is not available quickly in a useful form, or it is accessible only in qualitative rather than quantitative form. Geoscience knowledge and understanding must be rendered into a clear and concise form. In the 21st century, Canadians look to the Internet for information and expect to receive timely up-to-date information customized to their particular needs.

INFORMATION MANAGEMENT

Current geoscience information management (IM) systems, designed to produce discrete published products, cannot meet these new requirements and must be redesigned. While analyzing its current information systems, the ESS concluded that, while some units conducted their IM in a world-class manner, at a corporate level IM systems were often incompatible, making it very difficult to integrate data.

To rectify this problem, in 2002 the ESS developed a corporate IM strategy based on the development of a hierarchy of integrated policies, plans, and standards. The goal of this program is to establish a consistent information infrastructure that will facilitate integration of information to support new on-line information services operated by both government and the private sector. Each of the new programs is required to establish an IM plan that is compatible with the corporate IM strategy and compliance is closely monitored. Additional investments are being made in digitizing legacy maps and reports.

GEOSCIENCE STANDARDS

In order to achieve maximum benefit from these investments, it is important that standards be implemented, particularly for scientific language. Geoscientific dictionaries, thesauri, and lexicons have traditionally been developed to meet local requirements with little consideration of the consequences for exchange and integration of data. In the process of establishing its geoscience standards, the ESS is actively participating in a number of international geoscience standards initiatives and adopting international standards wherever possible. While establishing standards, is important to establish easily understood core standards quickly and avoid the tendency of experts to pursue never-ending development of the elusive all-encompassing and perfect standard. These core standards will hopefully address all the geoscience data needs of non-experts and 80% of the needs of specialists.

INFORMATION DISCOVERY, VISUALIZATION, AND ACCESS

Even if well managed, geoscience information and knowledge is only of value if it can be discovered and then easily accessed. On-line search engines and digital geoscience metadata catalogues are an ideal combination for discovering information. Adoption of ISO (International Organization for Standardization) standards for both metadata and online catalogue access ensures widespread compatibility. In Canada, the Canadian Geoscience Knowledge Network (CGKN) (http://cgkn.net) is coordinating the development of the 'CGKN On-line Geoscience Data Catalogue' which allows searches for geosciences data held by the 13 Canadian Government Geoscience Agencies.

Once the user has discovered appropriate geoscience data on line, the next steps are typically on-line visualization and access. Again, the adoption of international standards is important, and in this case Open GIS Consortium (OGC) standards, such as the Web Mapping Service (WMS), are the emerging international standard.

PRODUCTS FOR NON-TRADITIONAL CLIENTS

Online discovery and access systems are ideal for the expert user who understands what he is looking for and the appropriate geoscience terminology. Unfortunately, only about 1% of potential users have the knowledge and the equipment to use the data they might discover. This leaves 99% of the populace unable to effectively use the available geoscience data.

Much additional work is needed to develop systems and products that deliver geoscience information and knowledge in a manner that can be understood by non-specialists. Methods will include simplification of information, and customization of delivery systems to target the needs of special interest groups and deliver what they need in a simple and preferably quantitative form. One of the ESS's 17 new programs has specifically targeted the need to develop specialized information systems that deliver geoscience information customized to meet the needs of specific target groups.

'Outreach' products will also play a role in educating Canadians about the relevance of geology to their lives. A series of 'GeoScape' urban geology posters has been developed for major Canadian cities to communicate how geoscience shapes and influences their lives. Another series of posters on Climate Change is designed to both communicate the links between geoscience and global warming and raise awareness of the potential impacts of global warming. The GeoScape and Climate Change poster series are available either free or at minimal charge to all Canadians and have proven very successful.

CONCLUSION

Geoscience is at a crossroads. A wealth of geoscience knowledge is available, but the geoscience community has done a poor job of communicating its relevance to modern society. The future vitality and relevance of geoscience is dependent on developing systems and products that meet the needs of the 21st century. Achieving this goal will require a profound change in the culture of the geoscience community combined with rapid adoption of appropriate standards, information management systems, and outreach initiatives.

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REVIEW BY EARL BRABB

A voice from a prominent national geological survey lamenting that "the geoscience community has done a poor job of communicating its relevance to modern society" commands attention. While I salute and admire most of the points in Broome's article, I believe that other factors may be more important in the down-sizing of geological surveys. Fortunately, an example from the San Francisco Bay region (SFBR) can be used to test whether communicating our relevance to modern society might stabilize or even increase funding for geological surveys at a time when nearly all their budgets are shrinking.

In 1970, the US Department of Housing and Urban Development (HUD) provided $2 million to the US Geological Survey (USGS) for a five-year study to develop maps and techniques for locating geological hazards in the SFBR, and for communicating the results of these studies to urban planners and the public. The HUD hoped the maps would slow or stop development in geologically hazardous areas so that the HUD would not be stuck with defaults on loans when the structures failed.

With these funds the USGS developed landslide inventories and susceptibility maps, maps showing areas vulnerable to flooding, the location of active faults, and maps showing which areas might liquefy during earthquakes. We hired a planner to help us make certain the maps were in a format and language that planners and the public could understand and use. The planner talked to colleagues in state, regional, county, and local planning agencies to determine their priorities and to educate them about our program. Perhaps as many as 20 of us expanded our volunteer activities to educate decision makers and the general public about geological hazards and how to avoid them. I talked to members of perhaps a dozen Rotary clubs, church groups, an association of real-estate appraisers, bank loan officers, an airline pilot association, homeowner groups, a waste disposal advisory group, city, county, and university planning departments, a Corps of Engineer public meeting about waste disposal, an association of independent insurance agents, the Advisory Council for Environmental Education, high school and elementary school classes, and more than 1000 people who asked questions by telephone. We participated in city, county, regional, and State public hearings and watched with satisfaction as some of our maps were incorporated into ordinances and regulations to require geologic reports in hazardous areas, and to re-zone land where hazardous geologic processes were most active. A talented Public Affairs Officer prepared press releases for our published reports (more than 100 in five years) pointing out possible impacts on public policies and land use. The press releases led to interviews for comprehensive and 'preventative' articles in newspapers, interviews on television news programs, panel discussions on local radio and the Voice of America, and articles in national magazines. I doubt that any other geoscience community anywhere had such a 'profound change' in our culture, to quote Broome.

Did any of this work lead to increased funding or even much appreciation from the people who received the data? No. The USGS terminated the project in 1975 and moved the funds to the Seattle area, later deemed a colossal failure. Not one person in the SFBR voiced dismay or even displeasure that the work had stopped. No political support from a government agency at any level was ever forthcoming.

I believe that political factors and a change in public attitudes toward science have had the most adverse impact on the USGS and state surveys in the USA during the past two decades. In 1994, newly elected conservative congressmen, including some with ties to what I call the 'creationism faction', stood on the steps of the US Capitol and announced that they intended to abolish the USGS. I believe the main reason is that some of the USGS scientific leaders had publicly opposed creationism. In 1995, the USGS underwent the first Reduction in Force (RIF) in its history. Hundreds of the ‘best’ (highly paid) scientists were literally put out on the street with hardly a thanks for their service. The bitterness of that action still permeates the organization. The Geologic Division in Menlo Park is 25% of its size in 1980. More ‘blood letting’ is forecast for next year in a time of severe budget deficits.

Actions taken against scientists in other US agencies document some of the current political attitudes about science. According to newspaper accounts, the former Director of the National Park Service stated that alteration and deletion of scientific information for political purposes is standard procedure in the US Department of the Interior, home of the USGS. In 2001, according to these same accounts, the Interior Secretary falsely claimed that caribou would not be affected by oil drilling in Alaska, and she substituted findings financed by an oil company for the scientific report prepared by the Fish and Wildlife Service. A report by scientists working for the Environmental Protection Agency (EPA) in 2002 indicated that chemicals injected into the ground to increase oil production could contaminate ground water in excess of Federal standards. The report was changed in response to ‘industry pressure’ to indicate that the standards would not be exceeded. A scientist working for the National Marine Fisheries claims that his estimate of the amount of water needed to sustain salmon in the Klamath River was lowered after pressure from local businesses. The resulting fish kill of an endangered species was the largest ever in the West. Subsequent actions have been to try to change the definition of a ‘wild’ salmon so that the lower amounts of water can be re-imposed. The scientist involved has resigned in protest. The newly-appointed Chief of the Food and Drug Administration believes that prayer, not drugs, heals people. The article with this information concludes by stating: “The present administration now plans to systematically turn government science over to private industry by contracting out thousands of jobs to complaints consultants already in the habit of massaging government data to enhance corporate profits”.

In this environment, the steps taken by the Canadian ESS to address specific societal needs will not work in the USA unless the needs enhance corporate profit or religious fervor. The information management plan developed by the ESS would be difficult to implement in the USGS because security threats, and perhaps the fear of information that does not comply with Administration goals, have made computer communication increasingly difficult. Coincidently, all of the computers in the Interior Department were shut down recently by a Federal judge who believes that the Interior Department is hiding information about the production of oil on Indian land. My problems with imposing geoscience standards are expressed in my review of the Mihalić article and will not be repeated here.

I do support Broome's contention that we need to develop more systems and products that can be understood and used by the non-specialist, but I caution that we have devoted much time and energy to this type of work without any measurable success, unless continuing to exist is a form of success. Whether or not enough talented scientists will remain working in the present environment long enough to provide the advice and unbiased reports needed can be debated. Whether or not geological surveys will be around long enough to make any of the changes recommended by Broome is not assured.

ADDRESSING THE REAL NEEDS OF ALL THE USERS OF GEOLOGICAL INFORMATION: THE OPPORTUNITIES, ISSUES AND PROBLEMS

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Abstract: The role of geology in ensuring environmental protection, sustainable resources and a safer environment is not widely understood. Not many people outside the geological profession can understand a conventional geological map and can comprehend what that map has to say about risks and resources; the fact that geological maps also reveal what is happening at depth—the third dimension—is appreciated by even fewer people. The information technology (IT) revolution has provided sophisticated new hardware and software—database, geographical information system (GIS) and three-dimensional (3-D) modelling packages—so that we no longer have to be restricted to producing one complex and highly scientific document as the result of our survey and research work. In the new IT datasets, however, products and services need special attribution and quality control. Providing full national cover with novel products and services, digitising legacy and map data causes many problems with ensuring consistency and thus the need to agree and work to standards. And, there arise problems of liability, intellectual property rights and charging policy when digital products become more widely available.

Keywords: Information technology (IT), innovative geological mapping, customer's need, social knowledge of geology

INTRODUCTION

As every geologist knows, geology is a science that is relevant to the everyday lives of most people. Unfortunately most people, including those in powerful commercial, industrial and political positions, do not appreciate this. The role of geology in ensuring environmental protection, sustainable resources and a safer environment is not widely understood. Could the reason be that for decades we geologists have been largely creating products that have meaning to only one audience: ourselves? How many people

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outside the geological profession can understand a conventional geological map and how many can comprehend what that map has to say about risks and resources? The fact that geological maps also reveal what is happening at depth—the third dimension—is appreciated by even fewer.

The information technology (IT) revolution has provided us with sophisticated new hardware and software—database, geographical in formation system (GIS) and three-dimensional (3-D) modelling packages—which should now allow us to reach out and better meet the needs of these users (Figure 1). We no longer have to be restricted to producing one complex and highly scientific document as the result of our survey and research work. While such high-quality geological maps and models (digital or analogue) are the crucial base, they must not be seen as the end point; they are only a means to an end. That end must be ensuring that our science is understood and meets the needs of all our potential users and not just geoscientists.

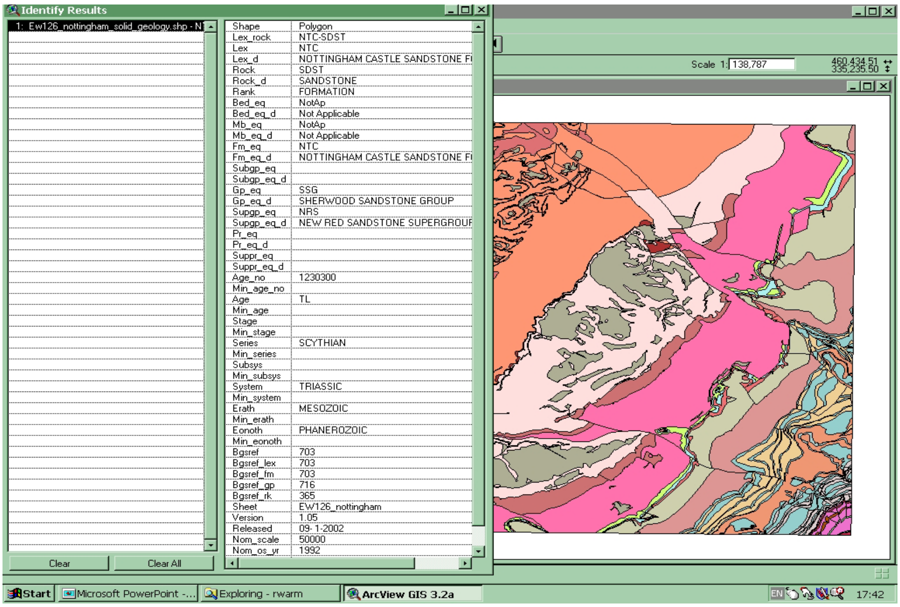

Figure 1. DiGMapGB-50: a fully attributed digital geological map database for the whole of Britain.

BUILDING THE MAP DATABASES AND THE PRODUCTS

In order to address these challenges, the British Geological Survey (BGS) has instigated a number of major projects: the first was to build multi-scale digital geological map coverage of Britain (at 1:10 000, 1:50 000, 1:250 000 and 1:625 000 scales); the second has been to develop new products by integrating the digital map data with other geoscience datasets; the third is to research and implement a fully 3-D workflow and knowledge framework in the organisation—the Digital Geoscience Spatial Model (DGSM) project.

William Smith produced the first geological map of England and Wales in 1801. Exactly 200 years later, in October 2001, the BGS completed Version 1 of the 1:50 000-scale digital geological map of Great Britain. It is the availability of geological map data in digital form that is providing the opportunities to deliver many new products and services to users who are not traditional users of geological data. The products range from basic vector geological map data attributed with lithostratigraphy and lithology, to national geohazard datasets (e.g. radon, landslides, swell-shrink clays), to risk datasets for insurance companies, to customised reports on specific properties available via the internet (Figure 2) and zip code (Figure 3). Digital mapping has also been draped over digital terrain models to provide tourists and others with a better appreciation of the relationship between geology and the landscape.

Figure 2. GeoReports: a Web-enabled GIS providing geoscience information on line.

It is the move into the third dimension that is perhaps the most exciting step. Geology has always been a 3-D (arguably 4-D) science, but the field geologist has always had to reduce his 3-D mental model to a 2-D map or section because of the need to commit it to paper. With the availability of increasingly powerful and inexpensive computing technology, this no longer has to be. The DGSM project is exploring the opportunities to move the BGS from a mapping to a modelling culture.

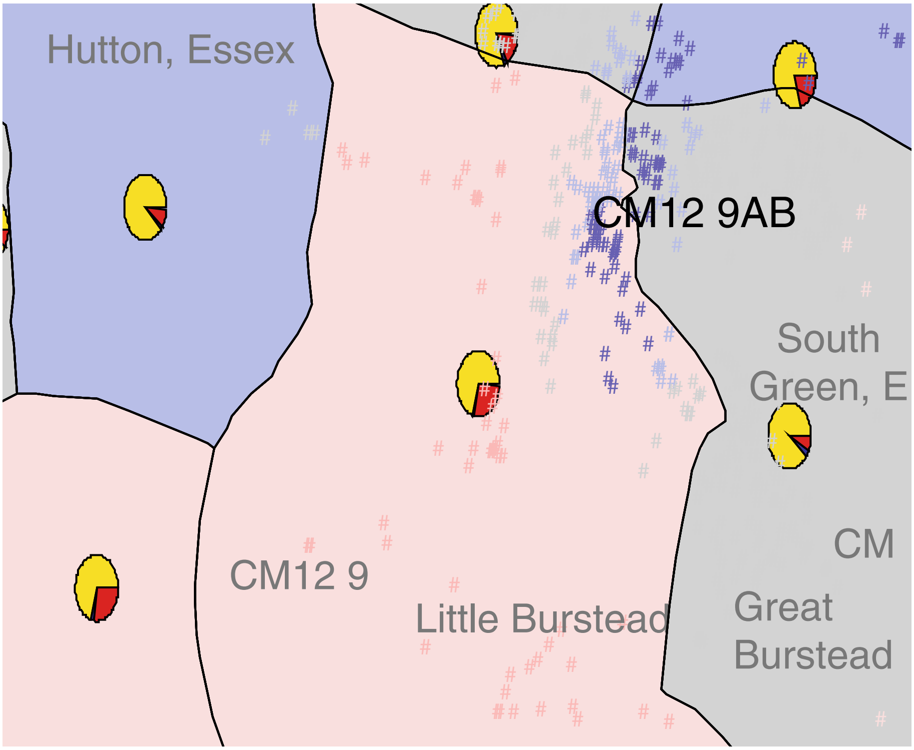

Figure 3. Geological hazard information presented by post code for the insurance industry.

THE OPPORTUNITIES, ISSUES AND PROBLEMS

Creating these new datasets, products and services has not been without problems. Identifying the resources needed to undertake the map digitisation, attribution and quality control is still a major issue. Providing full national cover (Figure 4) meant digitising legacy (and sometimes out-of-date) map data and this caused many debates in the BGS. There are problems with ensuring consistency, and thus the need to agree and work to standards. Developing the novel products and services also requires resources and new skills. And there are new problems (liability, intellectual property rights and charging policy) - issues that arise when an organisation makes digital products more widely available.

Despite these problems, the opportunities that arise from having geological map data in digital form are huge and are only just beginning to be appreciated. The possibilities for integrating these data with other geoscience datasets (Figure 5) and data from different sciences and professions, to do new science and develop new products, seem endless!

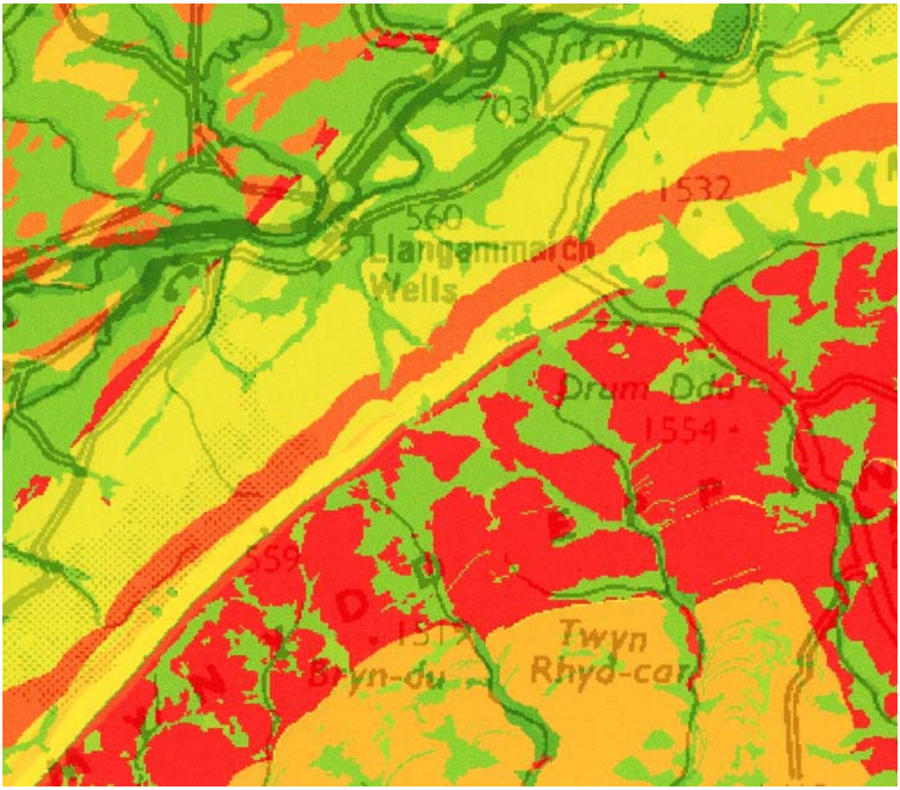

Figure 4. 1:50 000 geohazard information (examples of landslide detail and national cover for dissolution hazards).

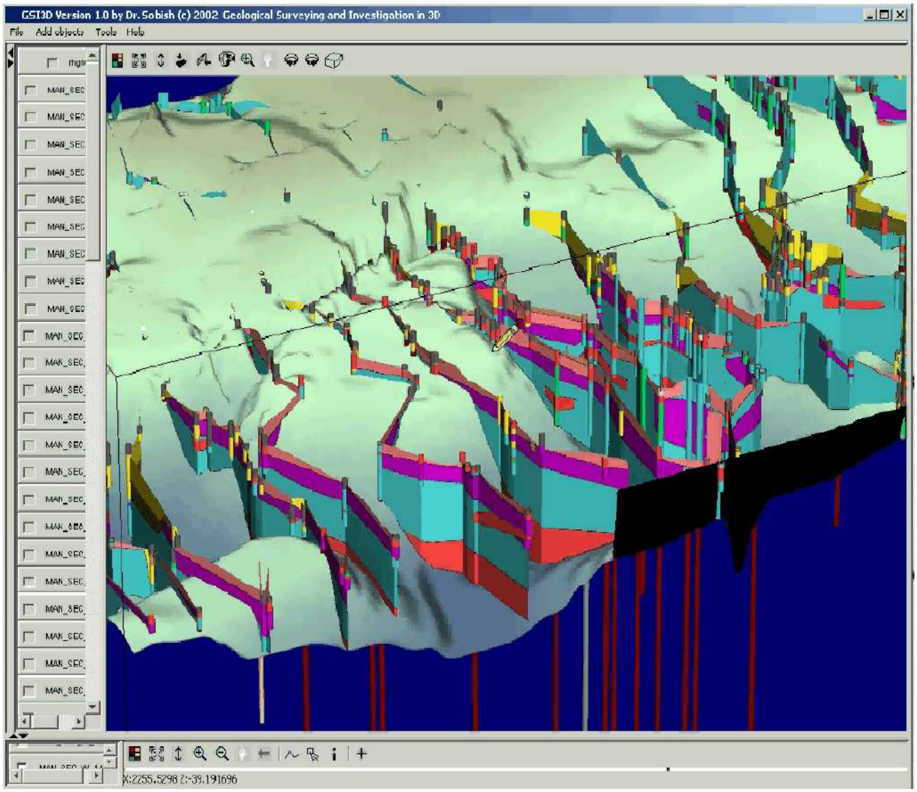

Figure 5. A model from the Digital Geoscience Spatial Modelling (DGSM) project.

REVIEW BY EARL BRABB

Once the reader is able to step over the horse that has been beaten to death, this article makes sense and has a lot of good points. Geologic maps were prepared largely for the oil and mining companies, to provide them with a broad framework to do detailed studies in promising areas. This need has largely ended, at least in developed countries. Few geologists ever imagined that the public could use their maps. Even William Smith, as I recall, thought his maps would be useful to civil engineers concerned about canal construction, and geologists have used their maps and knowledge to help engineers ever since.

Beginning in the 1960s with widespread student revolts against established authorities clinging to past practices and unpopular wars, coupled with rising public concerns about the degradation of our environment, geologists suddenly had a need to become more relevant in a world with substantially different public attitudes. At that time, more than three decades ago, many of us changed our work habits to prepare maps the public could understand and use. We evolved into GIS and digital technology later, as we saw that this technology provided a means of avoiding tedious work and the opportunity to make derived maps that we would never attempt by hand.

To illustrate this point more forcefully, in 1972 I was attempting to produce a landslide susceptibility map for San Mateo County near San Francisco. The concept involved measuring the area of landsliding in each geologic unit, comparing this area to the total extent of the geologic unit to determine which units were most susceptible, and then calibrating this factor by slope information. I did this by using a plastic template with one inch divided into 10 parts, making an area with 100 grid cells. This template was then used to count the squares (and therefore area) in each landslide and for the extent of the geologic unit. The landslide inventory map was then superposed on a slope map to estimate the original slope before the landslide moved. The information from the slope map was combined with the failure record for each geologic unit to establish a matrix. If an area is in *X* formation and has *Y* slope, the susceptibility factor is *Z*. Using this matrix, a landslide susceptibility map was constructed for the entire county, and this map has been in daily use by the country since 1975.

A colleague helped me to experiment with doing this work by computer. At that time (1976), the computers we had could construct a matrix for a small part of the county area and provide a plot with grid cells having numbers related to the susceptibility factors. The squares were coloured by hand, with red having the highest susceptibility and yellow and green having lower or no susceptibility. The eye could integrate the separate red cells to come up with an image of a highly susceptible area in much the same way that the tiny dots used by Impressionist painters like Pissaro and Seraut would form an image.

I attempted, without success, to have the US Geological Survey (USGS) publish this experimental map in colour. The Chief of the Publications Office said that since the computer would not provide the map in colour, he would not publish it in colour. My colleague then went to computer centres across the USA and discovered a machine invented by an Israeli for their textile industry. The machine would display the image of a rug on a screen, and as the image changed the effect of using more costly dyes for some patterns could be calculated. Using this machine, we were able to obtain a colour image and colour separation negatives for our small test area. These materials were sent to the Publications Chief, along with a request to print the map in colour.

Many months went by. My phone calls to the Publications Chief were never returned. Fate intervened when the Director General of the German Geological Survey (GGS) visited my office to get a briefing on the landslide maps prepared for the San Francisco Bay region project. His tour guide, fortuitously, was a close friend of the Publications Chief. When the Director of the GGS heard that I was unable to get my experimental map published by the USGS, he said, “Send it to me and I will publish it”. He expressed delight that the concept had been computerised. One week later, I had confirmation that the map had been approved for USGS publication (1978 USGS Bulletin 1443).

In 1978, the standard way to produce colour-separation negatives for a geologic map was to prepare peel coats by hand, stripping areas on a negative for each colour needed by using a type of razor blade. The process could take as long as 10 years for a complex map, during which time no changes could be accepted even if the geology shown was wrong. Using the Israeli machine, colour-separation negatives could be produced in hours, and changes were easy to accommodate. As far as I am aware, the geologic map for San Mateo County (1983 USGS Map I-1257-A) was the first to be produced by computer technology.

To summarise, some of us were using GIS concepts before the term was invented. We were not “restricted to producing one complex and highly scientific document”, and we were in the business of investigating how geology could be used in different ways to solve societal problems more than three decades ago. Computers and GIS provided ways to greatly speed up the analytical process and let us do things we would not have attempted otherwise. The ability to publish and put on the Web digital images in colour has revolutionised the map-making business, and has provided us the opportunity to communicate more effectively with decision makers and the public. What is not assured is whether this makes any difference in a world sceptical of science and concerned with other matters.

The article by Dr. Jackson has two figures that should be examined closely in discussions about the need for standards. Figure 1, which gives the attributes for geologic maps in Britain, has a framework standard that any geologist could accept. The jargon is minimal and most of us already follow the standards used. Figure 2 shows an interface with the public that is innovative, clear and meaningful.

I agree that the move into 3-D geology is an exciting step. What may be needed to supplement the 3-D geology is information on risk and cost–benefits. What, for example, should accompany a block diagram of an earthquake fault with epicentres? Or a map showing an active landslide area? Interviews with people living directly on the San Andreas Fault in the San Francisco area indicate that they are not particularly concerned about the danger, and they do not like the idea of moving. A similar discounting of danger was experienced by a couple with children, who were trapped in a house filling with a debris flow. They were finally rescued as the debris reached their shoulders and they were holding the children above their heads. They rebuilt in the same spot. Our excitement about 3-D geology may be lost on a public with such attitudes.

THE AUTHOR'S RESPONSE:

I am not entirely sure what the dead horse comment is referring to, but if it is about geology and relevance, the message remains true and the sad fact is that too many of our colleagues still focus on the means (i.e. the geological map or memoir) and not the end (addressing the end-user’s problem/need), so maybe we did not beat the horse hard enough, early enough. Geological maps may have been prepared largely for the oil and mining companies in the New World, but this is only partially true in the Old—as you point out, William Smith was a canal surveyor, so his intended use was civil engineering too.

You ought to be right that few geologists ever imagined that the public could use their maps, but you are not. The sad fact is that too many geologists mistakenly believe that with a little effort and explanation their work is accessible to the public through a highly colourful geological map (others just do not seem to think about it at all). Less than 0.5% of the UK population have the training to begin to understand a geological map. But this is not the point; the point is that the geological map still remains our mainstream external product, in which we try to embed almost everything we know. In a digital era it no longer has to be. Technology makes it possible to produce simple derivative maps and plain-worded reports cheaply and with ease, not too mention the exciting possibilities of visualization.

To say that over three decades ago 'many' of us "changed our work habits to prepare maps the public could understand and use" is an exaggeration—a few did, and one or two Surveys moved a little too, but not enough. Too many of those applied products (then and in the digital era) were not a mainstream output but a little project here and a little project there—hardly a systematic strategic survey that society, government, industry and commerce would find widely available and could rely on. How many countries have digital national ground instability or radon risk data at a reasonable resolution for the whole of their territory? Further, if you look at these so-called applied/thematic maps then and now, too many of them used, and still use, technical language and concepts that are indecipherable to the people who should be using geological knowledge.

I do not think that I got my point across regarding the value of digital technology. For one thing, you still seem to be thinking in map mode—such thematic maps are only one product that computers make it possible/easy for us to generate; doing this digitally means that we can readily produce bespoke reports for people who cannot read and do not want a map, or virtual reality demonstrations for those who cannot 'see' 3-D from 2-D. But more fundamentally, while some of the concepts were certainly there in the past (I know—I was producing sand and gravel resource assessments based on geological maps at the time), the fact is that the take-up was not universal, and such applied/available/easy-to-use products did not become emplaced as a default and systematic output of geologists and surveys; and, last but not least, they were very time consuming and expensive to produce manually. The geological map for San Mateo County was not the first to be produced by computer technology. I think there is at least one earlier one: the BGS (then IGS) produced a geological map digitally in 1971 - the Abingdon 1:50 000-scale sheet. Concerning the use of GIS concepts at an early stage, you say you were not restricted to producing one complex and highly scientific document. However, for a variety of funding and cultural issues this complex output—the geological map—was/is effectively the mainstream product.

If you were in the business of investigating how geology could be used in different ways to solve societal problems more than three decades ago, why did this not become prevalent? And why does geology still have a low profile? The point of my paper is not that the concept of products relevant to society is new, but that we now have the tools to make them easily and cheaply, *and* that too many of us are still focusing too much on the 'high' science and not enough on applying that science to make it accessible.

I agree that the ability to publish on the web and communicate more effectively with decision makers and the public may not make any difference in a world sceptical of science and concerned with other matters. However, you may be interested to learn about a development that, using digital geological map (and other) data to produce geo-hazard coverage, is then translated into plain English descriptions of the hazard level across the UK at approximately 50-metre resolution. This information is already part of reports that are being purchased by 250 000 plus people per annum in the UK. All people need to do is enter their postcode and house name/number (and part with a small amount of money). In the next year or so we hope that it will be part of the mandatory house transaction procedure in the UK, i.e. 1.25 million reports per year. I think that is getting science to the people and reaching far more of society than the geological map ever would in its ‘raw’ form.

I agree absolutely that information on risk and cost–benefits may be needed to supplement the 3-D geology, and work we are doing with insurance companies right now might interest you. We must not give up just because our excitement about geology is lost on a public that discounts dangers such as earthquakes and landslides. And we certainly must not keep focusing on the geological map alone … (that dead horse again!).

THE CONCEPT OF NEW GENERATION GEOLOGICAL MAPS

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Abstract: Geological mapping is a specific research and exploration tool, indispensable in acquisition, storing, processing and presentation of information on continuously expanding list of geo-subjects, mainly:
- Geological structure of small and large areas;
- Geological resources and prospects of their development and utilization;
- Natural and men-caused hazards and their mitigation, protection of land and property to secure sustainability.

Rules of basic geological mapping remain unchanged in the 21st century, but considerable development was made in the exploration, especially, of the habited areas. Different become requirements of potential users of geological maps. Due to electronic technologies, the acquisition, management, compilation and presentations of the mappable data are greatly improved. While digital technologies are bettering efficiency of geological mapping and disseminating of geological knowledge, the standardization is needed for maintaining the compatibility of various portions of that knowledge. In this paper are presented technical concepts of innovative geological cartography, with strong underlining the importance of various digital geo-databases and models.

Keywords: Geological cartography, electronic means, base map, DTM, virtual database, interactive map, framework of standards

INTRODUCTION

The concept of overall digitalisation of the Earth was comprehensively outlined in the Al Gore's "Digital Earth Vision" (Gore 1998) who wrote "... we need a multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data" .... "collaboratory.. for research scientists seeking to understand the complex interaction between humanity and our environment" .... "a 'user interface' a browsable, 3-D version of the planet available at various levels of resolution, a rapidly growing universe of networked geospatial information, and the mechanisms for integrating and displaying information from multiple sources." The idea is becoming an obvious

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"must", when computer technologies have dominated almost of all aspects of humankind life (Foresman 2000). The transfer of digitised contemporary knowledge about the Earth from various means and sources to various users, also those without geological background, should be the mission of geology and her indispensable tool – the geological cartography and related visualization technologies. The international group of geologists gathered in 2003 at the Advanced Research Workshop on the 'Innovative Geological Mapping' held in the Kazimierz Dolny has summarized and articulated postulates addressed to politicians and decision makers regarding steps necessary for deserved recognition of importance of geological cartography in humankind existence (ARW 2003).

The current electronic revolution in computerization of graphic and numerical data has made surprisingly poor impact on the standard geological mapping, thus on the basic ways of recognition, synthesizing and presenting of geological knowledge. The geology, however, in her classical mode is currently in decline, thus needs rejuvenation if not reanimation. Even the official geological surveys of the most countries conservatively underestimate chances for improvement of their efficiency throughout the geological mapping, while the further improvement of our geological knowledge becomes dramatically important in understanding of our own surroundings full of environmental hazards, and securing the sustainability of, both, the Man and the Nature (4th European Congress, 2003).

There are several areas in geological cartography, which are already modernized due to application of computer technologies, however, the easiness in computer creativity makes more disorder than development in product utilization. Thus, innovative attempts in digitalisation of geological knowledge shall be canalised by a framework of principles and customs, i.e. standards, which will help in easy recognition and understanding of various information from various sources, and make easy their interoperability, processing and thematic applicability at various professional levels. On the other hand, any attempt of standardization of geological mapping endangers, by definition, the free creativity, thus diminishes chances for development of better solutions in data collecting, handling and presenting. In the author's intention the proposed standards aim at improving digestibility of geological knowledge derived from, both, the modern databases and the old published or archive materials.

GEOLOGICAL KNOWLEDGE OF THE TRANSITION ERA

The geology together with geological mapping has undergone deep crisis because of two factors, interrelated in many aspects: Firstly -

geologists have already collected enormous amount of facts by direct observations in the field. Supported by classical research tools i.e. well logging, and remote sensing technologies, geologists synthesized observed facts into knowledge, which become available through geological maps and related graphs. Secondly - the breath-taking development of electronic technologies opened new opportunities for reviewing and re-synthesizing the contemporary knowledge, beginning from satellite observation of superficial geological features within their regional and global context, through deep seismic soundings of the Earth globe, towards the successful comparative geological penetration of extra terrestrial bodies within our Solar system. Thus, the new generation of geologists is either happily turning into being electronic media operators, digesting, reshaping and elaborating new views of old geological knowledge or, remaining within the classical geology, continue digging locally into geological details down almost to molecular scale.

The specialists within the both contemporary trends are basing their geological commotion on the original "geological" facts collected in the field, by the field geologists, while the wisdom of "field geology" is itself fading. Repercussions are already visible. Geology becomes less important politically, funding at all levels of geological activity is being reduced gradually, while products of geological mapping are commonly in use by geology related professionals. Field trips and field geology are subjected to significant reduction in the University programmes, geology has been eradicated from high schools, not to mention total liquidation of technical schools of geology, which were producing technical assistants to geologists. Even the geological surveys worldwide are being reduced, by reducing number of staff geologists. That is somewhat understandable, since enormous load of basic geological data still remains unprocessed according to contemporary standards. Recently, most of geological knowledge is in the second-hand use worldwide by environmentalists, civil engineers, miners, hydrologists and the scientists, mainly geophysicist. The inlet of new geological facts to the geological knowledge is thus almost nil. Professional geological expertise, still needed everywhere in relation to subsurface activities, large construction works, determination of geological hazards etc. is still provided by geologists, who know geology by practice. When this transitional, generation of geologists vanish, the new-era geologists will begin re-discovery of field geology throughout several generations to come.

But, as it was proven in many attempts, the geological mapping, hence recognition of geological substance, cannot be provided by remote sensing alone. Somebody must touch the rock with geological hammer and combine his knowledge with what he sees. And, what he sees must be already programmed in his mind by his field experience.

The new tools, as e.g. earth-penetrating radar, are also needed for poking-in under the soil. It is so, because number of outcrops of older rocks on the surface is diminishing recently for two reasons. Due to prevailing global changes weathering processes intensify in many climatic zones and the weathering cover thickens. Another reason is that due to environmental regulations all artificial outcrops, i.e. quarries, engineering earthworks, and opencast mining works must be immediately re-cultivated by refill, forestation, and plantation. Data material provided by such tools needs to be subjected to geological identification with reference to natural outcrops, which were studied macroscopically and described by somebody somewhere else in the field. In other words – what is presented on the map shall have a reference to the field documentation point. But, construction of geological map cannot be solely based on documentation points. What is between documented points must be interpolated under a guidance of regional geological practice. The geometric interpolations should be excluded. Regretfully, judging from the many geological maps, geometrical – even proportional interpolation is very attractive when computer processing is applied to generation of geological maps. Apart from computers, even non-computerized geologists prefer interpolation against geological interpretation, as the former is easier, and repeatable, while interpretation and extrapolation are trending towards an art performance. Thus, growing number of newly edited geological maps, show typical rounded patches of mappable small units, as they represent observations solely derived from the documentation points – wells, dug-out outcrops, or even a data reading points in geophysical or geochemical surface surveys.

The electronic technologies open new possibilities for collecting, categorizing and synthesizing data, and promulgation of knowledge. Thus the innovative geological cartography shall use computer technologies and other electronic tools (as e.g. InSAR, GPS) with the benefit to mapping efficiency. Obviously, real adaptation of modern technologies will result in the deep transformation of the cartography itself. A long list of the most essential changes leading to modernization of geological mapping shall begin with the expanding specter of mappable topics, generally, relating to sustainable development. Other important news will be production of modularized multidimensional geological maps interrelated with databases, regularly updated and selectively addressed to users.

COMPULSORY ADDITIVES TO TRADITIONAL MAPS

New tools and processing capabilities provided by computer technologies, should be recommended as compulsory additives to traditional maps. These are:

- **Digital terrain elevation model (DEM)** customarily condensed for geological purpose (Figure 1), custom generated from DEM data kindly provided by Military Geographical Inspectorate ZGW (2000).

- **Satellite color imagery** showing of vegetation and infrastructure cover of land (Figure 2), shall be a standard supplement to geological map-related database, geometrically compatible with other map modules.

- **Fast zooming map-formatting program**; it should be applicable to raster color images, drawings and maps. Allows continuous flow-change of presented image scale for observation of geological details within the wider terrain context (Figure 3):

- **Animation** – especially important contribution of electronic technologies to geological mapping is animation of the forth (4^{th}) dimension i.e. transformation of shapes of geological units with the passage of geological time on a map presented in acceleration on the computer screen. another application is blink-highlighting of thematic details, i.e. selected well location, or just-being-described outcrop or formation.

Another applicability of animation is an impressive motion of geological sections across a pseudo 3-D geological block-diagram, or map. Traditionally, the 4^{th} dimension is presentable on series of still-frame maps ordered side-wisely (Figure 4), or in echelon.

Section moving through the structure can be oriented vertically at any direction, and also horizontally. Such a tomographic presentations are advisable for large, regional structures (see Malolepszy in this issue).

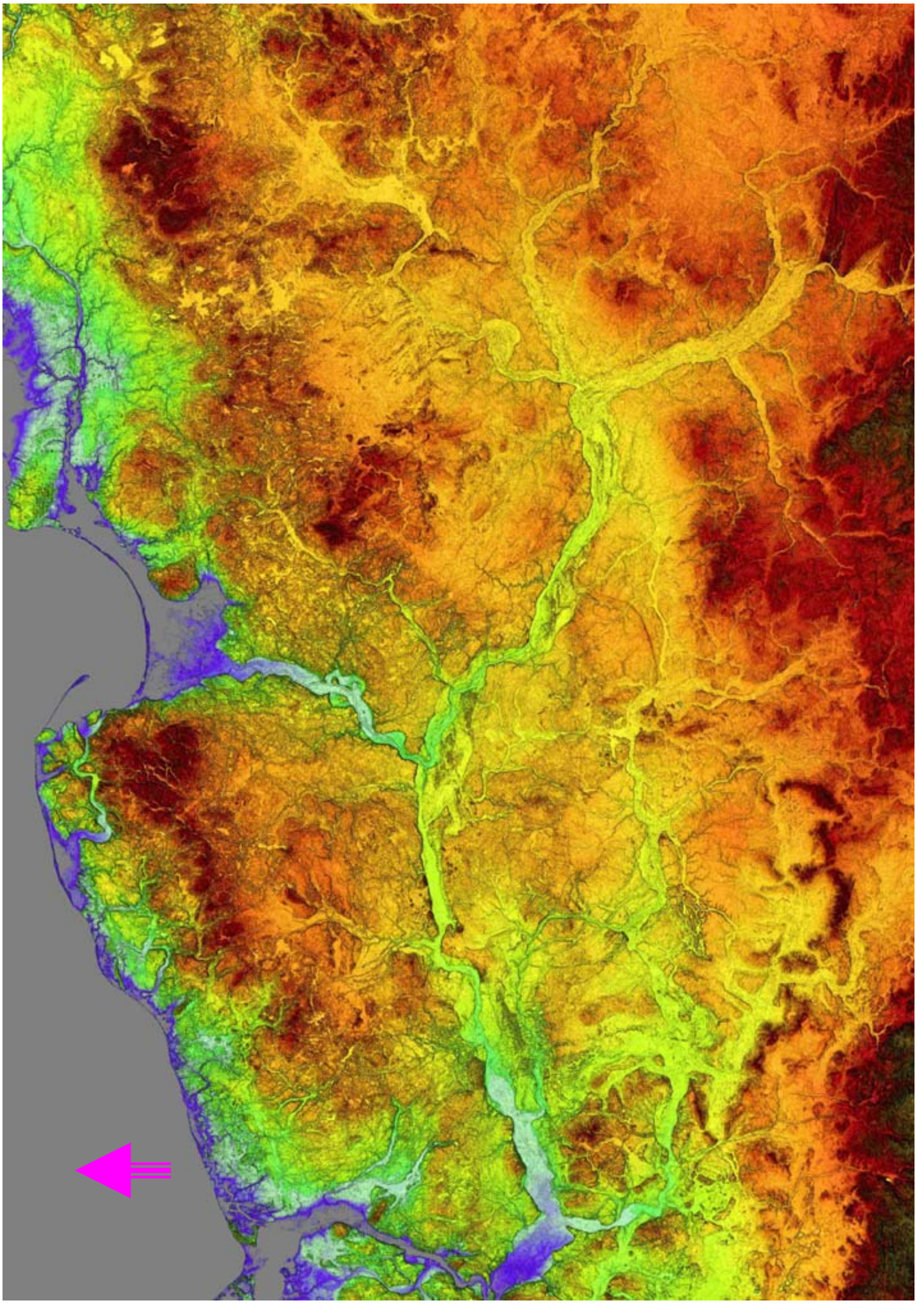


Figure 1. DEM (by ZGW WP 2000, visualization parameters by Ostaficzuk 2003) of Central and Northern Poland; condensed image of surface sculpture reveals details of glacial dynamics and an impact of lithology and neotectonics on the postglacial shaping of terrain surface.

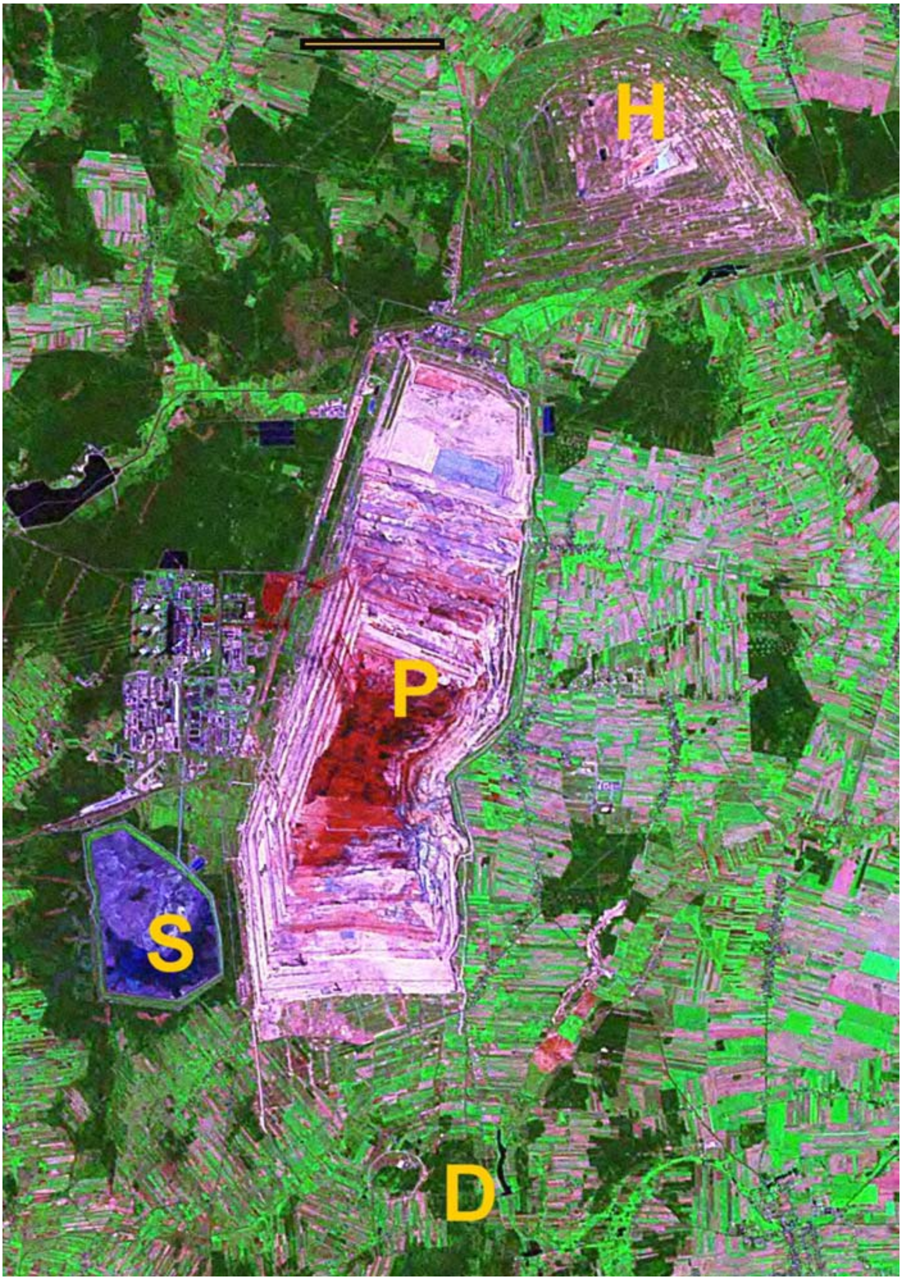
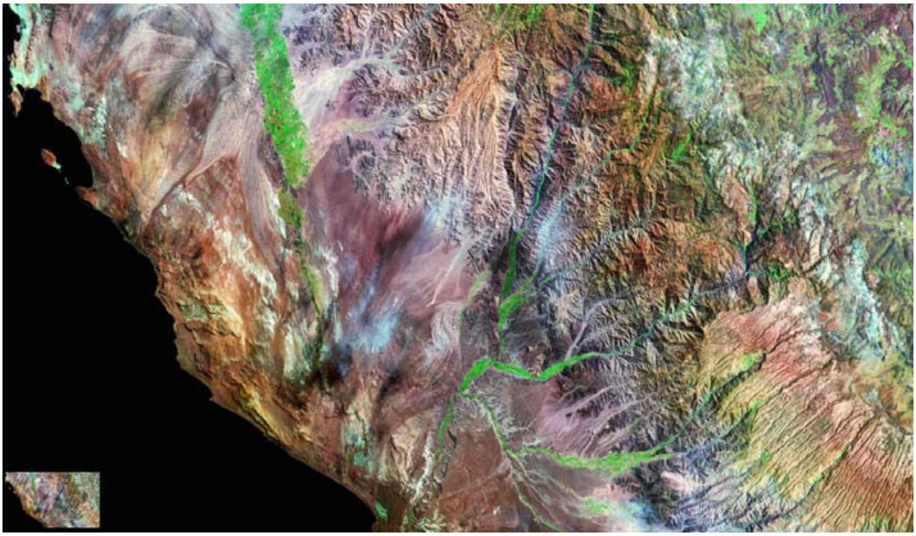


Figure 2. Landsat mosaics (NASA, courtesy MrSID); portion of the south central Poland; besides forests, meadows & arable lands, uncovered soil and subsoil, and settlements there are recognizable details of: H – spoil dump, P – open-pit lignite mine, S – settlement pond, D – dewatering screen surrounding the salt diapire; the upper bar is 2 km long.

A



B

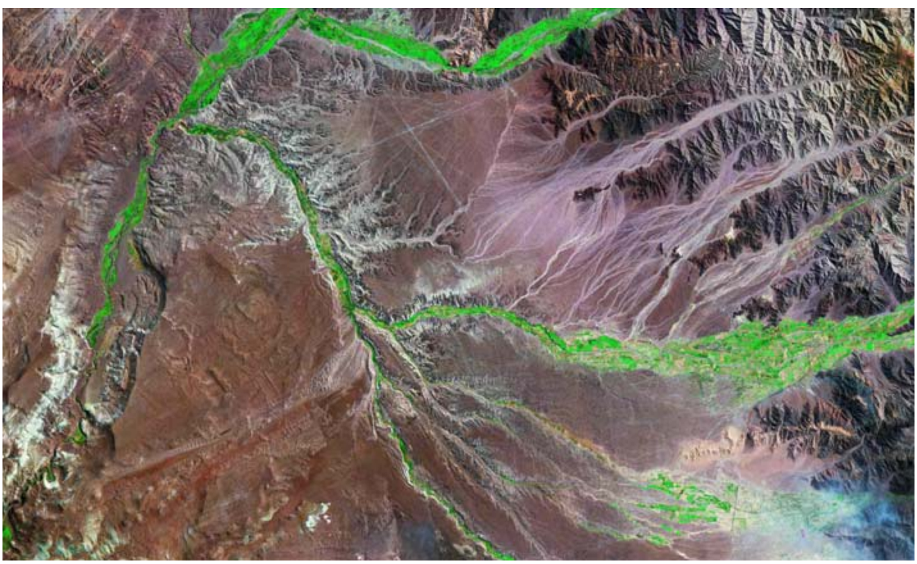


Figure 3. An example of fast image-zooming capacity of MrSID viewer program; A – inset, and zoom-up picture; B – further zooming – detail close-up look: giant landslides along the east side of the river Rio Grande in Peru (west side of the image) are developing at the tectonic lineament (upper image, diagonal line in the center); Landsat mosaics, NASA, courtesy of MrSID. The width of presented area is about 400 km.

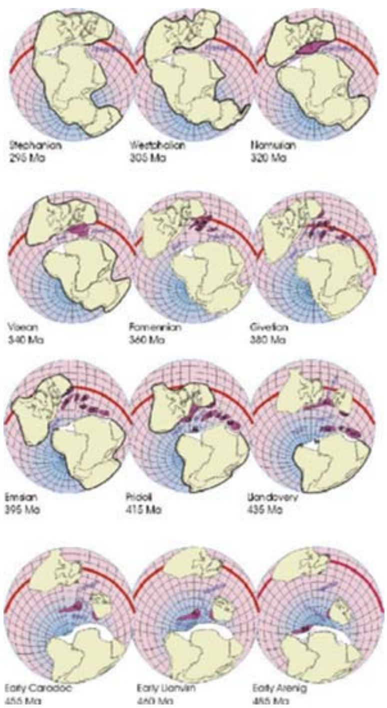
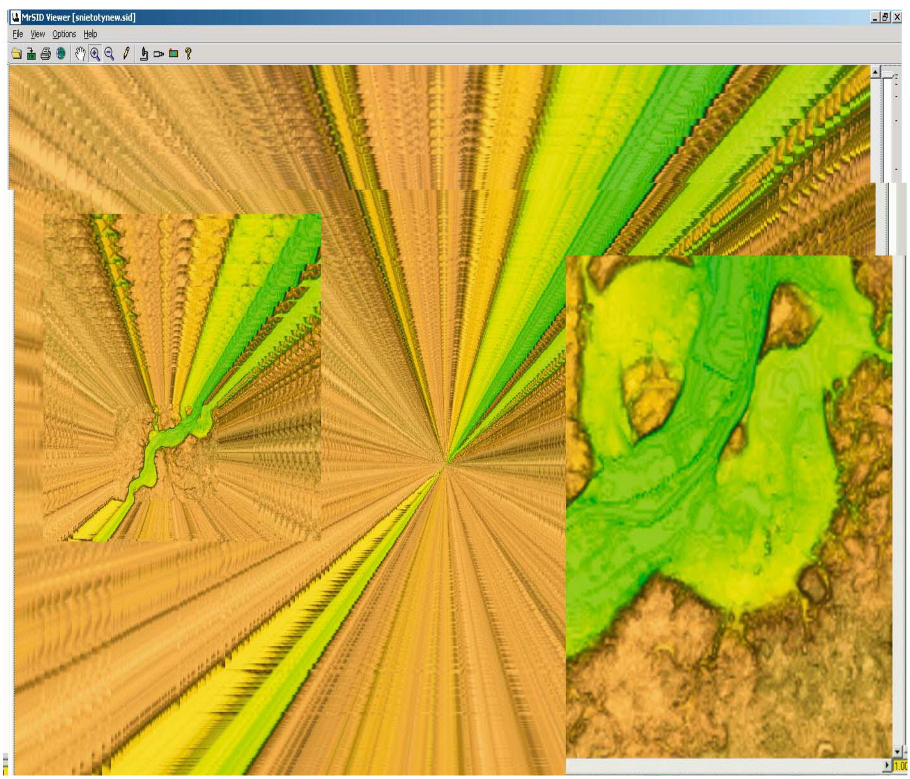


Figure 4 (left). Traditional presentation of 4th dimension on the 2-D map; while electronically animated, the time sequence development and break-apart of continents in motion can be presented on the screen as a slow- motion movie. Courtesy of Marek Lewandowski (2003)

Figure 5 (below). The zooming of DEM image; the right inset shows a maximum possible enlargement ratio; the extent of enlargement is between 1 and 255 (the bacground picture; radials show in "freeze" the slide dynamics) linearly i.e. 66 000 by area , left inset shows 7 X linear reduction. (The MrSID zooming slider controls were kindly applied to this image by M.Osuch)



GEOSCIENTIFIC DATABASE – THE ORIGINAL MODERN GEOLOGICAL MAP

Recently, due to a trend towards sustainable development of society, the need is growing for, both, large-scale (i.e. 1: 10 000) and regional scale (i.e. 1:500 000) geological and eco-geological maps containing widened spectrum of geo-information subjects. Especially, with the progress in globalisation of economy, the proper map information on various resources available for mankind becomes an essential issue. However, the wide-spread shearing of map information can be effective only when the maps, mapping, and the information-digesting technologies are standardized in order to be uniquely understandable, applicable, and transferable everywhere. But, that is far from being achieved, because the contemporary maps are not being worldwide unified, thus that their universal applicability is much limited.

Each government, local, regional and the state, shall and may be gradually supplied with the standardized sets of large-, medium-, and small-scale eco-geological maps, containing thematic modules on geology and environment (i.e. eco-geology) – soils, building grounds, geotechnical conditions, open and underground waters, mineral resources, geological processes and their trends, vegetation cover, land use, areas to be protected, natural hazards, and engineering structures. This goal may be achieved only throughout the standardized cartographic method, with, and under the international understanding and cooperation.

New challenges caused by impact of human existence on natural global processes arise demand for a very small-scale maps showing the whole globe or, at least its substantial portions. These are maps of very small scale, usually showing simple, singular theme.

Original geoscientific map shall compulsorily comprise:

1 – **The comprehensive modularized thematic data**: digital terrain data (DTD) as a map base, coordinate system, identity details, and technical information.

2 – **Generated map images in layers** related to separate thematic modules, geographic network, explanation and symbols to be placed inside and outside of the map frame.

3 – **Set of interpolation grids of mapped themes**; the grid density shall be proper for the bottom-line scale of the related map.

4 – **Each original map and individual layers should be related to topographic base module**, which shall be also divided into several thematic layers:
4a – **Surface elevation** data;
4b – **Drainage** pattern
4c – **Natural land cover**
4d – **Settlements/population**
4e – **Infrastructure**
4f – **Topographic names**

For medium and small scale maps, the physiographic divisions should be secured inside the map database.

a) The core of the original map will, thus, be an integrated database comprising:

1 – **Original data**, segregated and modularized thematically

2 – **Reference data (archive data, units, standards, definitions)**; mostly derived from the virtual databases

3 – **Reference addresses**; mainly to virtual database and to original data sources,

4 – **Data processing software** system,

5 – **Self-generated thematic modules** and thematic layers

6 – **Verification system** based on cross-checking of archive and reference data

7 – **In/out steering** control system

b) The connections of database:

1 – **The sources of original data**; temporary or permanent (these could be archives, field-laptop, field monitoring equipment, author's typed-in data

2 – **The virtual database;** shall be usable as a reference for processing of original map data, and generating specific layers in various thematic modules

3 – **Software**; for generating of thematic layers, diagrams, visualization compositions, and tables
4 – **Visualization system** – monitor screen, printer, multimedia beamer.

VIRTUAL GEOSCIENTIFIC DATABASE

There is no need to furnish individual databases with what can be easily approached virtually via the Internet (Ostaficzuk 2003a). Substantial portion of common data available via Internet, becomes a virtual database (VDB).

In order to making the VDB operable the geoscientific database shall be composed of www. links to various sources of geodata. The links would furnished with the Internet addresses of direct access to existing publicly available global information, under in hierarchic order from general scope to detail information. Hopefully, the same should apply to regional and even local databases maintained by national and local governmental agencies, and private companies.

According to the Table 1, much information is already available via the Internet, considerable portion remains in private databases and in the university collections. But, the access to that in principple available information is not simple. Normally, one has to find an address, which in most cases appears leading to something else than expected or opens further addresses need to be checked – what is time consuming and discouraging if time is pressing. From amongst thousands related pages only few contain the needed information, others are usually irrelevant, what means that so many pages must be checked for getting access to few reliable. The more detail is the information the less is, usually, available, because a general lack of free accessible digital materials at local levels. When the idea of a virtual geoscientific databases is commonly accepted, the availability of detail local data will undoubtedly become developed. Some efforts, mainly financial will be needed for digitization of published detail materials or, for standardizing formats of already existing collections of data.

What should be essentially improved is a reduction to three a number of steps necessary for accessing the needed data:
Step 1st – “geo-virtual” shall lead to the virtual global database
Step 2nd – “subjects” according to Tab 1.
Step 3rd – “discrimination” according to:
3.1 - “**date**” [of origin],
3.2 - “**size**” [a – to certain scale, b – extreme, c – average],
3.3 - “**location**” [1 – geographic coordinates, 2 - continent, 3 – country], and the
3.4 - “**mode**” [1 – numeric, 2 – graphic, 3 – raw, 4 – processed].

Table 1: **The tentative structure of virtual databases at various levels, free accessible via virtual geo-db links; aster (*) marks sources to be digitized**

Subject\level, source, availability/level	**a/Global**	**b/Regional**	**c/Local**	**d/Private, e/Academic**
1/ Geological Standards 1a/ Units 1b/ Stratigraphy 1c/ Lithology 1d/ Graphic symbols 1e/ Colors 1f/ Procedures	World Map Committee, and thematic International Commissions	Country Geological Surveys	Customary Customary	
2/ Offered Services	UNO agencies NASA and USGS	Statutory consulting, advising, reviewing	Ads Ads	
3/ Legal regulations, requirements, acts	UNO	USA, EU legal acts	Rules and customs	Customary, proposed
4/ Demands	UNO Development and prevention programs	EU Development programs, country programs	Open tenders	Concourses
5/ Products	Information, ads			
6/ Restrictions	Availability, classified, political, cultural, commercial			
7/ Satellite images	USA, occasionally other sources			Occasional
8/ Aerial photos	Occasionally, selected areas			
9/ DTM	NASA		USA and local sources	USA and private sources
10/ Models	NASA	Occasional, various sources	Occasional, various sources	Occasional, various sources
11/ Land cover	UNO, USA	USA, published materials (*)	Published materials (*)	Occasional and published materials (*)
12/ Landuse	UNO, USA		Published materials (*)	Occasional and published materials (*)
13/ Hydrographic network	Occasional			
14/ Volcanoes	USA			
15/ Areas of special interest – parks, cemeteries, out of bound	UNO, occasional	UNO, occasional		
16/ Natural resources	UNO	Geological Surveys, country information services		Occasional
17/ Mines	UNO			
18/ Water dams	UNO			
19/ Zones of endangerment	UNO			
20/ Geological discontinuity zones	Published materials*			Occasional
21/ Magmatic rocks				Published data*
22/ Sedimentary formations				
23/ Base maps	USGS	USGS, local	Local	Occasional
24/ Climatic data	NASA		Local information	Occasional, projects*, published data*
25/ Global changes	NASA, UNO		Occasional, historic*	Occasional
26/ Current climatic data			Local information	Occasional, projects*, published data*
27/ Hazard event data 27a/ Floods 27b/ Storms, hurricanes 27c/ Snowfalls 27d/ Avalanches 27e/ Earthquakes 27f/ Extraterrestrial 27g/ Drought 27h/ Other				
28/ Energy sources	UNO		Published data*	Occasional
29/ Energy resources	UNO		Occasional	Projects*, published data*
30/ Freshwater resources	UNO		Geological surveys	Occasional, projects*, published data*
31/ Published materials 31/a Books, papers 31b/ Maps, 31c/ Tables, statistic graphs	USGS, UNO		National library catalogues	University libraries, private catalogues

STANDARD REQUIREMENTS FOR ORIGINAL GEOSCIENTIFIC MAPS

The original map must agree with several standard requirements for purpose of its merit clearness, compatibility, and reliability. Maps of the same kind from various countries and institutions shall be made in similar manner as to secure possibility of compilation with others, and easy visual recognition and understanding its merit contents at a glance. Thus, the international committee for digital map standards should be established, and national geological surveys shall be obliged to obey such a committee directives.

Formal requirements

The formal requirements are:
- defined bottom line scale,
- required gridding resolution,
- accuracy of basic data,
- the smallest size of presentable polygons,
- location of data points,
- map technical data, and
- the map identity symbol.

The standard scales:
In practice, there is a need for four-order scales of original (i.e. directly composed from formal data) geoscientific maps:
1 – Large scale, 2 – Basic scale, 3 – Regional scale, 4 – Global scale.
- **Order 1:** Large scale surface maps shall be within the range of 1:500 to 1:5 000, prepared mostly for engineering purposes, according to legal standards, bearing information on soils within a 3 m deep zone;
- **Order 2:** Basic scale geo-ecological maps 1:10 000 to 1: 50 000 for planning and managing of land use and resources; shall present geology of outcrops to 2 m below the soil cover, according to international mapping standards;
- **Order 3:** Regional scale geological and eco-geological maps 1:100 000 to 1:2 mln. for summary and review of geological information, strategic planning, forecasting and for other scientific and government-administration activities; shall be composed of original geoscientific information, superimposed on maps generated from the satellite land cover and elevation model, supplemented with the 2nd order map information; for some geoscientific units shall be generated directly from regional and global –

satellite and airborne sensors data, and of offshore and onshore fixed platforms data;

- Order 4: Global scale maps 1:5 mln. to 1:200 mln. for scientific presentation of global events, global changes, and for global strategic purposes. These maps shall comprise original geoscientific data superimposed on the compiled base containing continental boundaries and geographical coordinate reference; optional mountain chains, permanent snow, and vegetation cover.

Map generalization:

No units, boundaries or any other features shall be generalized on original maps generated from the related database. Generalization of map content and the format variation of presented maps shall be allowed for sketch-maps, synthesized maps and the ”executive-summary” maps derived from original maps; that shall be clearly stated in the subtitle. Explanations and symbols overlying the map inside a map-frame can be subjected to re-edition for all the derivative maps according to the specific needs of such map users.

Normally, the traditional generalization process shall be substituted with optical condensation of an image-content along with reducing of map size, similarly as is in the case of aerial photos or satellite imagery of the Earth’s surface. Only symbols, characters and numbers superimposed on the maps shall be resized or gradually eliminated with the diminishing scale of presentation.

Gridding size:

The gridding density should be related to the accuracy-bottom line determined by scale. At the greatest scale of the original map a gridding should not be visible with naked eye from the distance of 1 m, i.e. should be within a range of 1/10 – 1/5 of milimeter. For the 1:1 000 map scale, gridding should be within a range of 10 to 20 cm sq. For the map 1:10 000 accordingly 1 to 2 m, while maps 1:50 000 should be generated from gridding ranging 5 to 10 m, 1:500 000 - 50 to 100 m, and so on. Each layer shall contain a fixed scale bar, and the information on bottom scale of the original map data. The postulated gridding may appear too dense, especially in multi-layer composition; in any case, it must be much denser that the distribution density of original data points.

According to the current experience at medium latitudes, the optimum density of DTED for map scale 1:200 000 was 3600 x 1800 points per one geographic degree square for the lowlands, and 3600 x 3600 in mountainous areas (i.e. circa 35 x 35 m, and 35 x 20 m). That in practice such gridding density was difficult to apply for maps 1:100 000, and was not acceptable for the scale 1:50 000 and greater.

Graphic accuracy:

Location accuracy on original maps shall be of 0.33 mm for firm boundaries or center of point details e.g boreholes, crossings, benchmarks. Thus, topographic-base gridding density for geological maps shall be within a range of 0.2 mm.The smallest size of polygons as separate units shall not be smaller than 1 mm, and the thinnest black line 0.1 mm.

Location of data points:

For each original map thematic module a documentation layer with data points location shall be pop-up available in the related database.

Map technical data:

For each original map thematic module an information table shall be pop-up available in the related database. The table shall comprise the copyright information, authorship, source and format of data, date, bottom scale, project id., editor, and map generating technologies.

Map identity symbol:

Each original map thematic module shall bear a logo of issuing institution, a name, digital and character symbol, and geographic coordinates of central point and map corners in degrees and decimals of degree.

Other requirements of standard

The frames of maps shall be rectangular, or polygonal according to geographical coordinate system. Large-scale maps and basic geo-ecological maps shall be supplemented with metric Gaussian grid, while regional and global maps must have geographical grid presented.

No administration boundaries shall limit the extent of geoscientific information. On maps prepared for the local government use, the areas outside administration borders may be presented in bleached manner.

Each basic geoscientific map shall be available as a compatible collection of separate thematic modules in digital form on conventional, standard magnetic, optical or electronic record means.

Each thematic module must be accompanied with the explanation of used symbols, colors, coordinates, and unit value scale, interactively readable.

Standard colors, symbols and classification units

Computer technologies allow unlimited inventions in visualization of knowledge. It, however, should not be misused, because images which do not fit to what the user is accustomed by habit, are usually difficult to recognize, understand or read without laboriously studied explanations. Colors, symbols, selection and classification of units shall be related to international standards agreed for the map of the world, and to actual international classification standards in geosciences, proposed, accepted and provided by international commissions (ICS 2004, FGDC).

Geological units on all maps shall be described in stratigraphical order. The small-scale geological map units shall be grouped according to regional differences, and described according to lithology, and genetic complexes. The medium scale map units shall be discriminated and described according to regional, stratigraphic an lithological formations, while for the large-scale map geological units shall be discriminated, grouped and described according to genetic, lithologic and, for engineering purposes – physical properties.

Dimensions:

All original maps except these from the global group must bear at least real three dimensional (3D) information substance. The 3D means that in each place of the map there is known the third, vertical dimension, the depth from the surface, or the vertical thickness of presented unit(s). The fourth dimension – represents the time interval. It means that the shadowed, or contoured map presenting a surface of certain age of rock formation or structure, remains two-dimensional (2D). To make the flat 2D map distinguished from shadowed map, the latter can be called <pseudo three-dimensional> (pseudo 3D), but never <3D> because, the terrain elevation value is only a surface points attribution, and not the third dimension (i.e. thickness).

The 3D maps shall be generated as a block-diagrams subjected to electronic possibility for slicing along any arbitral plane. Presentation could be done in a combination of a 2D map and a series of vertical cross sections, or as a half transparent block-diagrams.

The forth dimension can be presented as an animation of 2D or 3D maps, or as a sequential series of 2D or 3D maps.

It seems important, that digital maps are related to the area (administration, regional or physiographic), but should not be limited by artificial boundaries. However, the large-size maps should necessarily be arbitrary divided into standardized sheets, the most possibly according to the geographical coordinates.

For the purpose of inserting fragments of maps into reports and other printed documentations, the sheeting should be adjusted to standard formats e.g. A5, A4 or A3.

The most important in unification of efforts regarding the modern mapping methodology is direct exchange of cartographic materials, and comprehensive discussions amongst specialists. Cartographic problems and the need for the standardization, the presentation of current situation in research and development of mapping principles in geology, are already discussed on many occasions (e.g. 4^{th} European Congress, 2003, GIS-Europe 2003). Despite of that, the essential problems still remain unsolved:

1 - The necessity and ways of introducing into common practice the standardized thematic modules of modern geological maps. The merit

content of modern geoscientific maps should be much more expanded than it used to be a dozen years ago. Common thematic modules representing surface and subsurface geology, shall be routinely supplemented with standardized interrelated map derivatives presenting concepts and ideas, human presence, land use, infrastructure and many related subjects.
2 - A long series of atypical maps, which are showing probability (of e.g. occurrence), reliability (of e.g. reference data density), prospectivity (a chance for successful exploration e.g. for water or certain mineral deposit), value (of e.g. building grounds), pollution (of e.g. soil or, underground waters), and trends (in e.g. desertification), hazard of natural or of man triggered disasters - dangerous directly for man, for infrastructure or for the environment), shall be standardized for their better interoperability. As for today, all or most of these maps are widely produced according to arbitrarily outlined formats, so that their lateral or vertical compatibility with others is in most cases nil.
3 - The sets of complex geological thematic maps must bear the inspirational, conceptual, and decision supporting values in a graphical form. Especially, that a cultural transition of modern times leads towards a pictographic communication culture, which substitutes a scripture culture, the geological maps must appeal to user equally through the merit and, their analogous looks. Noteworthy is that symptoms of such a transition in information technology are already seen as pictograms e.g. at the international airports.
4 - Moreover, the modern geological map shall be interactive and must bear the main load of information modularized thematically, with links to various geological and other related databases. Only summaries, and concise specific report texts with addition to data tables shall be considered as essential supplement of geological map.
5 - The modern map shall be, and in some cases already is mainly in virtual form, recorded in digital format, and kept in a relational database as a collection of several preprocessed thematic modules bearing information on:

Preprocessed basic thematic modules of virtual map

- **Topography**, including the digital terrain model (DTM) and drainage pattern
- **Geology**: lithology, stratigraphy and structure, possibly supplemented with cross sections, litho-stratigraphic columns and 3-D, 4-D models (the 4D is the method of presentation the paleography, history, trends and prognoses),
- Mineral, water, energy, and soil **resources**
- **Geophysical and radar data**: anomaly maps, key horizons
- **Land resources**, values, use, and recommended usability (soil units and geotechnical data, landuse and building grounds, restricted, protected and excluded areas)

- Ecological and civilization **hazards**
- **National and natural heritage** important areas
- **Recreation and tourist activity**,

Such a virtual map should bear compulsory and optional information, made ready for updating, presentation, and supplementation. As that information comes from various sources, the essential problem is the data exchange procedure. Its technical, formal and legal aspects shall be made operable at the governmental levels.

6 - Because of a wider topic spectrum [in modern geo-maps], the data on new subject to be mapped should be collected, authorized and delivered to the map-core database (for incorporation into a complex peri-geological map and its related database in a GIS manner by various specialists. This can be done by specialists representing geology and other sciences - as geography, hydrology, forest and agriculture, soil science and civil engineering, climate, urban and land use planning, architecture, environment protection, and even monument protection).

7 - The International Committee on the Earth Digital Mapping Standards (ICEDMAS) could be the best solution for further establishing of close working relationship between the international scientists with different professional experience in geoscience. The existing knowledge, unified by formal frames of standards, and synthesized by cartographic means, may help in establishing the joint maintenance and security of sustainable mankind development on the global and the local scale. So far, the global modification of geoscientific mapping remains in the sphere of good wishful thinking. The first few steps have been, however, made. The whole globe has been already covered with the satellite interferometric radar pictures, and the DEM maps are free available, as available are Landsat images. The resolution of these materials remains good as reference material for maps within the range of 1:1 mln. and a smaller scale. At that scale much information on land sculpture, and land cover is extractable, thus supplementing other thematic maps of the same scale with data on landcover and landuse information is already possible.

CONCLUSIVE REMARKS

1. Due to successive gathering results of geological researches, enormous load of data still awaits processing and re-processing according to modern knowledge.
2. Modern geological mapping shall result in configuration of dedicated database with related links and algorithms enabling supplementation of base with original field data, preliminary processing of basic maps, access to and

visualization of the database content in various thematic compositions, and for various applications.

3. Classification, systematisation, pre-processing of geological database content, and user-oriented visualisation must be ruled by universal framework of standards, necessary for quick outlook of visualized data without the necessity of studying detail explanations.

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NEW BASE-MAP FOR GEOLOGICAL MAPPING - THE DEM

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Abstract: Since the XIX century detail geological maps were produced in series of sheets with standardized format. At least three factors in all sheets of series were unified and controlled:
- The location of geological unit in geological space was controlled by a base-map made of standard topographic sheet according to conventional flat co-ordinate systmem; the third ordinate the elevation with respect to see level, was controlled by the topographic elevation, and the depth, determined by drilling data or geometrical contruction according to geological intersection rules.
- The location in time was determined according to order of geological layers, sequence of events leading to development of certain structures, and in more Recent times according to various independent dating technologies.
- The third location - within the various classification tables was controlled by the current geological knowledge and by conventional classification tables.
All map units were documented by rock samples, descriptions and drawings in a field notebook, and by the laboratory analyse results. All the documentation related to certain map-sheet was kept in archives. With the introduction of computer technologies, that relatioships between the map and map documentation is subjected to the GIS standards. However, the modern computer technologies may provide additional tools for geological mapping - which shall improve better agreement of determined geological units with the terrain topography. One of such tools is the Digital Elevation Model, which can serve as both, the an information source for fining geological boundaries, controllong elevations, and at the same time play a role of mapping base for various surficial thematic maps.

Keywords: Geological cartography, electronic means, base map, DTM,geological intepretation of DEM, terrain sculpture

Since the Rene Descartes invention, for several centuries now, all maps were related to geographic grid. For better perception, all maps are bearing some reference items, which are not directly related to the map topic. Usually these are known, obvious topographic elements of the terrain – mostly ecological features as the main rivers, lakes and seashores, mountain peaks, and settlements with names. For the obvious reasons, the reference matter was selectively discriminated and generalized in order to keep map free of overloading with trivial information. New maps of digital technologies era can and shall be furnished with optimum terrain reference information held in relational database. The most important in a whole geoscience, is the relationship of structure, and the processes within the Earth' lithological substance represented by rock-mass and its superficial

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 89–96.

sculpture imaginable by digital elevation model – i.e. DEM. Thus, the DEM, besides the geographical coordinates shall be the main element of a reference base in cartographic presentations in geoscience (Ostaficzuk 2003).

The applicability of DEM

The digital elevation model (DEM), selectively refined, can be purely used as a base for various thematic maps. It may be also used as an original additive to other thematic maps, allowing their adjustment in many ways. The one set of available terrain elevation data can be used for generating various terrain models with specific projection, shadowing, vertical exaggeration, colouring and graphic structure, serving as inspirational, controlling, and comparative material in modern geological cartography. The limitations are practically made by original resolution of data grid.

Graphical examples of DEM demonstrated below are all derived from the single DEM level 2 (kindly provided by Military Geographic Inspectorate of the Polish Army (ZGW 2000), of the following properties: Catalogue DTED was organized according to STANAG 3809 with data in exchange standard DTED 2000 LEVEL 2 on the territory of Poland. Digital Terrain Models were generated in GRID format, Intergraph, 1998-2000. The map data were gridded with accuracy 3600 x1800 per 1^{o} quadrangle, and the southernmost part of Poland with accuracy of 3600x3600 per 1^{o} quadrangle.

The elevation data source were digitised contourlines from topographic maps 1:50 000, what limits the geological applicability of DEM to regional scales only; the greatest presentation scale acceptable without a loss of quality remains 1:200 000.

The DTED was used for generating models of geological sculpture of the whole territory of Poland, see the:

www.igf.edu.pl~so/dem

The selected parts were generated in the condensed contourline form, some were shadowed, and some were presented as colour-elevation maps (ditto). No perspective view was considered fit for geological interpretation, however for general outlook of pseudo 3-D surface view, the oblique models were generated.

All the digital terrain models appeared applicable for the large- and small-scale geological mapping of widened spectre of mappable subjects including of eco-geological problems, landuse, engineering and hazard zoning, anthropopression, and landuse. Various coloured and shadowed models were generated for standard-sheet geological quadrangle map 1:200 000 on the purpose of the best presentation of geological features, as imprinted in the terrain sculpture. Figure 1 presents various images of DEM surface quadrangle typical for the Polish Lowlands.

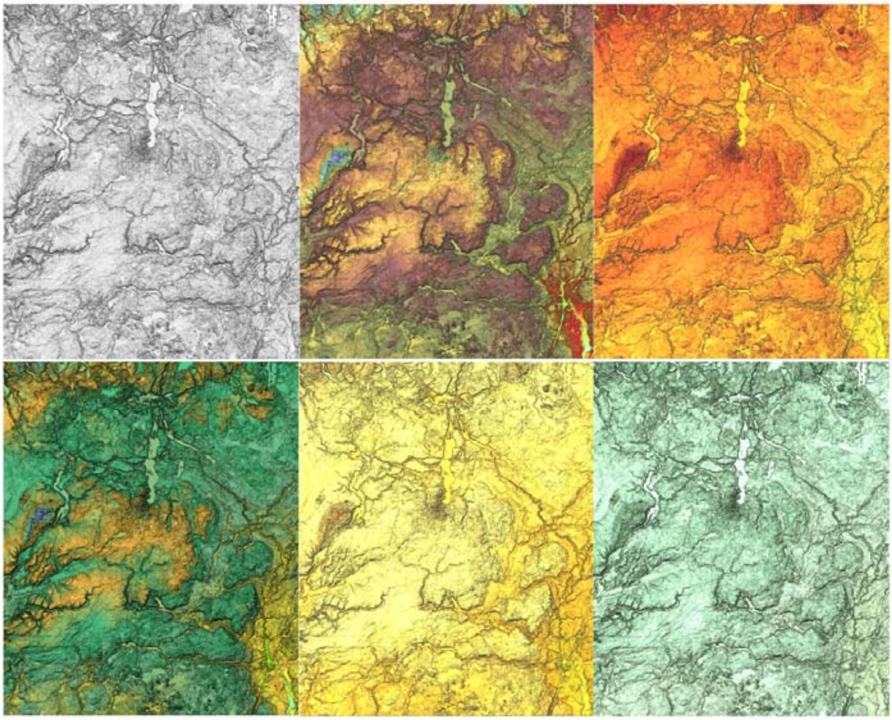

Figure 1. The 1:200 000 standard sheet quadrangle (60'x 40') Chojnice. DEM generated cartographic base for geological analyse of genetic background of terrain forms. Polish Lowlands; in order to emphasize various terrain features, the DEM was subjected to changes of angle of elevation and direction of lightning, colouring scale and vertical exaggeration; (DTED kindly provided by ZGW). Width of each picture is equal to about 70 km in terrain.

During geological interpretation of the postglacial landscape of central and northern Poland some minor morphological features not mapped there so far by specialists (compare e.g. Figure 2, quadrangle Leszno) appeared surprisingly clear in the condensed contourline manner.

By minute changes of coloration, contour intervals and an angle of light one can emphasize normally diffused features on standard images, what may help in better understanding of dynamic history of the terrain. These were (Ostaficzuk, in: ARW 2003) gigantic rippled tongs, fossil suspect rockslide, terminal moraines of various morphologies, linear mega-scratches, dunes, and dune-fields hidden in the forest.

The more specifically applicable are condensed DEM pictures for verification of older versions of geological maps. On Figure 3 is compared a portion of geological map, with DEM presented by shadowed morphology. What is significant regarding geological maps and DEM expressions can be summarized as the lack of matching with DEM of these map units, which were determined on the genetic base. The terminal moraines, alluvial fans, eolian sand dunes, terraces on the geological map do not fit their expression on DEM either presented in the form of condensed contour lines, or variable shadowed images.

The same DEM can serve generation of images good for detecting small structural features, as landslides, sequences of debris cones, faults and folds, and the young tectonic features e.g. cutting through the loessial plateau. The advantage of digital terrain elevation models lays in the total elimination of the terrain cover from images. E.g. most of landslides in Carpathians are obscured by forests. For the same reason, the complicated pattern of subglacial valleys on the Polish Lowlands is totally available to observation only on the DEM image.

Figure 2. Condensed contourlines emphasize minute terrain features diffused or masked in the field by forest cover; DEM. Width of the picture is equal to about 70 km in terrain.

Attempts for innovating the geological cartography can not be successful without extensive use of the DEM at the almost all stages of geological mapping procedure – from the work plan for mapping, through the remote sensing documentation, to outlining (or contouring) of geological units, to supplementary sketch-maps on geomorphology, engineering geology and hazards.

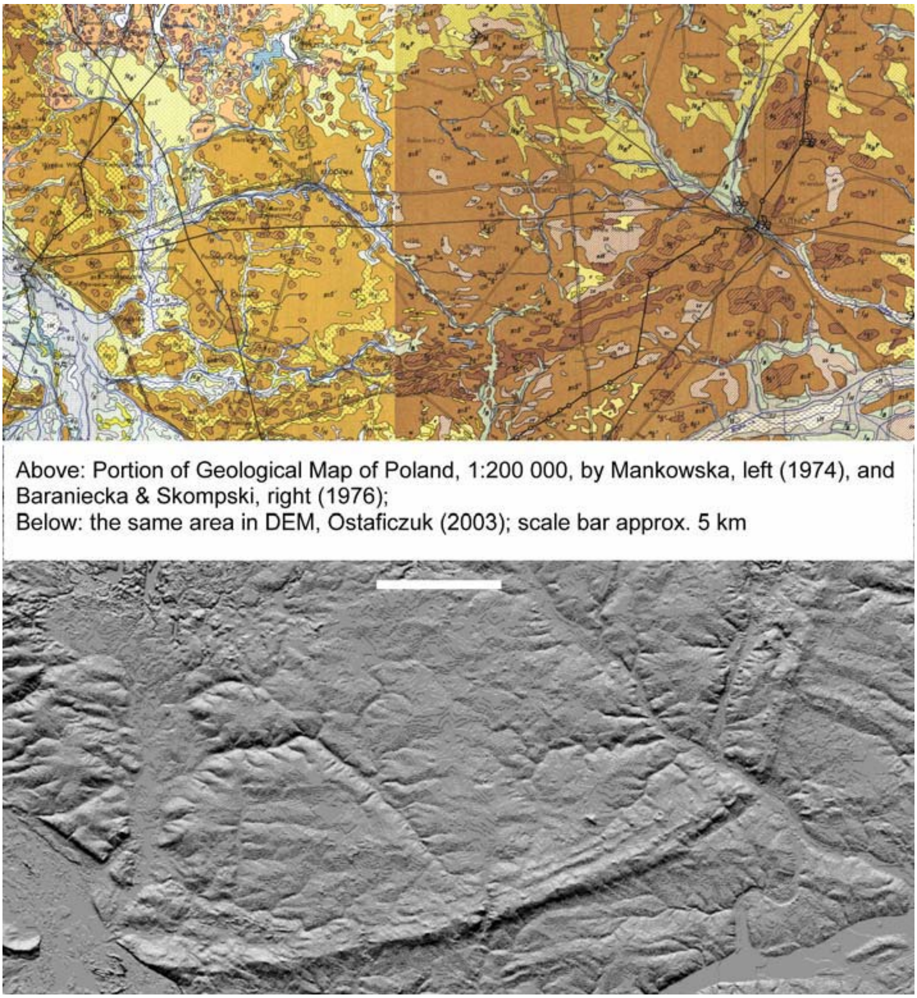

Figure 3. Comparison of shadowed DEM of the terminal moraine with its representation on geological maps 1:200 000. The regular and significant form on DEM appears diffused and disintegrated on geological maps. Width of the picture is equal to about 50 km in terrain.

As shown on Figure 4. even the DEM derived from 1:50 000 scale topographic maps may reveal bedding within monotonous silty-clayey flysch deposits obscured by two meters thick soils, and weathering and deluvial debris.

Thus, the DEM shall be made available through the web for all mapping geologists, and they must use it obligatorily. The easy access to DEM cannot result in random production of arbitrary configured materials. Therefore, in a production of serial maps, the DEM, amongs other applications, should be utilized as a basic editorial material for verifying and controlling draft materials provided by various authors.

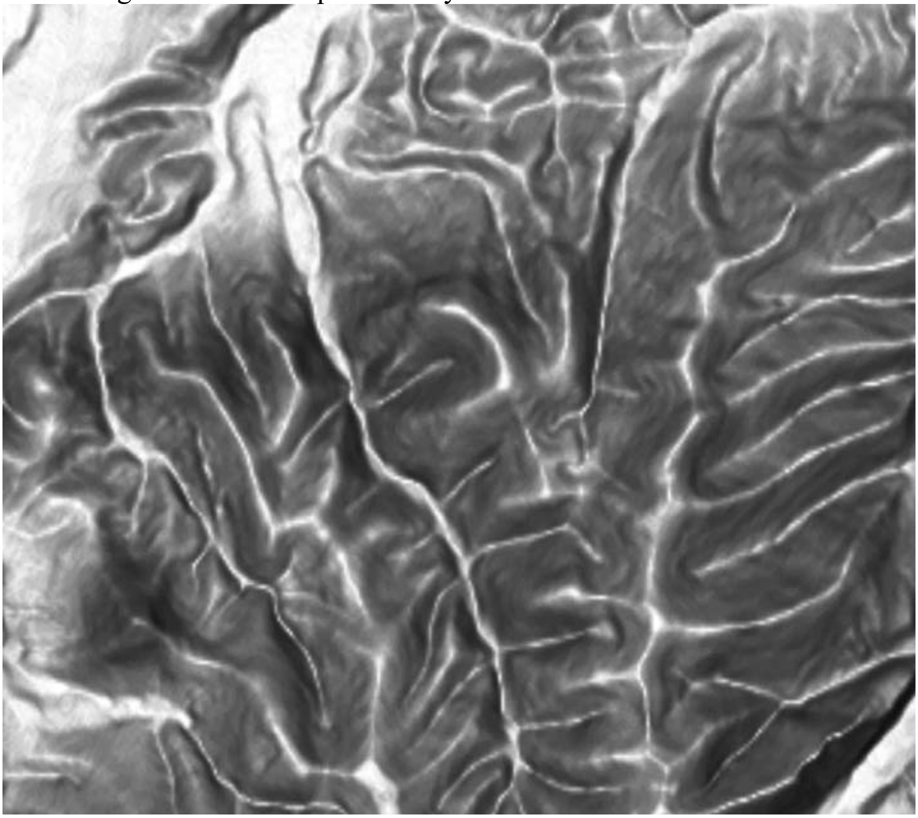

Figure 4. Condensed contourlines generated from DEM; Podhale flysch; Inner Carpathians; note in the erosion clefts delicate bedding marked by darker and lighter bands diagonal to contourlines. In places, continuity of bedding is apparently disturbed either by tectonic faults, or by landslides. Width of presented area is about 15 km.

Efforts should be made for producing DEM of a resolution standard higher than the level 2. Elevation data for the level 2, being derived from topographical maps 1:50 000 are affected by map-generalization process, which mainly deprives model of minute morphologic features of great importance in recognizing impact of geological various features on terrain morphology. The optimum terrain elevation model shall be made either from direct terrain elevation data acquired by photogrametric, laser, or other such a method or, from the non-generalized basic topographic maps, issued in the terrain-gradient dependable scales 1:5 000 to 1:25 000. Such a model will be of, difficult to overestimate high value for engineering geologists, landuse planners, and for hazard mitigation and land security maintaining actions.

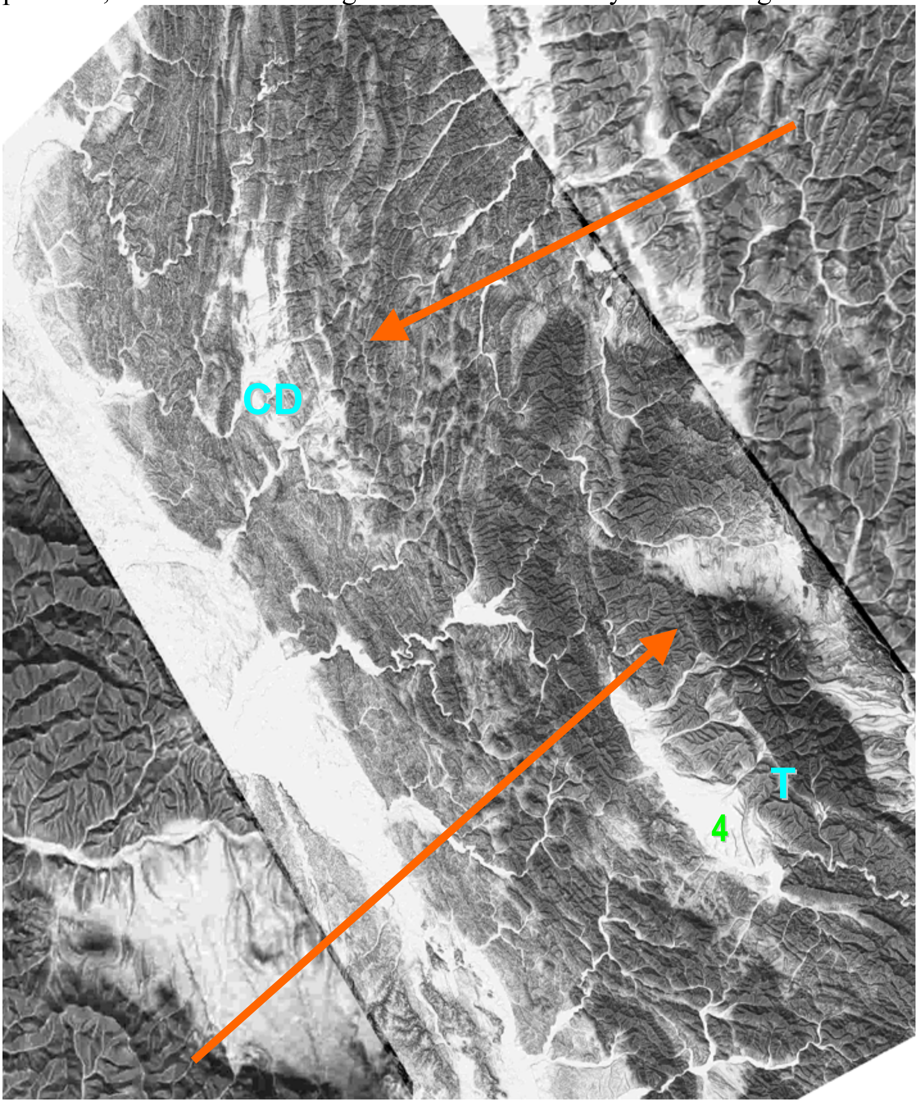

Figure 5. DEM, Carpathians; perspective view from SW. Note the distinguished Central Carpathian Depression (CD), differentiated lithological flysch complexes, faults and folds. The width of presented area is about 150 km. Arrows show location of insets; Tatras (T), (4) - approximate location of Figure 4.

In attempt to providing unaffected by author's suggestion materials for reader's assessment, the examples presented here are void of any interpretation or selective corrections (Figs 4 and 5). All pictures are shown, as they appeared on the screen during overly determination of model parameters.

It must be also mentioned, that in the process of preparation for printing reproduction, a considerable portion of the geological information derivable from pictures was lost. Thus the best way of extracting information from DEM is making geomorphological interpretation on the computer screen or to make a tapestry of pseudo 3D terrain image upon the draft geological map.

CONCLUSIVE REMARKS

1. Digital terrain elevation model (DTM) constructed according to geological requirements shall be obligatorily used for identification and delineation of geological map units, and as a base for their presentation.

2. Satellite imagery shall be considered as an integral map module within the set of documentation material, and kept in the relative map database.

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SOCIETAL AND ECONOMIC BENEFITS OF THREE-DIMENSIONAL GEOLOGICAL MAPPING FOR ENVIRONMENTAL PROTECTION AT MULTIPLE SCALES: AN OVERVIEW PERSPECTIVE FROM ILLINOIS, USA

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Abstract: Since the late 1960s, the Illinois State Geological Survey has been developing three-dimensional (3-D) geologic mapping methods specifically for the protection of groundwater and for helping decision makers and the public assess the environment of the State. When the geologic framework is well understood, land-use planning can be more effective in preventing contaminants from entering aquifers. Approaches and procedures for creating issue-driven geologic maps for groundwater protection have been developed for scales from 1:24 000 to 1:500 000. Because the procedures for developing 3-D geological information have been consistent, the resulting maps are relatively uniform. Issue-driven maps for aquifer sensitivity derived from interpretations of the 3-D successions of geologic materials provide guidance to regulators seeking to ensure maximum protection for groundwater where aquifers are especially vulnerable, and avoid overprotection where natural safeguards exist.

Scientifically defensible benefit:cost studies in Illinois and Kentucky document the economic importance of having geologic information available to a wide variety of users over extended periods of time. The economic studies showed that for every State government dollar spent on geologically mapping 21 1:24 000-scale quadrangles in Winnebago and Boone Counties, Illinois returned as much as $55 in potential reduced costs for environmental cleanup. The comprehensive 20-year geologic mapping program that produced 707 1:24 000-scale quadrangles for the State of Kentucky yielded between $25 and $39 in returns for every State and Federal dollar spent.

Keywords: Three-dimensional geologic maps, aquifer sensitivity, benefit:cost studies, scale-independent maps

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 97–114.

INTRODUCTION

Geologists at the Illinois State Geological Survey (ISGS) in the United States (US) have worked diligently since the 1960s (see e.g. Larson and Hackett 1965) to supply the geological information needed by water and land-use planners to make science-based decisions about environmental and land-use problems. Geologic information must be provided to decision makers in an understandable fashion so that they can recognize the importance of properly locating and mapping aquifers, and evaluating their potential to become contaminated. It has been essential that maps are consistent from both a geologic and a cartographic perspective, regardless of map scale. Once identified, existing environmental problems can be better understood and mitigation efforts can procede, prevention efforts can be developed to eliminate situations where environmental problems may occur in the future, and the water-resource potential of groundwater can be optimized. A goal of the ISGS program has been to provide decision makers with a meaningful basis for balancing environmental protection and economic development.

The purpose of this paper is two-fold: (1) to provide an overview of how the ISGS has developed three-dimensional (3-D) geologic mapping specifically for the protection of groundwater and for helping to assess the environment of the State, and (2) to discuss the societal and economic benefits of geologic mapping. The former is based on case studies of several mapping programs conducted at various scales (Berg 2002). The latter involves evaluation of how geologic information was used by various public agencies and the private sector. Included in the discussion are results of two detailed economic benefit:cost analyses by Bhagwat and Berg (1991) and Bhagwat and Ipe (2000). The location of Illinois in the US and areas of case studies are shown in Figure 1.

Figure 1. Location maps showing Illinois and discussed study

BACKGROUND

In Illinois, aquifers are composed of glacially deposited sands and gravels, porous and permeable sandstone, or fractured/jointed carbonate bedrock. By definition, an aquifer is saturated and sufficiently permeable to yield economically useful quantities of groundwater to wells, springs, or streams. Since aquifers yield significant supplies of water and allow water and/or contaminants to travel at relatively rapid rates, those that are buried at shallow depths potentially are vulnerable to contamination from a wide variety of surface and near-surface point and non-point sources. Fine-grained low-permeability materials are not considered aquifers even if they are water saturated.

The continuity and depth of aquifers and non-aquifers directly controls the movement of contaminants and groundwater. The potential for an aquifer to become contaminated depends on the natural protective properties of the geologic materials that lie above and below it. The greater the thickness of fine-grained, low-permeability materials between an aquifer and a potential contaminant source, the less likely the aquifer is to become contaminated (Berg et al. 1984a, b).

Studies in Illinois (Schock et al. 1992; Mehnert et al. 2003) validated the above by investigating the presence of agricultural chemicals in aquifers. The results showed that shallow aquifers were more likely to be contaminated than deeper aquifers.

Determining the 3-D configuration of geologic materials and their water-transmitting properties is an essential part of an initial evaluation for protecting groundwater. The subsurface geology must be analyzed and mapped with as much detail and consistency as possible, such that the thickness, geographic extent, burial depth, and material properties of the aquifers are determined accurately.

A working sedimentological model is also an important ingredient because of its ability to predict the continuity of subsurface geologic units in areas of sparse data (Artimo et al. 2003). Once 3-D geologic information is available, various successions can be rated (based on the depth to the uppermost aquifer and aquifer thickness) according to the relative likelihood that an aquifer within the succession may become contaminated by a surface or near-surface source.

The final element is having consistent portrayals of cartographic, geologic, and other information on maps for ease of use by non-geologists. Critical questions can then be answered by using the maps, leading to wise development, water allocation, and environmental protection decisions.

PROTECTING GROUNDWATER USING AQUIFER SENSITIVITY MAPS AT VARIOUS SCALES

The following examples discuss the development of 'scale-independent' groundwater protection (or aquifer sensitivity) maps for Illinois. The same general approach is useful whether the mapping is done at a large (1:24 000) or a small (1:500 000) scale.

County Aquifer Sensitivity Mapping at Scales of 1:24 000–1:62 500 (Boone and Winnebago Counties)

In the early 1980s, the ISGS conducted a 3-D geologic mapping program for Boone and Winnebago Counties (see Figure 1—Winnebago County is highlighted and Boone County is to he east) (Berg et al. 1984b). The counties, with an area of 2059 km^2, had experienced rapid population growth and accompanying environmental problems. Winnebago County has the most vulnerable groundwater resources in Illinois (Figure 2); sand and gravel and bedrock aquifers are near the land surface, there is extensive industrial development, and the county has experienced problems with waste-disposal practices.

For this study, all data were plotted on 21 1:24 000-scale topographic maps. Data consisted of an analysis of 1800 samples from over 300 locations from field exposures and logs of engineering and construction borings, as well as 29 test borings done specifically for the project. Data from logs of about 5000 water wells provided information on depth to bedrock and the absence/presence of sand and gravel aquifers. All well locations were verified via plat book and field checks. The succession of geological materials as depicted on water-well logs was constantly compared to known successions at the 29 test-boring sites as well as to logs of engineering borings and examination of field exposures. The result was a workable predictive geological model of the two-county area.

Mapping the 3-D geology was accomplished using a stack-unit map approach where the various successions of geologic materials were depicted from the land surface to a depth of 6 m. Forty-three different geologic materials were given alpha-numeric codes depending on their thickness and degree of continuity. Cross-sections were used to portray the full succession of materials to the bedrock surface. All maps were reduced to a scale of 1:62 500 to best accommodate portrayal of the geologic and issue-driven maps for the two countries.

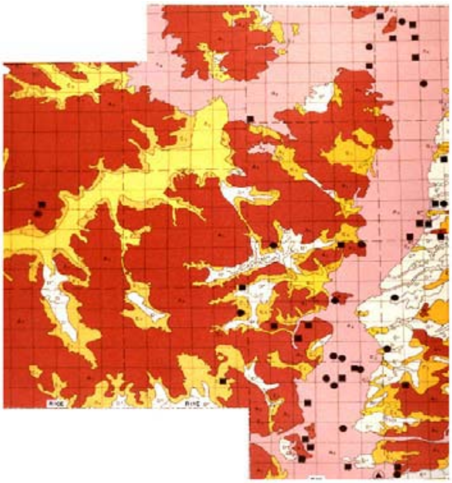

Figure 2. Aquifer sensitivity for part of Winnebago County, Illinois. Red and pink areas are highly vulnerable. Black dots and squares are contamination problem areas.

An aquifer sensitivity map extended to a depth of 15 m. Figure 2 shows a portion of that map for Winnebago County. A red, yellow, and green coloring scheme reflects various degrees of aquifer sensitivity. Areas rated ‘A’ and ‘B’ (red and pink) have highly permeable bedrock or sand and gravel within 6 m of the land surface. Areas rated ‘C’ (yellow) have highly permeable bedrock or sand and gravel at between 6 and 15 m of the land surface, overlain by low-permeability fine-grained materials. Areas rated ‘D’ (light green) contain no sand and gravel within 15 m of the surface and are composed of uniform sandy glacial tills. Finally, areas rated ‘E’, ‘F’, and ‘G’ (not shown on Figure 2) also contain no sand and gravel within 15 m of the surface. Areas rated ‘E’ have thick (>15 m) fine-grained tills at the surface, while areas ‘F’ and ‘G’ are underlain by >3 m of shale. The presence of sand and gravel or highly permeable bedrock was assumed to indicate aquifers or potential aquifers in the succession. The ISGS recommended that landfilling of wastes should not be permitted in ‘A’ and ‘B’ areas, and that landfills might be acceptable in ‘C’ and ‘D’ areas, but careful site investigations were needed before approving such a use. Areas rated ‘E’, ‘F’, and ‘G’ were considered to have the lowest potential for contamination because of the lack of aquifers. However, careful site investigations were still strongly recommended.

Benefits and Costs of the Boone–Winnebago Counties Mapping Program

Ten years after mapping was completed in Boone and Winnebago Counties, a follow-up investigation was conducted to assess how the geologic and issue-driven maps, had been used by local officials and the public to address critical water-related environmental issues. The investigation was performed in response to a State mandate that required the ISGS to document the costs and benefits of geologic mapping (Bhagwat and Berg 1991). This 1991 assessment was the first known economic benefit/cost study of a geological mapping program. The costs of the mapping were well documented because the two counties had provided contract dollars for the mapping program. The fiscal benefits were estimated based on future costs to society that could be avoided as a result of the knowledge gained through the mapping program. The benefit/cost study identified the following uses and benefits of the maps.

- There were reduced costs for selecting sites for waste disposal.
- Up-to-date knowledge of geology, hydrology, and geologic material characteristics was provided for use by county officials and consultants.
- There was improved confidence in environmental decision making.
- Costly oversights, such as building subdivisions over buried peat bogs, were prevented.
- ‘Hot spots’ were delineated, indicating areas where leaking underground storage tanks may be causing groundwater contamination problems.
- Land-use zoning and ordinances were developed to minimize septic-tank densities and restrict sewage sludge applications in areas where aquifers were close to the land surface.
- Water-well drillers used the maps for locating water supplies.

Estimates of avoidable costs arising from the use of the maps were derived from 55 personal interviews with officials from health and planning agencies, as well as private consultants and industry representatives. Because only part of the avoidable costs of cleaning up contaminated waste disposal and industrial activities could be attributed to use of the maps, the value of the benefits was very conservative. It only dealt with one potential use of the maps and not all of the potentially avoidable costs. It was realized that geologic mapping and aquifer sensitivity assessment could not eliminate all the costs of cleaning up contaminated sites, but the maps could have reduced these costs considerably if they had been available and used properly.

Based upon a $300 000 cost (in 1990 dollars) of the early 1980s mapping program and estimated benefits from avoided costs of $1.4 to $16.3 million, the benefit/cost ratio for the Boone and Winnebago Counties mapping program ranged between 5:1 and 55:1. The range in avoided costs depended upon various degrees of regulatory effectiveness (based on assumptions that existing and future laws and regulations would prevent contamination from occurring) and economic discounting (to account for delays in proper utilization of knowledge gained from the mapping program).

Since the 1991 study, continued follow-up work has revealed further benefits from the 1980s 3-D mapping program. J. Maichle Bacon, Director of the Winnebago County Health Department (personal communication, 2003), states that 3-D geologic information has provided a framework for understanding the environmental context for groundwater resource availability and protection issues. Three-dimensional geologic mapping greatly enhanced the identification of problems and focused attention on vulnerable areas so that education, inspections, and land-use planning could get ahead of potential problems. Specifically, the geologic information provided incentives for targeting of prevention initiatives because high-risk ('hot spot') locations to test for potential contamination were identified. Three-dimensional geologic maps and aquifer sensitivity maps were overlain with maps showing areas of industrial and residential development. Evidence of contamination consistently was found in areas where the geology and industrial development patterns indicated it was likely to occur. Winnebago County residents were warned of contamination problems and prevented from drinking contaminated water in eight or nine specific situations. In addition, because limited sampling resources were focused in these areas of higher risk, there was far more efficient use of the limited financial resources to deal with contamination and related human issues.

Aquifer Sensitivity Mapping at a State-wide Scale of 1:250 000–1:500 000

In the 1980s, the Illinois Environmental Protection Agency (IEPA) supported an ISGS project to map the shallow aquifers (within 15 m of the surface) throughout the State (Berg et al. 1984a), an area of about 150 000 km^2. Information on the distribution of aquifers within 15 m of the surface was compiled by reviewing descriptive logs of water wells, engineering test borings, and coal and oil exploratory borings. Subsurface information from about 25 000 wells was plotted on 1:62 500 or 1:24 000 topographic maps.

Building on the procedures used in the Boone and Winnebago Counties study, a state-wide stack-unit map to a depth of 15 m was constructed at a scale of 1:250 000 (Berg and Kempton 1988). The map has 5199 individual map polygons and 815 different successions of geologic materials. The 815 successions were rated according to their water-retaining/water-yielding properties, the capacities of the geologic materials to attenuate waste chemicals, and the positions of aquifers within the successions. The successions were then grouped into 18 aquifer sensitivity categories. Map units A, B, and C all had aquifers within 15 m of the surface (Figure 3, red, orange, and brown areas), whereas map units D, E, F, and G lacked aquifers within the upper 15 m (Figure 3, yellow areas).

The 1984 map was used to assess State-wide aquifer sensitivity and set priorities for future site-specific studies of hazardous waste sites. It also was used to develop groundwater protection legislation (1987 Illinois Groundwater Protection Act) by showing the variability of State-wide geologic conditions (i.e. location of sand and gravel and highly permeable bedrock aquifers) and relating the map to water quality data.

In 1990 the State-wide map of aquifer sensitivity was updated (Figure 4) by including recharge rates and identifying areas of the State where recharge was rapid and plentiful. It included both hydraulic conductivity information from surface soils (as a proxy for recharge potential) and, more importantly, information about deep aquifers (Keefer and Berg 1990). Figure 4 shows major (those producing >378 000 liters per day (lpd) sand and gravel aquifers at any depth and major bedrock aquifers within 90 m of the land surface (purple, red, orange, and brown areas). Specifically, the 1990 map was used by the IEPA to establish Regional Groundwater Protection Planning Regions in Illinois, as well as to delineate potential problem areas of the State where more detailed studies may be warranted. Regional Groundwater Protection Planning Regions advocate region-specific groundwater protection matters and recommend to the IEPA whether there is a need for regional recharge protection.

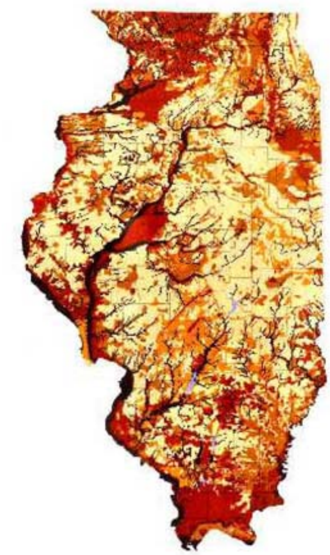
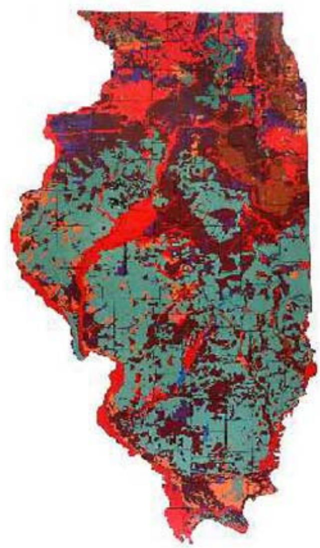

Figure 3. (Left-hand) State-wide aquifer sensitivity to a depth of 15 m.
Figure 4. (Right-hand) State-wide aquifer sensitivity to a depth of 90 m.

The State's aquifer sensitivity map was improved again in 1995 when the IEPA and US Environmental Protection Agency proposed that agricultural pesticide application rates should be regulated or banned in individual counties, or across the State, based on groundwater's use, value, and vulnerability to contamination. To help the State respond to this need to assess groundwater vulnerability, the ISGS developed soil leaching maps and aquifer sensitivity maps by employing map units based on all the aforementioned criteria, as well as amounts of soil organic matter and soil hydraulic conductivity (Keefer 1995). This mapping has also served as the basis for establishing a dedicated monitoring well network to validate the relationship between the map units and the presence of agricultural chemicals in aquifers.

Quadrangle Aquifer Sensitivity Mapping at a Scale of 1:24 000

The ISGS program of 3-D geological mapping and modeling of 1:24 000-scale quadrangles began in the late 1990s and the Villa Grove Quadrangle (Figure 1) was selected as a pilot study to assess various field mapping techniques and related map production procedures. In the Villa Grove Quadrangle, an area of about 145 km^2, the mapping was based on data extracted from descriptive logs of water wells, highway and bridge borings, ISGS test borings, and outcrop field observations. Data from about 250 logs and field observations were used to delineate the thickness and areal distribution of diamictons and sand and gravel deposits in the subsurface. All data were assembled and evaluated in a digital environment. Structure contour (elevation) and isopachous maps of subsurface aquifer and non-aquifer units were compiled and a 3-D model of the geology was developed (Figure 5).

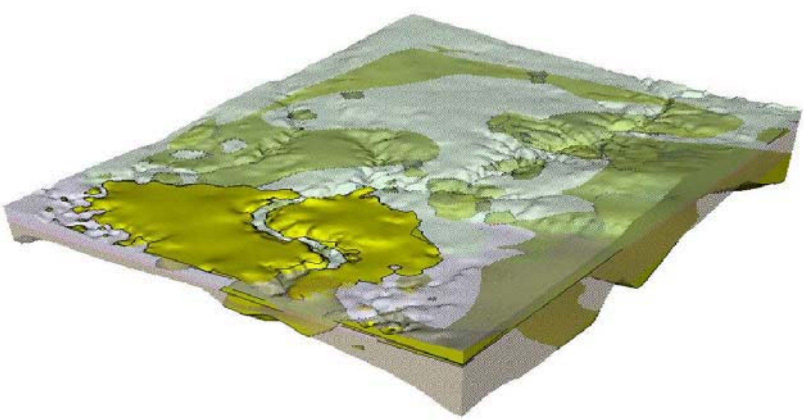

Figure 5. Three-dimensional block showing the Quaternary geology of the Villa Grove Quadrangle.

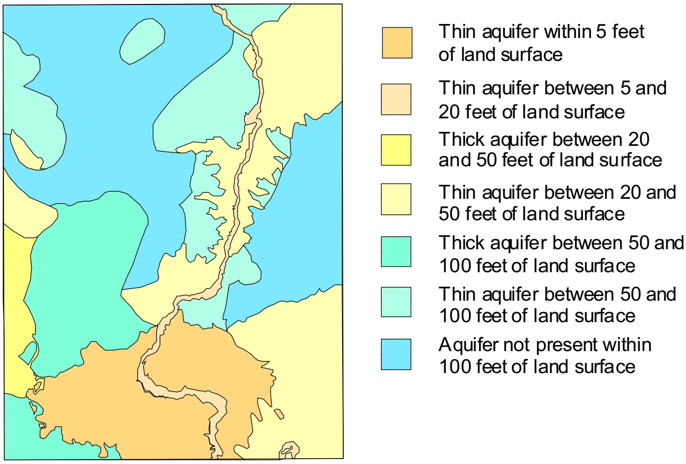

Figure 6. Aquifer sensitivity map of the Villa Grove Quadrangle; surface and buried aquifers are shown as yellow and tan.

Development of the aquifer sensitivity map for the quadrangle followed the same general protocols that had been established for the county- and State-wide aquifer sensitivity assessments, except that this quadrangle map assigned sensitivity ratings to successions of geologic materials extending to a depth of 30 m (Figure 6) (Berg and Abert 1999). The 15 different geologic successions mapped on the quadrangle were assigned to seven aquifer sensitivity classes according to the decreasing sensitivity of aquifers to contamination, based on the ability of the geologic materials to protect groundwater in the uppermost mapped aquifer material from potential contamination from a variety of sources. Map Unit B (Figure 6, orange areas), the unit in the quadrangle with the greatest potential for aquifer contamination, comprises sand and gravel deposits less than 6 m thick that are within 1.5 m of the land surface. Map Unit E (Figure 5, blue areas), which has no potential for aquifer contamination, has no sand and gravel or fractured and jointed carbonates present within 30 m of the land surface.

NEED, VALUE, AND IMPORTANCE OF GEOLOGIC INFORMATION: THE KENTUCKY MAPPING PROGRAM

Illinois has been mapped in its entirety at a State-wide scale of 1:500 000, and several counties, like Boone and Winnebago, have been mapped at larger scales. However, comprehensive and systematic mapping at 1:24 000 has not been accomplished. Only about 5% of the State has been mapped at a scale that planners and other users deem necessary for proper evaluation of water and land resources and for dealing with associated environmental problems. In contrast, Kentucky is the largest State that has been mapped completely at the 1:24 000 scale. Between 1960 and 1978, the US Geological Survey and the State of Kentucky geologically mapped all 707 of Kentucky's 1:24 000-scale quadrangles. Kentucky is the first and only State to be completely geologically mapped at this detailed scale. The purpose for mapping was primarily to support the mineral resource industry of the State.

According to Anderson (1998), before the geologic mapping program commenced, the benefits of geological mapping for Kentucky and the significance of complete State-wide large-scale map coverage were clearly demonstrated to government officials and politicians. As a consequence, the Kentucky State legislature matched Federal funding, and the 707 quadrangles were mapped over an 18-year period. Anderson (1998) reports that the benefits for the State have been tremendous, and a benefit:cost ratio was conservatively estimated at 100:1, based mainly on the value of newly discovered oil and gas deposits, coal beds, mineral deposits, and cost savings for strategic planning in highway and engineering construction.

In 2000, ISGS economists Bhagwat and Ipe (2000) conducted a detailed and scientifically defensible benefit:cost analysis of the Kentucky geologic mapping program by surveying, via questionnaires, over 500 users of Kentucky geological maps. The results of this evaluation provided many insights into geologic mapping needs and standards. Figure 7 shows that, although the mapping was justified as a way to support the mineral resource industries of Kentucky, only 30% of the use of the maps was for coal, oil and gas, and industrial mineral exploration and development, whereas over 70% of the use was for groundwater purposes.

Those involved with pollution prevention, industrial siting, and site clean-up activities were all heavy users of the maps, as were those involved with hazard prevention and protection (particularly those dealing with karst and subsidence issues), and engineering applications. Figure 8 shows that the maps were also used extensively for city and regional planning, and to help value property for taxing purposes.

Those involved with locating waste disposal sites and issuing permits for industrial development and activity in particular were heavy users of the maps (about 45% and 38% respectively).

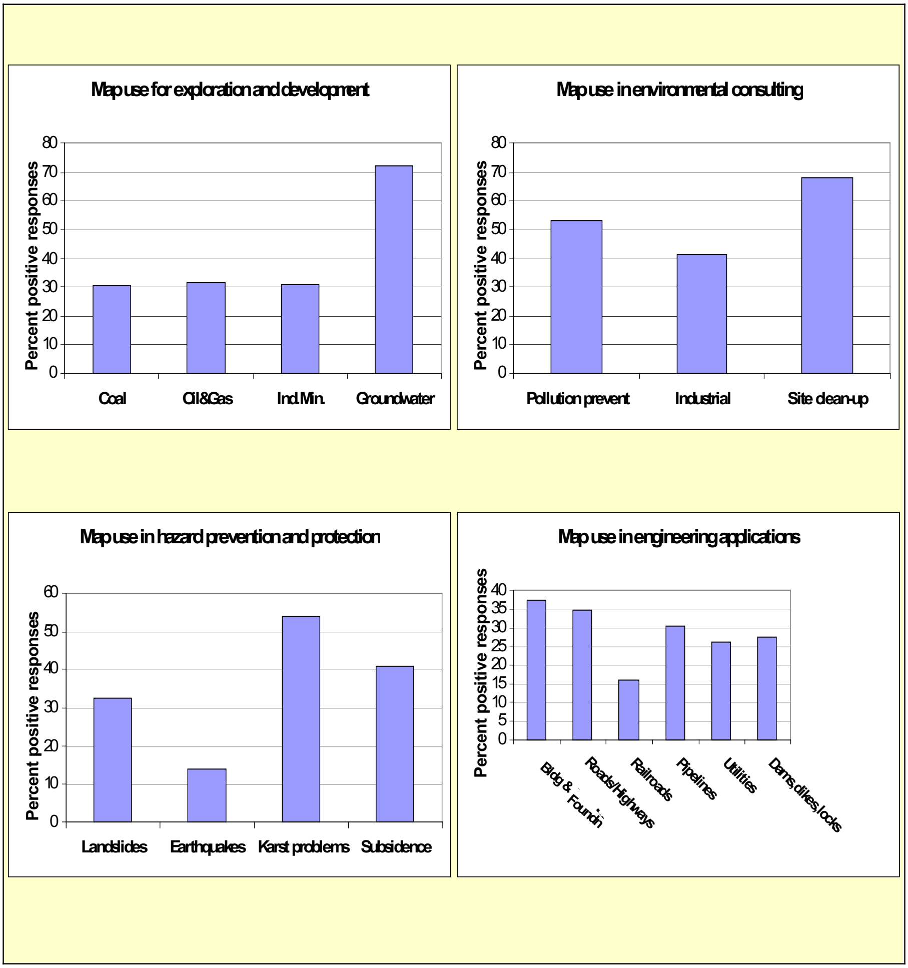

Figure 7. Uses of Kentucky geologic quadrangle maps for exploration and development, environmental consulting, hazard prevention and protection, and engineering applications.

Figure 9 shows the map features and scales and modes of map use most desired by users of the Kentucky geological maps. Over 70% thought that lithology, structural features, and formation contacts were very important. Also, over 70% used the maps as overlays and copied and enlarged them. Only about 38% of the users viewed and utilized the maps in a Geographic Information System (GIS). However, since 2000, when the Bhagwat and Ipe report was published, the Kentucky Geological Survey has had an active program to digitize their maps, and the 38% figure would be considerably higher today. Figure 9 also shows that about 90% of the users stated that the most useful map scale was 1:24 000. Less than 25% of the respondents said that larger or smaller scales were most useful. In the questionnaire, users were asked how much they thought the maps were worth to their particular activities. They estimated a minimum expected value per quadrangle to be $27 776, and a maximum value to be $43 527. The aggregate expected value of the maps was calculated by multiplying map sales by the value of the geologic quadrangles.

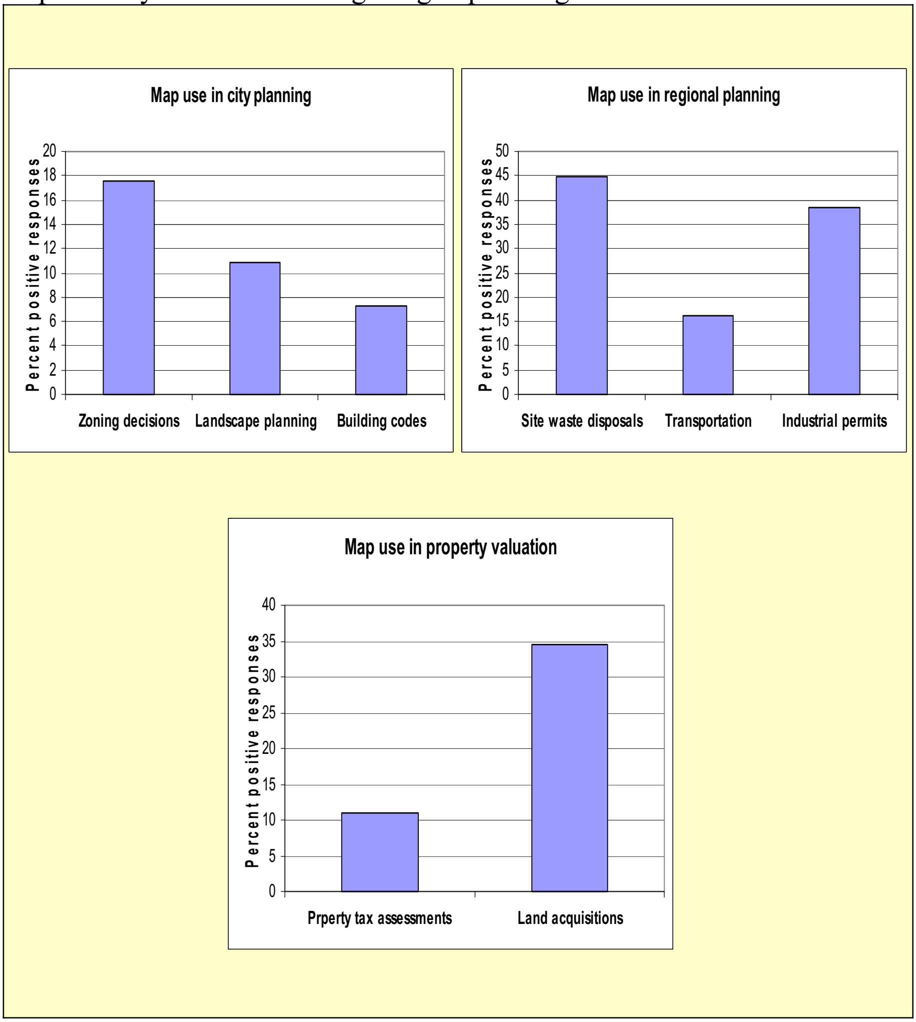

Figure 8. Uses of Kentucky geologic quadrangle maps for city and regional planning, and property valuations.

Map sale amounts are very conservative because they only include sales by the Kentucky Geological Survey for an 11-year period and by the

Kentucky Department of Conservation for a 3-year period. Data on sales of Kentucky maps by the US Geological Survey were unavailable. Therefore, using the very conservative number of 81 000 maps sold produces an aggregate value of map use ranging from a minimum of $2.25 billion to a maximum of $3.5 billion in 1999 dollars. Considering that the cost of the mapping program was $16 million dollars, or about $90 million in 1999 dollars, the benefit:cost ratio ranged from 25:1 to 39:1. In other words, Bhagwat and Ipe (2000) report that for every Federal and State dollar spent to produce geologic maps, there was a return of between $25 and $39.

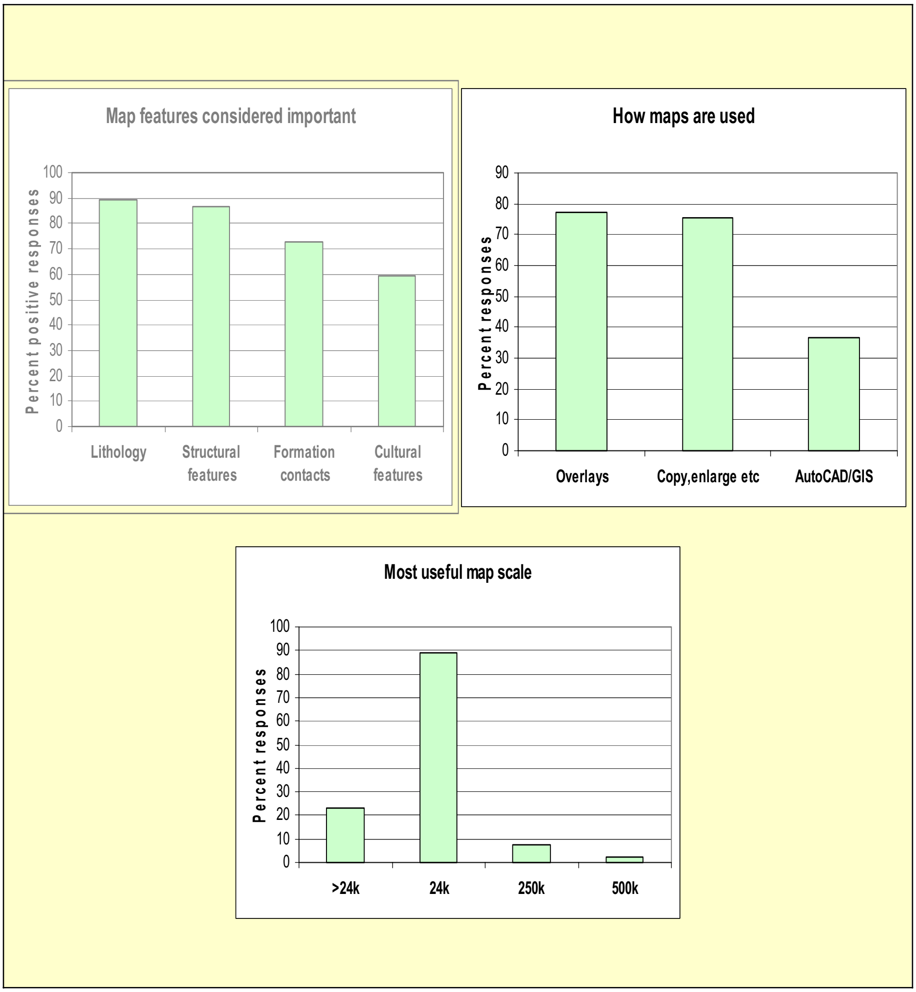

Figure 9. Desired Kentucky geologic quadrangle map features and scales, and modes of map use.

CONCLUSIONS

The ISGS program for developing aquifer sensitivity maps has helped planners and public health officials, engineering and geologic consultants, developers, and the public to better understand their environment and make informed decisions regarding land and water use. The maps have guided regulators seeking to maximize protection of groundwater resources where they are especially vulnerable, while avoiding overprotection of resources in areas where natural environmental safeguards exist. In addition, the maps can and have been used to direct the installation of waste-disposal and industrial facilities and other potentially polluting land-use practices to areas where the sensitivity of aquifers to surface contamination is low, thereby reducing the potential for future harm to drinking-water resources.

Establishing the basic geologic framework in 3-D is the first step in determining aquifer sensitivity and the suitability of various successions of geologic materials for specific land uses. Accurate delineation of the continuity, thickness, and inferred hydraulic properties of aquifer materials and their confining units requires 3-D mapping of the geology. Once mapped, the hydrologic properties of aquifers and non-aquifers and their 3-D distribution can be placed within a proper context. Because the procedures for developing the 3-D geological information were consistent regardless of the scale of the mapping, the resulting maps are relatively uniform and serve as a practical basis for deriving information about aquifer sensitivities and determining the potential for contamination problems at specific sites.

When the basic 3-D geologic information is combined with hydrologic data, geologists and hydrologists can develop detailed groundwater models that will accurately predict: (1) optimal water-well locations; (2) aquifer yields; (3) the degree to which aquifers are protected by fine-grained deposits; and (4) capture zones for high-capacity municipal wells. This, in turn, helps regulators and land-use planners establish setback zones to protect municipal wells from surface contaminants, delineate the recharge areas for various aquifers, and possibly restrict potentially adverse land-use practices within sensitive recharge areas. Such models also provide the technical information needed to meet many Federal and State regulations for water-well disinfection, sole-source aquifer designation, source-water and watershed protection, development of classification systems for groundwater standards, and risk-based remediation.

Finally, geologic mapping programs are one of the few services provided by governments for which the costs and derived benefits of the programs can be evaluated scientifically using statistics and economic theory. This is because geologic maps are a product that is used, map sales can be tracked, customers can be questioned about the value of the information to them, and/or the value of potential avoided costs of environmental remediation can be ascertained. The economic benefit and cost studies that were done for mapping programs in Boone and Winnebago Counties, Illinois, and the State of Kentucky emphasize the millions of dollars of derived benefits that can occur when geologic information is available over extended periods of time and used by a wide variety of public and private sector institutions. It is important to note that the Kentucky mapping program produced traditional 2-D maps showing geologic materials at the land surface and having one or two cross-sections. The 3-D geological mapping program that is the cornerstone of modern mapping in Illinois and elsewhere provides more detail to users, and logic would conclude that additional economic and societal benefits will be delivered, even though the cost of 3-D mapping is greater than that of traditional 2-D mapping.

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REVIEW BY EARL BRABB

The Illinois Stage Geological Survey (ISGS) is one of the most respected State geological surveys in the United States, so the impact of this article on other State surveys and local governments could be considerable. The use of new techniques for applying geology to the solution of societal problems can mean much to the survival of geological surveys at a time when funds for government services are in short supply and when the Federal and some State governments are perceived to be anti-science.

The techniques used by the ISGS to prepare maps that help planners, public health officials, engineering and geological consultants, and the public make informed decisions regarding land and water use are impressive and seem technically sound. As a trained skeptic, however, and as someone who has used some of the same techniques in the San Jose, California, area, I would like to know more about the quality of the data sources, in particular the water-well records. Water-well records in California are notoriously poor in quality, with some drillers, for example, indicating granite in a well where independent information indicates that the section consists entirely of sand, mud, and gravel. Caving of the holes is another widespread problem, making the preparation of a well record difficult. Borings for bridge abutments, in contrast, are prepared by geotechnical engineers or engineering geologists using rigorous standards, and these records have been used by geologists with considerable scientific success.

The assessment of how the aquifer sensitivity maps were used in Boone and Winnebago Counties is commendable, but I wonder if the reliability of the maps themselves was assessed? As additional drilling was done, how good were the predictive models? Typically, the energies involved in preparing innovative new maps are dissipated as the map is produced, and the team moves on to another area and another project. For example, in the San Francisco Bay region, where maps predicting areas of future slope instability were available in 1975, no follow-up studies were made to determine the reliability of the maps. In 1982, unusually severe rainstorms triggered 18 000 new debris flows, many of them in areas predicted as stable on the 1975 maps. The older maps had to be reclassified as good only for deep-seated landslides, and new maps had to be made predicting where debris flows might occur. Unfortunately, the political process may not respond as quickly as the science, so that decisions about land use are still made on the basis of the 1975 maps.

Regardless of these comments, the ISGS is a leader in showing how geology can be used in a GIS and 3-D environment to produce innovative maps and models showing aquifer sensitivity.

AUTHOR'S REPLY

Earl Brabb had two main comments on my paper:

1 - He wanted to know more about the quality of the water-well records used for our data source. Several thousand logs from water wells were used in the mapping study of Boone and Winnebago Counties. All well locations were verified via plat book and field checks and/or were located in subdivision house lots. Only those logs that reached bedrock or displayed multiple geologic units were used. We were particularly looking for sand and gravel versus till/lacustrine sediments, and the depth to bedrock. At the time we were selecting and verifying water-well logs, we also did our own test drilling at 29 locations. Almost half of the 29 test holes were geophysically logged. The succession of geological materials as depicted on water-well logs was constantly being compared to the known successions at the 29 sites, as well as sites where construction borings had been made and field exposures were present. This is one of the few parts of Illinois where nice field exposures of materials exist. I also had a personal 'rule of thumb' regarding what is depicted (mainly sands ands gravels) on water-well logs: in areas of sparse data further away from test holes, one log depicting a sand and gravel at a particular depth was not enough for me to add a sand and gravel map area. I required at least two well logs to 'verify' its possible existence. Lastly, we had an excellent predictive geological model for the two-county study area, particularly after the test drilling program. It was relatively simple—erosion and thin drift in the western portion and thick drift in bedrock valleys in the eastern portion. Sediments were very uniformly distributed and tills had very uniform compositions and thicknesses. Comparison of the lower-quality data from well logs with our predictive model based on glacial sedimentology and our test drilling program was quite easy.

2. He wondered if the reliability of the maps was ever assessed and, if additional drilling was done, how good the predictive model was. He is correct in stating that the energies involved in preparing new maps dissipate after project completion and staff move on to other areas. However, we made it a policy to NOT 'drop off' maps and reports from this study on county desks and then leave. We developed a semi-formal 'maintenance agreement' with county officials, agreeing to be at their beck and call to explain details of the geologic information and help them implement decision making based on the information. No follow-up drilling was done to test the model, because this would have been thousands of dollars at our cost. However, as mentioned in the paper, the county has tested the model many, many times. The example of identifying hot spots 8–9 times based on the 3-D model is testament to the mapping accuracy. Also, as mentioned above, our predictive model was quite straightforward even though the geology was not simple. In the 20 years since this work was completed, not one consultant or county official has told us that 'we were wrong'. I do welcome that comment, however, because if someone has additional data refuting our maps, this new information only improves the accuracies of our mapping boundaries. As a sidebar, Winnebago County has been trying to get us to update the report and maps, particularly in an electronic format. Unfortunately, they are on a waiting list!

GEOLOGY AND ENVIRONMENT BETWEEN CANOSSA AND QUATTRO CASTELLA: AN INNOVATIVE GEOLOGICAL MAP FOR THE GENERAL PUBLIC

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Abstract: A basic geological knowledge is a powerful tool for increasing public awareness of the need for a balanced relationship between citizens and the environment, but often geology does not attract the interest of the general public because it *seems* to be dealing with something too distant, in time and space, from our everyday life. The aim of this kind of 'innovative geological cartography' is to bring geology to the general public, by stimulating the innate curiosity that is harboured by every human being.

This initiative, realised by the Emilia-Romagna Region, falls within the category that can be defined, in a broad sense, as 'geological tourism'. In this new frontier the mission of cartography is to transform geological maps into something comprehensible by not only geologists but also the general public.

In this map (the Italian version is furnished with a booklet where several topics are investigated thoroughly), the Matilde di Canossa myth and the 'living' landscape are used as tools to arouse the attention of the casual reader, demonstrating a fundamental principle—that Lyell's 'Actualism': geology is a science that wants to prepare the future through the study of the past.

A copy of the English version of the map is included in this book.

Key words: Innovative geological mapping, geology and tourism, geology and history, communication with society

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SPREADING THE GEOLOGICAL CULTURE

The more that mankind spreads over the Earth's crust, the more its geology has a direct impact and influence on its inhabitants' living conditions and environment.

A basic geological knowledge is a powerful tool for increasing public awareness of the need for a balanced relationship between citizens and the environment.

In spite of this, geology does not attract the general public because it *seems* to be dealing with something too distant, in time and space, from our everyday life.

Since the 1990s, the international geological community has developed several activities in order to reduce this discrepancy by promoting educational and popular initiatives. Notable among these are the establishment of United Nations Educational, Scientific and Cultural Organisation (UNESCO) Geoparks and European Geoparks to promote global networks of selected territories, integrating the preservation of examples of the Earth's geological heritage in a strategy for regional economic development.

Around the world, several researchers have turned their attention to 'geotourism' (defined by Hose 1995), through educational projects and the establishment of study courses.

Although it is a term only recently introduced in the terminology of local development, geotourism has already found application in many areas in Europe with significant prospects for dynamic continuation and expansion.

National and regional governments, geological surveys and local communities are now beginning to discover the benefits of geological tourism. In Italy the 'Associazione Italiana di Geologia e Turismo' (G & T) was recently founded, with the contribution of several geologists from the Administration of Emilia-Romagna Region, to support a series of initiatives focused on making geological information available to the public.

Emilia-Romagna is involved in an information campaign to enhance and promote its geological heritage through several media, such as the Internet:

http://www.regione.emilia-romagna.it/geologia,

documentary videocassettes, educational CDs, special trails on the most interesting geological aspects of Emilia-Romagna, and the publication of a series of books and information leaflets on the main geo-environmental

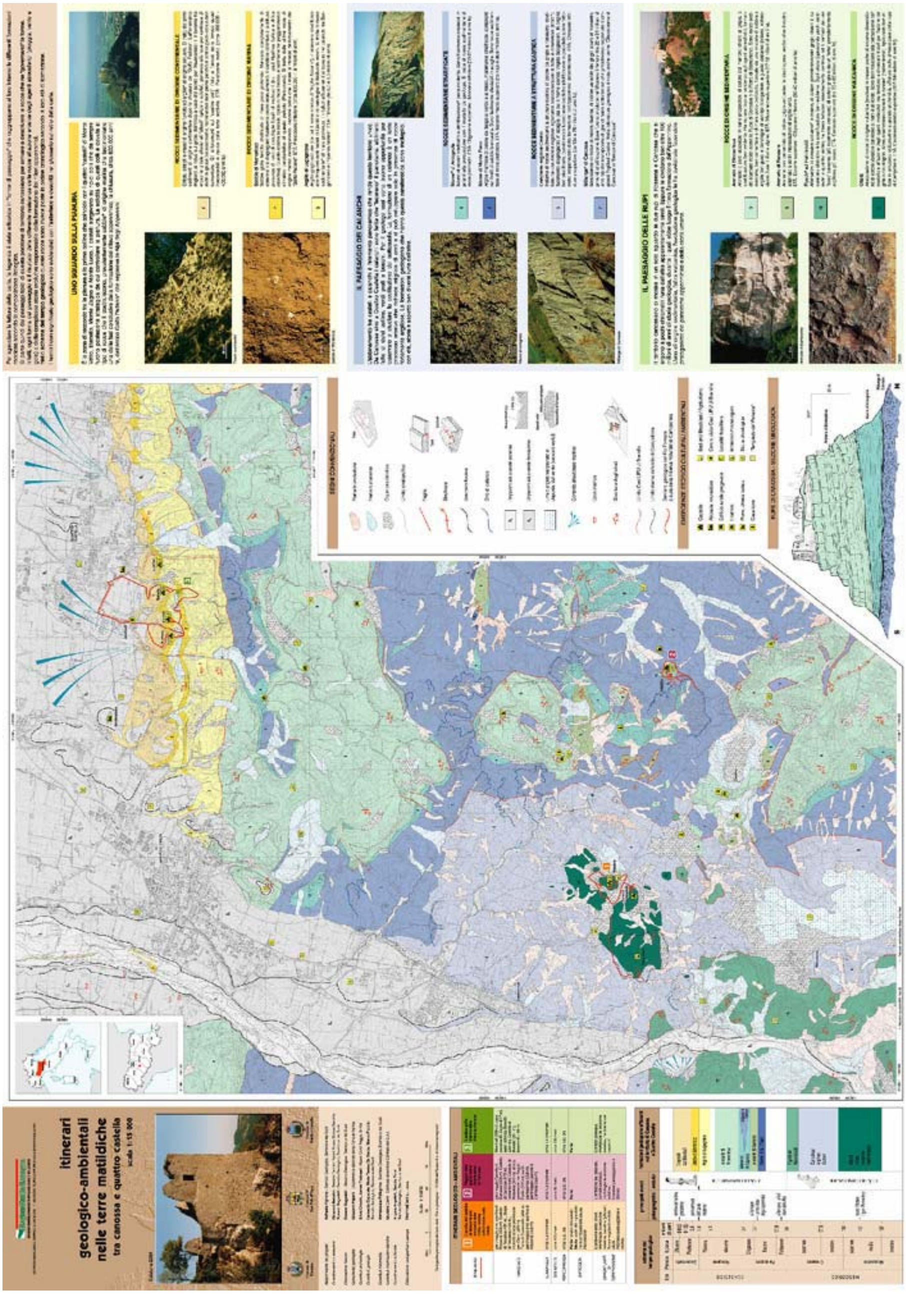

Figure 1. The front side of the sheet, showing the geological map and the legend with many photos and schemes. Descriptions of the itineraries are on the back (See also the original map attached).

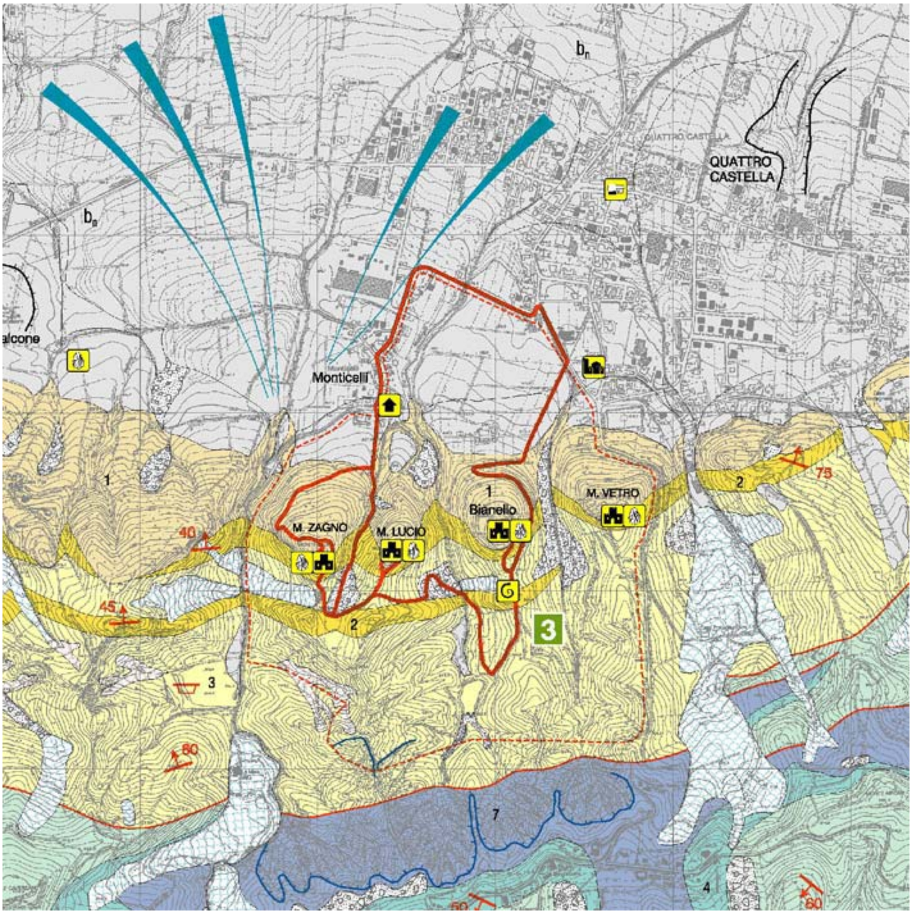

Figure 2. Detail of the geological map: the tracking tail of the third itinerary.

themes. Furthermore, a project has been created to popularise geoscience and to heighten society's awareness of the environment as a common heritage. The project consists of a detailed census of the geological heritage of the Emilia-Romagna Region that takes into account the data collected by the Geological Survey during more than 25 years of regional geological mapping (1:10 000 to 1:25 000 scale). A digital database stores all the information about regional geosites, facilitating the production of innovative geological maps at different levels of resolution. One example of this is the series of maps of geo-environmental itineraries, to which belongs the map of Canossa and Quattro Castella described in this paper. This map is the fifth of this series, but it is the first one in which the educational and popular aspects are strongly stressed. See Figures 1 and 2.

TOURISM MEETS GEOLOGICAL MAPS

The geo-environmental map of Canossa and Quattro Castella falls within the category that is generally defined ‘geotourism’ or ‘geology and tourism’.

The term ‘geotourism’ came into common usage from the mid 1990s onwards and the most accepted definition of it was given by Hose (1995): geotourism is “the provision of interpretative and service facilities to enable students, tourists and other casual recreationalists to acquire knowledge and understanding of the geology and geomorphology of a site beyond the level of mere aesthetic appreciation”.

Unluckily, the term ‘geotourism’ was more recently adopted by *National Geographic* and *Travel Industry Association of America (TIA)* with a different meaning. Following these, ‘geotourism’ is a tourism that sustains or enhances the geographical (not ‘geological’) character of a place, its environment, heritage, aesthetics and culture, and the well being of its residents.

In order to avoid the confusion between these definitions, in the ‘geological’ sense it seems advisable to use the other term, ‘tourism geology’ (or ‘geology and tourism’), given by Komoo (1997). As this author stated, ‘tourism geology’ is a new branch of applied geology that will support the growth of ecotourism worldwide. This new approach will place geoconservation at the same level of importance as the widely recognised bioconservation and will push geology to the fore.

In our view the unquestioned aim of these activities is to ‘bring the culture of geology to the general public’, by stimulating the innate curiosity that is harboured by every human being.

Our thinking is that, generally, the geological element alone is not sufficient to attract the general public to visit a site or a region. Geological heritage becomes a complete exploitable touristic product only in combination with a variety of other services and offers connected with the geological sites. The best way to gain the attention of the general public is to propose scenic drives and walks which link sites of geological interest with established tourist attractions, visitor centres and sites of archaeological and mythological or folkloristic interest.

In the case of the territory of Canossa, the historical heritage is the most powerful tool available to capture the attention of the general public. The myth of the great countess Matilde di Canossa, her castles rising from steep crags and the uncontaminated medieval landscape are useful items to link mankind to the geological history.

This initiative is directed not only towards the general public, but also towards the local inhabitants. One objective is to enable local inhabitants to re-appropriate the values of the territory's heritage and actively participate in the territory's cultural revitalisation.

HISTORY AND GEOLOGY IN THE MATILDE DI CANOSSA'S TERRITORY

The Italian version of this map is furnished with a booklet that explains the geology, history and environment of this territory in 60 pages. In order to give the reader the complete picture, the main items described in it are treated in the following paragraphs.

From the middle of the 10th to the beginning of the 12th century the ridges of the Apennines constituted a natural defensive threshold where the main part of the fortified system of the Attoni dynasty was laid out. Many castles, such as Canossa and Rossena, along with a dense network of interactive elements, became the executive instruments of defence and the symbols of dynastic power. During the War of Investitures, the small castle of Canossa, which rises on a steep crag of arenites situated in the mid-Apennines, represented one of the most important logistic and emblematic sites in medieval Europe. Under the resolute running of the grand Countess Matilde di Canossa (1046–1115), the fortified system—and particularly Canossa castle—reached maximum importance, becoming the 'last defence' of the Vatican power against the arrogance of the German Emperor Enrico IV. In more recent times it has become also the symbol of the Italian people's rising self-consciousness.

Canossa become important in history thanks to an episode related by the monk Doninzone, the confidant and spiritual director of Matilde, in his masterwork *Vita Mathildis*: here, in Canossa castle, the German Emperor Enrico IV kneeled before and begged Pope Gregorio VII to repeal his excommunication. In memory of these events, which occurred in 1077, even today the saying 'to go to Canossa' means to beg someone's pardon both in Italian and in German ('nach Kanossa gehen'), as in over 30 other languages.

Matilde's fiefdom stretched from the foothills of the Alps all the way to the gates of Rome. She was always a valiant defender of the Vatican power and that is why she was appointed Vice Regent of Italy and was the sole woman to have the privilege of being buried in the S. Pietro cathedral in

Rome. The great poet Dante glorified her as an extraordinary example of active life.

The historical heritage of the castle attracts many foreign tourists (mostly from Germany), although the view of the few ruins is quite disappointing. Unlike Canossa, Rossena Castle and the nearby Bianello Castle are well preserved.

Canossa, aside from being a monument of extraordinary historical interest, is also a myth of ideological and cultural relevance. Over the centuries, the portrayal of the castle has ranged from the real to the imaginary as a cultural phenomenon of the collective imagination. Denying the evidence of facts, this small fortress became a great castle and the imaginary figure of it ("… with towers and majestic roofs", according to Doninzone, chronicler of Matilde) has contributed to its survival in memory, in art (*ars canusina*) and in literature.

The landforms of this territory, despite its closeness to the industrial Po Plain, are well preserved and even today represent a glimpse of the medieval landscape. However, its medieval military and political fortunes are also due to its geological features. The castles of Matilde (Canossa, Rossena and Bianello) rise up on crags formed up of Jurassic ophiolites, Miocene arenites and Pleistocene sands, all emerging from deep and wide badlands, here called 'calanchi'.

The vertical slopes around the fortresses constituted a natural defence, while the badlands hindered the outflanking movements of the enemy army.

In the art of war, natural landforms are the determinant factor of defence, and—as always—geology is the most important factor controlling them.

FROM THE LANDSCAPE TO THE GEOLOGY

On this map, the 'landscape' is the tool used to arouse the attention of the casual reader. We think that the landscape is the shorter route to reach the interest of the collective imagination. The landscape is always under everyone's very eyes, and everybody, during the course of their normal life, can notice that the landform is slowly changing: rivers are deepening by digging their channels into ancient rocks (Figure 3), landslides are recurrently reactivating, beaches disappear under a rising sea, badlands' crests *seem* (Figure 5) to be getting more and more sharp …

Figure 3. The Enza riverbed in January 2004. The stream has completely eroded the recent, loose alluvial gravel (grey) and the Pleistocene gravel (yellow) is now cropping out. The cause of this is both natural (climate warming starting after the end of the Little Ice Age, in the 1860s) and anthropogenic (the excavation of gravel occurred in the 1960s, now forbidden).

These small changes are evidence that the Earth is living: they are the proof of those major changes that geologists are always talking about. The reader will understand that the present landforms are the result of a fight between the changing climate and geological evolution.

The ordinary person has to be aware of the important role of geology in their life. If we can recognise the trends of the changing Earth, we can foresee which the future trends will be. Hence a fundamental principle that is at the basis of geology: if the present is the key to the past (Lyell's Actualism), the past is the key to the future. In other words: geology is a science that wants to prepare the future through the study of the past.

In this territory, the castles of Canossa, Rossena and Bianello, founded on red and white crags emerging from rough, argillaceous, grey badlands, are the peculiarity of this landscape.

Three castles, three different possibilities to discover the geology:

- Approaching **Canossa castle** (Figure 4), large expanses of Epi-Ligurian clayey breccias (the 'Canossa olistostrome', Late Oligocene–Burdigalian in age) are visible in outcrop within the large area of badlands (Figs 4 and 5).

The olistostrome is formed by submarine mudflows and debris flows, resulting from the reworking of the underlying Ligurian nappe and deposited in the Miocene satellite basin. The olistostrome is about 150 m thick and shows a typical block-in-matrix structure. Above it are sandstones of the Bismantova Group, where the castle of Canossa sits.

- Rossena castle rises on a wide and thick Jurassic ophiolite, reddish in colour and lying on Late Cretaceous Ligurian Chaotic Clay Complexes ('Argille Scagliose', Auctt) showing features very similar to the Canossa olistostrome. The Rossena crag is very similar in shape to that of Canossa, but they are divided by more than 100 million years of geological history, during which the entire Apennine ridge was formed. One of volcanic origin, the other sedimentary, geological evolution has brought them close together, making them dominant features of the Apennine scenery.

- The third **castle, Bianello**, rises on the margin between the Apennines and the Po Plain, on a steep hill formed by marine beach sands and continental gravels of fluvial origin. Along the footpaths climbing the hill, several outcrops offer evidence of the final phases in the formation of the Apennines: the closure, 800 000 years ago, of the ancient sea 'golfo padano' which separated the Alps from the Apennines.

In the legend of the map, geological units are classified by their tendency to form a certain kind of landform. The relationship between landscapes and geology is made clearer by the use of different colours. Yellow is reserved for the Apennine foothills and the Plio-Pleistocene sediments outcropping there, blue for badlands landscapes ('calanchi') and the argillaceous units exposed by erosion inside them, and green for the landscapes of steep crags and their rock units, whether of sedimentary (arenites) or volcanic (ophiolites) origin.

In the legend, large clear photos of each unit are placed next to their description. On the reverse of the map are described the geology and environment along three itineraries, with many photos, sketches and diagrams. The geological terms are sparingly used and explained in a special glossary, through figures and block diagrams.

Figure 4. The Canossa crag in 1907 (top) and in 2004 (bottom): the features of the vertical slope are largely identical. On the top of the crag the ruins of the castle are visible. The crag is formed by well-stratified Miocene arenites of the Bismantova Group.

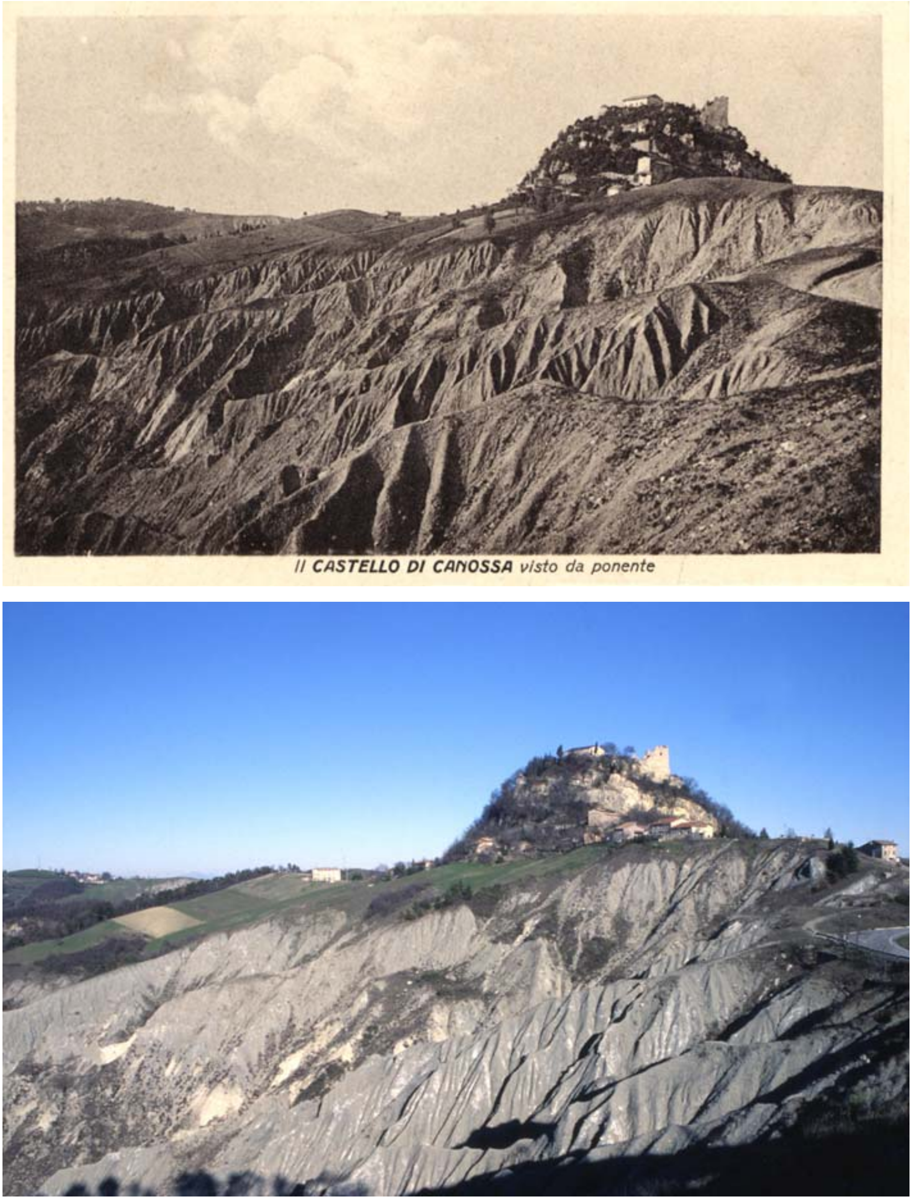

Figure 5. Panoramic views of the Canossa crag from the south in 1927 (top) and in 2004 (bottom). The features of the badlands are unchanged. The sedimentary mélange of Canossa (Olistostrome of Canossa, Oligocene in age) outcrops inside the badlands, while the Miocene crags from it.

Finally, the Italian version of the map is furnished with a booklet of 60 pages, in which several topics are investigated in detail: the geological history, the geomorphological features of the territory (causes and effects), the ophiolites (here traditionally called 'devil's stones'), the medieval history of Matilde di Canossa, the archaeology, and vegetational and faunal characteristics.

A few main topics are treated exhaustively, for example the relationships between climate and landform changes during the last millennium and the last century. The following is an example. One of the more interesting arguments between local historians is the question of the real dimensions of the original Canossa castle. The ruins are reduced to a very bad state and the present top of the crag is no bigger than 2000 m^2, but—following the Doninzone's exaggerations—the collective imagination transformed the fortress of Canossa into a mythical and wide castle, as was always depicted in historical iconography. The Vulgate tells that several large landslides destroyed the historical mount and the castle, but it is probable that things went differently. A reliable geological analysis of the landforms confirms that rock falls occasionally occurred (including one in 2004), but they could not have reduced the crag by very much. Certainly, the medieval crag and the fortress were not much larger than at present.

CONCLUSION

The Emilia-Romagna Geological Survey is in the forefront of geological mapping in Italy. In the 1990s the geological map of the mountainous part (11 000 km^2) of the region was completed at 1:10 000 scale and it is now available in multi-scale digital form. In 1999 and 2002 the Survey completed, once again in digital form, the Landslide Inventory Map (40 000 landslides at 1:10 000 scale) and the Landslide Susceptibility Map (at 1:25 000 scale). Today the Survey is working on several mapping projects of regional, national and international relevance, such as the 3-D geological map of the Po Plain. Many of these geo-thematic maps have been used as basic documents for the compilation of municipal, provincial and regional development plans and the results of these applications are extremely positive.

In spite of this, the Survey is aware that there is a widening gap between geoscience and the general public. In Italy, this is reflected in the progressive decrease of enrolments in the faculties of geosciences. In the field of geological mapping the situation is the same: as documentation was perfected, it became less and less comprehensible to the non-geologist. As a matter of urgency, the geological community must make a great effort to interest again the rest of the world.

The Geological Survey of Emilia-Romagna wants to bring geological maps within the reach of non-geologist users: students, teachers, tourists, and even inhabitants.

This map,1 as a tool of 'geological tourism', offers answers to tourists' quests and to inhabitants' requests for cultural enrichment. It longs to link the geological heritage with a variety of other cultural, natural and environmental items, becoming a complete exploitable touristic and educational product.

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REVIEW BY EARL BRABB

The Bertolini paper is a great document that may save some geological surveys from extinction. The accomplishments of the Geological Survey of Emilia-Romagna (GSER)are awesome, complete digital coverage of geological maps of the mountainous areas at 1:10,000 scale, a landslide inventory with 40,000 landslides, and landslide susceptibility at 1:25,000 scale. The one map selected for illustration has superb colors, block diagrams of landslides and faults, cross-sections, an illustrated geologic time scale, and photos to illustrate interesting outcrops. The concept of using geologic features to interest the public in an area has been done before, but rarely with as much variety and finesse. A lot of people have spent a lot of time making these beautiful "eco-tourist" maps, and even at small scale their value is evident.

The USA lacks Count Dracula's castle and many of the tourist attractions we travel to Europe to visit, but one map has been prepared (USGS Map !-1257-B) that combines geology, scenery, and history, with photos around the margins to attract the public. The map even has a photo of the last known dueling site in California. The map supply was quickly exhausted, which should be a good sign that the public is interested. However, funds for the sale of the map go into the general U.S. Treasury, not the USGS, and no funds are available to reprint the map. The USGS should take some lessons from the GSER.

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1) A copy of the English version of the map is enclosed in this book. Both Italian (map and booklet) or English (only the map) versions can be requested from Regione Emilia-Romagna, Archivio Cartografico, Viale Silvani 4/3, Bologna, Italy; e-mail: archiviocart@regione.emilia-romagna.it

Dr Giovanni Bertolini has kindly provided originals of the map he describes in his paper; the map is attached to the inside of back cover of this book.

The Editor

URBAN GEOLOGY: INTEGRATING SURFACE AND SUB-SURFACE GEOSCIENTIFIC INFORMATION FOR DEVELOPMENT NEEDS

David Bridge, Edward Hough, Holger Kessler, Simon Price and Helen Reeves
British Geological Survey, Keyworth, Nottingham, UK

Abstract: The British Geological Survey (BGS) operates an urban geoscience programme that aims to provide up-to-date information on ground-related issues for the towns and cities of the UK. Research in the major conurbations of Manchester, Swansea and Glasgow is demonstrating the value of integrating surface geological mapping with sub-surface geoscientific information through the use of three-dimensional models. This approach provides a more holistic view of the near-surface environment and provides a means of identifying potential problems and opportunities at an early stage in any proposed development. If implemented over a wider area, it could assist in designing site investigation strategies and reduce costs by ensuring a more focused approach to strategic planning.

Keywords: urban geology, 3-D modelling, planning

INTRODUCTION

The role of geo-environmental information is becoming increasingly important as legislative changes have forced developers, planning authorities and regulators to consider more fully the implications and impact on the environment of large-scale development initiatives. To comply with the principles of sustainable development, developers are increasingly required to demonstrate that proposals are based on the best possible scientific information and analysis of risk. Nowhere is this more relevant than in the context of urban regeneration. In the UK, studies commissioned by the Department of the Environment in the 1980s and 1990s promoted the use of applied geological maps to identify the principal geological factors which should be taken into account in planning for development. Since this work was completed, advances in the use of geographical information systems (GIS) and modelling packages have meant that there is now far greater opportunity to develop geo-environmental products that take greater account

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 129–134.

of the third dimension. Because the information is captured and manipulated digitally, the outputs can be tailored to user needs, and more readily updated. The potential that the new technology offers is illustrated in this short communication, which focuses on the Greater Manchester conurbation in northwest England. Additional details are published in Hough et al. (2003) and Ellison et al. (2002).

GEOLOGICAL SETTING

Geologically, Manchester straddles the southern part of the South Lancashire Coalfield and the northern part of the Permo-Triassic Cheshire Basin (Figure 1). The coalfield was extensively worked up until the late 1970s. The overlying Permo-Triassic rocks of the Sherwood Sandstone Group form part of the second most important aquifer in the UK.

Quaternary superficial deposits laid down during the Devensian glaciation mantle most of the area, locally reaching thicknesses in excess of 40 m (Figure 2). The deposits include glacial till (pebbly and sandy clay), glaciolacustrine deposits (laminated clays and sands) and glaciofluvial outwash (sands and gravels).

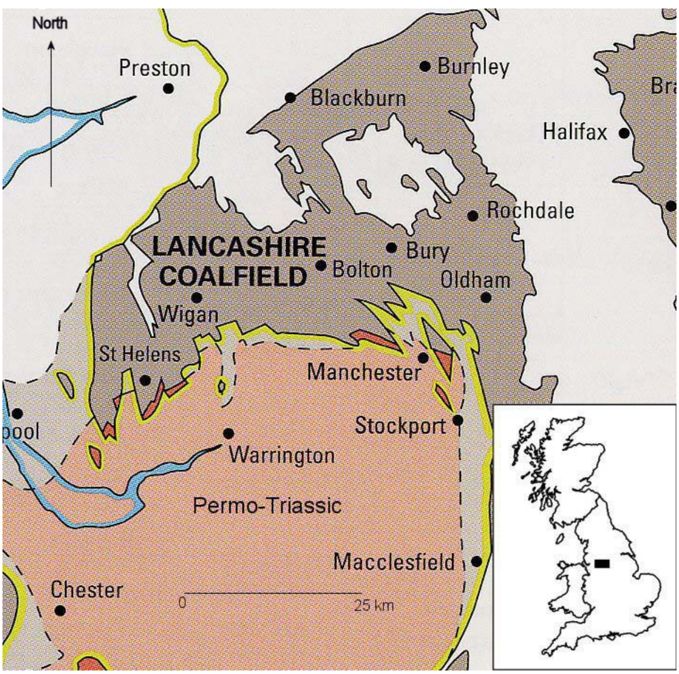

Figure 1. Regional geological setting.

Extensive areas of made ground are present, and include colliery spoil tips, material dug during the construction of the canal network, and general inert and biodegradable fill. Many of the natural water courses have been culverted and their valleys infilled.

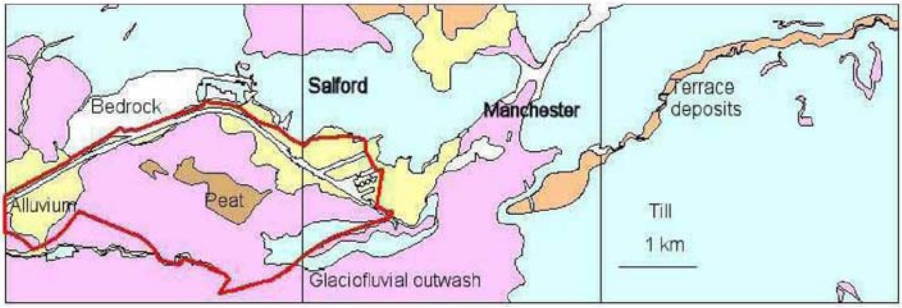

Figure 2. Quaternary geology of Manchester and Salford (Trafford Park Industrial Estate outlined in red).

GEOSCIENTIFIC ISSUES

Difficult ground conditions are a material consideration throughout much of the conurbation because of the heterogeneous nature of the superficial glacial deposits and the significant thickness of man-made deposits in certain areas. Damage caused to housing and roads as a result of piping or collapse of glaciofluvial sands is well documented, as are the subsidence effects caused by undermining for coal. There are also issues of contamination and groundwater protection. On a regional scale, uncertainty about the shallow groundwater regime and the role played by the surface drainage (natural and canals) are issues of strategic concern.

BUILDING THE MODEL

Software currently under development by Dr Hans Georg Sobisch of the University of Cologne is being used to construct a three-dimensional (3-D) model of the inner-city area. The 3-D configuration of the Quaternary superficial units in the sub-surface is built up from serial cross-sections, drawn interactively by integrating surface mapping with site investigation data (Figure 3).

Correlated surfaces are then gridded and stacked to produce the final geological model. Attribution of the model with a range of parameters (geotechnical, hydrogeological, geochemical) allows rapid generation of a range of thematic products.

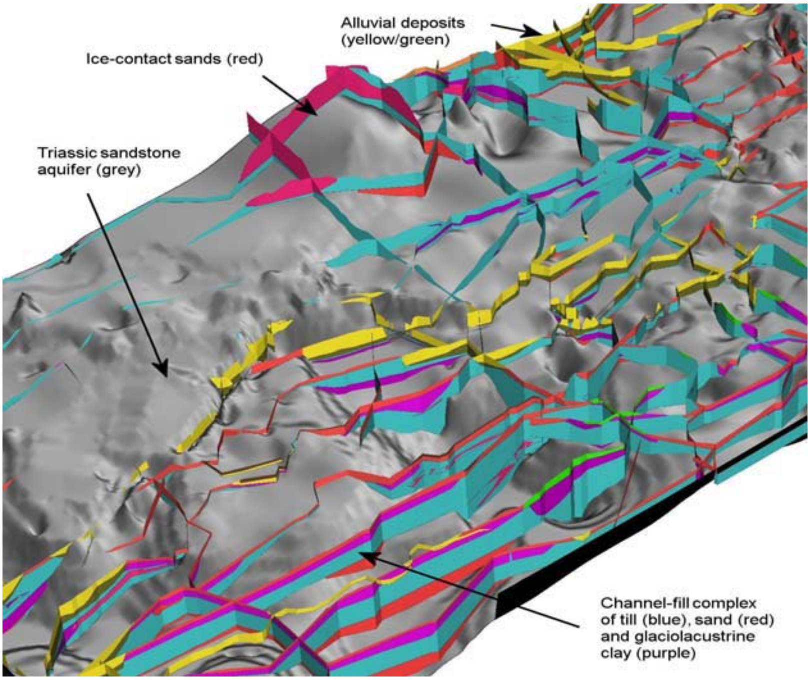

Figure 3. Cross-section framework for Quaternary superficial deposits, above rockhead (grey) in the Trafford Park area (Figure 2).

USE OF THE MODEL FOR THEMATIC MAPPING

The model has the potential to deliver information in a format relevant to a wide range of planning issues (ground stability, contaminated land, groundwater management). Geological information can be displayed as customized sub-surface maps or as synthetic cross-sections along user-defined transects (Figure 4). By attributing the model with a range of geoscientific information, the versatility of the model is increased to the extent that it can underpin a range of resource, environmental and hazard assessment needs. In the example given (Figure 5), attribution of the model with geotechnical data makes it possible to classify lithologies or groups of lithologies on the basis of their engineering geology behaviour. The example provides a comparison of the likely shrink–swell susceptibility of alluvial versus glacigenic clay deposits in the area of Trafford Park.

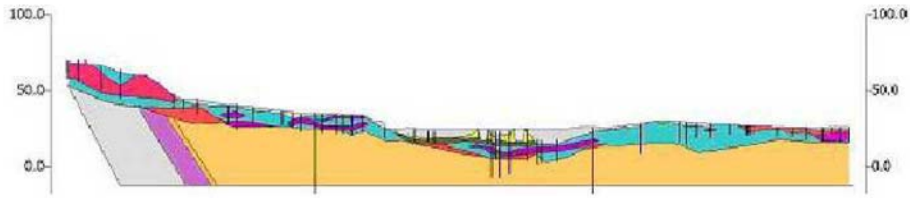

Figure 4. Synthetic cross-section along user-defined transect (e.g. proposed pipeline route).

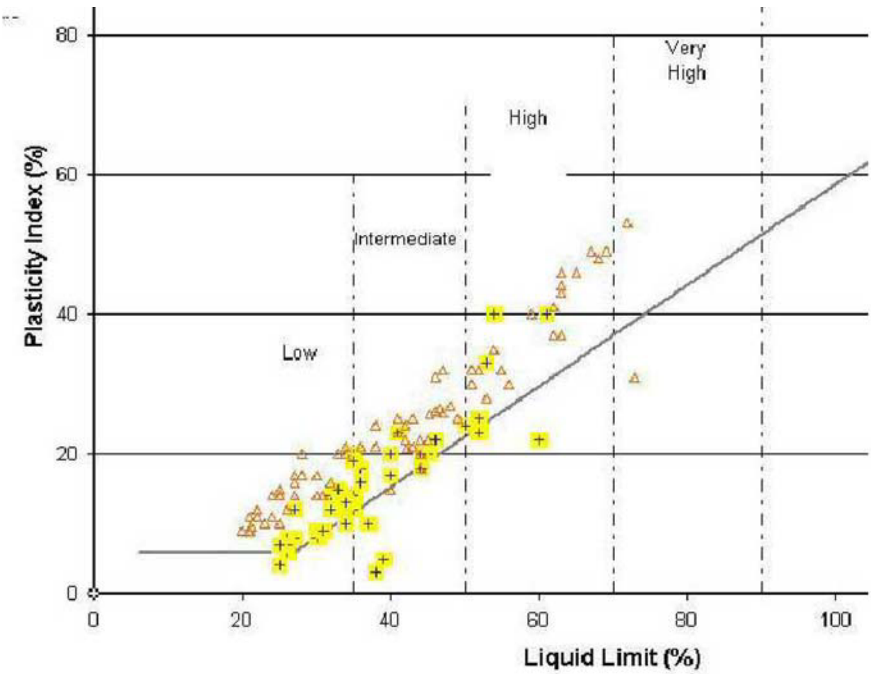

Figure 5.
Geotechnical properties of selected modelled units.
Plasticity chart for alluvial silts (+) versus glaciolacustrine clays (Δ). Under normal ground conditions, low and intermediate plasticity values generally indicate a low shrink–swell potential, whereas high and very high values indicate a high shrink–swell potential.

CONCLUSIONS

This brief article illustrates some of the uses and benefits of integrating geoscientific information in a 3-D geospatial model. The combination of modern modelling software and an improved knowledge base offers the potential to:

- provide interpreted outputs of spatial information in exactly the form required by users
- understand better the processes that bring about change
- deal with uncertainty.

Previous experience of applied mapping studies suggests that the success of this approach will ultimately depend on engaging more fully with a range of users (consultants, planners) and demonstrating that there are real benefits (financial and environmental) in taking a more holistic approach to environmental assessment.

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REVIEW BY EARL BRABB

I admire a country where a Department of the Environment “promoted the use of applied geological maps to identify the principal geological factors which should be taken into account in planning for development”. National land-use planning has never been accepted in the United States, where the Wild West philosophy prevails to such an extent that the City of Houston has no zoning laws and the Environmental Protection Agency has probably never heard of applied geological maps.

An extended abstract has few of the details needed to understand the scope of the work, such as the number of drill holes needed to develop the model, but two general questions come to mind. To what extent does the city government welcome geoscience information that could slow or stop development? To what extent has the engineering character of the regolith been mapped?

The lack of information about the regolith, in the USA at least, is probably the single most important factor preventing the preparation of accurate debris-flow susceptibility maps and in understanding the mechanisms of other landslides. Soil maps, which provide engineering and chemical information on materials within six feet from the surface, are reasonably accurate only on flat land, but not on hillsides where the regolith prevails. Studies in the San Francisco Bay region have shown that debris flows often begin where water collects in colluvial hollows that are not apparent at the surface, but mapping these hollows over large areas is not yet feasible. Satellite images may be helpful in comparing infrared radiation in early hours of the morning with images taken in late afternoon to establish the location of permeable materials, but no studies of this kind have been done, to my knowledge. We need to find a way to map the regolith.

INTEGRATED APPROACH AND APPLICATION OF GIS FOR MANAGEMENT OF GEOLOGICAL DATA

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Abstract: Information technology is increasingly used in geological studies and has significantly changed the approach to the compilation of the geological maps, access to and dissemination of study results, and application of the geological data by non-geologist users. The basic concepts of the Information Infrastructure of the Lithuanian Geological Survey consist of the following: (1) integrity of the geological data, as all available information is stored, used, and accessed via central applications; (2) extensive application of geographic information systems (GIS) technology; and, (3) easy access to the database for the global user, which ensures wider application of the geological information.

The integrity concept follows the mapping traditions introduced in the Lithuanian Geological Survey since the 1950s. The Lithuanian geological information system was developed during the past decade. The system is based on the idea of having Information Infrastructure that ensures a unified sequence of data collection, systematization, reprocessing, and delivery to users. Accordingly the unified data model was developed.

GIS consist of a powerful set of automated tools for collecting, retrieving, analyzing, and communicating spatial data. Different techniques are used for different tasks. Furthermore, Internet applications considerably increase access possibilities for geologists and public users. For the latter, a special geological language should be developed, as the specific geoscientific terms significantly reduce the applicability of the geological maps for public users.

Keywords: Information technology, geological mapping, GIS, geodatabase, unified data model

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 135–150.

INTRODUCTION

Information technology is widely used in geological studies. In Lithuania, information technology was introduced rather late, only during the past decade. On the other hand, this ensured successful creation of the Information Infrastructure as powerful tools were available by that time and considerable experience had been gained on management of the geological data by other institutions worldwide. Also, as a compensation for the lack of computer technology, very intense drilling, geophysical, and other field surveys were carried out until the mid 1990s, providing extensive data for the future users, now organized in a digital manner.

The introduction of information technology significantly changed the routine geological mapping system, compilation and application of geological maps, access to and dissemination of study results, and application of the geological data by non-geologist users. The basic concepts of the Information Infrastructure of the Lithuanian Geological Survey consist of the following: (1) integrity of the geological data, as all available information is stored, used, and accessed via central applications, and no initiative having separate databases is encouraged; (2) extensive application of geographic information systems (GIS) technology; and (3) easy access to the database for the global user, which ensures wider application of the geological information. The integrity concept follows the mapping traditions introduced in the Lithuanian Geological Survey since the 1950s.

A centralized database must be efficient (Belickas and Hatton 2003), but is often lacking in other geological institutions worldwide due to a number of different reasons. Whatever the kinds of study (e.g. geochemical, geophysical, petrophysical, stratigraphical, lithological), they will concern a common geological body, and therefore are intimately interrelated. Separate databases inevitably require supplementary information that is used in other databases, thus wasting time and, more importantly, loosing information quality. Moreover, communication between separate databases is usually difficult. Therefore, the Lithuanian Information Infrastructure concept is based on the central database approach, and no separate databases within the Survey are tolerated.

GIS provide a set of automated tools for collecting, retrieving, analyzing, and communicating spatial data. It is important that they ensure not only the automated handling of map data and imagery, but also are used for automated handling of records and attributes of different geological bodies shown on the maps. The technology is applicable to geologists, local authorities, and agencies. Creation of an infrastructure for the efficient exchange of geological information (maps) among geologists, private citizens, commercial businesses, and agencies is a priority initiative within the Information Infrastructure. It supports integration of multiple data sources into a single digital resource accessible to anyone via Intranet and Internet. Different technologies are used for different tasks.

CONCEPTS OF GEOLOGICAL MAPPING IN LITHUANIA

Systematic geological mapping of Lithuania started in 1946. Geological mapping at a scale of 1:200 000 during the 1960s–mid 1970s covered the whole territory of the country. It was of an integrated type, combining studies of the Quaternary and Pre-Quaternary stratigraphy and lithology, hydrogeology, tectonics, and mineral resources. In addition, some specialized mapping activities took place at the same scale, such as the geotechnical mapping and mapping of the Early Precambrian crystalline basement carried out during the 1970s–mid 1990s. The latter was essentially extensive in southern Lithuania and conventionally was preceded by gravity and magnetic field mapping at a scale of 1:50 000.

Geological mapping at the scale of 1:50 000 started at the beginning of the 1970s, and 36% of the territory of Lithuania has now been mapped. It is again of an integrated type, and was paralleled by specialized geotechnical mapping of Northern Lithuania, prone to karst activity. The key factor of the mapping at scales of both 1:200 000 and 1:50 000 is the deep drilling of wells to depths of 100–1000 m.

The mapping system changed drastically in the mid 1990s, related to a considerable decrease of fieldwork activity (e.g. drilling, geophysical survey). Priority was given to the creation of the Information Infrastructure of the Lithuanian Geological Survey, systematization of the available old geological information, as well as introduction of new information technology to assist ongoing mapping activities. Previously, all information had been stored at the geological archive in a paper version. The rearrangement of the information system was aimed at significant improvement of the geological data management. As a result of the new abilities provided by the new Information Infrastructure, the geological maps of the Quaternary and Sub-Quaternary surface of Lithuania at a scale of 1:200 000 were revised with the application of more than 20 000 wells during the period 1995–2000, which before would have been an impossible task (Guobyte 2001; Cyziene et al. 2002; Sliaupa et al. 2002).

A new concept for the geological mapping at a scale of 1:50 000 was elaborated in 1996; it envisages two levels of mapping. The higher, second-level mapping involves an integrated study of the Quaternary and the upper part of the Pre-Quaternary succession. It is aimed at detailed investigation of the areas important from an environmental point of view, such as the Siauliai area in the north of the country that suffers from a low-quality supply of drinking water, the Kretinga and Silute coastal areas, the Tetirvinai area of karst activity, etc. The lower, first-level mapping is carried out in areas that have problems with quality of the groundwater, and looks at the Quaternary mineral resources. Accordingly, only the upper part of the Quaternary succession is mapped. To date, the first-level mapping activities have been concentrated on central Lithuania; nearly 5% of the territory of the country is covered by this type of mapping.

INTEGRATED GEOLOGICAL INFORMATION SYSTEM

Information technology provides a powerful tool for geological data management. An integrated approach is the key to ensuring efficient management of the available information. The Lithuanian geological information system was developed during the past decade to manage geological data and make it accessible for users (Belickas et al. 2003). System development was based on the idea of the creation of infrastructure with a unified sequence of data collection, systematization, reprocessing, and delivery to users. The database of the Lithuanian Geological Survey is based on Oracle RDBMS. The system was developed by applying Oracle CASE methods and technologies (Barker 1990a, b; 1992; Dai Cleg and Barker 1990). Accordingly, a unified integrated model for geological data was developed (Figure 1).

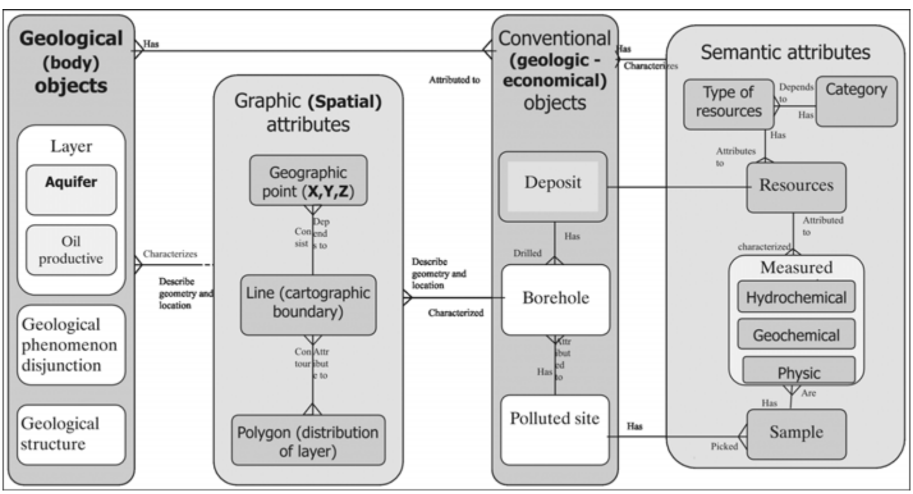

Figure 1. Model of integrated geological database.

The first step towards creation of the digital database was the establishment of the Geological Information Department at the Lithuanian Geological Survey. In 1992 a vision of information system development was presented and approved. It was decided to use Oracle Case Method and technologies. In 1993 the strategy phase of IS creation was undertaken (Krikstaponis et al. 1993). The implementation phase has been in progress since 1994. The important milestones are listed below:

1994: GIS implementation
1996: digital mapping using MapInfo
1997: integration of GIS and RDBMS (GIS-Geolis)
2000: reorientation to Intranet applications
2001: Internet Maps
2002: reorganization of WEB portal, implementation of 'shareware' software (MapServer, PHP, MySQL, etc.)
2003: reorganization of the IS infrastructure.

The geological database of the Lithuanian Geological Survey is administrated and used by applying a centralized approach (Belickas 1999b. The main geological data are stored in one integrated central databank. Management of the database and access to the data are possible through different client applications, based on Intranet and Internet solutions. Local clients and Internet users use the same data sets (Figure 2).

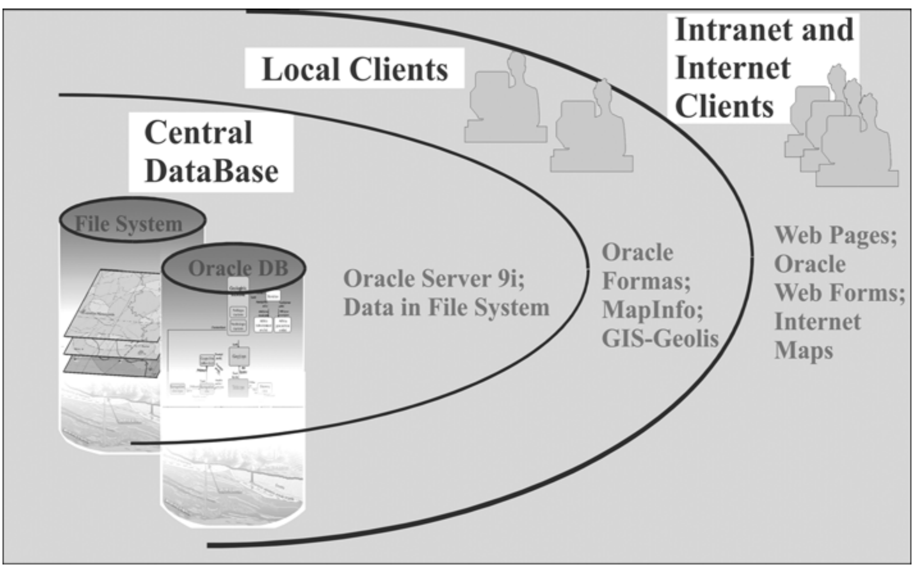

Figure 2. Integrated management of geological data.

There are several applications that have been realized and implemented to date:

- Classifiers
  - Stratigraphy
- Register of Boreholes
- Register of Underground Resources
  - Groundwater
  - Non-metallic Raw Materials
  - Oil
- Monitoring of Groundwater Level
- Contaminated Sites
- Geochemistry
- Hydrogeochemistry
- Bibliography
- Digital Cartography.

Classifiers are used in all applications as a tool for data input to the system. There are 87 different classifiers used in the geological information system of the Lithuanian Geological Survey. The *Stratigraphy* application is the repertory of the stratigraphic classification systems used at different stages of geological studies. It is the biggest constituent part of Classifiers. As a systematic backbone of geological knowledge, Stratigraphy contains data of various local, national, and international stratigraphical schemes. It makes it possible to compare various geological layers classified according to different stratigraphical schemes.

The *Register of Boreholes* allows management of and access to various types of borehole data sets (Belickas 1999a, b). Information from more than 31 000 boreholes in Lithuania and surrounding areas is stored in the database, each item of data having a particular reference. This application is extensively employed by geologists for data recording and application. A simple interface for data transfer to interpreting packages is included. The first application released under the SQL form has since been regenerated to the Oracle form (under Windows, Figure 3). It is now released for Intranet and Internet applications using the Oracle Application server. Data from boreholes are accessible using the 'GIS-Geolis' application and Internet Maps.

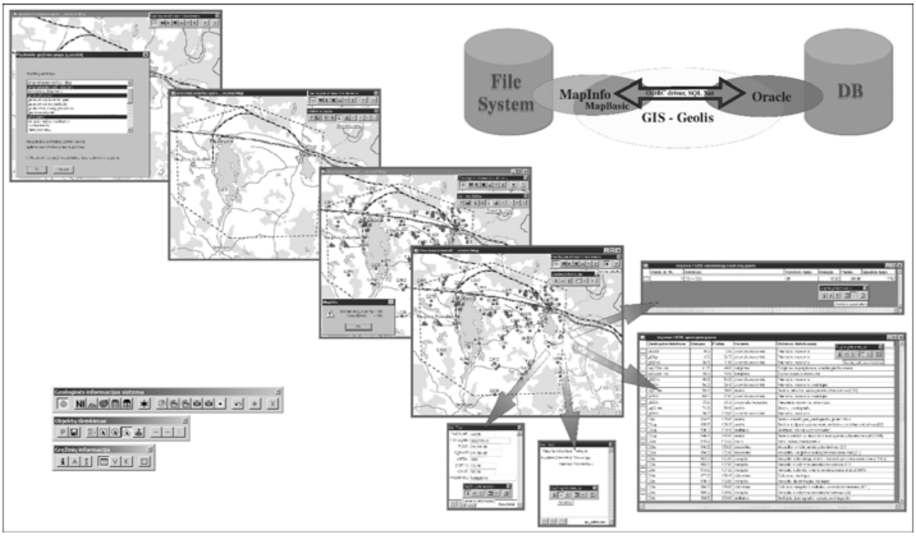

Figure 3. Search for geological data in Oracle RDBMS through MapInfo window.

The *Cadastre of Underground Resources* consists of three parts:

- Non-metallic raw materials
- Oil and gas fields
- Groundwater.

It contains data on deposits of non-metallic raw materials (e.g. peat, sand), water, and oil fields. The Cadastre of Underground Resources was designed in 1997. It has now been transferred to Oracle Intranet/Internet forms. There are 2050 deposits of non-metallic raw materials, 280 wellfields, 78 oilfields, and a number of potential oil structures available in the database. Data are also accessible through GIS-Geolis and Internet Maps.

The *Monitoring of Groundwater Level* application provides the user with the interface to routine data of observations of the groundwater level of the State Monitoring Network collected since 1946. This application stores 1 760 000 records of the groundwater level.

The *Geochemistry* application is designed to store and work with geochemical data. Every sample is linked to a borehole or surface point with special references. This application was installed in 1995 and contains the results of more then 41 000 geochemical analyses.

The *Hydrogeochemistry* application is used for the management of groundwater test results. It is very similar to the geochemistry application and contains data from more than 33 000 hydrogeochemical analyses.

The *Contaminated Sites* application is designed to register information on polluted areas. This is linked to the objects of the above-listed applications through an application interface, such as drilling, geochemical, or hydrogeochemical data.

The *Bibliofond* application is established to help management of the geological bibliography data, library and archive routine, and client service. Bibliofond contains about 5000 bibliographical records on publications by Lithuanian geologists. Information is accessible to Internet users.

The *Digital Cartography* subsystem is an important part of the geological information system. The graphical form of representation of geological knowledge has been in use for centuries (Asche 1998). Nowadays geological maps are often compiled using GIS, and geological graphical databases have become as important as printed geological maps (Belickas and Denas 1998, 2000). Graphical geological information is stored in a centralized way; it is accessible to local users using MapInfo GIS, and is also adopted for Intranet and Internet applications. Today, all graphical data are stored in the file system, but some data will be transferred to Oracle Spatial in the future. For this reason Oracle 9i with Oracle Spatial was installed as part of the reorganization of the Information Infrastructure in 2003. The Digital Mapping subsystem consists of three parts: (1) topographical background, (2) geological layers, and (3) compiled geological maps.

Three major topographical data sets are used as a topographical background for plotting the geological information, i.e. vector data at scales of 1:200 000 and 1:50 000 and raster orthophotographical maps at 1:10 000. Each data set covers the whole territory of Lithuania (Kanopiene et al. 1997).

Implementation of the database of geological layers has been in progress since 2002. The geological information is subdivided into thematically different parts, for example Quaternary geology, Pre-Quaternary geology, Hydrogeology, Engineering Geology (geotechnics), and Ecogeology (environmental geology). Geological layers of maps of Quaternary Geology, Pre-Quaternary Geology and Geomorphology of Lithuania at a scale of 1:200 000 are stored in the database. Data from the State Geological Mapping at a scale of 1:50 000 are also incorporated. The graphical information on geological objects such as mineral deposits, polluted sites, etc. composes a separate part of the database of geological layers.

All of these data are easily accessed using MapInfo or GIS-Geolis tools (Denas 2002). Internet users can access them using Internet Maps that are available on the web site of the Lithuanian Geological Survey Figures 4 and 5):

http://www.lgt.lt/maps

All geological maps compiled at the Lithuanian Geological Survey are stored for digital applications on compact disks (CDs). In the future they will be copied to the file server, allowing access for local users and (eventually) Internet users.

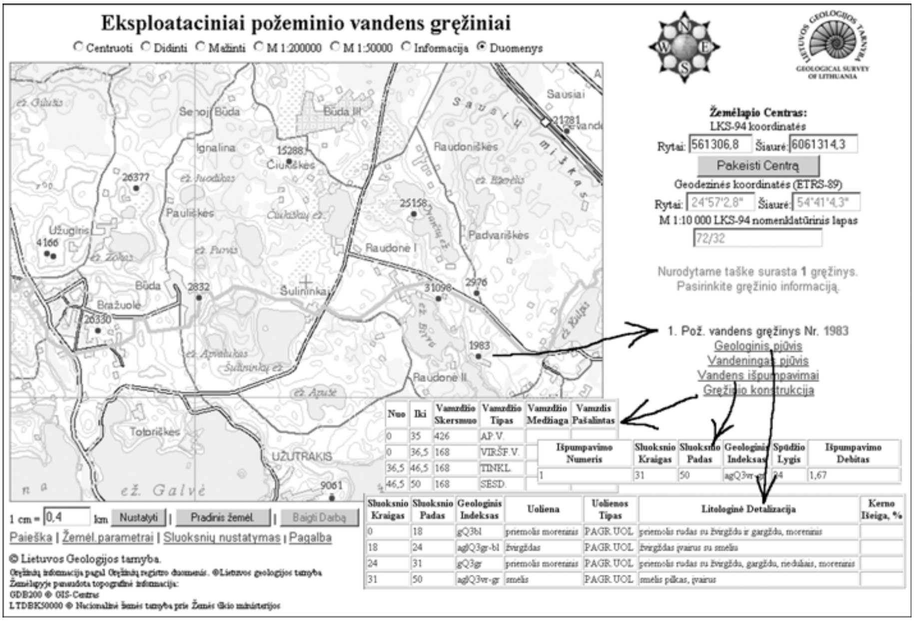

Figure 4. Accessing of boreholes data on web site of the Lithuanian Geological Survey.

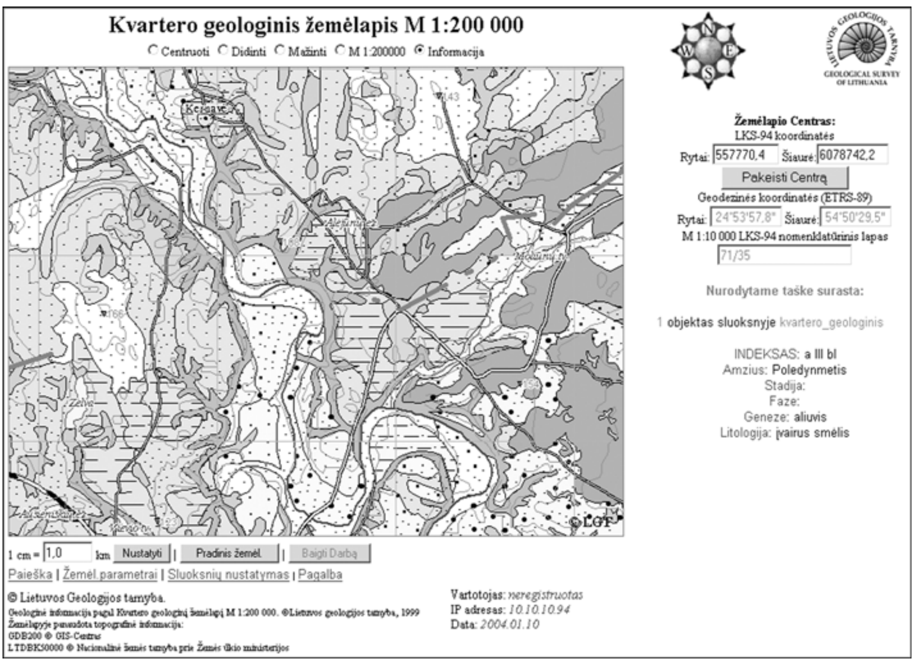

Figure 5. Quaternary geological map at a scale of 1:200 000 placed on web site of the Lithuanian Geological Survey.

GIS TOOLS APPLIED

GIS consist of a powerful set of automated tools for collecting, retrieving, analyzing, and communicating spatial data (Tomlin and Dana 1990). Such systems involve not only the automated handling of map data and imagery, but also the automated handling of records and attributes of anything that can be tied to a geographical location on Earth.

GIS Software

During the early stages of GIS implementation at the Lithuanian Geological Survey, ESRI and Intergraph GIS software was used. Since 1996, products of MapInfo Corporation, i.e. MapInfo Professional, MapBasic, MapInfo Runtime, MapInfo Viewer, Vertical Mapper, and MapXtreme, have been introduced (MapInfo Professional Users Guide 2001). These products are well integrated and cover most of the geologist's requirements (see e.g. Kanopiene and Denas 1999). Other products are applied for specific tasks, such as ERMapper for remote sensing and airborne image analysis, Surfer for advanced interpolation, and Geographic Transformer for coordination of scanned maps and transformation of them to the required coordinate system. For common projects with other institutions, ArcView and Arc/Info software is employed (Peuquet and Marble 1990). The Schlumberger complex is installed for management of a specific database of petroleum geology. Similarly, software from DHI (Mike She, Mike Basin, Mike 11, etc.) is applied for hydrogeological modeling.

MapInfo Professional

MapInfo Professional is the main GIS software used at the Lithuanian Geological Survey. It has an advantage in terms of price and functionality compared to many other types of GIS software. MapInfo Professional is stand-alone software; it does not require any other software to perform GIS data edition or analysis, or compilation of sophisticated maps. It has many applications, for example on-the-fly coordinate transformation, feature factory, SQL select, and Thematic Maps. MapInfo supports different file types and connections to various RDBMS, and to Oracle Spatial as well.

Compared to Arc/Info and many other types of GIS software that are intended for highly skilled users, MapInfo is relatively easy to handle. It is applicable through MapBasic, which provides powerful programming language facilities, and can be used for automating workflow, fitting MapInfo for particular user requirements, and adding new functions.

GIS-Geolis

GIS-Geolis is a 'homemade' application that provides integration between MapInfo GIS and Oracle RDBMS. It is programmed using MapBasic programming language. GIS-Geolis integrates data stored in Oracle RDBMS with graphical data stored in MapInfo format and makes the user interface for searching for the Oracle data more friendly. GIS-Geolis contains tools for quick and easy compilation of geological maps, such as automatic display of the topographical background of a study territory, design of map sheets, coordinate grids, etc. GIS-Geolis allows MapInfo to communicate with Oracle RDBMS tables through the ODBC drivers and Oracle SQLNET software. Depending on the user project in the MapInfo environment, GIS-Geolis makes SQL queries to Oracle DB, takes out necessary data, and sends them to MapInfo for display on topographical maps (Figure 3).

Internet Maps

There are many ways of delivering graphical geological information, such as printed or plotted maps, client–server GIS applications, delivery of digital information to particular users using CDs or Internet facilities, and standard www facilities:

gif/jpg images, image maps

All of these functions are used in the Lithuanian Geological Survey. Internet Map was introduced in 2000. It is a powerful tool for presentation of geological data worldwide, providing the end user with good control of the data presented.

Dynamical Maps on the Internet have a lot of advantages compared to other applications for delivering graphical information. One of the key advantages is an unlimited and speedy delivery of information worldwide. Another advantage is that that user does not need additional software or special GIS knowledge. Information is available to anyone using the standard www browser. www pages of Internet maps are generated dynamically, so they can be easily modified. There are good programming possibilities; it is possible to use API, and write client-side or server-side code that responds to user interaction. This way of delivering graphical geological information is relatively cheap. Dynamical Maps on the Internet require initial investment, but after installation they demand less expenditure compared to other facilities for delivery of information.

The web site of Dynamical Maps on the Internet is used in the Lithuanian Geological Survey for two main purposes: visualization of Oracle RDBMS data (Figure 4) and publication of geological maps (Figure 5) (Denas 2001).

It is very convenient for the end user to use via Internet Maps the data sets stored in a GIS. Internet users can obtain updated information on boreholes, water wells (Figure 4), mineral deposits, polluted sites, monitoring networks, and geological heritage sites. Users can see the location of a geological object and generic information on it. Registered users are able to obtain more detailed information, for example a borehole section.

Dynamical Maps on the Internet are used to publish the geological maps. The Quaternary Geological Map (Figure 5), the Geomorphological Map, and the Pre-Quaternary Geological Map at a scale of 1:200 000 are available. It is possible to obtain attributive information on geological layers using Internet Maps.

Internet Maps are compiled using MapInfo MapXtreme (Windows edition) software. This is the mapping application server released from the MapInfo Corporation. The core of the mapping application is MapX, MapInfo Corporation's mapping OCX. Because MapXtreme allows MapX to run on the server site, no plug-in is required in the client's web browser. MapXtreme, together with HahtSite Scenario Workbench and Server, form an integrated tool for building the Internet and Intranet web applications. It is important that MapXtreme is fully compatible with other MapInfo products, such as MapInfo Professional.

The Internet Maps of the web portal of the Lithuanian Geological Survey have most of the common facilities of a GIS map window, for example the possibility to control the map window and obtain information on the map layers. The user can re-center a map, zoom in, zoom out, set the map scale or coordinates of the map center. It is possible to obtain basic information on each object shown on the map or more detailed information about geological objects stored in Oracle RDBMS tables. Special web pages allow changing of the width and height of the map window, and adjusting map layers. Internet Maps have the powerful Search system implemented.

Free-Source GIS software

Implementation of free-source software started in 2002. This software is widely used in the web portal of the Lithuanian Geological Survey. MapServer is adopted for GIS applications. It is useful for the transformation of GIS functions into web pages (Figure 6). MapServer is free of charge; it works very quickly and has most of the common functions that might be used for Internet Maps. It is quite easy to integrate MapServer with other free-source software: PHP, MySQL, and others. MapServer works on every operating system; there are no problems of shifting from one operating system to another.

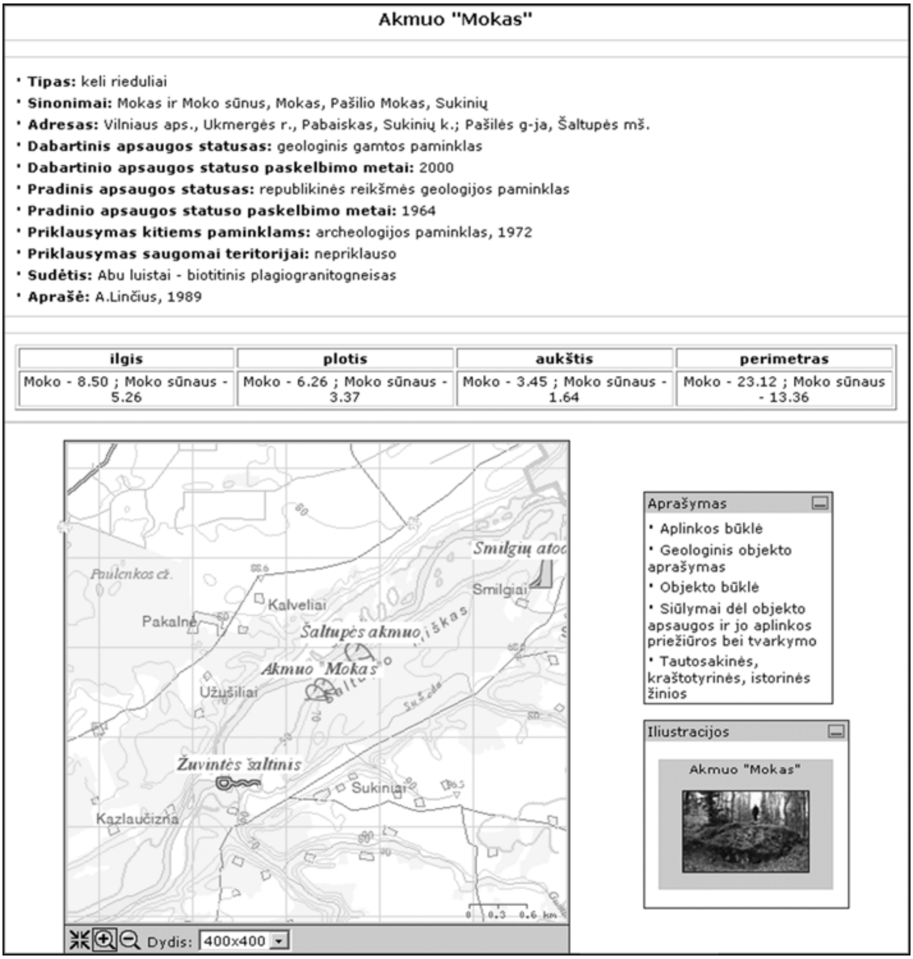

Figure 6. Web page with integrated MapServer map on web site of the Lithuanian Geological Survey.

DISCUSSION

The Information Infrastructure concept should be carefully planned to ensure efficient management of the data. A centralized approach is strongly recommended for geological database management, otherwise financial resources are wasted and access for geologists and essential public users to geological information is made more difficult. Different platforms can be used for the database. However, a common problem is the development of the classifiers system, which depends on different factors (geological conditions, tasks, etc.).

With the introduction of digital technology the concept of geological maps has changed. Regardless of whether a map is hand-drawn or digitized, it is still meant for the graphical representation of geological information. The method of data representation is, however, different. Information technology allows us to fill the map with unlimited data in the form of attributes, layers, and their combinations. Moreover, it provides the possibility of producing derivative maps by stacking together different kinds of information, such as lithology, land cover, and relief for definition of areas with different erosion potentials.

Dynamical Maps on the Internet considerably increase the possibilities of delivering graphical information to users, which is a key issue for public institutions such as the Geological Survey. One of the important advantages is an unlimited and speedy delivery of information worldwide. Furthermore, a user does not need additional software or specialist GIS knowledge, therefore the potential for non-geologists to use geological information is much increased (Platen 1995). However, for the public user, maps should be based on specific language that is easy for a non-geologist to understand. This idea was applied in part for the compilation of a set of Lithuania-scale maps for territorial planning at a scale of 1:400 000 (Kanopiene et al. 1997).

The future trend for the Lithuanian Geological Information Infrastructure will be (1) further expansion of application of IT and (2) adjustment of the geological mapping system to the possibilities that are provided by this technology. Regarding the former issue, one of the priorities is the introduction of three-dimensional (3-D) GIS tools (Lazauskiene and Sliaupa 2002). 2-D tools are applicable to show a certain surface, but the result is not very different to conventional hand-compiled maps. 3-D tools allow a complex characterization of the geological volume that is important for solving particular problems, such as exploration of underground storage facilities or groundwater flow modeling (Yamane and Sakakibara 1992). Accordingly, the concept of geological mapping should be changed to fit this approach.

In general, since early mapping activities, geological mapping has always focused on characterization of the area in the 3-D geological volume. However, the data systematization needs to be changed; it is necessary to use for the initial rock description a classifier language compatible with the database classifiers, thus making data transfer and organization much more efficient.

ACKNOWLEDGMENTS

The authors are thankful to their colleagues from the Geological Survey of Lithuania, J.Bitinas, J.Cyziene, A.Pozingis, and V.Rapsevicius, for discussions on the early draft of this paper.

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REVIEW BY EARL BRABB

This article indicates that Lithuania, a country one-fourth the size of Poland and about the size of Austria, Maine, and Portugal, has the most sophisticated and complete digital geological information system of any country in the world. The country has such an aggressive and well-formulated plan that leadership at the very highest levels of government must have been involved in providing the funding, human resources, and direction for such an impressive project. Congratulations are in order for members of the Lithuanian Geological Survey (LGS) who have formulated the plans in detail and carried out the work.

This well-documented article speaks for itself, so little critical comment is warranted. Perhaps most interesting is the widespread availability of free geological information to the public in a form that they can understand and use. Also of interest is that the LGS is in the process of converting 2-D geological information into a 3-D format so that problems of underground storage facilities and groundwater flow can be understood and addressed.

REMOTE SENSING IN GEOLOGICAL MAPPING

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Keywords: Remote sensing, geo-ecological mapping, complex computer processing, platform areas

EXTENDED ABSTRACT

In geological mapping based on remote sensing, photographic and optic-electronic camera systems are used which ensure registration of the reflected or generated electromagnetic radiation of the Earth. The following basic kinds of Earth-surface aerospace photography are applied: photography (0.4–0.9 mμm), television filming (0.4–1.1 mkm), multispectral scanner mapping (0.3–12.6 mkm), spectrometry (0.4–2.5 mkm), thermal infra-red filming (3.5–5.0 and 8.0–14 mkm) and radar mapping (0.3 cm and greater). Complex computer processing of remote sensing data allows the delineation of boundaries of homogeneous geological objects and controlled classification of aerospace images to be carried out.

The computer processing for aero image interpretation involves the following procedure:
1) digitizing of images
2) conversion and binding of the digital images
3) study and contrast adjustment of images
4) clustering of the digital images.

Some results of aerospace image computer processing are presented in Figures 1–3.

Figure 1. Results of computer processing of image

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 151–156.

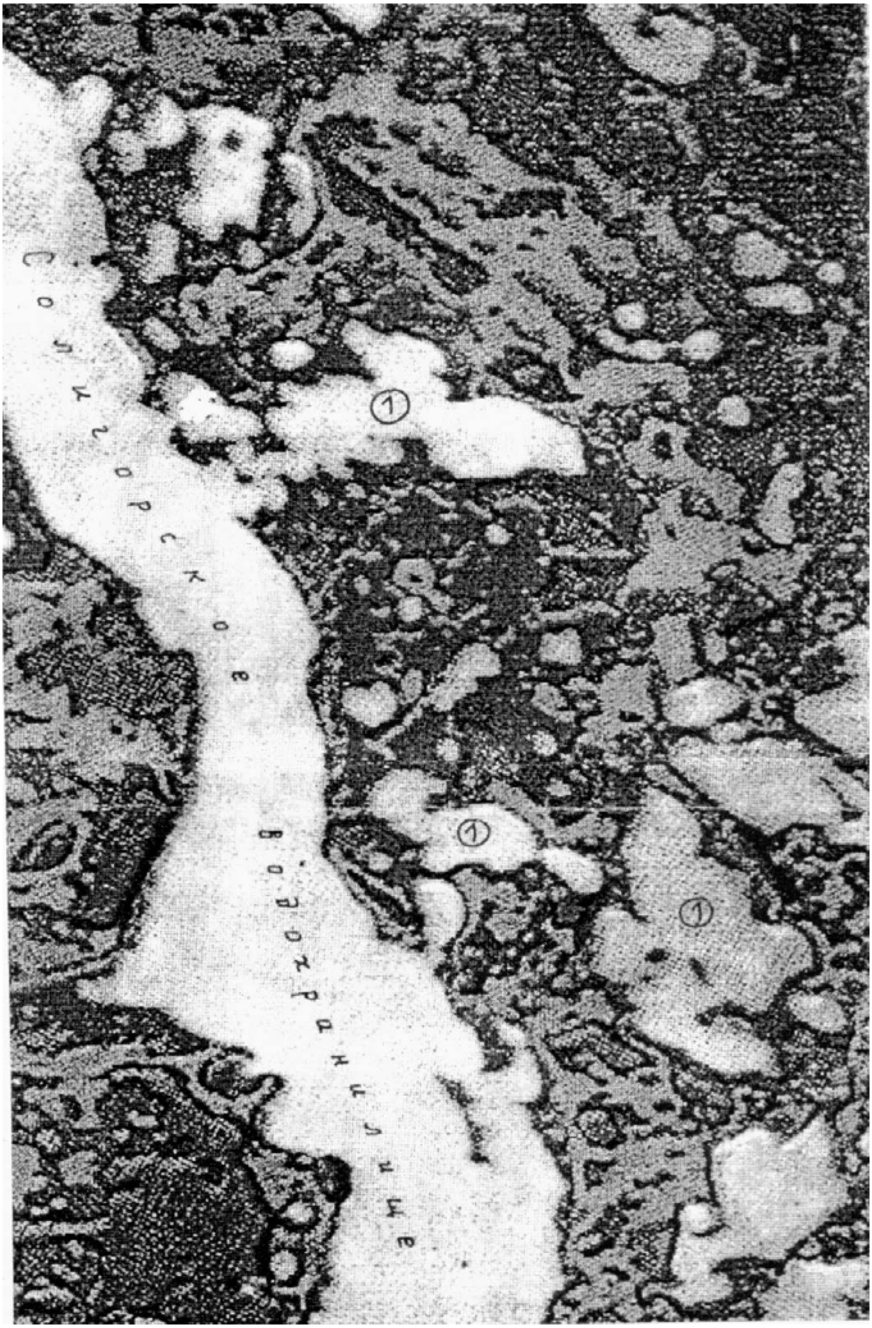

Figure 2. Fragment of a color-coded space image showing swamping of geosystems (1) due to mining subsidence, above-mine developments, and a submerged zone of Soligorsk reservoir.

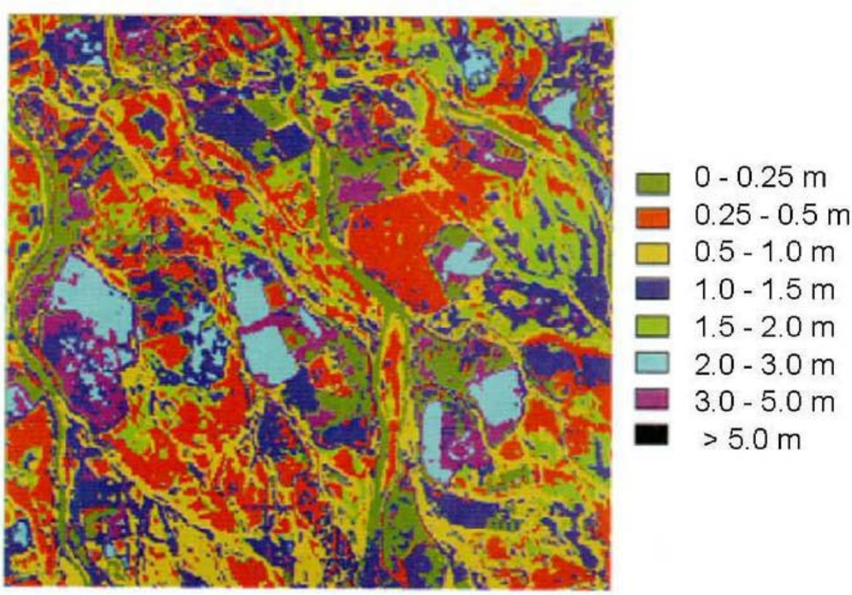

Figure 3. Map of groundwater depths, based on computer processing of space images.

Space information from Russian satellites RESURS-01 equipped with multizone scanners with a spatial resolution of about 45 m is becoming important in geological mapping. An example of the technological procedure involved in computer processing of space images for geological mapping is given in Figure 4.

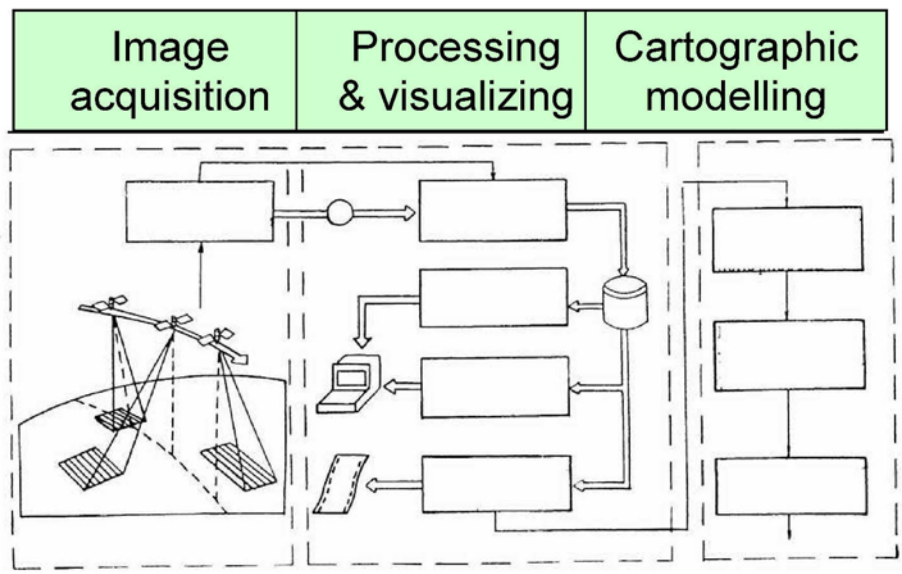

Figure 4. Computer processing of scanner images form RESURS-01; technological procedure.

In platform areas, remote sensing methods are used to record differently ordered lineament zones connected to the mantle- and crust- level faults displayed on the Earth's surface. The huge blocks related to such zones differ in terms of geophysical field characteristics, capacities and facies of sedimentary rocks (Figure 5).

Features interpreted as ring structures are represented by heterogeneous discontinuities (disconformities) of the Earth's crust, shown in the isometric outlines of landscapes. The basic contents of geo-ecological maps at a scale of 1: 200 000, created on the basis of remote survey materials, are used for cartographic display of natural and technogenic factors of geologic environment dynamics. They area also used to display areas with particular ecological environments, and protected natural territories and objects (Figure 6).

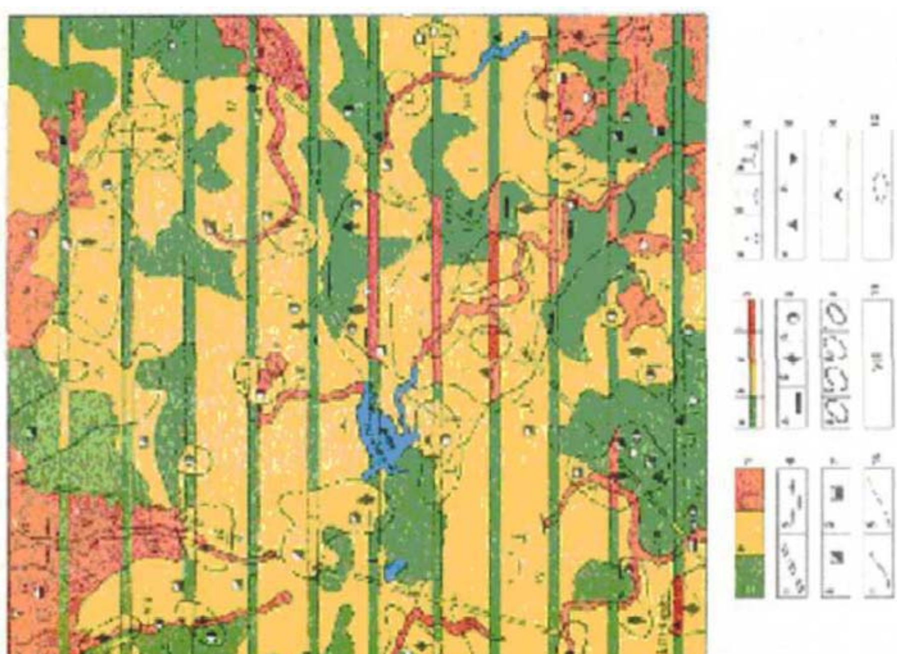

Figure 5. Geo-ecological map of the Minsk polygon of Belarus, showing geo-ecological conditions according to (1) natural and (2) technogenic factors: (a) favorable; (b) moderately favorable; (c) unfavorable; and (d) extremely unfavorable.

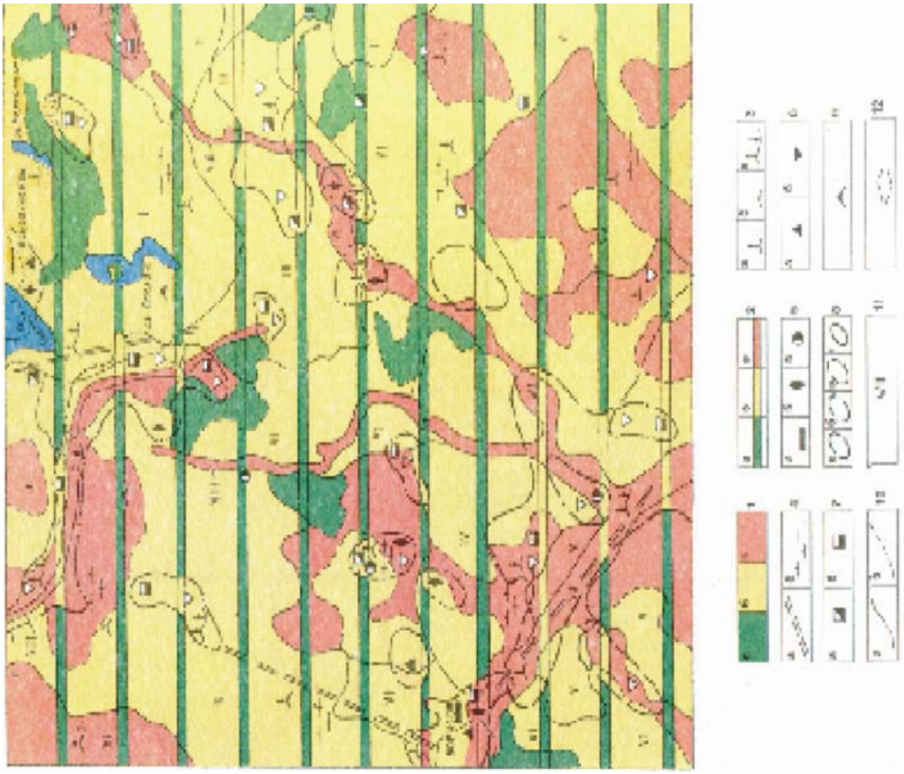

Figure 6. Geo-ecological map of the Berezensky polygon of Belarus, showing geo-ecological conditions according to (1) natural and (2) anthropogenic factors: (a) favorable; (b) moderately favorable; and (c) unfavorable.

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REVIEW BY EARL BRABB

The appearances of images from Russian satellites with multiband scanners and 45-m resolution is heartening after a period when even topographic maps were considered state secrets. Images with even greater resolution are available, of course, but are generally too expensive for the average geologist. The images in this report were used to show areas with mining subsidence, areas with different depths to ground water, and environmental maps for the Minsk and Belarus areas.

Very little text was provided, but one sentence with the words, “cartographic display of natural and tectogenic factors of geologic environment dynamics" is reminiscent of Soviet jargon that was barely understood by most scientists outside the former Soviet Union. I would hope that scientists from Belarus would leave behind forever this jargon and communicate with us in a more direct and understandable language.

NEOGEODYNAMICS PHENOMENA INVESTIGATION AND COMPUTERIZED MAPPING IN BELARUS

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Abstract: The solution of the several problems of neogeodynamics phenomena investigation and mapping was one of the main tasks of the IGCP project No 346 "Neogeodynamics of Baltic Sea Depression and adjacent areas". Investigations performed for the project resulted in a series of international geodynamic maps showing vertical movements at the neotectonic stage, bottom part of Quaternary deposits, recent vertical movements, tectonic stress, epicenters of earthquakes, Moho discontinuity, neotectonic zoning and so on (Aizberg et.al., 2001; Garetsky et. al., 2003). Hence, the water surfaces of the Baltic Sea and the east part of the North Sea, the southern part of Scandinavia, the German-Polish Depression, the Central European block mountains and depressions, western part of the Russian Plain and, partly the Carpathians, were mapped. Despite of, that was done in traditional manner without any digitization, the set of maps showing structure and its dynamics from the Quaternary capping down to the Moho surface fulfils requirements of the modern Information Technology, thus it may and can be computerized in follows of the GIS rules. That will enable authors to supplement project with the newest data, and restructure its visual appearance, in the attached presentation, authors review some problems of geodynamic researches in Belarus.

Keywords: Neogeodynamics, structural pattern, stress field, geological mapping, seismicity

INTRODUCTION

Among the main problems of neogeodynamics phenomena investigation and mapping were the issues pertinent to the geological and computer models explaining the nature of recent tectonic features, correlation between the recent geodynamics and deep structure of the lithosphere, tectonic stress field, seismicity and the active faults which are responsible for the distribution of earthquakes, definition of the most important factors controlling over the geodynamic processes.

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 157–168.

First of all are to analyse the problems concerning the nature of recent tectonic features and its correlation with the deep structure of the lithosphere. The East European Craton differs essentially from the young West European Platform in the depth to the Moho discontinuity (thickness of the Earth's crust). If the former is described by a rather thick crust (up to 40-60 km), then the latter - by the thinner crust (25-35 km). A regular increase of the crustal thickness is observed in both platforms within the positive tectonic features, and a decrease - within the negative ones. The same is true for the lithosphere thickness. If within the young platform this tendency increased due to recent movements, then within the craton their effect was not so pronounced. Exceptions were the areas of the Fennoscandian Shield and the graben systems in the East Baltic region. Despite scarse evidences about the crustal thickness, its decreasing was noted in the regions of the West and East Gotland, Bothnian and Finnish Grabens showing different depth to the Moho ranging from 10-15 km.

The inquiry into the nature of neotectonic movements revealed the most recent tectonic features (Aizberg et.al., 2003): Baltic-Belarussian Syneclise involving the East Baltic and Finnish Graben Systems (within the East European Craton), North Sea Depression, Central European Zone of subsidences, Central European Zone of uplifts, etc. (within the young West European Platform). The features of the first group demonstrate a superimposed structural pattern against the older platform tectonic units. Those of the second group - are of posthumous character. In general, positive structures show the thicker crust and the negative ones-the thinner crust.

Still one of the debatable problems in geology of Europe is the genesis of the Baltic Sea Depression; This problem solution will provide the key to understanding the geological evolution history of territories of many countries situated in the Baltic Sea basin during the Late Cenozoic. At present there are two different ideas of the Baltic basin genesis. Some geologists associate the origin of the Baltic Sea Depression with glacial erosion, but lately we have many signs acknowledged the tectonic factor as the dominant cause of the Baltic Sea basin formation allowing for a new rifting system that was possibly initiated there. Hence, the most important factors controlling over geodynamic processes that occurred in Central Europe are the Alpine-Carpathian Orogen, downwarping of the North Sea Depression and Central European Zone of subsidences, as well as the development of the recent (embryonic phase) East Baltic Rift System of triple junction. The origination of the Baltic Sea Depression which dates back to Post-Holsteinian time (less than 0.4 mln.yrs.) is associated with it.

The analysis of distribution of the Quaternary strata thickness and composition and the calculation of proportions of materials removed from the central and eastern parts of the basin and redeposited rocks show that only about 40% of the total basin volume can be attributed to exaration. The tectonic genesis of the most part of the Baltic Depression is confirmed by some unconformities revealed in the pattern of glacial sheets and the sea water area, gradual subsiding of the Estonian glint below the sea level, which lower Paleozoic rocks occurred in the Early Pleistocene within an uplifted source area, and a lowered block of Upper-Proterozoic and Early-Paleozoic deposits pre served from erosion which exists in the Gulf of Bothnia.

The Baltic Sea depression had been mainly formed during the last 0.4 mln. yrs (Figure 2). Until the Early Pleistocene there was no evidences of the Baltic Sea existence. At that time, the surface runoff occurred across the territory of the future depression from Fennoscandia toward large freshwater bodies of Central Europe. Inversion movements are associated with the beginning of the Holsteinian. The water transgression occurred from the North Sea in the eastward direction, the Holsteinian Sea crossed Northern Germany and reached the territory of Lithuania and Latvia in the east, while the drainage develop centripetally crossing the territory of the western part of the modern basin from north to south. The sea basin appearance in the Holsteinian in the eastern part of the Baltic Depression was accompanied by the drainage network reconstruction and changes of the river courses within the adjacent regions west of the East European Craton. The Gulf of Bothnia and the Gulf of Finland formed after the Holsteinian. All the above evidences suggest a young age of the depressions of the East Baltic Sea, Gulfs of Bothnia and Finland that possibly form parts of an embryonic riftogeneous triple-arm system.

The last conclusion is supported by a number of various evidences. Firstly, these are deep depressions in the sea bottom relief, which maximum amplitudes of neotectonic downwarping are associated with. These are shaped as narrow linearly extended graben-type structures. The only Likhvin-Holsteinian downwarping shows there maximum values (150-200 m). The most recent fault system bounds and clearly delineates the graben-type structures. A number of block linear horst-type (Central Gotland Uplift) and graben-type (West and East Gotland Uplifts) structures are outlined by faults within the bottom of Gulfs and the East Baltic area. High seismicity values are confined to the bounding zones of Grabens. Local positive heat flow anomalies were determined in the inner sea parts (regions of the Gotland island, Gulfs of Kursh and Finland, etc.). The Earth's crust thickness was noted to decrease within the East-Baltic Graben System, a difference in the Moho depth being as great as 10-15 km.

The evolution of the East-Baltic Graben System and the deep North Sea Depression in the west margin of the Eurasian lithospheric plate was probably due to submeridional tension belts that occurred subparallel to the Mid-Atlantic spreading zone (Figure 1).

As the main reference horizons Lower Oligocene marine deposits (rupelian layers) were selected. In places where the above deposits were absent, the structural features of the bottoms of Miocene marine and Quaternary deposits were taken into account.

Within the territory of Belarus and the neighboring Recent strata are mainly formed by deposits of four formations (Figure 2). The oldest is brown coal formation accumulated during the Late Oligocene, Early and Middle Miocene and widespread on the south of the Baltic region, in Belarus and the Ukrainian Polyessie area (sand, brown coal, clay). The overlying formation of montmorillonite clays (included in the Upper Miocene and Lower Pliocene strata) is found mostly in the southeastern and central parts of the Pripyat Trough and adjacent areas of the Dnieper Trough, to a smaller extent - on the southeast of the Brest Depression, and as spots - within the Belarussian Anteclise territory. Within the Brest Depression, west and south of the Pripyat Trough there is a formation of Pliocene silts and diatomaceous clays. All of Late Oligocene-Pliocene formations are situated in the Early Oligocene sea area. As opposed to old formations the thickness of Mid- and Late Pleistocene glacial formation in general is concordant to the recent tectonic features of the region and the surface of Pre-Quaternary deposits presents a monocline gently inclined from southeast to northwest toward the Baltic Sea basin, is being known that linear marginal glacial landforms, as well as systems of glacial hollows occur above fault zones. It also testifies to the very young age of the Baltic-Belarussian Syneclise, which was formed in the Quaternary time. The important part of investigation are the reconstructions of the tectonic stress field and the active faults. The investigation of recent tectonic stresses have shown that the mechanism governing the development of recent structures west of the East European Craton was largely dependent on shear stresses that have submeridional compression and sublatitudinal exterisional axis. In such a stress field faults of NW strike are right shifts, and those of NE strike - left shifts.

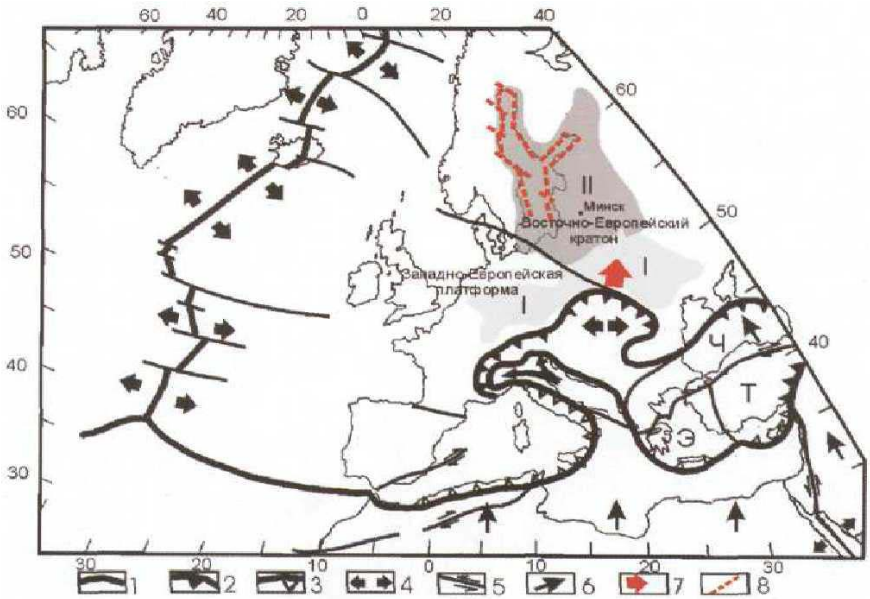


Figure 1. Recent tectonic features and factors controlling over neogeodynamic processes in Central Europe: I-II – neotectonic structures: I - Central European Zone of uplifts, II - Baltic-Belarussian Syneclise; 1-3 – the boundaryes of lithosphe plates: spreading and transform (1), collision (2), subduction (3), 4 – tension, 5 – shear, 6 – direction of plate moving, 7 – direction of the dynamic impact of Carpathian orogen on the East European Craton, 8 – faults of the East Baltic and Finnish Graben Systems

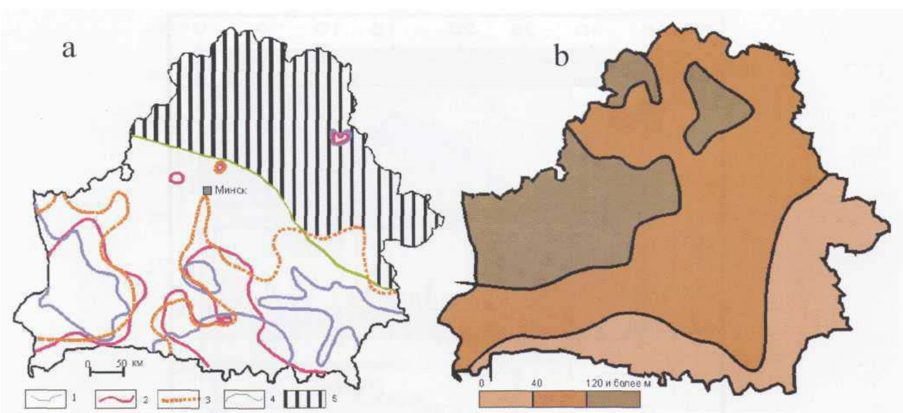


Figure2. Recent formations within the territory of Belarus: a - formations of Late Oligocene-Pliocene: 1-2 – distribution area of browncoal formation, Late Oligocene-Mid Miocene (1 – sand-clayey subformation, 2 - browncoal subformation); 3-4 - distribution area of silt and clays formation Miocene-Pliocene (3 - montmorillonite and diatomaceous clays subformation, Upper Miocene, 4 - silt and hydromicaceous clay subformation, Pliocene); b – average thickness of Pleistocene glacial formation

The orientation of compressive stresses changes appreciably, sometimes to the reverse in the area adjacent to the Baltic Sea basin. Orthogonal faults most often show evidences of faults or shear-faults. This conclusion is confirmed by geological data and investigation of ruptures (Figs. 3,4) in the potassium-mine (Soligorsk).

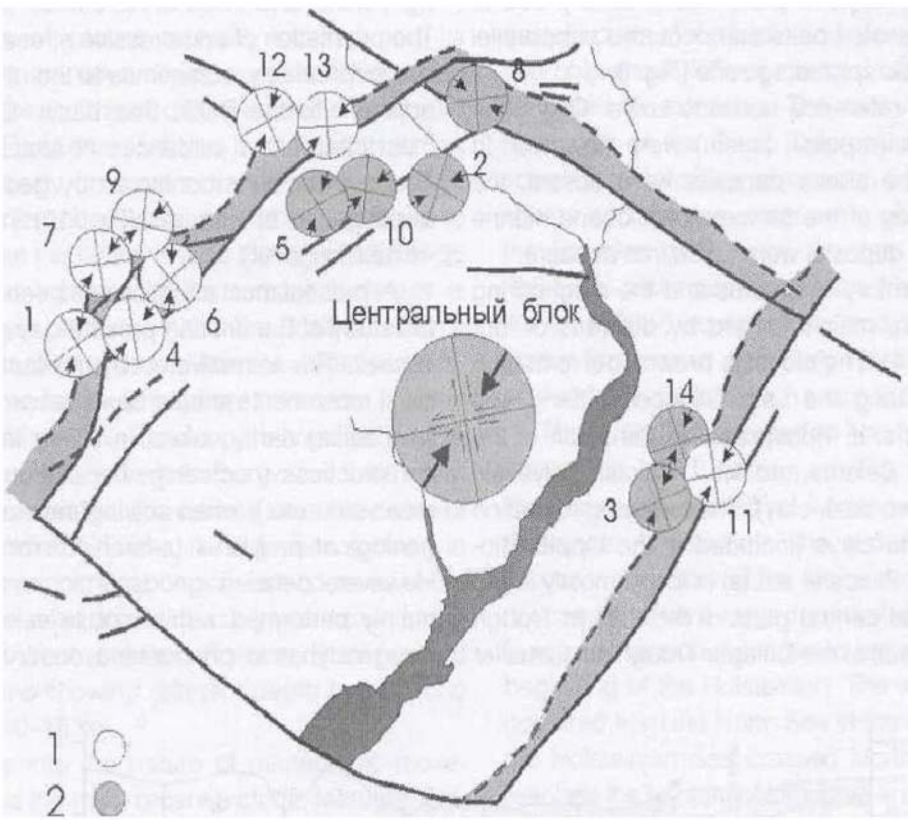


Figure3. The example of reconstruction of the stress field in the potassium-mine (Soligorsk): the full and dotted lines shows the fault zones on different depth (in the south-east runs the zone of Central fault), the numbers show various domains; 1–2 - measuring points in the second (1) and third (2) potassium layer (horizon)

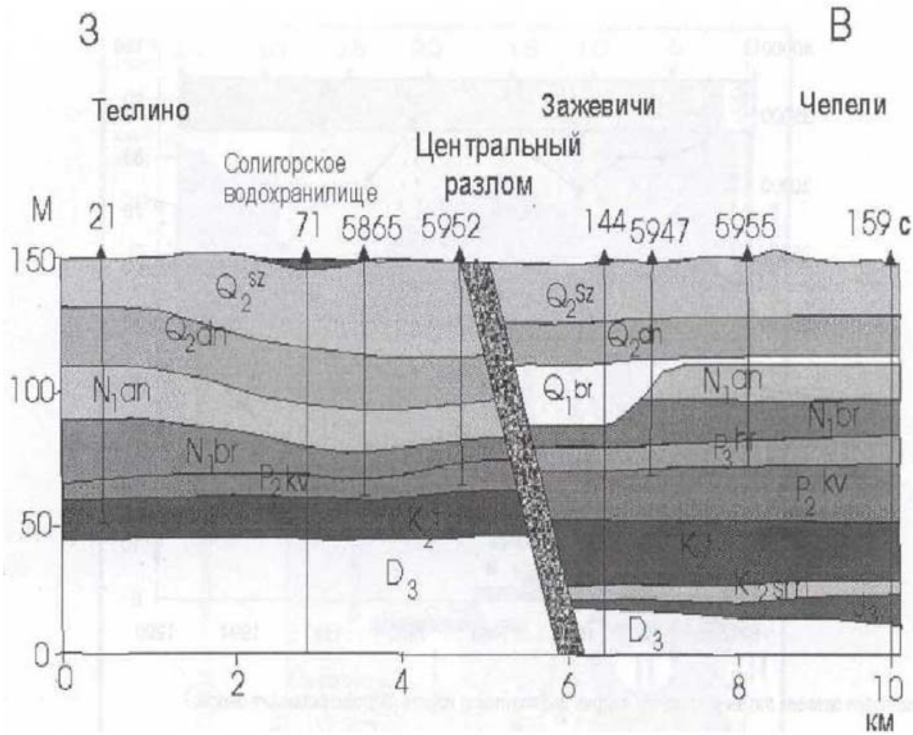


Figure 4. Geological profile across the Central fault near Soligorsk (drawing: looking north)

At present most attention has been concentrated on the study of Recent and present-day geodynamic pro-cesses. This is motivated by the fact that the Earth's crust movements should be necessarily considered in forecasting earthquakes, in sitting large engineering constructions (nuclear power stations, water-storage reservoirs, etc.), when solving several ecological and geological problems (search for minerals included). However, detailed geodynamic investigations were mainly performed within mobile seismoactive areas.

Neogeodynamic phenomena observed within rather stable intra-plate regions have not yet been adequately studied. The seismological data demonstrate that within the territory of Belarus active faults are responsible for the distribution of the earthquakes.

Arc View GIS 3.2a software was used as a tool to design the GIS project entitled "Earthquakes & Faults of EEP + Soligorsk area", that involves the digital layers as follow: border, geogrid, territorial waters, rivers, settlements, countries, open sea, faults, EEP earthquakes, Soligorsk earthquakes (Figure5).

At the first stage of the GIS implementation a topographical basis was created by automatic vectoring of image graphics on a recording surface ″Vertical movements since the beginning of Rupelian stage (Oligocene)″ involving digital layers as follow: border, geogrid, territorial waters, rivers, settlements, countries, open sea. A bit map was processed with Adobe Photoshop 6.0, and automatic vertoring was made in a vectorizer R2V (R2V Group, Russia). Each digital object was supplied with an information entered line-by-line in attribute tables.

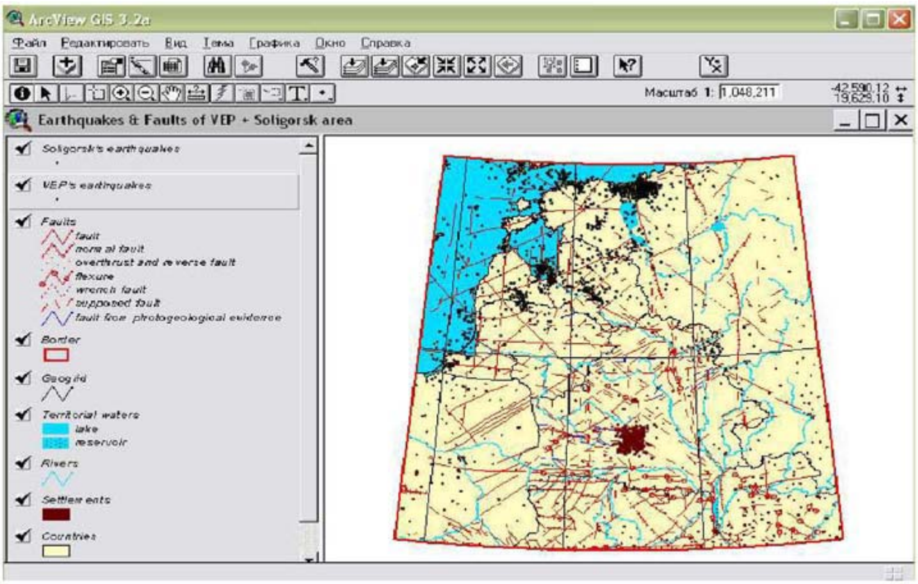


Figure 5. General view of the GIS project ″Earthquakes & Faults of EEP + Soligorsk area″

The second stage expected the creation of digital topics as follow: faults, EEP earthquakes, Soligorsk earthquakes (Figure 6). The faults topic including 523 faults was created with the map ″ Vertical movements since the beginning of the Rupelian stage (Oligocene)″ used as a basis by image graphics digitizing. Dot patterns of EEP earthquakes (1, 673 earthquakes) and Soligorsk earthquakes (729 earth-quakes) were obtained from the database geographical coordinates using Arc View 3.2a Enter Point by Coordinates.

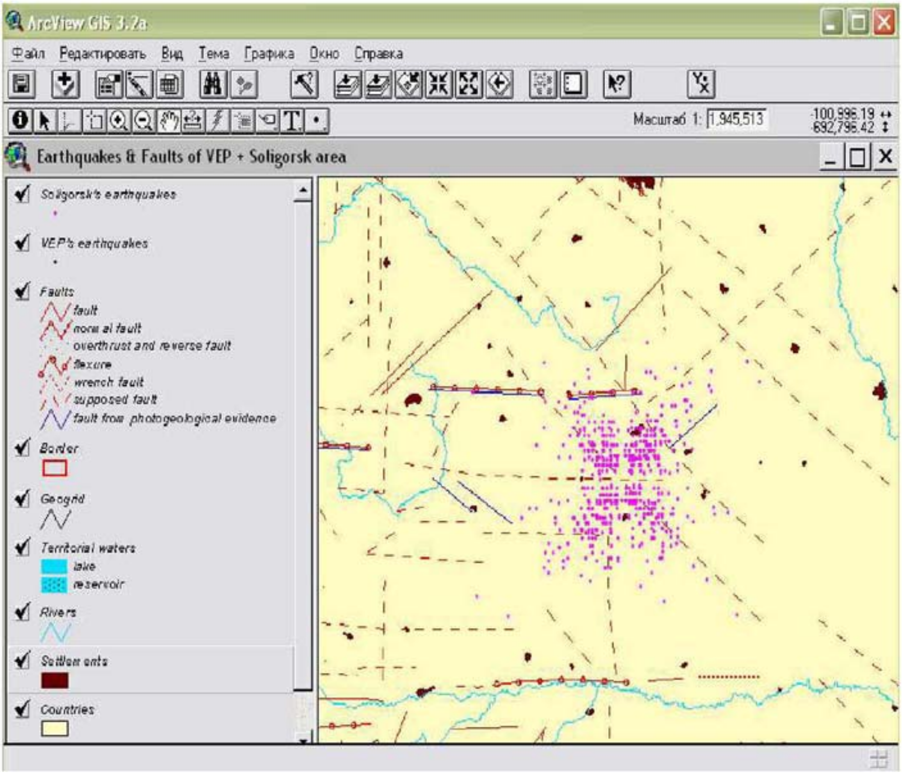
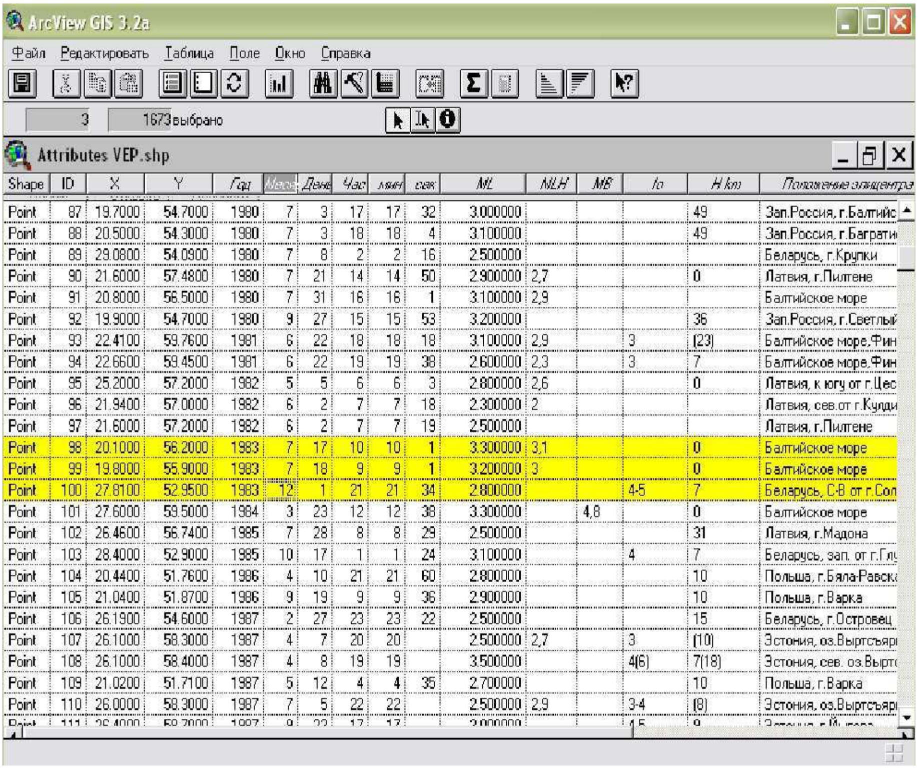


Figure 6. GIS project fragment (Soligorsk geodynamic testing ground)

The final third stage consists in matching graphic objects from EEP earthquakes and Soligorsk earthquakes with the EEP database available at the Centre of Geophysical Monitoring of the National Academy of Sciences of the Republic of Belarus. For this purpose, SQL was connected with the database, and attribute tables were combined with Arc View GIS 3.2a (Figure 7).

So, at the present-day stage of the GIS implementation in the seismic information display system, a topographical basis for the East European Platform western part, as well as the following actual layers: faults, EEP earthquakes, Soligorsk earthquakes were developed. Digital models of the relief, structural horizons, basement surface and some other geological and geophysical parameters are expected to be created later on.

At the same time there are observed the positive connection between the seismic activity and some man-caused factors (Figures 8, 9).



Shape	ID	X	Y	Год	Меся	День	Час	мин	сек	ML	MLH	MB	Io	H km	Положение эпицентра
Point	87	19.7000	54.7000	1980	7	3	17	17	32	3.000000				49	Зап.Россия, г.Балтийс
Point	88	20.5000	54.3000	1980	7	3	18	18	4	3.100000				49	Зап.Россия, г.Баграти
Point	89	29.0800	54.0900	1980	7	8	2	2	16	2.500000					Беларусь, г.Крупки
Point	90	21.6000	57.4800	1980	7	21	14	14	50	2.900000	2,7			0	Латвия, г.Пилтене
Point	91	20.8000	56.5000	1980	7	31	16	16	1	3.100000	2,9				Балтийское море
Point	92	19.9000	54.7000	1980	9	27	15	15	53	3.200000				36	Зап.Россия, г.Светлый
Point	93	22.4100	59.7600	1981	6	22	18	18	18	3.100000	2,9		3	(23)	Балтийское море,Фин
Point	94	22.6600	59.4500	1981	6	22	19	19	38	2.600000	2,3		3	7	Балтийское море,Фин
Point	95	25.2000	57.2000	1982	5	5	6	6	3	2.800000	2,6			0	Латвия, к югу от г.Цес
Point	96	21.9400	57.0000	1982	6	2	7	7	18	2.300000	2				Латвия, сев.от г.Кулди
Point	97	21.6000	57.2000	1982	6	2	7	7	19	2.500000					Латвия, г.Пилтене
Point	98	20.1000	56.2000	1983	7	17	10	10	1	3.300000	3,1			0	Балтийское море
Point	99	19.8000	55.9000	1983	7	18	9	9	1	3.200000	3			0	Балтийское море
Point	100	27.8100	52.9500	1983	12	1	21	21	34	2.800000			4-5	7	Беларусь, С-В от г.Сол
Point	101	27.6000	59.5000	1984	3	23	12	12	38	3.300000		4,8		0	Балтийское море
Point	102	26.4600	56.7400	1985	7	28	8	8	29	2.500000				31	Латвия, г.Мадона
Point	103	28.4000	52.9000	1985	10	17	1	1	24	3.100000			4	7	Беларусь, зап. от г.Глу
Point	104	20.4400	51.7600	1986	4	10	21	21	60	2.800000				10	Польша, г.Бяла-Равска
Point	105	21.0400	51.8700	1986	9	19	9	9	36	2.900000				10	Польша, г.Варка
Point	106	26.1900	54.6000	1987	2	27	23	23	22	2.500000				15	Беларусь, г.Островец
Point	107	26.1000	58.3000	1987	4	7	20	20		2.500000	2,7		3	(10)	Эстония, оз.Выртсъяр
Point	108	26.1000	58.4000	1987	4	8	19	19		3.500000			4(6)	7(18)	Эстония, сев. оз.Вырт
Point	109	21.0200	51.7100	1987	5	12	4	4	35	2.700000				10	Польша, г.Варка
Point	110	26.0000	58.3000	1987	7	5	22	22		2.500000	2,9		3-4	(8)	Эстония, оз.Выртсъяр

Figure 7. Attribute Table of the EEP earthquakes topic combined with the Database

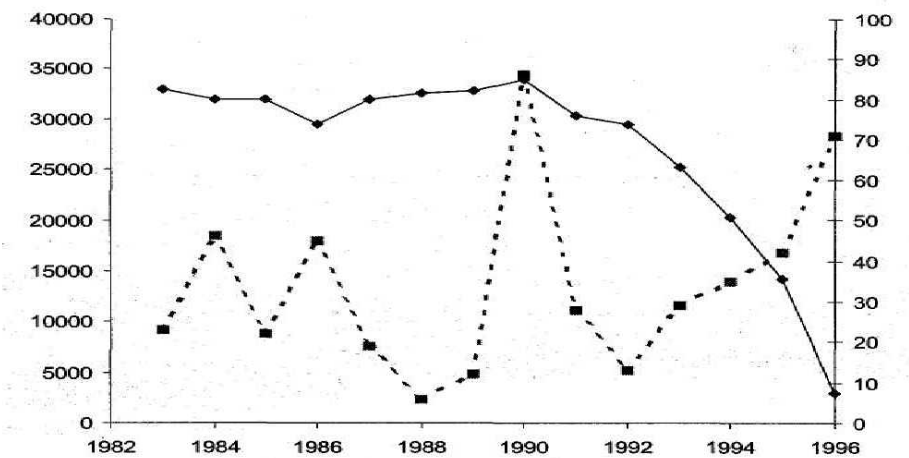


Figure 8. The correlation between the seismic activity (purple) and the mining volume (Starobin potassium deposit)

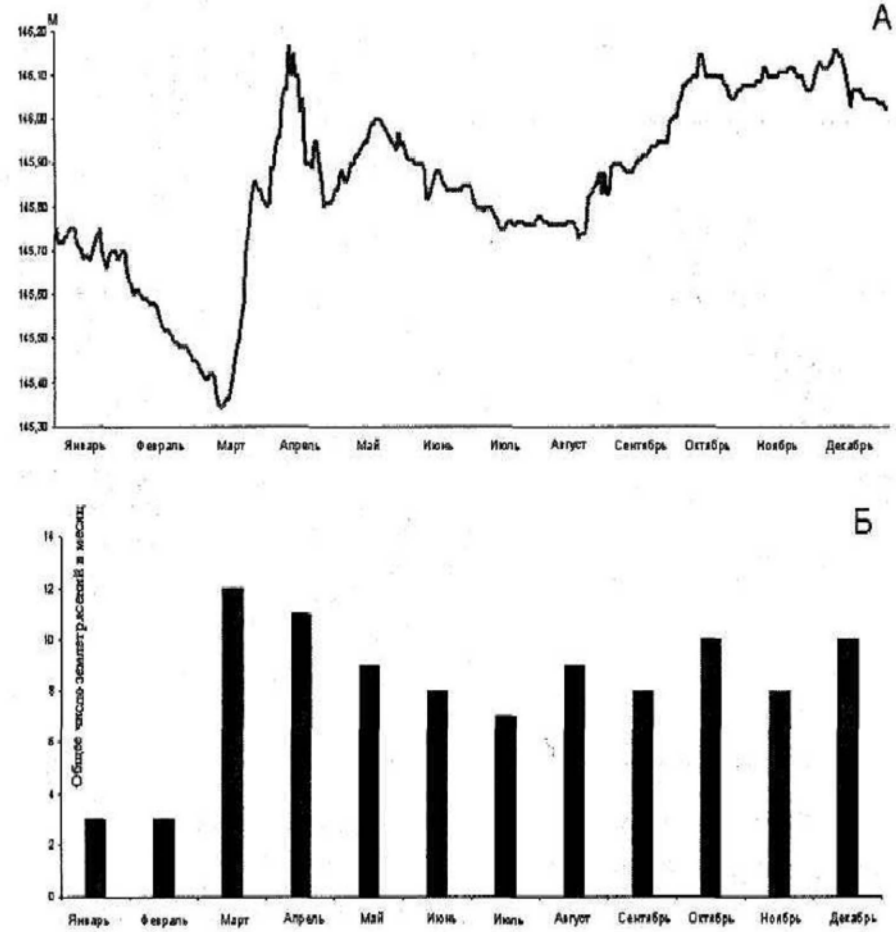


Figure 9. The correlation between the frequency of the earthquakes (red) and oscillations of the water level in Soligorsk reservoir

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Garetsky, R.G., Ludwig, A.O., Stackebrandt, W. et. al. (2003): Neogeodynamics of the Baltic sea depression and adjacent areas. Set of the neogeodynamic maps. - Verhandlungen des Naturwissenschaftlichen Vereins in Hamburg. , (NF) 40: CD-ROM (10 Karten).

DIGITAL GEOLOGICAL BASE MAP OF ESTONIA (1:50 000): AIMS AND PROSPECTS OF REALIZATION

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Abstract: Large-scale (1:50 000) geological mapping covers more than 50% of Estonia's territory, the regions of major economic importance. The long-term strategy of the compilation of the geological base map focuses attention on maintaining and digitizing the maps of already-mapped regions and making them available for public use as quickly as possible. The maps together with explanatory notes are compiled by the Geological Survey of Estonia and will be published in digitized format. They consist of different layers (separate maps): geology and relief of bedrock, Quaternary sediments and their thickness, geomorphology, hydrogeology, groundwater vulnerability, mineral resources, gravimetric and magnetometric anomalies. When compiling the geological base map, it is important to relate it to the existing databases, which provide abundant information on drill holes, bored wells, drill cores, results of chemical analyses etc.

Keywords: GIS, geological mapping, digital geological cartography, geological information system, bedrock, Quaternary sediments, hydrogeology, groundwater vulnerability, mineral resources, gravimetry, magnetometry.

In Estonia, geological mapping was previously (and is still) carried out by a public or state-owned company, presently named Eesti Geoloogiakeskus (EGK, Geological Survey of Estonia). Systematic medium-scale (1:200 000) geological mapping was done between 1958 and 1975. Integrated geological–hydrogeological mapping was carried out on 18 sheets covering the whole territory of Estonia. Differently from classical surface geological mapping, the whole sequence was studied, including the Quaternary cover, bedrock and crystalline basement. Field work included mainly geological methods, drilling of drill holes, and less often geophysical methods. As a result, geological maps at a scale of 1:200 000 were compiled for the whole territory of Estonia. These maps are in Russian and the number

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 169–174.

of copies printed was small. The maps were secret (for official use only), therefore their distribution was restricted and only few copies are now left.

When Estonia gained its independence, the first task was to make the existing geological maps available for public use. The maps at the scale of 1:200 000 were digitized and issued as plotter maps (Quaternary deposits, bedrock, crystalline basement, hydrogeology) at the scale of 1:400 000, supplemented with explanation.

Simultaneously with the medium-scale mapping, large-scale (1:50 000) mapping was initiated in regions of major economic importance. In different areas the large-scale mapping was carried out using different methods: integrated general geological mapping focused on mineral resources (region of oil-shale and phosphorite deposits in northeast and north Estonia), on hydrogeology (surroundings of major towns), or on land reclamation (central Estonia). Large-scale geological mapping was performed for a total of 58% of Estonia's territory. The hand-drawn map sheets together with voluminous explanations are stored at the Depository of Manuscript Reports of Estonia (Geological Fund). Many of these map sheets have been compiled using a disfigured topographic base, the legibility of which is not adequate. As the map sheets are drawn by hand they are not easily accessible for the public and are in need of updating since a lot of new information has been obtained. In addition, the conception of the geological setting of these areas has also changed and stratigraphic units have been made more exact. and modern.

Medium-scale (1:200 000) maps provide a review of the geological setting of a region and allow us to make decisions related to planning at the state level. Large-scale (1:50 000) maps provide more detailed information for making decisions at county or municipal level. Thus, the range of users of large-scale geological maps is considerably wider, including mainly:

— officials of counties and municipalities in the fields of construction, utilization of minerals, environmental management and perspective planning, as well as issuing of permits and approvals related to the cited fields;
— entrepreneurs (designers, building engineers, real-estate agents, companies dealing with extracting and processing of minerals and officials in the field of real-estate markets (lawyers, notaries)).

One of the main tasks of EGK as a national geological survey is the systematic investigation of the geological setting (geological mapping) of Estonia's territory, compiling and managing related databases and making them available for public use. Therefore a programme 'Geological Base Map of Estonia 1:50 000' has been devised. According to this, for each map sheet a set of digital maps will be composed, comprising three principal maps (Quaternary deposits, bedrock, hydrogeology) and a minimum of nine additional maps (levels). The main phenomena shown on maps are as follows.

Map of Quaternary Deposits:

Genetic type of sediment (colour area) — alluvial, aeolian, lacustrine, etc.
- Lithologic type of sediment (pattern area) — peat, sand, clay, etc.
- Line of cross-section

Map of thickness of Quaternary deposits (additional map)
- Isopach of Quaternary deposits
- Thickness of Quaternary deposits in drill holes

Geomorphological map (additional map)
- Forms of relief (drumlin, esker, etc.), areas and boundaries, colour depending on age
- Large erratic boulder; boulder field

Map of mineral resources of Quaternary deposits (additional map)
- Boundaries of mineral deposits (peat, gravel, sand, etc.) and reserves
- Name and number of mineral deposit in the State Register of Mineral Deposits

Map of Bedrock:

Stratigraphic index (regional stage—formation)
- Areas and boundaries of formations
- Faults (proved and supposed)
- Stratotype of geological unit
- Drill hole (in bedrock, in crystalline basement)
- Line of cross-section

Map of bedrock relief (additional map)
- Contour line of bedrock relief
- Buried valley
- Escarpment in bedrock (exposed, buried)
- Fixed data point

Map of mineral resources of bedrock (additional map)
- Boundaries of proved and prognostic reserves
- Type (oil shale, phosphorite, limestone, clay, etc.) and register number of mineral deposit in the State Register of Mineral Deposits

Gravity anomaly map (additional map)
- Bouguer anomaly contours (isolines and colour areas)

Gravity residual anomaly map (additional map)
- Residual anomaly contours

Aeromagnetic anomaly map (additional map)
- Aeromagnetic anomaly contours

Map of Hydrogeology:

Aquifers of different origin and specific capacity (colour areas)
Contour lines of potentiometric surface of different aquifer systems
Quality of groundwater (mineralization, Fe content, etc.)
Bodies of surface water and karst
Man-made features and alterations to the natural groundwater regime (wells, groundwater consumption, etc.)
Line of cross-section

Map of groundwater vulnerability (additional map)

Vulnerability to contamination of groundwater of the uppermost aquifer system in bedrock (five degrees of protection shown by colour areas)
Nature of the uppermost aquifer system in a bedrock (pattern areas).

Each principal and additional map is supplemented with at least one layer characterizing the existence and allocation of factual material. The principal and additional maps are designed with elements (headings, frames, grid lines, legend, cross-sections, etc.) for independent printing, but the client can order or compile for himself various combinations of all existing levels according to his needs. This opportunity is especially important and it takes digital maps to a new qualitative level as compared with printed maps.

When compiling the geological base map, a most important task is to relate it to the existing EGK databases, which provide abundant information on drill holes, bored wells, drill cores and their place of storage, results of chemical analyses of rocks, sediments and water taken in the area under discussion, thin sections and their place of storage, etc. Data about each deposit in the State Register of Mineral Deposits are presented on a register card, which is updated annually. Each map sheet is supplemented with an explanation, including, in addition to traditional information, also references to the databases, which allows a client to obtain a detailed source of information if needed. In this connection, the creation of an EGK central database has been started.

The topographic base has been modified after the Estonian Base Map (1:50 000), Lambert conformal conical projection (LAMBERT-EST), ellipsoid GRS-80, standard parallels 58°00′ and 59°20′. Maps are accompanied by a legend, cross-sections, index map and schemes of information sources. At present the map-sheet nomenclature (joint for the Baltic States) of mainland Estonia embraces 102 map sheets, 25×25 km^2 each. On some of these sheets bodies of water occur (Baltic Sea, Gulf of Finland, Lake Peipsi, Lake Võrtsjärv) and some are divided between Estonia and neighbouring countries (Latvia, Russia). The land area to be mapped is circa 45 000 km^2.

Changes in the projection system and map-sheet nomenclature act as constraints on digitizing and issuing of the maps in the planned base-map system. All the earlier maps are in the Pulkovo-1942 system of coordinates and the map sheets form trapeziums according to the grid lines of geographical coordinates, but the modern system is based on Lambert conformal conical projection and the map sheets are of square form. Digitizing of one map sheet according to the new system requires simultaneous processing of a minimum of three to four map sheets of the former system.

Today the compilation of the digital geological base map of Estonia is in the initial stages. From a total of 102 map sheets, complete sets of maps have been finished for eight sheets in northern Estonia, while for three sheets from southern Estonia not all of the above-mentioned maps have yet been compiled (Figure 1).

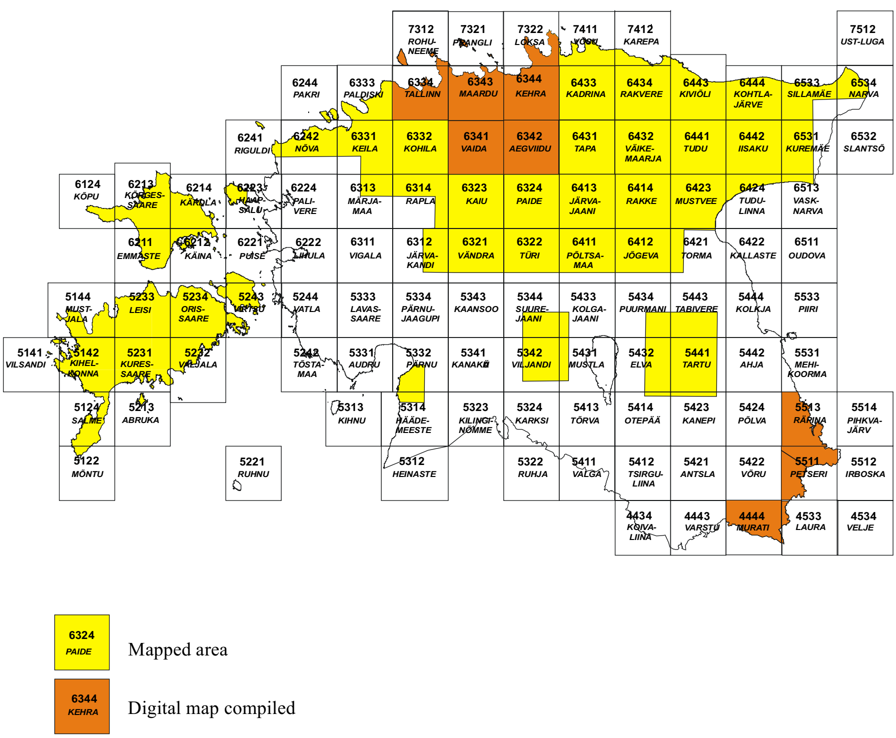

Figure 1. State of large-scale (1:50 000) geological mapping of Estonia.

At the moment there are two major tasks facing map makers:

— to guarantee that the digital maps compiled meet the internationally accepted principles and standards. This requires that such standards exist and are accessible for users;
— to relate the geological objects on the map (areas, lines, points) to the digital source information stored in databases. This requires the creation and keeping of a modern central database by EGK; the latter in turn requires investment in hardware and software.

The long-term strategy of the compilation of the geological base map focuses attention on maintaining and digitizing the maps of already-mapped regions and making them available for public use as quickly as possible. New mapping fieldwork will be carried out if finances permit. Considering the present financial policy of the Estonian government, the geological base map for the whole territory of Estonia could not be completed before 2020–2025.

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REVIEW BY EARL BRABB

The favourable comments for this report on Estonia can be taken almost exactly from the critique on Lithuania. Both countries seem to have support at a high level for innovative and long-term projects.

Some of the challenges of projection changes and other digitizing problems have been solved years ago by geologists at the US Geological Survey in Menlo Park and the California Geological Survey in Sacramento. Some free software programs to help solve the problems are available, but merely getting copies of these programs is not enough. A better way of learning what techniques are available is to visit these centres for a few days. Send geologists with well-honed computer skills to talk to similar people. Alternatively, they could take courses in these topics at the International Institute for Aerospace Survey and Earth Sciences in the Netherlands:

http://www.itc.nl/education

The Italian National Research Council Institute for Hydrological Protection of Central Italy in Perugia recognized the great value of exchange visits for computer-oriented Earth sciences when they sent two geologists to Menlo Park for a year. The technology has since been used to prepare landslide inventory and susceptibility maps for Central Italy, a shaded relief map for the whole of Italy, and a database of landsliding for the past 700 years:

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PECULIARITIES OF FAULT TECTONICS IN BELARUS: INVESTIGATIONS AND MAPPING

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Abstract: All faults in the territory of Belarus can be separated into two main types: pre-platform and platform faults. Geophysical (seismic sounding, gravity and magnetic surveys, borehole logs, etc.) and geological (structural, stratigraphic, etc.) data have been collected for all of these faults. Platform faults are the main object of the investigation because numerous mineral resources are connected with these faults, for example oil, gas, fluids, gypsum and potassium salt. Platform faults appear in the sedimentary paleo-basins formed in the Pripyat Trough, Orsha and Podlyasje–Brest Depressions, and in some smaller synformal structures of Belarus (Figure 1).

Keywords: Digital mapping, Belarus, platform faults, mineral resources, paleorift

GENERAL OUTLINE

Conventional and new methods were used for investigations of the faults. The complex geodynamical method (CDM) was applied; this includes not only traditional geological–geophysical investigations, but also fracture analyses of cores, calculation of absolute curvature of surfaces and the history of evolution of individual faults. The CDM was applied largely in the Pripyat Trough.

The *Pripyat Paleorift* is situated in the southeastern part of Belarus and stretches for 280 km from west to east with a width of up to 150 km. This paleorift represents the northwestern part of the Sarmath–Turanian Lineament and belongs to the Pripyat–Dnieper–Donets Aulacogen. It is the western continuation of the Pripyat–Donets Aulacogen and the axial part of the Pripyat belt of continental rifting. The rifting belt as a whole is defined as a listric faulting zone of the Earth's crust above an asthenospheric diapir and consists of the Pripyat Graben (paleorift) and the North Pripyat and South Pripyat Shoulders. The width of the belt is approximately 250 km. The Pripyat Paleorift is separated from the northern and southern shoulders by the North Pripyat and South Pripyat super-regional mantle listric faults.The Pripyat Paleorift shows three main stages in its evolution: pre-rift, syn-rift and post-rift stages. These stages are connected with the stress regime in this region and its surrounding areas. The processes occurring in the lower part of the Earth's crust and the upper mantle are responsible for this regime.

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 175–186.

At the pre-rift stage the Pripyat Paleorift territory was under the influence of a tangential compression stress of NE–SW orientation and low NW–SE extension. Regional shear fault zones of NE–SW strike formed before rifting in this area. These included the Berezina (including the regional Zhitkovichi sub-regional fault) and Pervomay–Zaozerye super-regional fault zones, and the Loev super-regional fault. These zones are evident to the northeast and southwest of the Pripyat Paleorift.

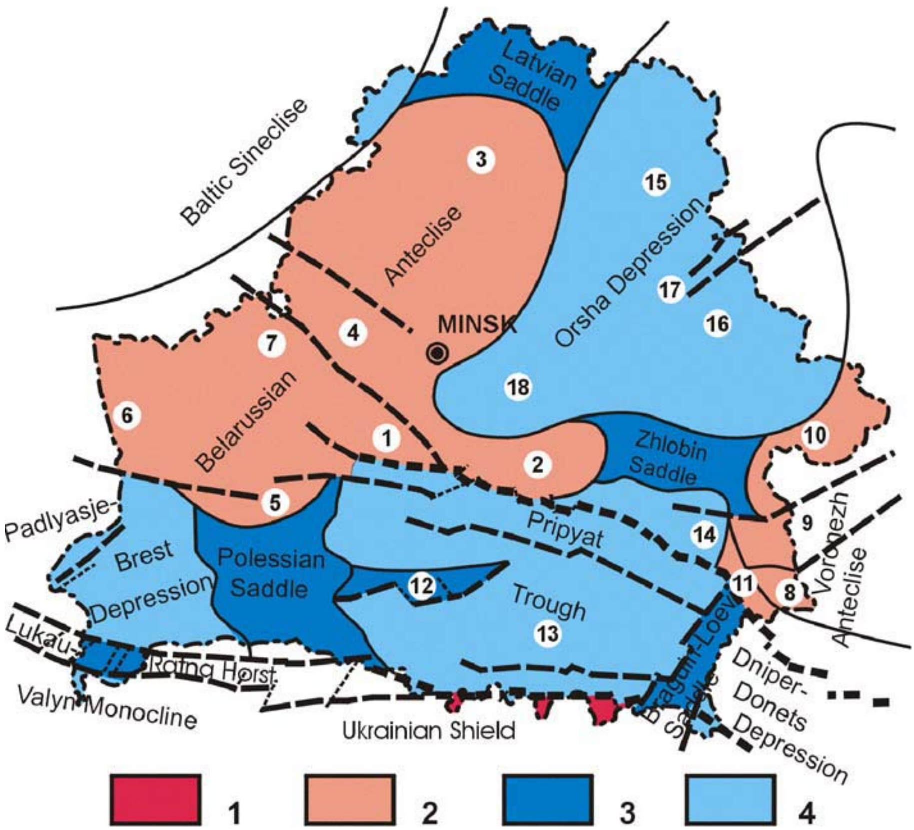

Figure 1. Tectonic Map of Belarus: 1 - Subcrops of crystalline basement; 2 - Anteclises; 3 - Saddles; 4 - Depressions; Subregional structures of basement (in blank circles): 1) Babounya Inlier, 2) Babruisk Inlier, 3) Vileika Inlier, 4) Valozhyn Graben, 5) Ivatsevitchy Inlier, 6) Central Belarussian Massif, 7) Voranau Uplift, 8) Gramyachy Inlier, 9) Klintsy Graben, 10) Surazh Inlier, 11) Homel Inlier, 12) Mikashevichy-Zhytkavichy Inlier, 13) Inner Graben, 14) Northern Pripyat Shoulder, 15) Vitebsk Mulde, 16) Mahilou Mulde, 17) Orsha Horst, 18) Cherven Structural Bay.

The syn-rift stage began in Frasnian times during the continued ‘opening’ of the Dnieper–Donets paleorift. First, during Frasnian times, it involved the western end zone of the Dnieper–Donets paleorift between the Ukrainian Shield and the Belarussian Anticline. Numerous faults in this zone were of shear nature and showed small vertical amplitudes. A 'fan-shaped' fault system emanated from the Dnieper–Donets paleorift. The direction of faulting changed to almost W–E (in a counter-clockwise direction) within the Pripyat territory as a result of leaning towards the stable Belarussian Anticline that was situated in the path of rifting from the Dnieper–Donets paleorift. By the end of Frasnian times, the Pripyat tectonic structure had formed as a rift with an extensional stress regime that created normal listric faults of almost W–E strike.

After the first rifting stage (Frasnian), a calm tectonic regime was observed within the Pripyat Paleorift. Following a break in tectonic activity a second (maximum) activation of rifting began.

During Famennian times the main extension axes in the Pripyat Paleorift rotated clockwise through an angle about 20 degrees, as a result of the changing stress regime. The N–E and S–W extension was strong. Subsidence along listric super-regional faults (bordering the North and South Pripyat, Rechitsa, Chervonaya Sloboda–Malodusha, Narovlya and other faults) was very rapid, and long steps of almost W–E orientation appeared. Salt structures (banks and swells) were formed during the Famennian. The *B*(stretching)-factor of the upper part of the Earth's crust was as high as 1.2 in Famennian times. The vertical amplitude of the main faults increased up to 3–5 km over a period of less than 2 million years. By the end of the rapid rifting subsidence (at the end of the Famennian), pre-rift faults of NE–SW orientation were reactivated. Local NW–SE-oriented shear faults also appeared, as a result of the tangential extension stress.

At the post-rifting stage, thermal subsidence took place in the Pripyat paleorift. Thick sedimentary strata accumulated under the normal compressional stress conditions during the Mesozoic period. Fault activity was very low. Most of all the small faults appeared in supra-salt deposits and were connected with salt tectonics that continued at the beginning of the post-rifting stage. During the post-rifting stage the Pripyat paleorift was not an independent tectonic structure and existed as a zone influenced by the other structures activated at that time.

Two periods of salt sedimentation occurred during rifting in Livenian (Frasnian stage) and Lebedian (Famennian stage) times. These periods were connected with active movements along faults. Salt accumulation indicated volcanic activity in the northeastern part of the Pripyat Trough. Volcanoes in the eastern part of the Pripyat Trough separated this from the Dnieper–Donets Depression and thick layers of salt were accumulated in the paleobasin. These thick salt layers (up to 50% of the total thickness of the sedimentary succession) were formed by salt tectonics during rifting and also during the early post-rifting stage. Salt tectonics had a great influence on the syn-rift and to a lesser extent on the post-rift sedimentation. Post-rift basin evolution can be explained by thermal subsidence of the lithosphere. This stage continued during early and middle Carboniferous times. A break in sedimentation occurred within the Pripyat Trough during the Late Carboniferous and part of the Permian. During the Triassic the Pripyat Trough was subject to transgression as part of the East European Platform (EEP).

Using the CDM we revealed two new definitions for the Pripyat Trough fault types: wrench faults and lateral faults. Wrench faults on the horizontal and vertical section have a curved line. Fault structural plans are different on the two fault limbs. These characteristics appear not only at a small scale but also in fractures that are situated in the zone of dynamic influence of the wrench fault (Figure 2a). Lateral faults are presented on the border between layers, especially above salt or saliferous beds. These faults are not shown in the horizontal projection of the map and are presented more clearly on the vertical sections. They are also illustrated in fractures of cores (Figure 2b).

a) b)

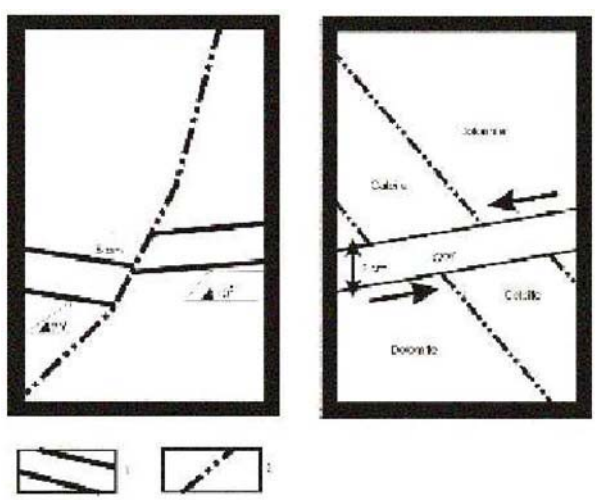

Figure 2. a) Wrench fracture in dolomite; Pripyat Trough, Eas Drazdy-2 Borehole, depth 1704 m; 1 - layers, 2 - fracture; b) Lateral movement of calcite vein in dolomite; Pripyat Trough, Loev-3 Borehole, depth 2142 m.

Analysis of structural plans and configurations of fault surfaces shows that the angle of fault dip changes in different kinds of rocks; it is more vertical in crystalline rocks and more gently sloping in plastic rocks such as salt and gypsum.

A lot of local faults are found from measurements of the regional positive structures with the help of bed curvature. Plastic deformations transformed to disjunctive ones when absolute curvature of dolomite or limestone beds was more than 2 × 10^{-6} m^{-1} (Figure 3). Investigation of fractures in cores using their re-orientations in space, and the complex geodynamical method made it possible to show local faults on the structural maps, within structures that could be subject to the mining of mineral resources (oil, gypsum, etc.).

Numerous micro-deformations of rocks were revealed in cores from the gypsum-bearing layer and its underlying and overlying beds. Before our investigation these fractures were identified as lithological (catagenetic), appearing without the tectonic factor effect as a result of gypsum swelling due to hydration of anhydrite. Careful studies of geological (cores, structural and lithological maps) and geophysical (time sections, logs) data confirm that the fractures are of tectonic nature. Evidence for this is as follows: (1) fractures in the marly beds within the gypsum layer were linear and filled with gypsum; (2) fractures grouped to form some systems with the same kinematics and strike as faults bounding the Brinev Structure; (3) horizontal and vertical micro-shears were found in non-gypsum beds within the gypsum layer; and (4) the very steep angle of dip of the marly bed (30–40º and sometimes even 80–90º) in the gypsum-bearing fold limbs.

The Brinev Gypsum Deposit is an example of gypsum tectonics by analogy with salt tectonics that appeared in the Pripyat Trough during the syn-rift and partly post-rift stages. The gypsum tectonics is a combination of tectonic activation (faulting and folding), and the physical peculiarities of gypsum (increasing of its volume as a result of anhydrite hydration). Geological–geophysical data (structural and lithological analyses) suggest that hydration took place in the western end of the Pripyat Paleorift in Late Famennian–Early Carboniferous times, during a transition between post-rift thermal subsidence and post-rift compression (uplifting). The hydration was the result of the more intensive uplifting of this part of the paleorift basin as compared to that of its eastern part. This is also evidence of the paleorift basin's eastward retreat.

The 35–40-km-wide *North Pripyat Shoulder* is located on the south of the Belarussian Anticline and Zhlobin Saddle, separating these from the Voronezh Anticline. On the north it is bounded by the Zhlobin listric mantle fault and is divided by the Malinov–Glasov mantle fault of W–E strike into Northern and Southern zones of steps. The Buda–Koshelevo and Medvedovo steps are distinguished in the Northern zone of steps and show the southern inclination of surfaces of the basement and bottom parts of the platform cover. The Gorodok, Kitin–Khatetsk and Parichi steps are situated in the Southern zone of steps, are divided by the Gorodok and Parichi crustal faults of W–E strike, and show the northern inclination of surfaces of the basement and covering deposits. Within the North Pripyat Shoulder there are pre-rift Rhiphean, Vendian, Middle Devonian, Lower and Middle Frasnian, syn-rift

Upper Frasnian and Famennian, and post-rift Mesozoic and Cenozoic deposits. However, the Middle Famennian deposits are absent there. The Upper Frasnian saliferous beds, supra-salt Devonian, Carboniferous, Permian and Triassic deposits are also absent from the stratigraphic sequence within the greater part of the shoulder. This is why the thickness of the cover rocks there ranges from 1.0 to 2.5 km, while in the Pripyat Trough it is as great as 6 km.

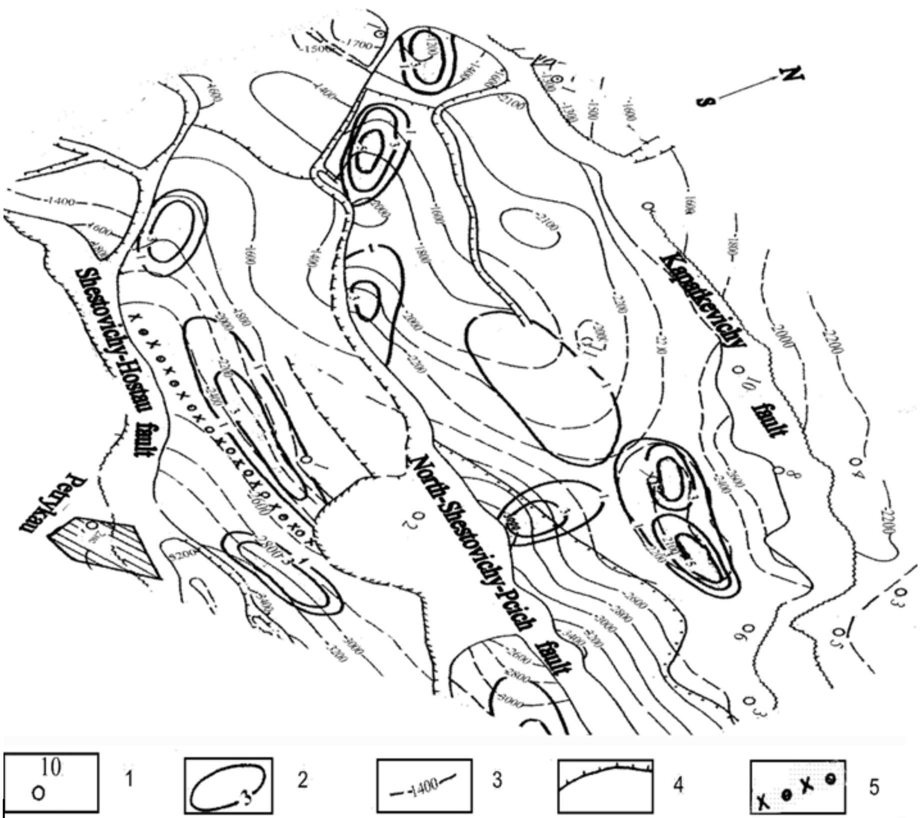

Figure 3a. The structural Map of the Frasnian deposit top with isolines of its absolute curvature in the central part of Pripyat trough; 1 - Boreholes; 2 - Isolines of absolite curvature; 3 - Isolines of the Fransnian deposits top; 4, 5 - Faults: 4 - according to geological/ geophysical data, 5 - according to geodynamic analysis data.

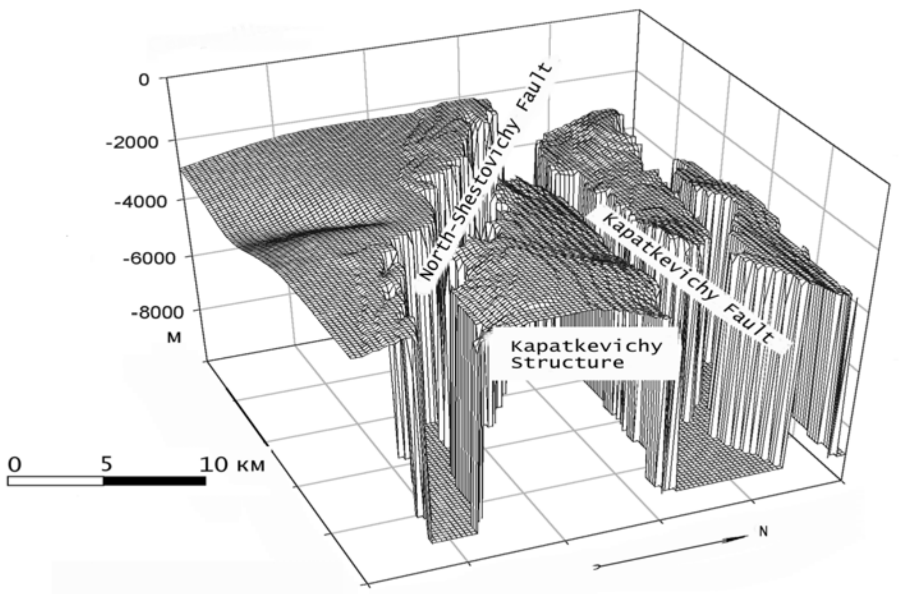

Figure 3b. The block-diagram of the Frasnian deposits top as in Figure 3a;

The South Pripyat Shoulder covers a narrow area adjacent to the graben. This is a zone of the Ukrainian Shield, which is about 40 km wide and is bounded by the Southern Pripyat marginal mantle listric fault. No appreciable subsiding occurred along this fault. Therefore, within the South Pripyat Shoulder pre-rift and syn-rift deposits are absent. Post-rift sedimentary deposits and Cenozoic sediments overlie the crystalline basement rocks.

The distinctions in the structure of the Pripyat Shoulders contribute to their asymmetry, which is caused by an asymmetry of the deep structure and the peculiarities of its evolution.

The *Orsha Depression* (OD) is an older sedimentary basin that is situated in the northeastern part of Belarus. It appeared in Riphean times as a southern continuation of the rifting in the Moscow Syncline. Evidence of the lowered position of this structure is shown by the crystalline basement and Middle Riphean–Lower Vendian deposits. It is bounded by faults that show a present-day vertical amplitude of 200 to 1000 m. These bordering faults have an angle of dip of about 50–60º. The OD consists of the Vitebsk and Moguilev Minor Depressions that are situated in the northern and southern part of the OD and have basement subsidence of 1.7 and 1.4 km respectively. The crystalline basement occurs at a depth of 1.2 km within the Central Orsha Horst that separates the Vitebsk and Moguilev Minor Depressions. It is bounded by sub-regional faults oriented SW–NE that are upthrusts that penetrated from the basement to Devonian deposits. A lot of faults are found in the Minor Depressions. Their amplitude from the basement varies from about 20 to 200 m, with SW–NE orientation and penetrating from the basement mostly to Riphean and sometimes to Devonian deposits. Information about the specific structure, geodynamics and evolution of the Moscow Syncline and the OD as part of it is undoubtedly important in the search for mineral resources, and firstly for oil and gas.

The evolution of the OD as a whole consists of four stages: the Gothian Quasi-Platform Stage (Early Riphean), Early Baikalian Kataplatform Stage (Middle Riphean–Late Vendian), Late Baikalian Orthoplatform Stage (Late Vendian–Early Cambrian) and Hercynian Orthoplatform Stage (Early–partly Late Devonian). These stages are clearly reflected in the seismic picture of the platform cover.

The Gothian Quasi-Platform Stage (Early Riphean) was the beginning of the rift structure formation. The depression appeared in Early Riphean on the site of the OD. It was filled in with arkosic greywacke and sand-quartz phosphate-bearing formations. Northeastern faults were formed at that time.

During the Early Baikalian Kataplatform Stage (Middle Riphean–Late Vendian), a few formations appeared in the OD. These were a red-coloured siltstone–sandstone formation, a red-coloured quartzitic sandstone formation, a carbonate–terrigenous formation and a continental glacial formation. These formations were developed under rifting conditions that took place in the OD as part of the linear Volyn–Central Russian Zone. The Early Baikalian Kataplatform Stage was a period of maximum subsidence under the tensional stress regime. Northeastern faults continued to form and the Central Orsha Horst was formed in the central part of the OD.

The Late Baikalian Orthoplatform Stage (Late Vendian–Early Cambrian) was characterized by the deposition of the tuff–sedimentary terrigenous formation that was created within the post-rift depression. After this stage, during the Middle and Upper Cambrian–Early Devonian times, the territory of the OD was an uplifted area and processes of erosion took place.

During the Hercynian Orthoplatform Stage (Early–partly Late Devonian), three formations were created in the OD. These were a sulfate–terrigenous–carbonate formation, a variegated terrigenous formation and a carbonate formation. These formations were developed under marine conditions associated with a transgressive sea. In Late Devonian times a stress regime commenced in the OD and up-throw faults were formed, especially near the Central Orsha Horst.

After this stage the territory of the OD was uplifted again and erosional processes took place in this area during Carboniferous, Permian and Mesozoic times. Only in the Cenozoic did sediments appear in the depression. These were moraine deposits that created a clay–terrigenous–glacial formation.

Thus five stages can be distinguished in the evolution of the OD. These stages are evident in different formations that show special seismic pictures in the two- or three-dimensional models (Figure 4). Sedimentation breaks existed between these stages; these breaks are represented in the seismic profiles as clearly defined long reflectors.

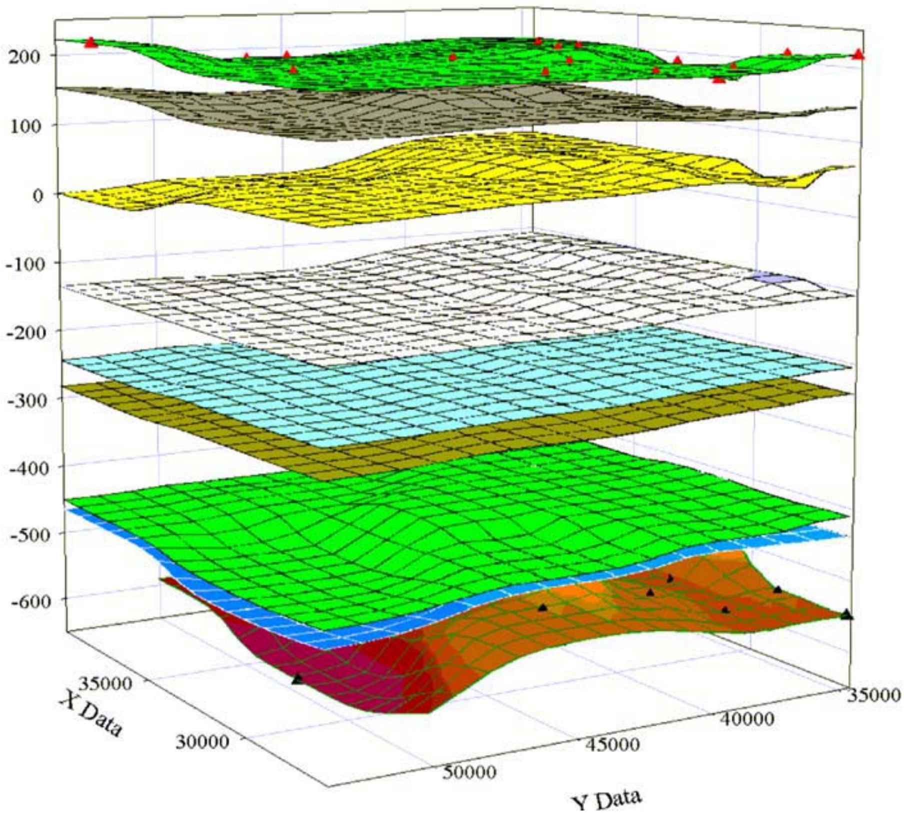

Figure 4. 3-D model of sedymentary cover of the Central Horst (see Figure 1).

The problem of the influences of the Late Paleozoic stresses within the southwestern margins of the East European Craton during the evolution of the Pripyat–Donets Aulacogen and the Podlasye–Brest Depression is solved on the basis of structural formation analysis. Correlation between the Upper Paleozoic lithological units in the Dnieper and Pripyat Troughs, Podlasye–Brest Depression and Lviv Border Trough was carried out, taking into consideration geological events in the Central European Mobile Belt, Trans-European Suture Zone and the Carpathian part of the Paleo-Tethys. This made it possible to determine a connection between geodynamic processes in the southwestern margins of the craton and sedimentary conditions inside the plate. Extension and compression inside the plate increased in cases of coincident stress directions inside and outside of the structure. The interaction of opposite stress directions made these processes more gentle. It was shown that the late phase of the evolution of the Pripyat and Dnieper Troughs during Early–Middle Carboniferous and Carboniferous–Permian times respectively was the final part of the rifting stage in the evolution of these structures.

The *Podlyasie–Brest Depression and Baltic Syncline* are constituent parts of the Baltic–Dniester zone of peri-cratonal subsidence, which during the Cambrian covered the whole western margin of the EEP from Moldavia to the North Sea. The western part of the EEP was intensively downwarped under the influence of the Iapetus paleo-ocean Tornquist Sea opening and submerging.

Monoclinal sinking of the western margin of the EEP was accompanied by the formation of the Baltic, Podlasie–Brest and Volyn structural bays, separated in paleoplan by structural noses (uplifts). Sediments were deposited in semi-closed basins following the same pattern. Terrigene rocks with dominant either clayey or sandy deposits, depending on the basin depth, were deposited everywhere over the zone of peri-cratonal subsidence. Three structural formation zones of sub-meridional strike formed and replaced each other in succession from west to east: a deep-water zone with accumulated clayey rock, a middle sandy–clayey zone and an eastern shallow-water, essentially sandy zone. The material composition of deposits does not change over the whole of the basins. Over the whole zone of peri-cratonal subsidence, Cambrian deposits are promising for oil and gas occurrences.

Although there is a general pattern of structure and evolution of Cambrian basins in the western part of the EEP, each is described by some specific features of their formation and structure. In particular, they differ in the thickness of Cambrian deposits, stratigraphic volume, and oil and gas potential.

The lower formation of the Cambrian system includes the Rovno, Lontova, Dominopol, Vergale and Rausve horizons, which are correlated with suites of the local stratigraphic scheme of Cambrian deposits. The Cambrian deposits of northwestern Belarus form part of the Baltic Basin and are represented by the Lower and Middle series. The Lower Cambrian is composed of two horizons: the Rovno and Lontova.

The main oil and gas complex at the western margin of the EEP is the Caledonian structural complex. The most favourable conditions for the formation and preservation of oil pools existed within synformal structures

(Baltic Syncline, Podlyasye–Brest and Volyn Depressions). Oil deposits have recently been discovered in the Baltic Syncline. The most important pools are confined to Middle Cambrian deposits. Rocks showing good oil reservoir properties and cap rocks have been determined in Lower Cambrian deposits of the whole of the western margin of the old platform. Major oil and gas occurrences are confined to just Cambrian deposits. Non-commercial oil seeps were produced from fissured carbonate rocks of the Ordovician; signs of oil have also been determined in Silurian deposits. Cambrian deposits are considered to be the main oil- and gas-bearing horizons within the studied territory.

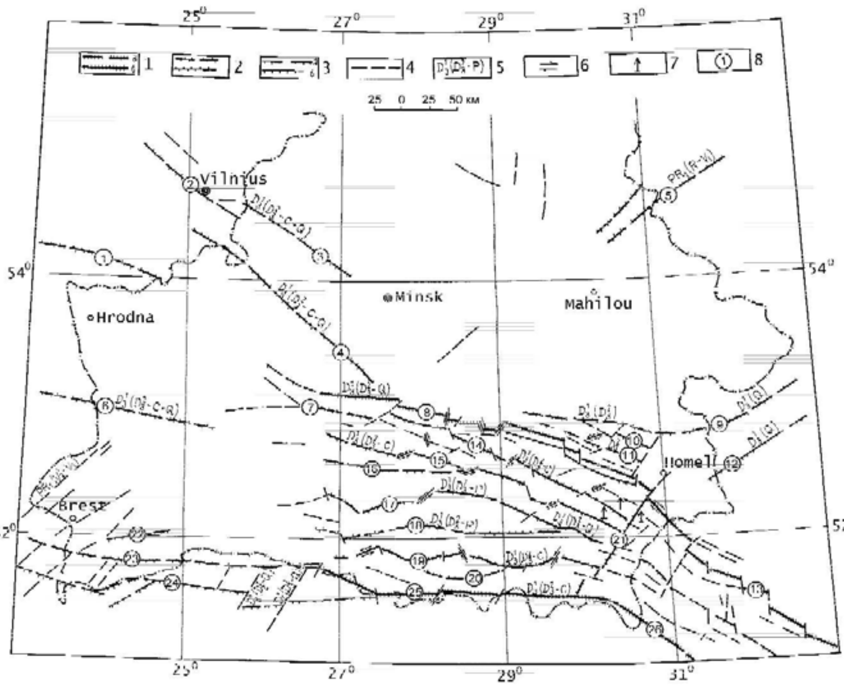

Figure 5. **Main fault system in Belarus**

The Podlyasye–Brest Sedimentary Basin is full of deposits that are separated into the Early and Late Baikal, Hercynian and Kimmerian–Alpinian structural complexes. All of these complexes, except the Kimmerian–Alpinian structural complex, are faulted (Figure 5).

Two main fault systems occur: northeastern and sub-latitudinal. Northwestern faults occur as a result of the main systems. The northeastern faults are the oldest. They are borrowed basement faults. They were re-activated on the platform mega-stage during the Vendian (Volyn) Stage as a basic and alkaline lava outpouring, during the Caledonian Stage as block movements and during the Hercynian Stage as block and shear dislocations.

Sub-latitudinal and northwestern faults were formed perhaps in the Hercynian Stage. The Svisloch fault and the North-Ratno fault border the Podlyasje–Brest Basin. These faults are western continuations of the Pripyat–Dnieper–Donets Rift bordering faults of the same (Late Devonian) age. Data from the geological investigation of the Lviv–Lublin Trough show that the northwestern faults are younger (between the Middle and Late Carboniferous—Asturian Folding Stage). Shear dislocations along northeastern faults that separate sub-latitudinal and northwestern faults on segments are younger than these faults. Northeastern faults form borders to major structures such as the Podlyasje–Brest Depression, Polesje Saddle, Lukov–Ratno Horst and Lviv–Lublin Trough.

To summarize, new methods have been used for the investigation of fault tectonics in the sedimentary basins of Belarus. New faults and their types were investigated in these basins. A map of faults in the territory of Belarus, showing peculiarities of its dynamics, genesis and age, was created. . This new information is important in the search for mineral resources (oil pools, gypsum beds, etc.), and in the building of oil and gas storage facilities and of reservoirs for industrial waste.

USE OF OLD DATA FOR INNOVATIVE MAPPING TECHNIQUES IN GEOTHERMAL EXPLORATION

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Abstract: The paper presents an application of computer mapping methods to geothermal. The examples of maps and crossections are inserted which show the structure and geothermal conditions in north-west part of Poland, where the most prospective for geothermal energy utilization areas are located. Presented digital cartographic materials are the results of the data processing in which the professional software was used, mainly GeoGraphix Exploration System by Landmarc and Tecplot by Amtec Engineering. With the purpose of using that software and generating the new cartographic and geothermal materials, firstly the computer data base had been created. The paper explains some typical Polish problems in access to geological, geothermal, hydrogeological, hydrochemical, engineering and other information necessary for geothermal exploration. Finally the article shows an example of applying the computer software to calculations, evaluation of geothermal resources, mapping the results of calculations and defining the areas for the most effective geothermal energy extraction and utilization.

Keywords: Geothermal exploration, subsurface digital mapping, existing data, prospectivity

INTRODUCTION

Geothermal exploration is a very wide subject of several disciplines, like topography, geology, hydrogeology, geophysics and geochemistry and is connected with several other subjects, like drilling, reservoir engineering, power and heat engineering, environmental and economy. Before undertaking a geothermal project it is necessary to collect and analyse all available local data, which can be useful in geothermal research. In the consequence there is always the huge collection of data, which can and must be ready for, digesting and processing. The best method in geology for

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 187–202.

ordering and maintaining huge amount of data is so far mapping and multidimensional modelling in order to visualise and compare various geological issues. The analysis of maps and models of geological structure, their temperatures and temperature gradients of deep rock complexes, reservoir properties of the strata, differentiation in chemical composition of geothermal waters, hydrogeological features of the area, potential resources of geothermal energy and finally even administrative maps - leads to define as closely as possible the location and characteristics of areas, in which the geothermal energy can be extracted. Application of geological cartography, as a significant research method in geothermal exploration, allows utilization of enormous quantities of data, remaining dormant in, both, the geological archives, and geological publications - maps, reports and research papers.

In this paper are presented examples of successful application of computer techniques into digital subsurface mapping based on reusing of old geological data from the northwest Poland. The main software used to process geological and geothermal data and to prepare presented materials were GeoGraphix Exploration System 7.5 - GES (Landmark) and Tecplot 8.0 (Amtec Engineering, Inc.).

DATA FOR GEOTHERMAL EXPLORATION

One of the most prospective areas for geothermal development in Poland is the western part of the Polish Lowlands. In 1955 on the Polish Lowlands a programme of deep boreholes drilling has been initiated with the purpose of examine the geological structure and search for hydrocarbons. Also, the geophysical and reservoir research had been undertaken in the wells and the geothermal logging and geothermal waters examination had been included. For more than 40 years the researches on geological structure, geothermal, hydrogeology and reservoir engineering of Paleozoic, Mesozoic and Cainozoic have been realised, what has resulted in collecting huge amount of data, stored as a paper documentation in the archives of geological, geophysical, and exploring and drilling institutions and enterprises.

Structural Maps

At the earliest, the geological information from the wells had been utilised for recognition of geological structure. On the basis of data from wells and data from geophysical transects the geological and structural maps had been created. That previous cartographic materials could be used in geothermal exploration but they must be verified, improved and completed.

Today's possibility of digitalisation and digital processing of old cartographic materials enable such verification on the screen of the computer. One of the methods that enable to check the correctness of

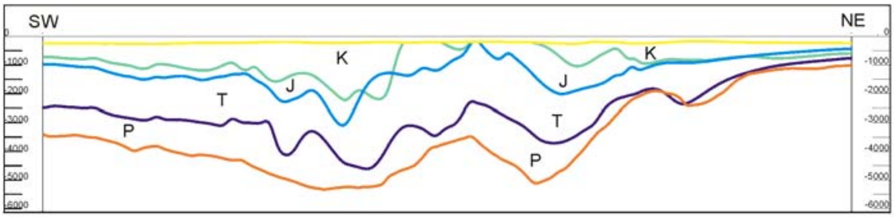

Figure 1. The Crossection through the north-west part of Poland; generated on the basis of digital structural maps. The displacements of the fold axes are shown; the errors are particularly clearly seen between Jurassic and Cretaceous base surfaces as well as Zechsteinian and Triassic.

structural maps is generating geological cross sections. It is possible using GES program. In that way it is possible to control the structural models showed on old cartographic materials and it enables to control the newly created models. In the process of generating digital structural maps the errors are clearly visible on cross sections. For example the displacements of the axes of folds are shown on the cross section on Fig. 1. Such the controlling cross sections help to eliminate the errors and to create reliable models of geological structure in research area.

Having the most accurate model of geological structure in the area of potential geothermal utilisation is essential for geothermal exploration, so it was necessary to analyse all available geological materials, as it was made for the western part of Polish Lowlands.

The Fig. 2 shows a structural map of Jurassic basement generated in GES programme using compiled data set: digitalised of conventional structural maps of Sokołowski and Tomaszewski (1987) and geological data from about 400 boreholes located in north-west Poland. The digital map was additionally verified with reference to tectonic map of Zechstein-Mesosoic complex, prepared by Dadlez (1997), and crossections through Midpolish Trough prepared by the same author (2001). In the same way the other structural maps were made for the Paleogene and/or Neogene, Cretaceous, Triassic and Zechsteinian substratum maps (Fig. 3a). The relationships of cartographic patterns of the layers were controlled by cross sections, also generated in GES program, so that in the result the maps in the set are mutually fit to each other. Fig.3b shows an example of the geological crossections combined with the temperature crossections along the line shown on Fig. 4.

Geothermal Data

Another key issue for geothermal exploration and development is to recognise the thermal conditions of deep rock complexes as accurate as it could be possible. The temperature data should not refer only to areas that are obviously “hot” but also to surrounding non-thermal areas so that the thermal anomalies can be characterised more effectively (Christopher and Armstead, 1978). Again, the best way of searching and presenting areas with thermal anomalies is mapping. The modern techniques of mapping enable to do it in relatively more detailed style than using conventional methods. Usually, the more thermal data are available, the more detailed geothermal pattern of the area can be presented. Unfortunately there is very diversified concentration of reliable geothermal data within the area of Poland. The greater number of such data occurs in mining areas, where rock temperature data comes from wells and from mine excavations. But there are some geothermal prospective regions, where the number of geothermal data is not satisfying. The example of such region is Szczecin - Mogilno Trough in the north-west Poland (Fig. 4)

Fig. 5 shows the map of temperature field on the level of -3000 m a.s.l. in north-west Poland which was generated in GES program on the basis of temperature data from 64 wells (i.e. one well with the temperature logging data per 740 km^2). The data were first placed into the computer database, so that could be useful at any time, also in the future. The data in the database are available at every moment and can be complemented with data from another newly drilled boreholes, so the model of the temperature at -3000 m a.s.l. or other levels can be easily updated.

The obtained image of temperature field is generalised but it shows thermal anomalies within troughs. It can be expected, that local geothermal anomalies exist in the area of research and they are surely connected with folds and faults occurrence. However low density of geothermal data in the area precludes presenting such anomalies on the maps and cross-sections. The Fig. 6 shows the cross-section drawn along the same line BB’ as the cross-section on Fig. 3b. In this new case the geological cross-section was drawn on the basis of structural maps generated using only geological data from the same wells as the thermal data. It is clear, that geological structure on the new cross-section is generalised and any of local folds visible on Fig. 3b are not shown. So it can be concluded that the number of the data determine the precision of graphic pattern on structural as well as geothermal maps.

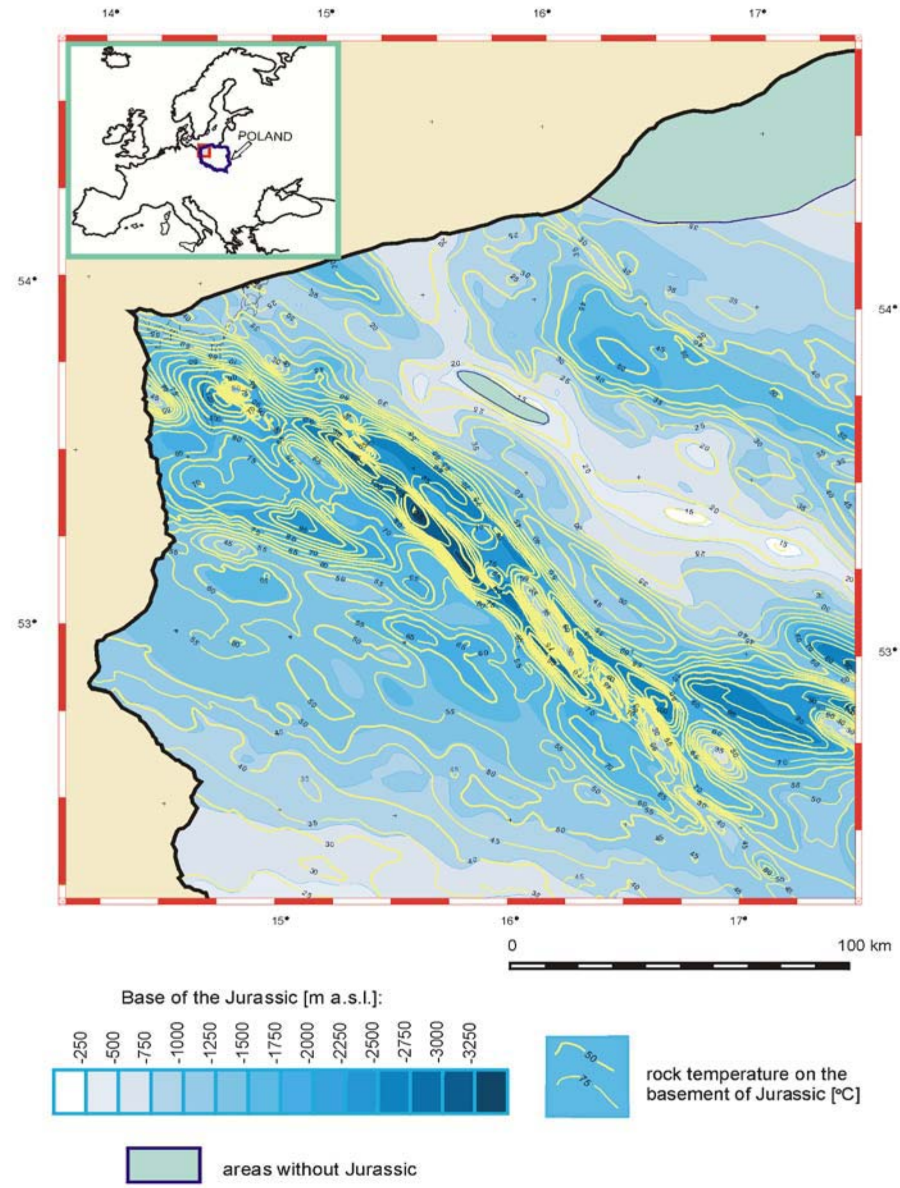

Figure 2. Structural map of Jurassic basement in north-west Poland generated in GES programme using compiled data set of digitalised conventional structural maps and geological data from boreholes. The map was additionally verified according to other cartographic materials. There is also a model of temperature distribution showed on the base surface of Jurrasic.

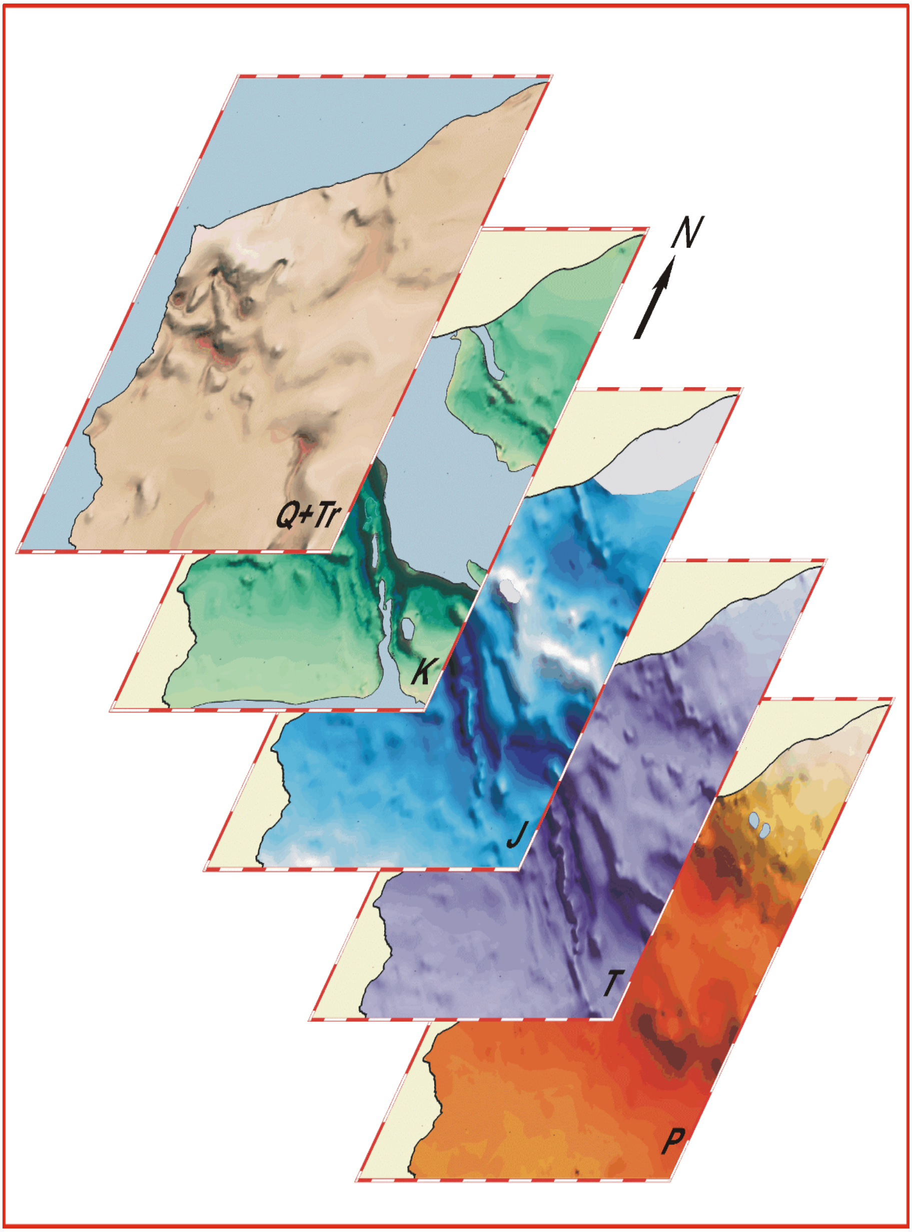

Figure 3a. The set of the shaded structural maps of north-west Poland

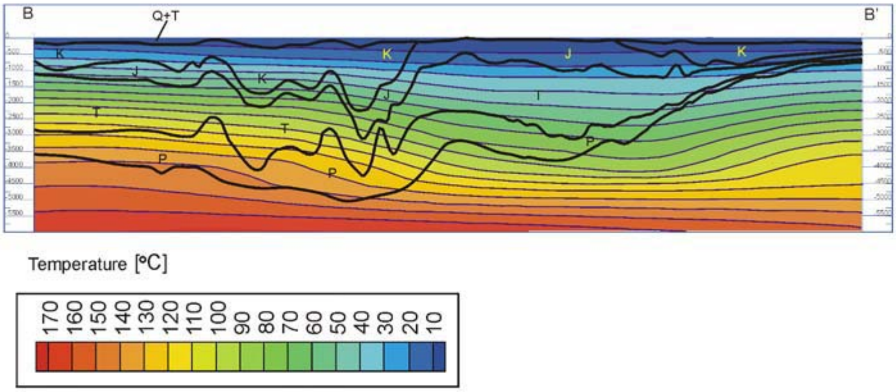

Figure 3b A cross section controlling mutual relationships of the structural maps. The structural maps and cross section show basements of the Zechsteinian (P), Triassic (T), Jurassic (J), Cretaceous (K) and Cainozoic (Q+Tr) complexes. The structural model showed on the cross section is additionally compiled with temperature cross section generated from Tecplot program.

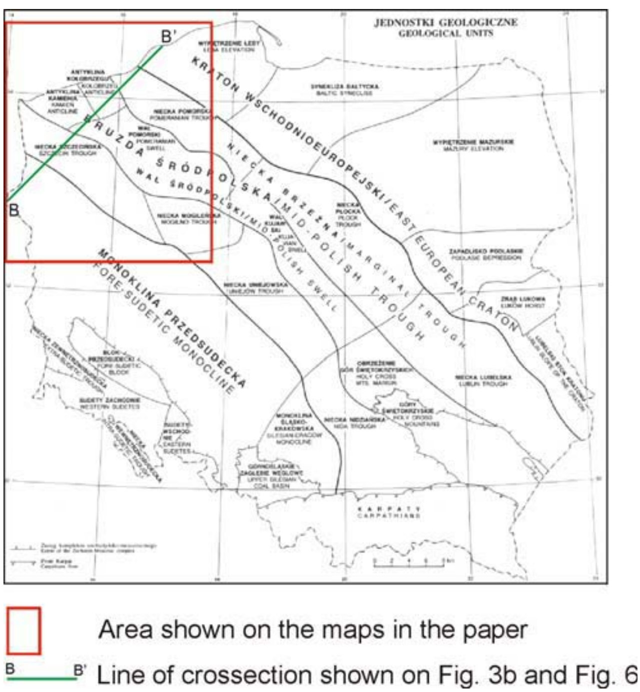

Figure 4. Location of Szczecin - Mogilno Trough and other structural units of Poland.

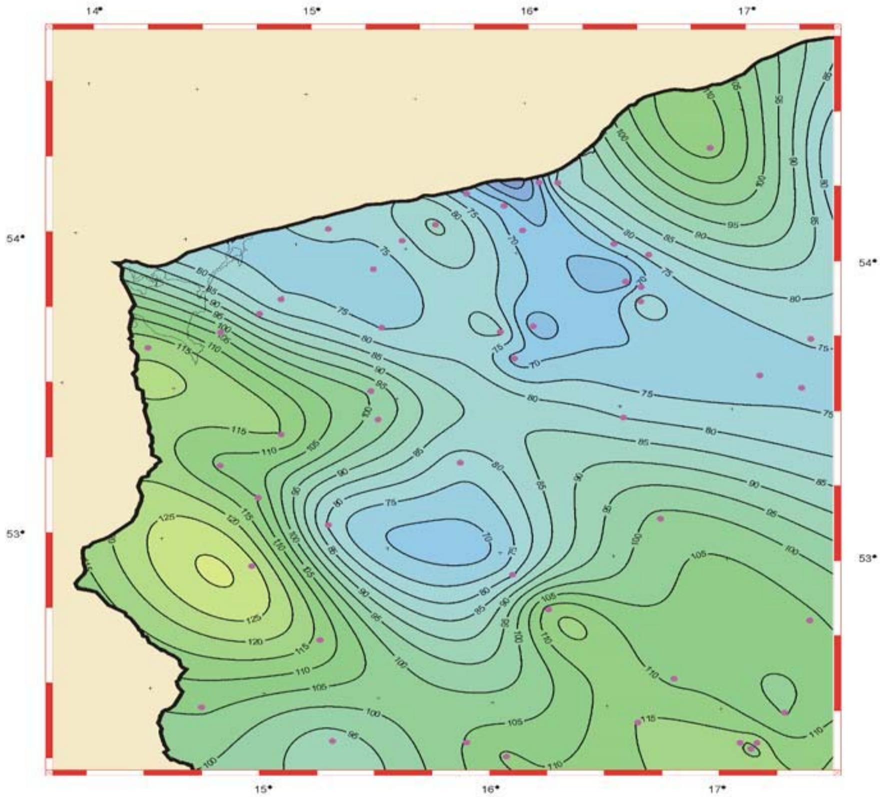

Fig. 5. The map of temperature field [ºC] on the level of -3000 m a.s.l. in the north-west Poland, generated in GES program. Location of boreholes from which the temperature data come are shown as the red points.

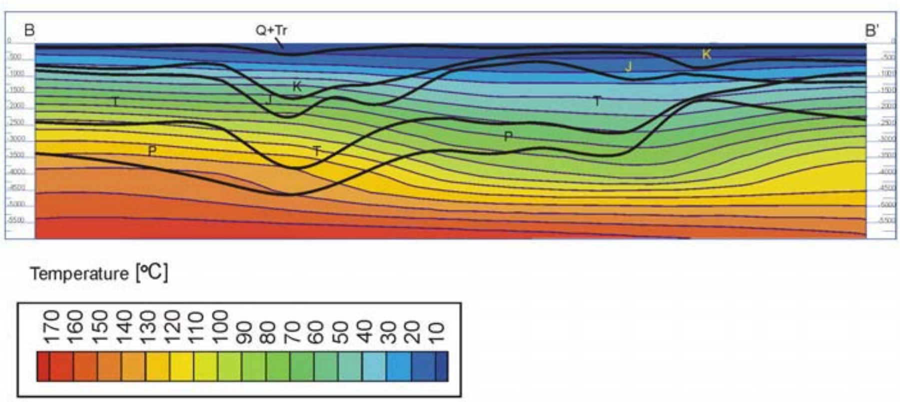

Fig. 6. The geological and geothermal cross-section drawn along the line BB' shown on Fig. 4.Tthe geological cross-section was drawn on the basis of structural maps generated using only geological data from the same wells as the thermal data.

The geothermal maps presenting only regional differentiation of rock temperatures on deep levels are not enough for defining the most promising places for geothermal water extraction. It is necessary to know what are the temperatures on the structural surfaces of the strata filled with geothermal water. However having so small number of data it is more difficult to obtain the pattern of temperatures on structural surfaces than temperature maps on selected levels. For the region of north-west Poland the maps of geothermal gradients were generated (Fig. 7) on the basis of geothermal data collected in database. Then, applying the method of calculations on the grids of structural, temperature and temperature gradient maps, the maps of temperatures on the base surfaces of the rock complexes were obtained. The Fig. 2 shows a model of temperature distribution on the base surface of Jurassic. The Fig. 8 shows the distribution of temperature on the base of the Reed Sandstone rock complex, which is a part of Keuper (Triassic) and is a geothermal water collector.

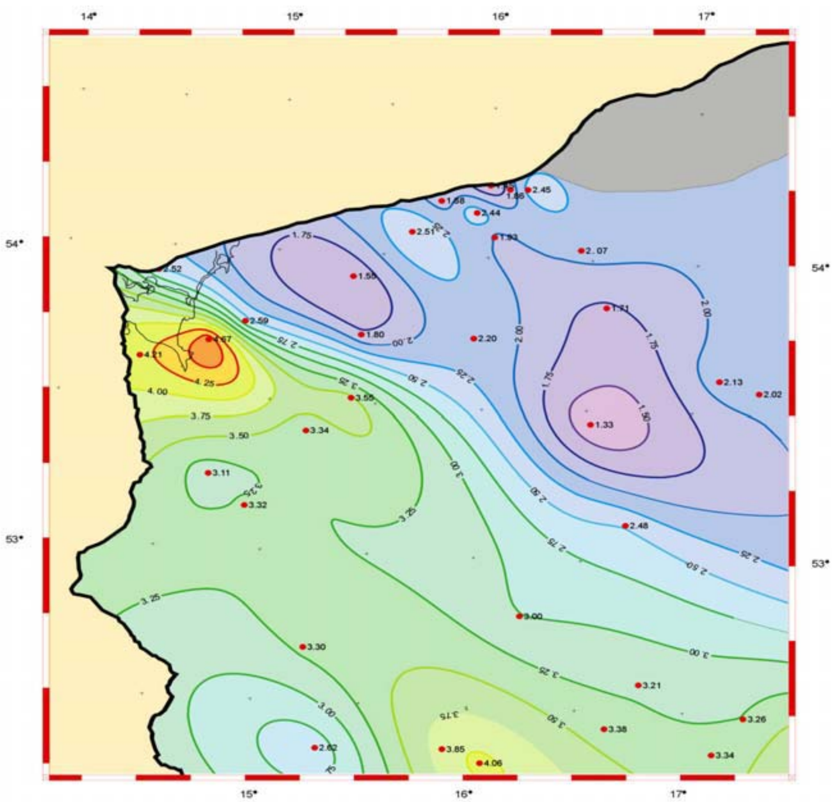

Fig. 7. The example of the temperature gradient map (the gradient of Jurassic complex) [ºC/100m]

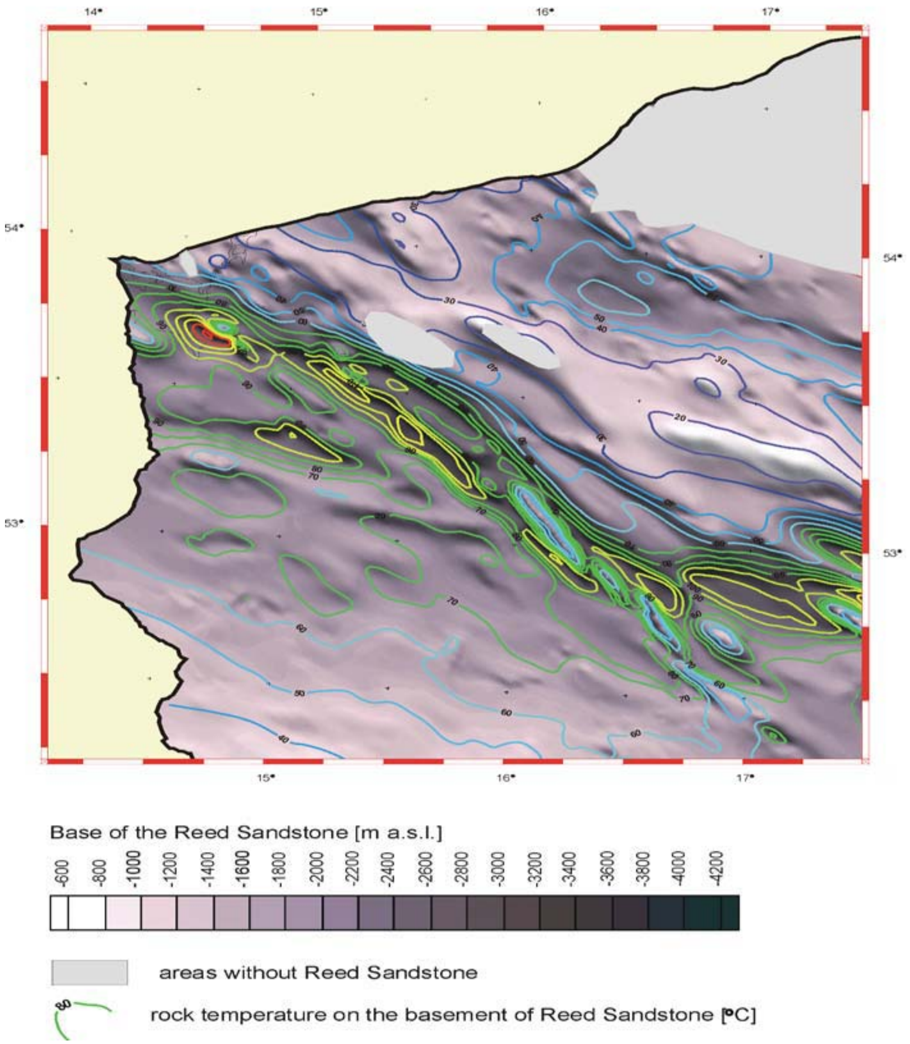

Figure 8. Model of temperature distribution on the base surface of Reed Sandstone. The structural surface is presented as a shaded model generated from Tecplot program on the basis of grid imported from GES. Such a shaded model reflects clearly relief of the surface showing areas of structural depressions, which can be prospective for geothermal water occurrence. At the same time the map of temperature shows the increase of temperature within that depressions.

Reservoir Data

Collecting various kinds of data from boreholes in a computer data base enable to obtain the maps of different features of deep rock complexes including reservoir properties of geothermally interesting strata, important for the assessment of geothermal potential. The most important parameters that can be mapped are porosity and permeability of reservoir rocks, content of dissolved solids in geothermal waters or brines, reservoir pressure and output, thickness of water bearing rocks in whole analysed complex. Previously, such the maps of reservoir properties were made by Gorecki (1990, 1995) for the best recognised geothermal water reservoirs in Polish Lowlands - the Liassic and Lower Cretaceous.

Also, the maps of hydrochemical and hydrodynamic properties of the rock complexes in Polish Lowlands were made by Bojarski (1996). The project partly presented in the paper concerns, amongst the others, of geothermal prospects of Triassic formation in north-west Poland. Unfortunately, it was impossible to make the maps of majority of parameters mentioned before due to a lack of the essential data. But there was possible to generate the maps of reservoir layers thickness and than to calculate the total thickness of water bearing sandstone, which is important for calculation of geothermal resources.

Fig. 9 shows the total thickness of water bearing sandstone in the Reed Sandstone complex in north-west Poland. That complex consists of impermeable and free from water mudstone and siltstone, and water bearing sandstone. To generate the sandstone thickness map, first the thickness map of the whole Reed Sandstone were made on the basis of thickness data stored in data base of GES program. Than the map of sandstone percentage in a profile of Reed Sandstone by Gajewska (1988; 1997) was digitalised and used for mathematical operations on grids.

EVALUATION OF GEOTHERMAL RESOURCES

The modern computer programs specially created for geological purposes or for visualisation, like GES program or Tecplot, enable to make mathematical operations on map grids and additionally to apply even very complicated equations for calculations. That ability is helpful in geothermal energy evaluation. It is necessary to know what are the potential resources in order to find out if the geothermal energy utilisation will be economically profitable. The geothermal estimations call for information and parameters characterise the reservoir and geothermal water features.

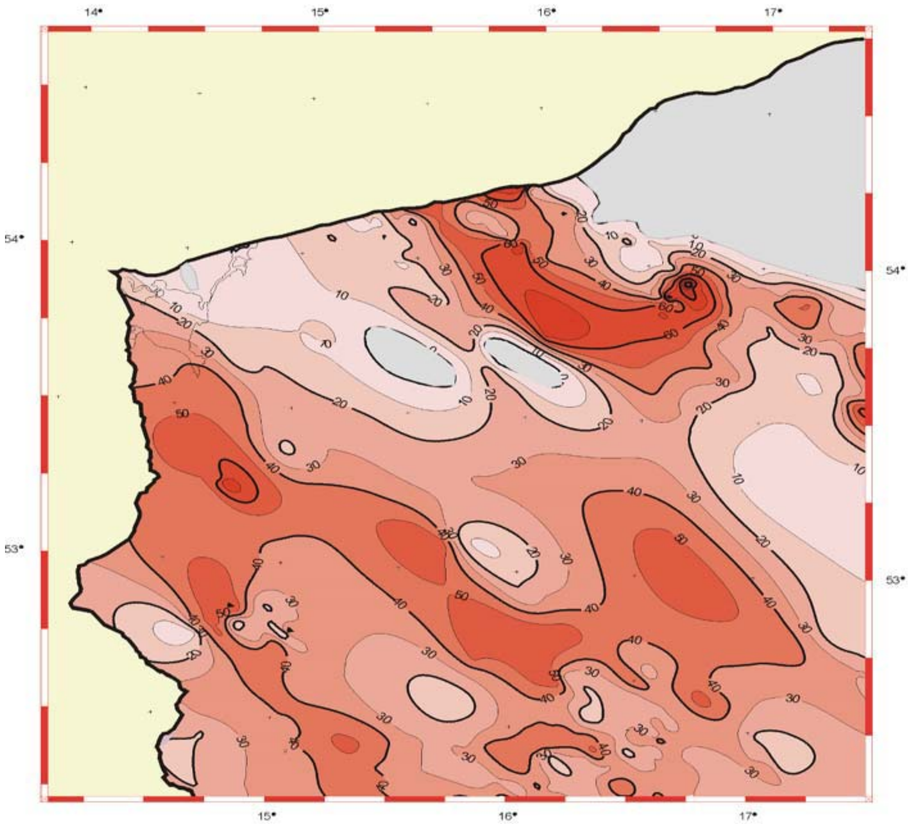

Figure 9. The total thickness [m] of water bearing sandstone in the Reed Sandstone complex (Keuper, Triassic) in the north-west Poland.

Having many of that parameters mapped and stored them in a base of the program it is possible to make calculations quickly and to generate the maps of geothermal resources in the area of interest, as it was done for Reed Sandstone in north-west Poland (Fig. 10). The formulas presented beneath were applied for calculating static geothermal resources and static recoverable resources of the layer:

1) $Q = [(1-\varphi) \cdot C_s \cdot \gamma_s + \varphi \cdot C_w \cdot \gamma_w] \cdot A \cdot h\,(T_{srs} - T_{sn})$,

where:

Q – static geothermal resources of the complex [J],
φ – porosity of the rocks,
C_s – specific heat of the rock [J/kg°C],

C_w – specific heat of the water [J/kg°C], γ_s – density of the rock [kg/m^3],
γ_w – density of the water [kg/m^3],
A –area of calculations [m^2],
h – thickness of the layer [m],
T_{srs} - medium temperature of the layer [°C],
T_{sn} – temperature on the base of thermally neutral zone [°C]

2) $Q_r = R_e \cdot Q$,

where:
Q_r – static recoverable geothermal resources of the complex [J],
R_e – geothermal energy extracting factor
(Edwards et al., 1982; Górecki, 1995; Kapuściński et al., 1997).

During the calculations, instead of selected values needed for the equation, the grids of the maps were used. These were grids of water bearing sandstone thickness map and the maps of temperatures. On the basis of final maps of geothermal energy resources covering large area of almost 1/6 of Poland it is possible to define small areas of potential most profitable and effective geothermal energy utilisation.

CONCLUSIONS

Nowadays it is hard to imagine effective work in geology, also in geothermal, without computer tools. In geothermal exploration and development within large areas we usually collect huge number of data, coming from different sources, obtained in different years using different tools. Therefore creating the computer databases and digital processing such data is necessity. Having limited period of time for realising geothermal projects it is necessary to have easy access to data we are interested in, and to generate cartographic materials concerning particular areas relatively quickly. Professional computer programs enable collecting data, revision of cartographic materials created in conventional way, producing the new ones and finally they enable better and faster progress in research. However one of the principals problems in geological research in Poland is lack of the digital database with geological data easy accessible for scientists. Looking for data needed to a project it is necessary to start searching the thousands of paper sheets of documentation in geological archives. The same goes for geothermal information. People, who use computer techniques in geology and geothermal research, usually, create their own computer databases only for their own needs.

The databases with borehole data, however, uncover that the geothermal issues were not amongst the principal interests of the drilling investors. Amongst the more than thousand boreholes used for that geothermal project only for 64 (sixty four) were available thermal data, some of them rather erratic. Even worse appeared comparison for the whole territory of Poland - out of over twenty thousand deep wells only less than 200 appeared fit for determining the Earth heatflow rate.

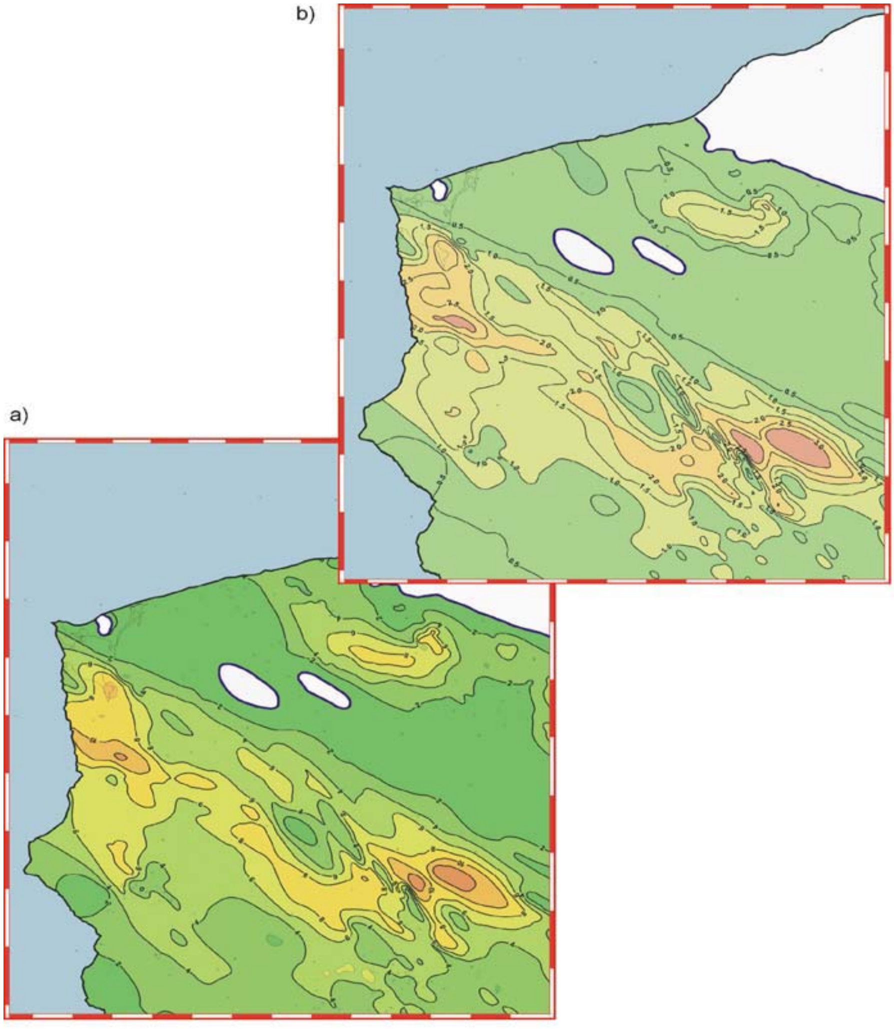

Figure 10. Map of unit static resources of geothermal energy (a) and unit static recoverable resources (b) of the Reed Sandstone layer in north-west Poland [GJ/m^2]

Another problem worth pointing out in the paper is insufficient use of modern geological methods in searching for ecologically clean geothermal energy. As it was shown on the examples in this paper, there is a wide range of possibilities in processing geothermal data in connection with geology what leads to evaluation of geothermal resources and specifying in details areas of potential utilisation of geothermal energy. However perhaps the most important problem in geothermal in Poland is not satisfying interest in development and usage of that kind of "green" energy.

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REVIEW BY EARL BRABB

The author points out that exploring for geothermal energy requires huge amounts of data dealing with geologic structure, temperature and temperature gradients in deep rock complexes, reservoir properties of the strata, differentiation in chemical composition of geothermal waters, hydrogeological features of the area, potential resources of geothermal energy, and even administrative maps. The best method for coping with the data, are mapping and multidimensional modeling in order to visualize and compare various geologic issues.

One problem explored is digitizing paper documents and checking the accuracy of structural maps to expose obvious errors. An accurate model of the geological structure is an essential first step in exploring for geothermal energy. Figure 2 is a fascinating map showing the depth to Jurassic basement rocks and their temperatures. Similar maps were prepared for five other stratigraphic units so that nested images (Figure 3) could be prepared in perspective views.

The lack of well data, of course, can adversely affect the model. Areas where data are scarce were noted, and cross-sections provided to show how structural features are subdued or eliminated if fewer wells are used.

Figure 10 showing static resources of geothermal energy in northwest Poland spoils, an otherwise excellent article. Units for the lines and colours should be provided, and a mention made of which areas are most favourable so that the casual reader can understand the figure. This figure seems to be the most significant in the article but it is left hanging in the wind.

One interesting statistic is that only 200 of 20,000 wells in Poland have sufficient thermal data to prepare the kind of maps in this report.

GEOMAPPING IN UKRAINE: STATE OF THE ART, ACHIEVEMENTS AND PROSPECTS

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Abstract: Geological mapping using geographical information systems (GIS) is now carried out in two ways. The first method involves a digitization of multi-thematic maps that were constructed by traditional approaches before the advent of GIS. Maps of different scales are now incorporated in the regional data bank. Regional maps are constructed on the basis of the data set. Examples are geological and tectonic maps of Ukraine on the scale of 1:1 000 000. The maps form the basis for the construction of regional maps of deposit distribution, as well as for developing new directions of geoexploration and exploration geophysics in different tectonic units of Ukraine. The second method of geological mapping with GIS involves the visualization of spatially distributed databases on mineral deposits. Such maps are used to create different types of numerical models and carry out further processing of the models.

Keywords: GIS, regional database, integration of thematic maps, visualization, mineral deposits

Information technology and geological cartography are widely applied to geological and geophysical surveys in Ukraine. The geographical information systems (GIS) that are generally used are ArcView, ArcInfo and Mapinfo. The sequence of GIS application is demonstrated in Figure 1.

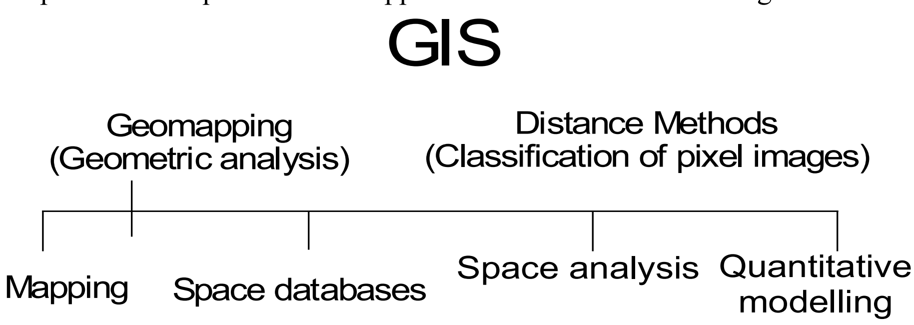

Figure 1. Diagram showing the sequence of the applied GIS procedure.

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 203–206.

In Ukraine, computer mapping forms almost 100% of geological map making. The development of regional and thematic databases for geophysics, geology, hydrogeology and engineering geology is the next stage for geomapping in Ukraine. These databases consist of both the initial data obtained by oil–gas exploration and geological/geophysical surveys, and the results of data interpretation.

The development of software for data processing is also an important area of the present-day GIS in many geological investigations in Ukraine. Ukrainian specialists have been developing software on the basis of tool libraries existing in GIS; an example of such a library is 'Spatial Analyst', which is part of ArcView. The software is used to create and analyse numerical models; the different types of software are based on original algorithms produced with Fortran Power Station, Visual C++, Visual Basic, etc. The 'GEOMAPPING' system that was developed in order to create structural models is one example of such software. An example of the software use is given in Figure 2.

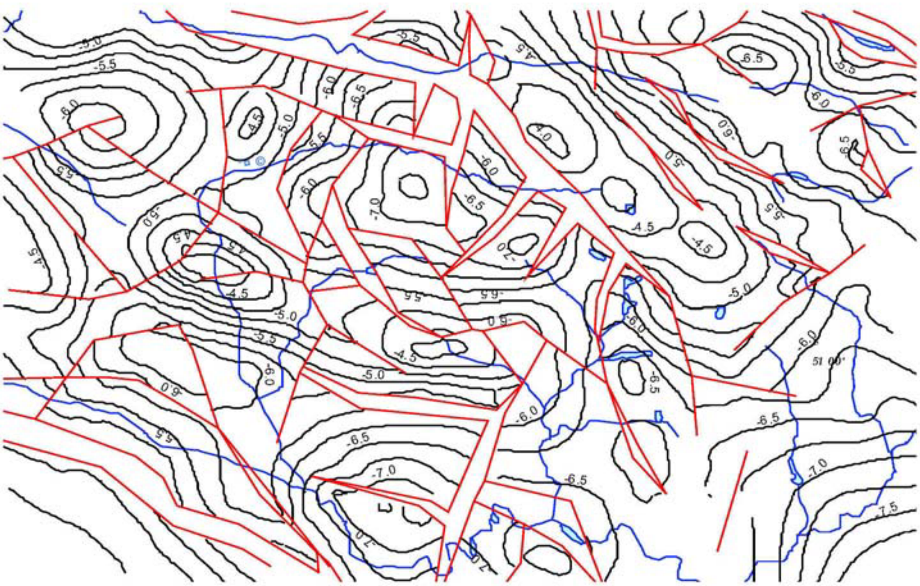

Figure 2. Dniepr–Donets Basin: a fragment of the regional structural map of the crystalline basement. The contour lines of the crystalline basement surface are in black, the faults in red and the rivers in blue.

A map of the crystalline basement of the Dniepr–Donets Basin at a scale of 1:50 000 was built using spline approximation of the initial database (Figure 2). The map covers an area of several hundred square kilometres. Every segment of the map can be rebuilt, printed or analysed by means of space mathematics. In the case of availability of different structural maps for the same area, all algebraic operations with surfaces existed on the maps are easy to access. The processing procedure for data consists of three stages:
(1) Interpolation: using the spatiallydistributed data;
(2) Approximation: both initial data and information about the surface features are used;
(3) Modelling: based on the mathematical models of geological processes.
The first two stages deal with data; the third operates with processes and is used for prediction of patterns by forward modelling. Forward modelling of geological processes is now implemented in Ukrainian organizations. An example of the modelling of pore distribution during the process of water filtration in deep-lying beds within the Dniepr–Donets Basin is presented in Figure 3.

Figure 3. Dniepr–Donets Basin: model of pore distribution in deep-lying beds.

The tectonic block delimited in Figure 3 by bold lines has been determined using data on the distribution of the major basement faults. The continuous lines indicate faults that are fluid-conducting; faults that can be considered as fluid traps are shown by dotted lines. The structure of the upper and lower surfaces of a bed, the temperature gradient, and the chemical system state of the bed under different temperatures (equilibrium conditions of calcite and quartz) were taken as input data. The violet colour in Figure 3 reflects the areas of formation of secondary pores that can be considered as oil and gas reservoirs during the following stages of hydrocarbon field formation; brown indicates areas where formation of secondary calcite and quartz took place inside the pore space of the bed.

We are now working on further development of forward and reverse modelling with GIS and a number of new algorithms based on the system approach. Application-specific GIS have also begun to be developed in order to solve other goals of geological exploration.

MAPPING OF NATURAL HAZARDS AND ITS APPLICATIONS IN KOREA

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Abstract: Modern disaster patterns are becoming increasingly complicated, thus disaster prevention action needs to be multi-hazard, multi-scale, multi-faced, and multi-disciplinary. The development of geographical information system (GIS) technology may help in the building of a related database for all phases of a disaster event, aided by thematic maps and spatial patterns of factors related to natural hazards. Geological maps form the basis for disaster management and GIS is a powerful tool. However, such a database has been initiated in diverse governmental bodies, and created by various departments for their own purposes. The government should appoint a single institution with universal standards to perform GIS research on natural hazards. Currently, National Institute for Disaster Prevention (NIDP) initiated natural hazard studies use GIS and remotely sensed images. The information extractable from GIS and images can help to improve understanding of topographic features and to extract natural disaster factors from various thematic maps.

Keywords: Natural hazards, prevention of disasters, integrated action, thematic mapping, National Institute for Disaster Prevention (NIDP), hazard database, data extraction

INTRODUCTION

Every year, Korea suffers from various seasonal natural phenomena, which cause tremendous property damage and human loss. The major types of natural hazards in Korea are hurricanes and heavy rains; earthquakes are less common. Another natural hazard, drought, has an adverse impact on agricultural land, but the actual damage can be hard to measure. Korean economic and social development in the last few decades has led to a number of densely populated areas and rapidly industrialized Korean cities. Modernized, industrialized, and urbanized Korean cities show a somewhat

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 207–214.

different trend from that of the past. The changing pattern has caused the Korean government to call for a critical look at natural disaster protection.

Modern disaster patterns can be summarized into three sets of features: (1) complexity of disaster causes, (2) increase in property damage, and (3) secondary disaster occurring as a result of natural disasters. Property damage and human loss caused by natural disasters in the last decade are illustrated in Figure 1. Property damage in the period from 1998 to 2001 doubled or tripled compared with that in the early 1990s. In contrast, human loss in the early 1990s followed the pattern of property damage, but recent human loss due to natural disasters has clearly decreased, except for the year 1998.

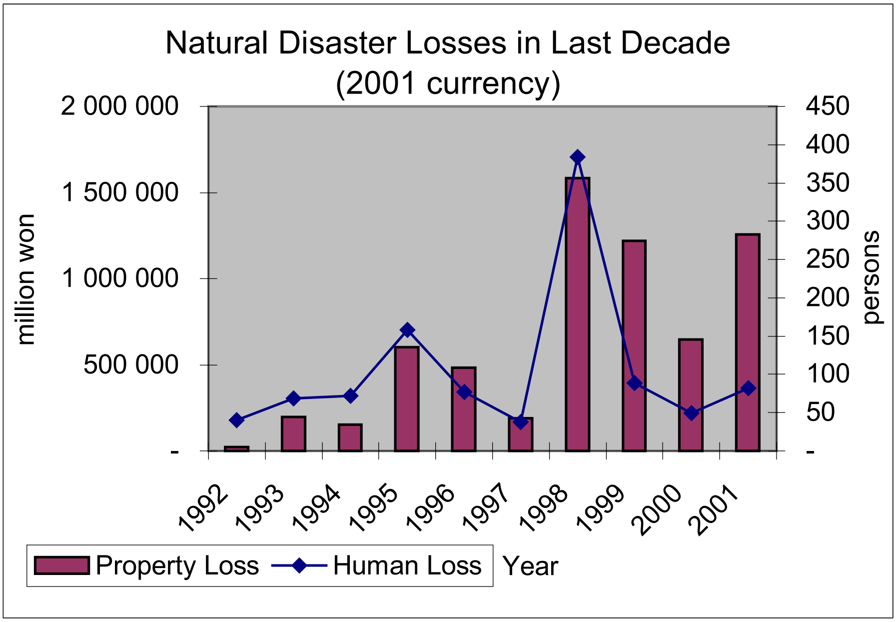


Figure 1. Natural disaster losses from 1992 to 2001. *Source:* Natural Disaster Prevention and Countermeasures Headquarters.

These damage and loss figures were summarized for the years to 2001 (See Table 1). In 2002, Hurricane Lusa hit the northeastern part of Korea and caused more than 5 trillion won of property damage and 246 human losses, roughly the same totals as for the whole of the previous four years (National Institute for Disaster Prevention (NIDP), 2003). In 2003, another hurricane, Hurricane Maemi, hit the southern part of Korea and the Korean Government reported terrific tragedy and loss; recovery work is still in progress.

Table 1. Top five natural disaster damages to 2001 (1000 won = ~US$1.00)

Rank	Damages (in thousand won)	Date	Type
1	1 246 819 091	31.07 – 18.08.1998	Heavy rains
2	1 070 442 512	23.07 – 04.08.1999	Heavy rains, hurricanes
3	730 622 313	09.09 – 12.09.1990	Heavy rains
4	596 572 769	15.07 – 16.07.1987	Hurricane Thelma
5	548 414 963	19.08 – 30.08.1995	Heavy rains and Hurricane Janis

Source: Natural Disaster Prevention and Countermeasures Headquarters.

GIS AND HAZARD MAPPING

Many studies on GIS technology in natural disaster prevention have been carried out throughout the world. For example, the Federal Emergency Management Agency (FEMA) has an MAC (Mapping and Analysis Center), actively implements GIS and provides related disaster maps to the EST (Emergency Support Team) and IPST (Information and Planning Support Team) (FEMA 2002). One of the most useful functions of GIS is that thematic maps can be integrated and calculated. Many areas of disaster analysis are supported by GIS database integration, hazard mapping, vulnerability assessment, damage loss calculation and estimation.

The GIS data related to disasters in Korea have not been systematically developed so far. Each government department has developed disaster-related maps for their own purposes, and these maps have not very often been used in disaster operations. The lack of GIS data is another barrier to disaster applications. In the case of flood prevention, rainfall data from many years are required and an accurate understanding of topographic features must be accompanied by flood data. Carefully studied mapping design and methods need to be applied in the creation of hazard applications (Monmonier 1997).

The NIDP has played an important role in hazard mitigation planning. Until a few years ago, the NIDP had concentrated mostly on physical prevention planning, such as dams, levees, structural safety, etc. The NIDP has now realized the importance of maps and spatial information in studying disaster prevention efficiently, and has gradually turned its attention to GIS and remotely sensed images.

Remotely sensed images can provide a broad view of topographic features and record much useful disaster-related information during an event.

These images can also help in estimating the likely aftermath after a disaster has hit. The GIS is known as a system able to collect, manipulate, and process data, and produce results in a visual form; it is more powerful when it is implemented with statistical packages to process the data.

APPLICATIONS IN KOREA

Korean disaster damage typically comes from hurricanes and heavy rains, resulting in floods and landslides. GIS disaster applications are therefore concentrated on these areas. Landslides caused by heavy rains or hurricanes can occur under many different topographies and degrees of rainfall. The GIS can map these various factors to investigate spatial patterns and integrate them in order to predict the most likely landslide areas (See Figure 2).

One application is in the investigation of Kangneung Province, South Korea, where frequent landslides occur every year. A number of landslide factors have been discussed in the literature and by experts. In 2002, this area was hit by Hurricane Lusa, which left behind severe damage and considerable human loss.

Remotely sensed images have been employed and are based on the creation of GIS layers. Figure 3 shows some factor maps of the study area. This work has included characterization of the rainfall patterns, which considers 5-day rainfalls instead of using simply the maximum rainfall. The rainfall data can be stratified into different flood years to show, for example, 10-, 20-, 50-, or 100-year trends.

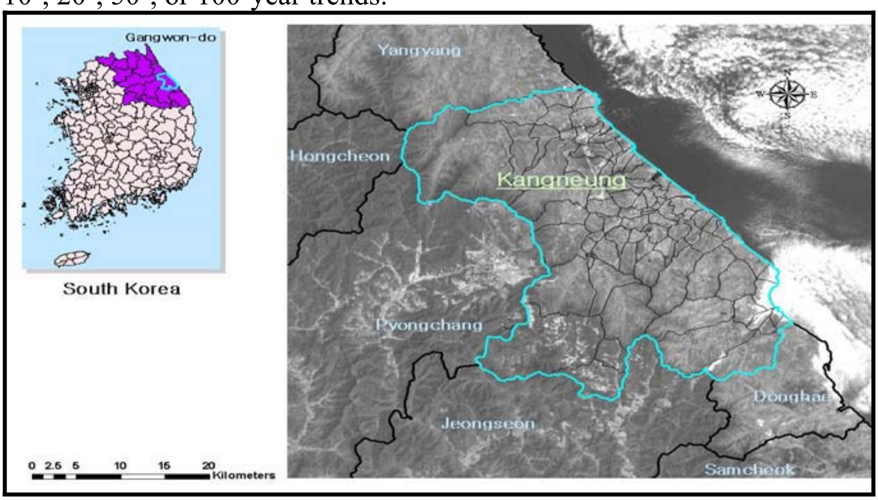
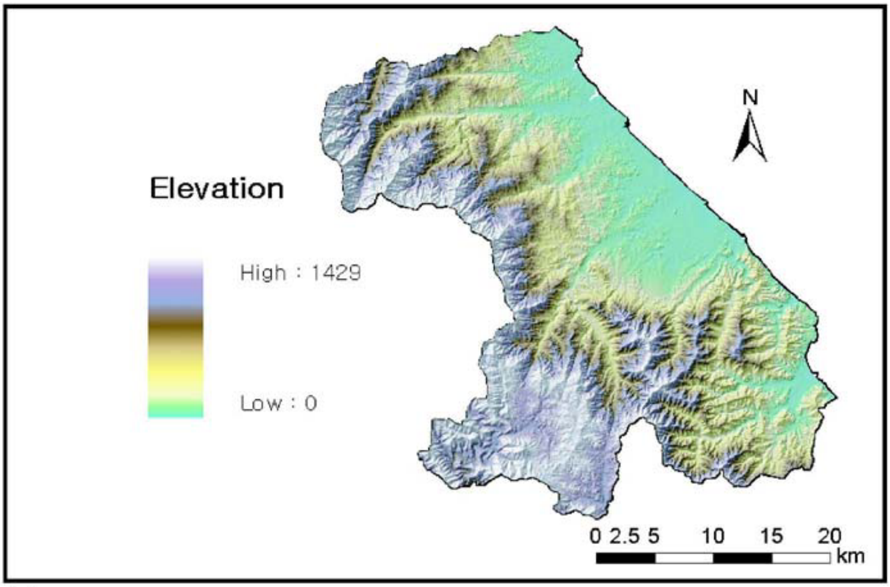
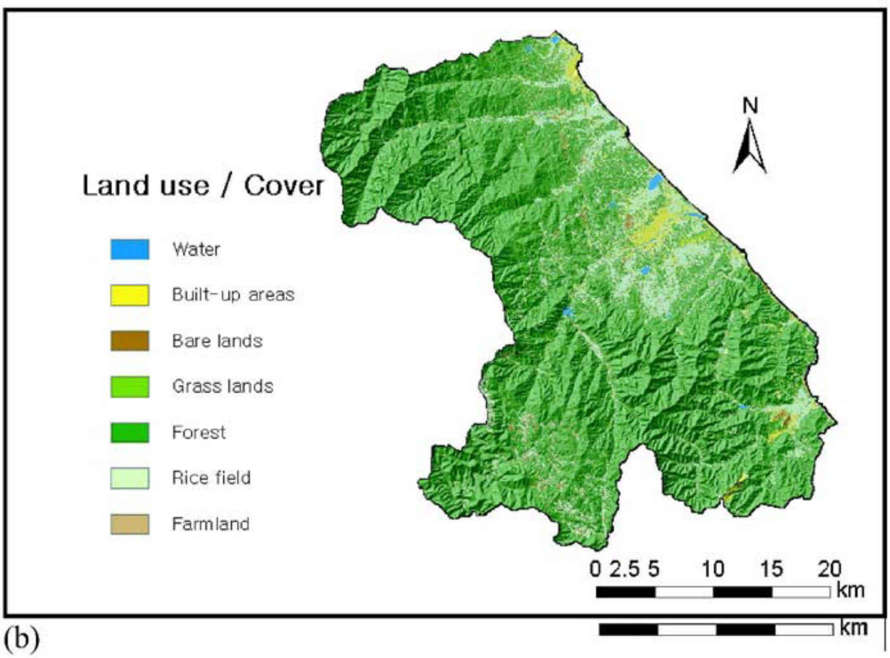


Figure 2. Satellite sensed image for landslides (2000, LANDSAT TM+).


Elevation
High : 1429
Low : 0
N
0 2.5 5 10 15 20
km

(a)


Land use / Cover
Water
Built-up areas
Bare lands
Grass lands
Forest
Rice field
Farmland
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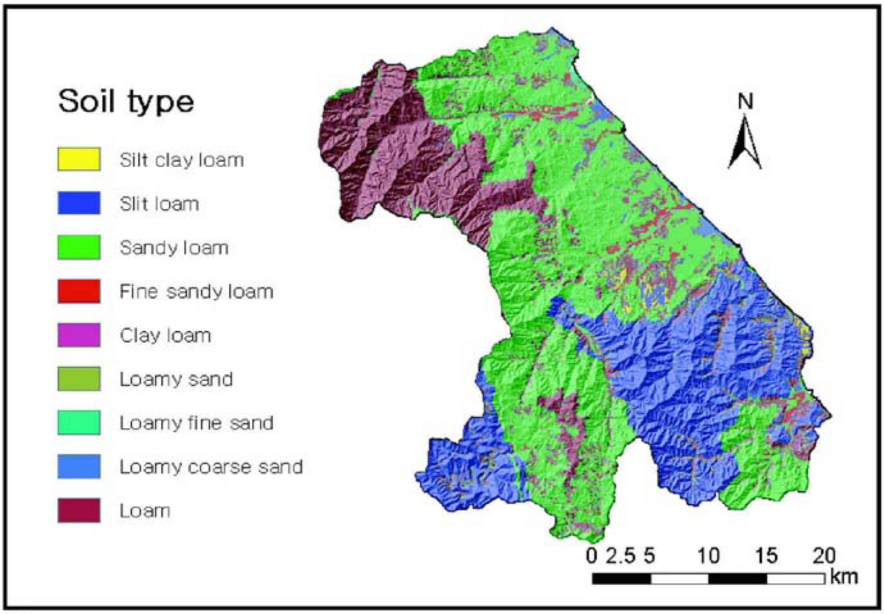
(b)



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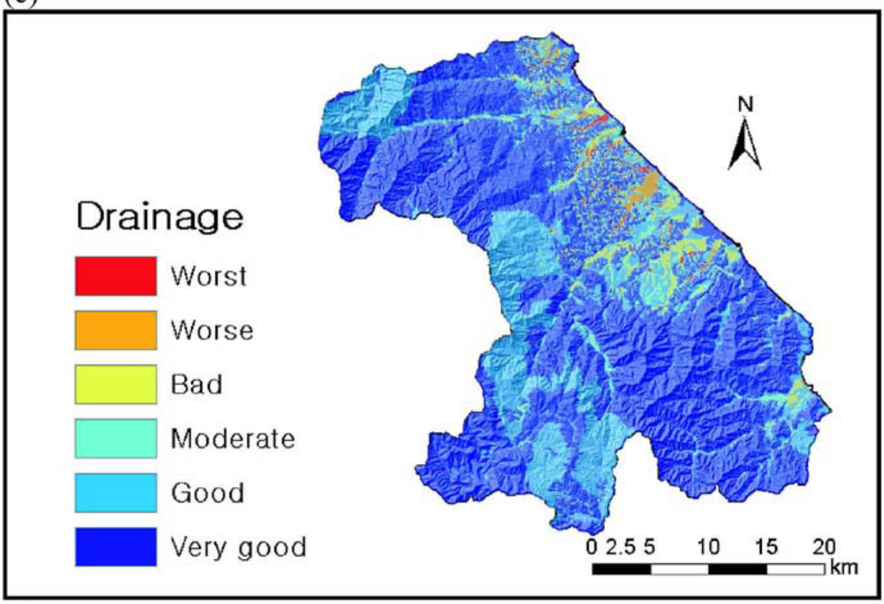

(d)

Figure 3. Basic modules of the thematic map of study area; a - elevation, b - landuse / land cover, c - soil type, d - drainage system

CONCLUSIONS

Modern disaster patterns are becoming increasingly complicated and damage is getting more severe and more widespread. Disaster prevention action should be multi-hazard, multi-scale, multi-faceted, and multi-disciplinary. The development of GIS technology may help in building the related database and methodology for natural hazards. All phases of a disaster event (pre-disaster, during disaster, and post-disaster) can be aided by thematic maps and spatial patterns of factors, that might be related to natural hazards.

Geological maps form the basis for disaster management and GIS is a powerful tool that can make various maps compatible. However, disaster applications using GIS in Korea have been initiated in diverse governmental bodies and a database has been created by various departments for their own purposes. It is suggested that a single government department or research institute should perform GIS research on natural hazards with universal standards and lead GIS activities on disaster prevention actions.

Currently, the NIDP initiates natural hazard studies using GIS and remotely sensed images. The information from GIS and images can be used to improve understanding of topographic features and to extract natural disaster factors from thematic maps.

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National Institute for Disaster Prevention (2003), "A Study on the Debris-Flow and Mitigation Techniques," Research Report NIDP-2003-07, Ministry of Government Administration and Home Affairs, December, 317p. (in Korean)

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REVIEW BY EARL BRABB

Dugkeun Park and Hoon Chang point out that damage from natural disasters in Korea has tripled and become more complex during the past decade. These changes have stimulated the National Institute for Disaster Prevention (NIDP) to change its emphasis from physical structures, such as dams and levees, to disaster prevention and mitigation using GIS technology. A sampling of land-use, rainfall, slope, and drainage factors**,** that could influence the distribution of landslides in northeast (part of the South) Korea is provided, but no analysis of the factors is shown, nor any attempt made to assess the role of rock strength from a geological map. The NIDP work is apparently at an early stage and requires interaction with the international community to determine how to make effective vulnerability and hazard susceptibility maps.

AUTHORS' REPLY

Various factors are analyzed using both statistical and deterministic methods. Bivariate statistical analysis is adapted to estimate weighted values, which can be determined based on the relationship between each affecting class and slope failure. Thirteen factors are selected for the analysis: slope degree, slope length, slope location, slope shape, type of bedrock, drainage, soil type, soil depth, vegetation type, vegetation area, vegetation time, vegetation density, and land use. For deterministic analysis, soil properties are selected and precipitation intensity is analyzed to determine the ratio between groundwater level and effective soil depth. As the reviewer mentioned, no assessment for the role of rock strength has been attempted. The only classification for the bedrock is a lumped rock type for the statistical analysis, i.e. metamorphic, sedimentary, igneous and volcanic, and Quaternary rocks. The project is at an early stage, and further efforts towards the production of effective hazard maps, including rock strength considerations, will be necessary.

THREE-DIMENSIONAL GEOLOGICAL MAPS

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Abstract: Conventional methods of numerical mapping (geographical information systems, GIS) are used widely to convert surface and subsurface geological maps into digital two-dimensional (2D) space, which can still be simply identified with a sheet of paper. Digital polygons, polylines and points represent geological information on intersectional surfaces (e.g. the terrain surface), without relief in most cases. This does not seem much different from traditional mapping. In general, conventional digital mapping deals only with the new technology of data acquisition, storage, processing and visualization. As in traditional mapping, the third dimension, which is so important for geologists, still remains hidden to the ordinary reader; one must interpret and penetrate the 2D map to imagine and understand subsurface structures. Should we, however, employ the third dimension, or even the fourth, in digital geological mapping? The computational power of modern hardware gives us the possibility to store, manage and visualize the voluminous and complex data necessary to present the 3D geological space. Recent industrial development presenting new techniques of computer modelling of spatial geological objects and processes can and may be applied in standard geological mapping.

A 3D geological map of Poland is presented as an example of a product of multidimensional computer-based cartography. The map is still in the developmental stage and techniques of model construction and visualization are refined using numerical methods. A relatively large area of interest covering several different regional geological units is included in this model and it creates new challenges in 3D map production. The map is based on existing interpretations—archival, analogue subsurface geological maps, mainly on horizontal-section maps with a depth interval from –500 to –5000 m a.s.l. Data from drill holes and cross-country geological sections are also used as input to the model.

A system of manipulation and visualization of 3D geological maps is proposed. The following topics are presented in the paper as features of the system: inclusion of 3D in GIS used in geological mapping (various techniques of geological data representation, intuitive visualization to display the multiplied, interbedded 3D objects in a form suitable for human perception and interpretation), 3D volumes (techniques of construction and visualization of 3D digital objects representing geological formations defined on stratigraphy, lithostratigraphy or lithology only) and faults (techniques of modelling and visualization of discontinuous tectonic structures in 3D).

Keywords: Geological mapping, innovative cartography, three-dimensional models, geographical information system

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 215–224.

INTRODUCTION

Conventional methods of numerical mapping are used widely to convert surface and subsurface geological maps into digital two-dimensional (2D) space, which still can be simply identified with a sheet of paper. Digital polygons, polylines and points represent geological information on intersectional surfaces (e.g. the terrain surface), without relief in most cases. This does not seem much different from traditional mapping. In general, conventional digital mapping deals only with the new technology of data acquisition, storage, processing and visualization. As in traditional mapping, the third dimension, which is so important for geologists, still remains hidden to the ordinary reader; one must interpret and penetrate the 2D map to imagine and understand subsurface structures. Should we, however, employ the third dimension, or even the fourth, in digital geological mapping? The computational power of modern hardware gives us the possibility to store, manage and visualize the voluminous and complex data necessary to present the 3D geological space. Recent industrial development presenting new techniques of computer modelling of spatial geological objects and processes can and may be applied in standard geological mapping at a regional scale.

Present technological progress in geology is focused mainly on detailed exploration of oil and gas fields, where large-scale subsurface structural and geological maps are created in the form of multi-dimensional models with application of complex, professional systems. Out of this area of the petroleum industry, the use of numerical methods for geological modelling is relatively less popular. There is a significant gap in the use of computers between oil and gas exploration and regional geology, which is rather closer to paper-era maps.

In the last couple of years, 3D geological mapping has been an expanding field of geology in many countries. On the basis of systems used in oil and gas exploration, models at regional scales are created (Courrioux et al. 2001; Jachens et al. 2001; Matile et al. 2002; Berg et al. 2004). However, different technologies are used from site to site. Models built in GoCAD, EarthVision OpenCascade or RockWorks are totally incompatible. This is common in the early stages of development of a new field, where there are several competitors. In general, 3D regional geological models are not yet common; it is expected that this situation will change over the next few years, so there is a need for the creation of a widely available geographical information system (GIS)-like system which could bridge the different commercial technologies of 3D geological visualization.

THIRD AND FOURTH DIMENSION ON GEOLOICAL MAPS

On a traditional map, geological data are presented in two planar dimensions; information on spatial distribution of strata can be read from intersectional lines on the surface and additionally is presented in the form of cross-sections along sparse section lines.

This method of visualization significantly limits the readability of the third dimension (Figure 1).

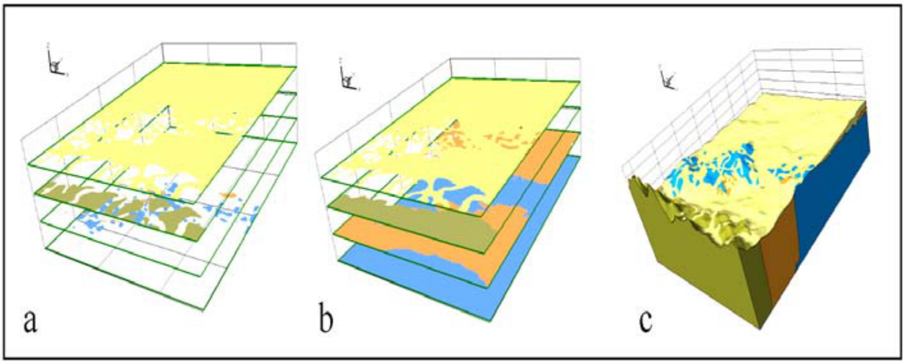

Figure 1. Three techniques of geological data visualization in numerical mapping. (a) Flat surficial geology presented in the form of limited polygons of outcrops on the intersectional surface. (b) Flat polygons in stratigraphic layer sequence presenting horizontal extents of the strata. (c) 3D volumes.

The first step to presenting the third dimension on a traditional geological map is to drape over a digital elevation model (DEM). This kind of pseudo 3D (2.5-D) map shows the relation of surficial geology and terrain morphology presented as shaded relief (see e.g. Thelin & Pike 2001; Nita & Malolepszy in press).

Surface and subsurface geological data integration is essential in 3D geological map creation (Malolepszy 2003). Conversion of different data types, point (surface observations), 1-D (wells) and 2D (maps and sections, seismic profiles), by digitizing and reconciling produces the 3D geological maps which exist in the computer as a huge data set in various formats (Jachens et al. 2001).

MULTI-DIMENSIONAL GEOLOGICAL MAP OF POLAND

A multi-dimensional geological map of Poland is presented here as an example of a product of multi-dimensional computer-based cartography. The map is still in the developmental stage and the methodology of model construction and visualization is being refined using numerical methods.

The relatively large area of interest (312 000 square km), covering several different regional geological units, distinguishes this model and presents new challenges in 3D map production. The project is directed by the Geological Mapping Survey of the Polish Geological Institute.

The map is based on existing interpretations—archival, analogue subsurface geological maps, mainly on horizontal-section maps in the depth interval from -500 to -5000 m a.s.l. (Kotanski 1997). Data from drill holes and cross-country geological sections are also used as input to the model.

The framework of the model consists of a few dozen deep wells (4000–7000 m) drilled across the country. Data on these wells come from a drill-hole database containing circa 130 000 wells. Some more of these will gradually be included in the model.

Preliminary results of the project address the needs of the creation of a multi-dimensional interactive system for data visualization. The animations which are the main display of the model show horizontal-section maps (Figure 2), cross-sections of the whole profile (Figure 3), cross-sections of selected bedrock (Figure 4), fence cross-sections (Figure 5) and removal of formations (Figure 6).

These simple animations are not interactive; there is no way to change the point of view or exaggeration. In the proposed system this kind of animated sequence will be interactively manipulated to change the geometrical parameters of the visualized model.

The author creates 3D geological models using the GeoGraphix Exploration System in the form of 2D grids which have to be merged into volumes using a couple of developed procedures. 3D volumes are presented in TecPlot software. This technique of modelling is time consuming and inconsistent. One significant problem concerns modelling of discontinuities in 2D grids.

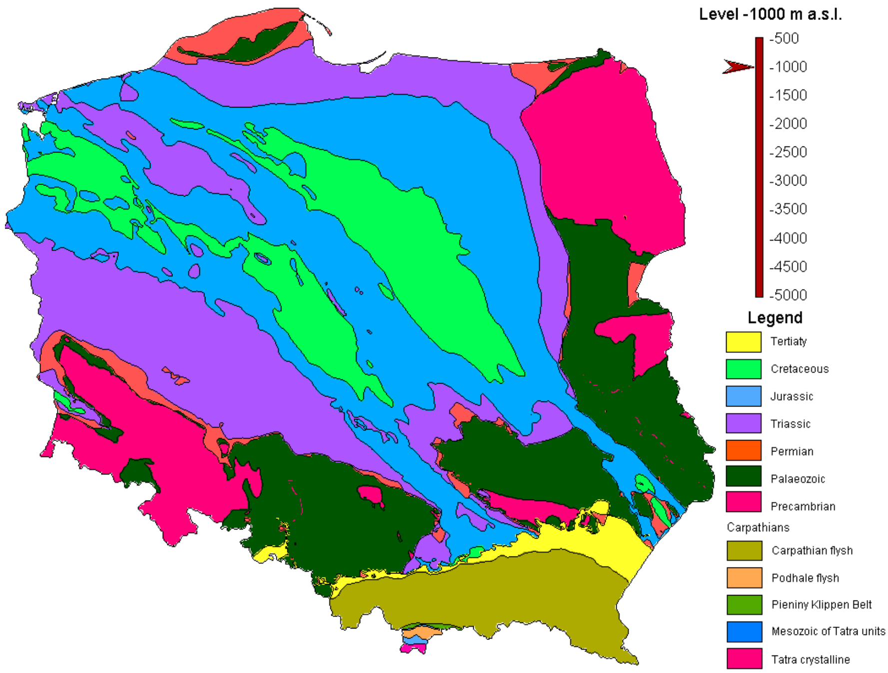

Figure 2. Screenshot of animation presenting horizontal section map of Poland at a level of minus 1000 m a.s.l.

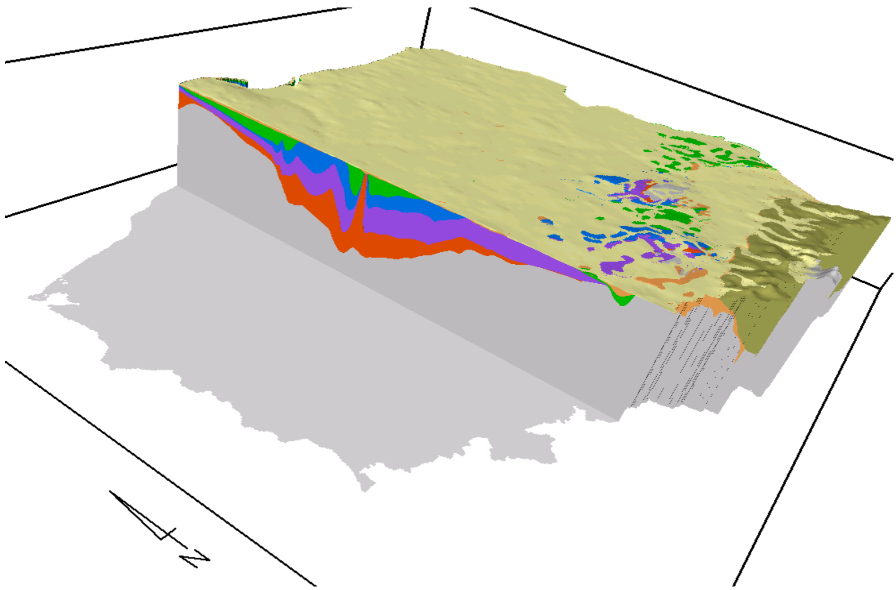

Figure 3. Screenshot of animation presenting the S–N cross-sections through Permo-Mesozoic formations of Poland.

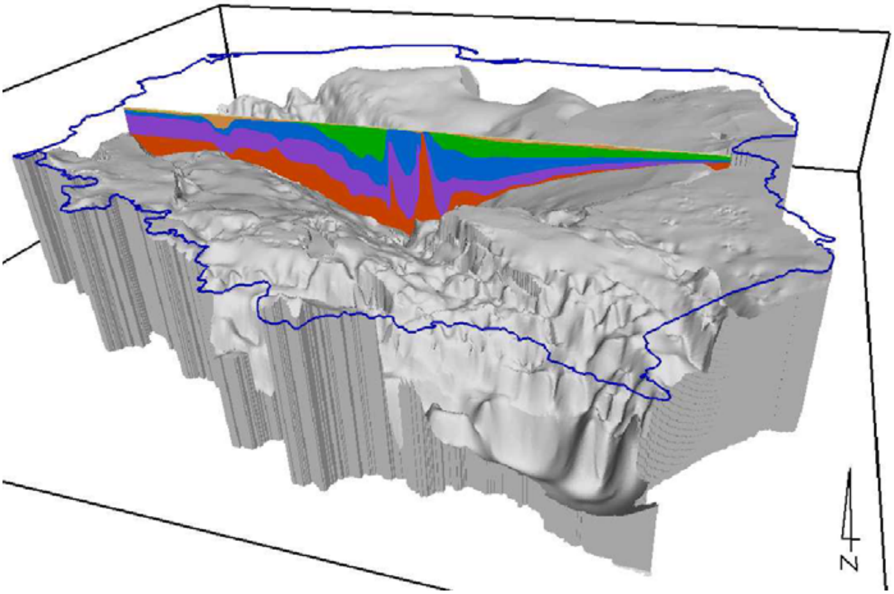

Figure 4. Screenshot of animation presenting W–E cross-sections on the top of Paleozoic bedrock of Poland.

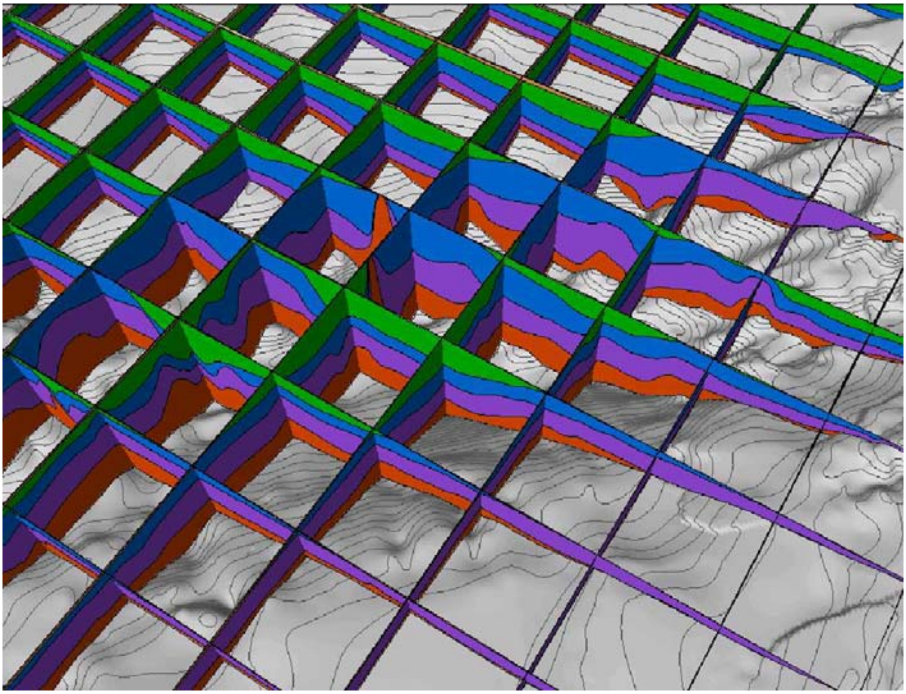

Figure 5. Screenshot of animation presenting fence cross-sections diagram of Permo-Mesozoic formation of the Polish Lowlands.

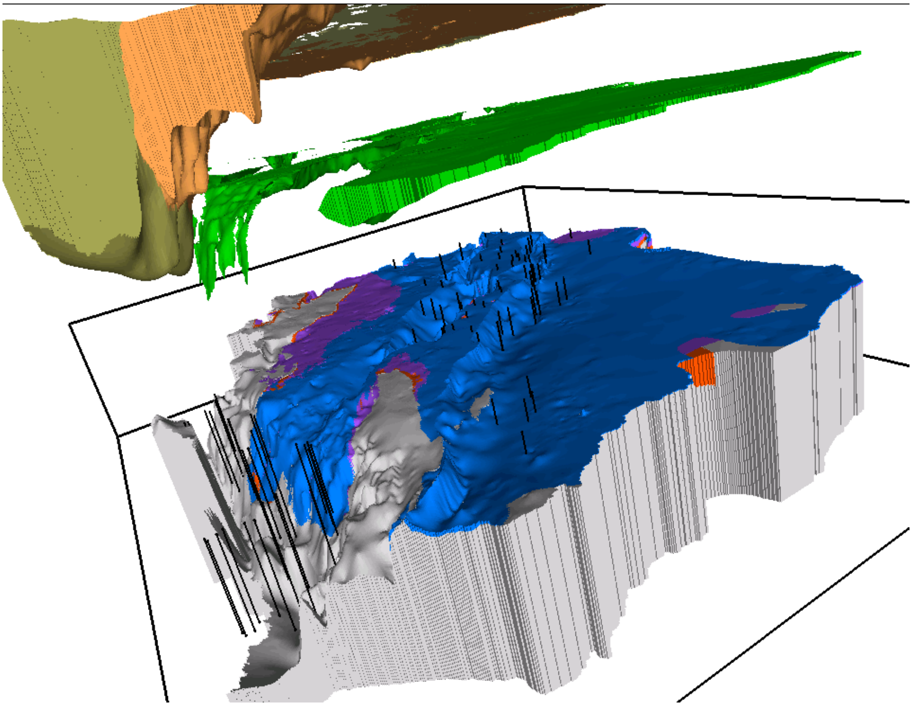

Figure 6. Screenshot of animation presenting removeable 3D volumes representing formations of the stratigraphic system of the Permo-Mesozoic of Poland.

3D GEOLOGICAL VISUALIZATION SYSTEM

The goal of this paper is to propose a GIS-like system for interactive multi-dimensional visualization of geological space in the form of a numerical map—a model which is an approximation of subsurface structures. The proposed system consists of several applications, which are able to present 3D geological objects representing stratigraphic, lithostratigraphic, lithologic or tectonic units. The system stores and visualizes a geological model created using other software. Geological modelling and spatial interpolation techniques will be used to create 3D volumes on the basis of drill-hole data. The main purpose of the system will be interactive visualization of 3D objects as volumes (or solids). The idea of the system is based on an intuitive visualization to display the multiplied, interbedded 3D objects in a form suitable for human perception and interpretation: user-defined cross-sections, horizontal-section maps, rotated blocks, animated sequences, transparencies, and cartoon models to help the reader's imagination to see and understand the third dimension of geological space (Figure 7). At any point on the model a lithostratigraphic profile could be displayed, and bore-hole profiles stored in a well database could be presented as a stratigraphic column.

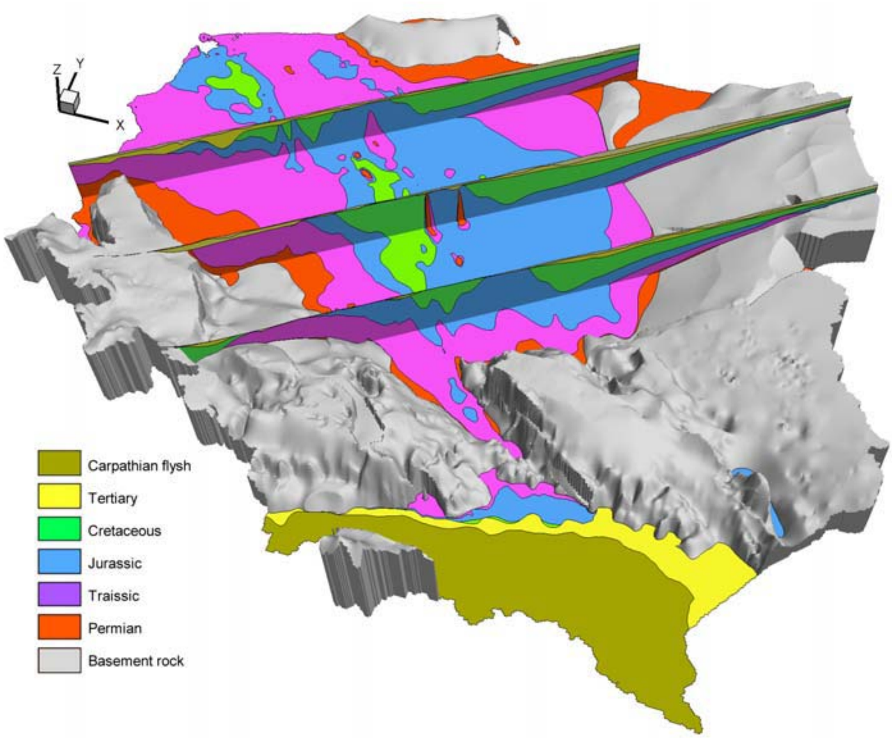

Figure 7. Example of intuitive 3D visualization of Permian-Mesozoic strata in diagram presenting horizontal section at level 1600 m b.s.l. and three cross-sections perpendicular to central axe of the Polish Lowlands sedimentary basin at the background of top of older bedrock.

The system should be freely distributed. The author expects this to lead to the establishment of standard 3D visualization of geological maps in academic, government, educational and commercial areas. One of the modules of the system will create simplified models for interactive presentation on the Internet using Virtual Reality Modelling Language (VRML) technology.

The main part of the system—the visualization module—will have an intuitive and friendly user interface understandable to wider groups of users, including geologists unfamiliar with computers; they will be encouraged by the easy, interactive manipulation of the model. For this purpose the system should be extensively tested on a group of geologists with different levels of computer skills, various areas of interest, and from different age groups. For wider applicability, the system will have modules for 2D and 3D data import from different systems of geological modelling, including commercial, consortium-based and open-source software. Conversion tools will be developed for storage of data from different sources in a unified format.

The following methods will be subjects of the system:

1) 3D volumes: techniques of construction
2) Visualization of 3D digital objects representing geological formations defined on stratigraphy, lithostratigraphy or lithology only
3) Merging of top and base surfaces along a zero isopach
4) Automatic building of solids from bore-hole data (Lemon & Jones 2003)
5) Construction of solids from sparse sectional contours (Sirakov et al. 2002, Patel and McMechan 2003)
6) Inner and outer meshes of geological solids
7) Layer pinching and lenses
8) Visualization of discontinuous structures in 3D (Xu &Dowd 2003)
9) Representation of faults in the form of surface disturbances
10) Integration of 3D geological models with spatial databases - drill-hole data, geophysical and seismic data, DEM data
11) Utilization of 3D geological models in basic geological studies, hydrogeology, engineering geology, environmental management, resource exploration.

CONCLUSIONS

The presented aspects of three-dimensional geological maps show the development of standard GIS-based digital, geological mapping into multidimensional cartography of the lithosphere. New, computer based methods are essential in order to advance the process of surface and subsurface data collection, storage, management, interpretation and visualization.

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APPLICATION OF SAR IMAGERY AND SAR INTERFEROMETRY IN DIGITAL GEOLOGICAL CARTOGRAPHY

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Abstract: One aspect of remote sensing application in geology, i.e. issues associated with the practical use of satellite SAR (synthetic aperture radar), is discussed based on examples of successful projects from a moderate climatic zone. Applications of radar intensity images as well as SAR interferometry are discussed based on examples from southern Poland where these methods have been applied for the measurement of terrain deformations.

Keywords: SAR interferometry, SAR imagery, digital processing, terrain deformation, mining

INTRODUCTION

Remote sensing (RS) is the acquisition and measurement of electromagnetic radiation of a phenomenon, object, or material by a recording device not in physical contact with the feature under surveillance. Nowadays, RS is stimulated by fast development of digital technologies and it is becoming a fully quantitative science. For geologists, however, RS is still a kind of quantitative 'art' of interpretation of images, and the capabilities of various RS techniques and data are not fully understood. This paper presents some selected aspects of radar RS which are supposed to be useful for geological mapping in a moderate climatic zone, i.e. in densely vegetated and highly anthropogenic areas.

1 Application of synthetic aperture radar (SAR) images, which present extraordinary sensitivity with regard to surface morphology and roughness differences. Utilization of multi-frequency and/or multi-temporal and/or polarimetric sets of images helps to understand land use and its changes, and its dependence on local geology.

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 225–244.

2 SAR interferometry is a technique for extracting information from the Earth's surface using the phase of an SAR signal. The height of a point on the Earth's surface can be reconstructed from the phase difference between the signals arriving at the antenna during repeated observations of the same platform. This method is able to measure deformations of the Earth's surface (tectonic, volcanogenic, anthropogenic) with centimeter accuracy. The same InSAR technique allows calculation of an accurate digital elevation model (DEM).

SAR IMAGERY

SAR, also known as coherent radar, overcomes the limitation of the antenna size typical of real-aperture radars by synthesizing an antenna which receives a series of reflected waves and electronically combines them with reference wavelengths. The resolution of an SAR effectively remains the same over all ranges (Gens and Logan 2003). SAR technology has become very popular in the past decade; it has provided, for example, terrain structural information for mineral exploration, oil spill boundaries on water, sea state and ice hazard maps, and reconnaissance and targeting information for military operations. There are also many other operational or potential applications. For general mapping purposes, SAR imagery is very interesting because it can produce high-quality images independent of cloud cover and solar illumination. A typical geological image interpretation in the case of radar is based on backscatter images, where variation of radar look angle and wavelengths can have a substantial effect (Henderson and Lewis 1998). The interpretation capabilities in the case of radar could be extended by application of color composition images constructed in the following ways.

1 Multi-frequency: constructed from images acquired at different frequencies/bands. The application of such data is usually limited to multi-frequency sensors such as SIR (shuttle imaging radar) or airborne missions, however it is possible to construct such images in 'multi-platform mode' using data from different satellites, e.g. SAR images acquired by ERS-1 and JERS-1 satellites (Figure 1).
2 Multi-temporal: compositions developed from data from the same sensor but acquired at different times. Colors are used to represent changes in backscatter over time between acquisitions (Figure 2).
3 Multi-polarization: composed images acquired simultaneously by the same SAR system but with different transmitter/receiver polarization configurations, e.g. H/H, V/V, H/V (Figure 3).

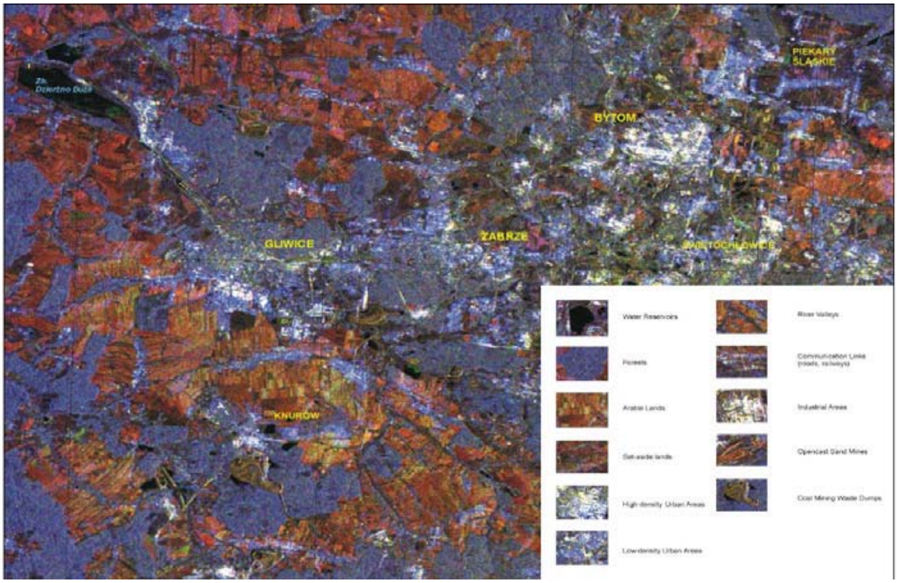

Figure 1. Multi-frequency RGB composition of satellite SAR images acquired during winter 1997/1998. Red and green channels are represented by images acquired by ERS-2 satellite (5.25 GHz = 5.67 cm); blue channel is represented by SAR image acquired by JERS-1 satellite (1.27 GHz = 23 cm). Area: Upper Silesia. ERS SAR SLCI and JRS SAR PRI images courtesy of ESA.

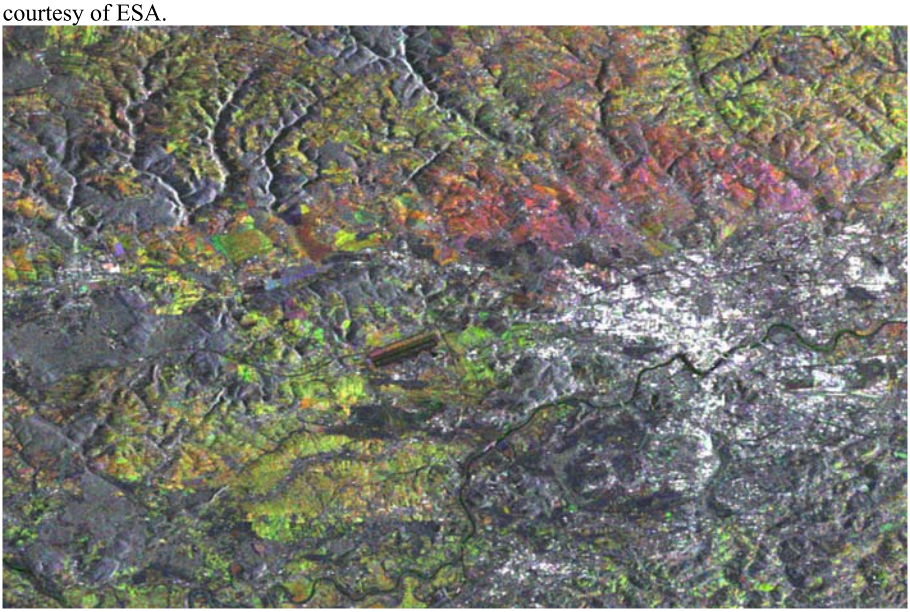

Figure 2. Multi-temporal RGB composition of ERS-2 SAR images acquired 10.09.1998 (red), 03.09.1999 (green), and 10.07.1998 (blue). White: urban areas (Krakow town on the right); grey: forests; green, yellow and red variable tones: seasonal, temporal and moisture differences on arable lands.

SAR systems produce images of the canopy that are enhanced by highlights and shadows which emphasize linear features (Henderson and Lewis 1998) due to the side-looking configuration of the radar sensor. This improves the visibility of subtle topographic expressions of geomorphological structures and thus improves geological interpretation.

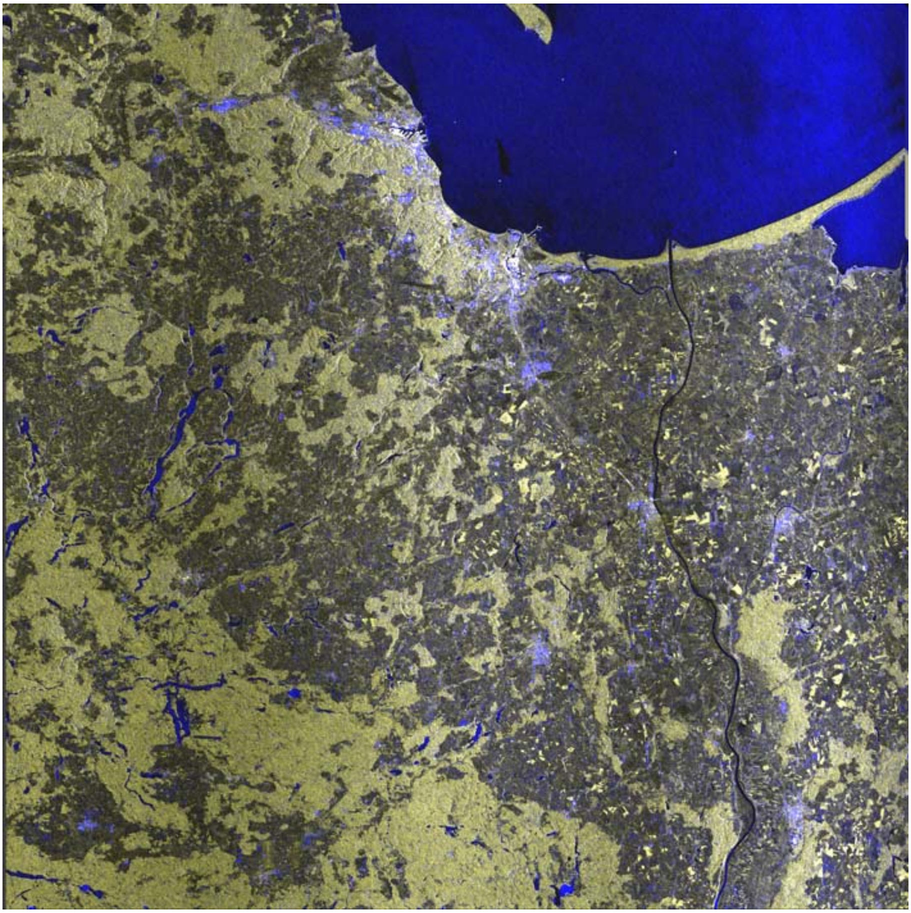

Figure 3. Color composition of Envisat ASAR polarimetric image acquired on 5 June 2003, showing the northern part of Poland with the Baltic Sea coast. White spots on the central part of the coast are the agglomeration of the cities of Sopot, Gdynia, and Gdansk. Geologically the area is covered by Pleistocene glaciogenic sediments with rough morphology and lakes in the left part of the area. The right side of the image includes the Vistula river delta covered by thick alluvial cover with flat morphology. ASAR SLCI image courtesy of ESA. The image was acquired and processed for ESA project AO-783.

SAR INTERFEROMETRY

SAR interferometry (InSAR) is a technique for extracting information relating to the topography of the Earth's surface (Zebker and Goldstein 1986**)**. It uses the phase difference between the radar echoes from repeated SAR observations of the same area. The result of this operation is presented in the form of a map called an interferogram, where phase differences are presented in the form of 'interferometric fringes' (Figure 4). -

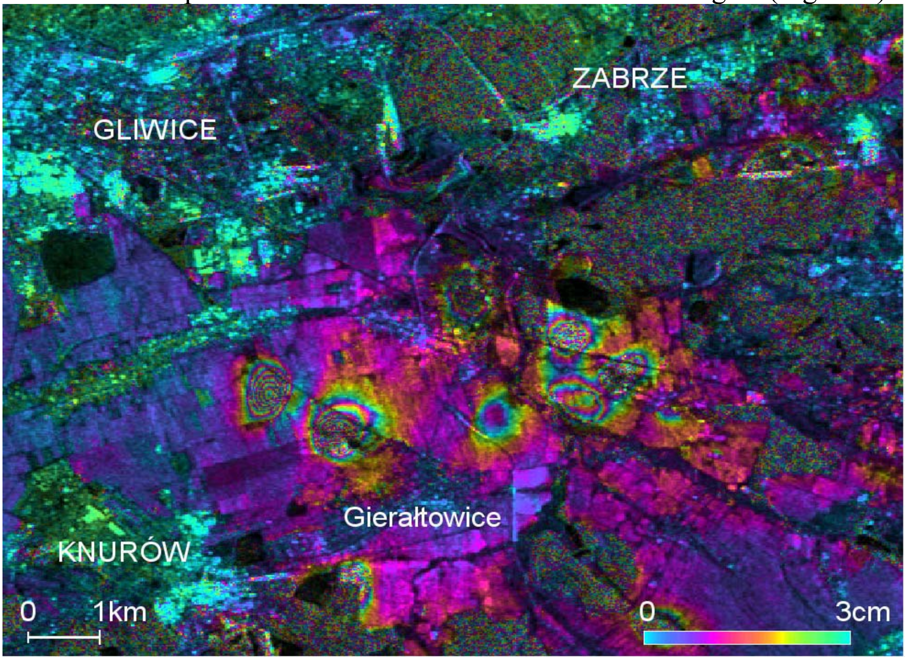

Figure 4. Interferometric image of land subsidence in the Gliwice area. Data have been generated using satellite radar interferometry. This method utilizes satellite radar images of SAR type acquired during repetitive satellite flights above the same area. The phase differences between the registered radar signals of the two images represent height differences occurring in the time between acquisitions. In this example these changes indicate subsidence caused by underground exploitation of hard coal some hundreds meters below the surface. The phase differences are represented on the interferogram by a set of color fringes, the full sequence of which indicates subsidence of about 3 cm—see attached color scale. For some areas there are visible repetitive sequences of fringes (in some areas amounting to more than 18 cm). Interferogram generated from SAR data from European ERS-2 satellite acquired on 19.01.1998 and 23.02.1998. ERS2 SLCI data courtesy of ESA.

The first interferometric studies, which were focused on topography retrieval, clearly showed the applicability of InSAR to DEM generation. Differential InSAR (D-InSAR) represents an interesting branch of InSAR, which exploits the phase differences to derive terrain displacements. DInSAR has already been successfully used in different applications: the monitoring of volcanic activity, earthquakes, glacier dynamics, landslides, and urban subsidence (Massonnet and Feigl 1998). In many cases D-InSAR has demonstrated its capability to measure surface movements of the order of centimeters. Since 1995 D-InSAR has been used to study the impact of underground mining on surface movements at a number of sites, for example in Southern France (Carnec et al. 1995), in the Selby Coalfield in the UK (Stow et al. 1999), and in Upper Silesia in Poland (Perski 1998). D-InSAR has been also applied to measure deformations due to other industrial activities such as copper-ore and salt mining (Poland), drinking-water pumping (USA, Mexico), geothermal water pumping (Italy), and hydrocarbon exploitation (USA, The Netherlands).

Dynamic and especially anthropogenic geological phenomena, such as, for example, subsidence, are very rarely presented on geological maps. However, for many types of economic activities such information is critical. There are also no standards for its mapping and cartographic presentation. SAR interferometry is one of the fastest and the most efficient methods for mapping of large areas subjected to deformation. The examples below present various case studies and various methods of presentation of different types of deformation. This review aims to inspire geological cartographers to learn how to map and then present deformational phenomena on maps.

CASE STUDIES

Upper Silesia Coal Basin—Regional Context

The Upper Silesia Coal Basin (USCB) of Poland has been one of the world's most famous mining centers, and also a center for the study of environmental changes in mining-influenced areas. An area of almost 600 km^2 is here affected by damage caused by underground exploration. Surface deformation and subsidence are the biggest and most visible impacts of underground mining which can be measured on the Earth's surface. They cause changes in topography and hydrography, and damage to buildings and other structures (Jura 1995). Furthermore, some areas have to be excluded from urbanization. These hazards are measured by the maximal surface strains that occur during subsidence. The mining subsidence above exploited coal seams reaches various velocities, for example up to 1 cm daily or a few centimeters per month over 3–6 months. The intensity of surface deformation in an area of mining activity can by described by the index of output, for example 2.2 t of coal per year, per 1 m^2 of terrain surface, which is equivalent to mining of coal 2 m thick per year per m^2.

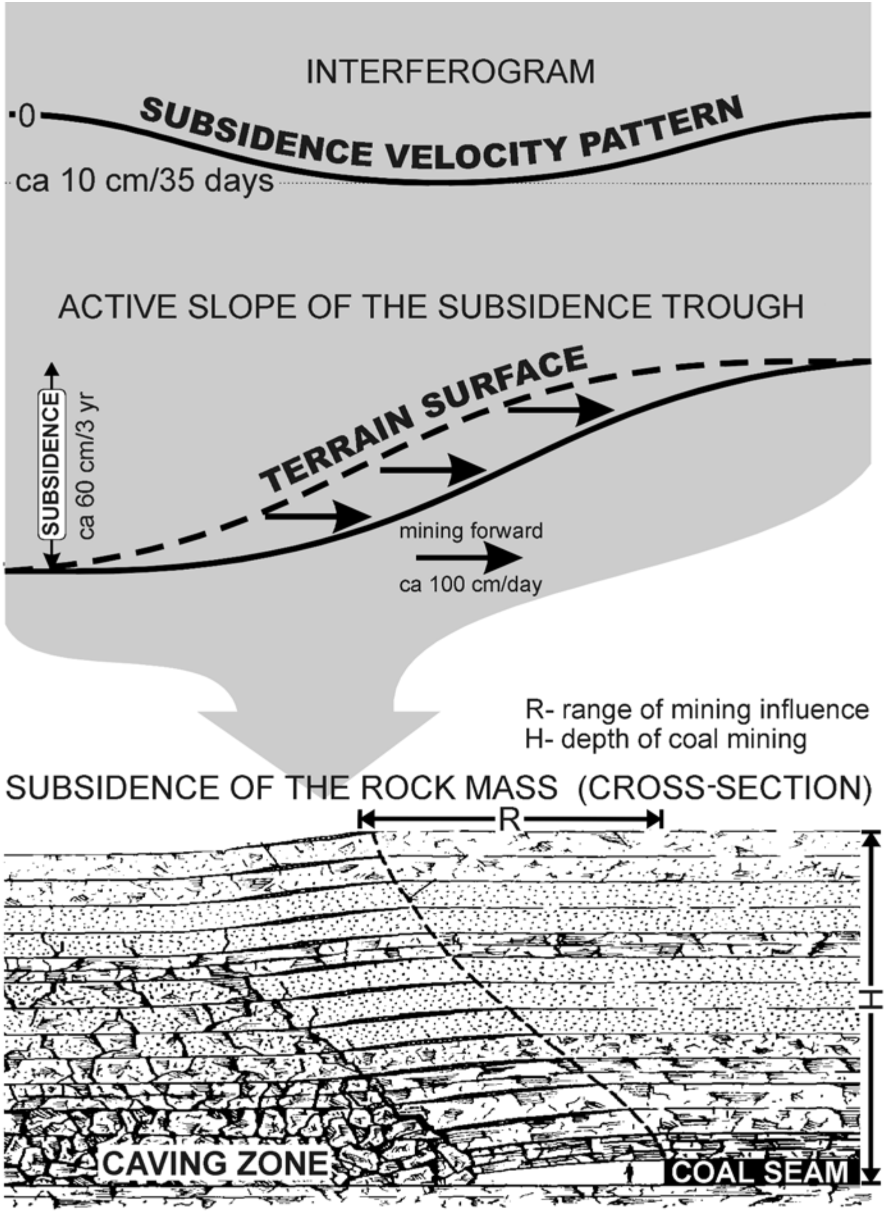

Figure 5. Scheme showing the surface change detected by SAR interferometry with respect to the development of a subsidence basin caused by underground coal mining (Perski and Jura 1999).

Interpretation of SAR Interferograms in the Case of Coal Mining Subsidence

In the case of underground longwall coal mining, the SAR interferogram presents only the terrain surface changes which occur on the active (advancing) slope of a developed subsidence trough. In such a configuration the center of the fringe—i.e. the area of maximum surface displacement (Figure 5)—is located in the middle of the active slope of the subsidence trough and thus indicates the zone of highest rate of surface changes (Perski and Jura 1999) with respect to the time base between SAR data acquisitions; for the satellites ERS-1 and ERS-2 applied in this project this is a 35-day difference or its integer multiplication.

Subsidence Caused by Multi-Seam Coal Exploitation: Szczyglowice Coal Mine

The area where the mining subsidence was measured by the application of InSAR is located in Szczyglowice village, 12 km to the south of the city of Gliwice. In this area the terrain deformation and damage caused by underground mining are also clearly visible in the field.

The Szczygłowice mine is located in the western part of the USCB, near to the city of Knurów. The coal-bearing Carboniferous strata within the Szczygłowice mine concession area of 34 km^2 are covered by Miocene and Quaternary sediments up to 250 m thick (Figure 6). The Carboniferous rocks explored by mine workings belong to the lower part of the Siltstone Series, (Westphalian A). The beds are formed into the longitudinal fold structure of the Knurów Fold, beginning in the eastern part of the Orlova–Boguszowice–Gliwice overthrust. In the asymmetrical synclines, 11 coal seams are subject to exploitation. The thickness of seams varies from 1.4 to 5.4 m of coal.

In Szczyglowice, underground coal mining has been carried out since 1960 at depths of 200–850 m below the surface. The system of single longwalls was applied for mining with caving (roof settlement) (Figure 6). The coal production is about 16 000 t per day plus 10 000 t of waste rock. For 25 km^2 of the area where mining is occurring, the index of output is 0.21 t per year per m^2. In Szczyglowice mine the subsidence in areas of mining activity reaches 0.7–0.8 m per year, per 1 m^2 of terrain surface. Maximum subsidence reaches 70–80% of the total seam thickness, i.e. up to 16 m.

Interferometric results are shown on an interferogram (from couple acquired on 19.01.98 and 23.02.98) with concentric fringes—typical of areas of land subsidence (Figure 7). This image corresponds to the pattern of mining works in seven different coal seams (Perski and Jura 2000). On the interferogram the migrating active slope of the subsidence trough is represented by an elliptical set of fringes (Figure 7). As explained above, movement occurs on the active slope of the mining depression, so the fringe ellipse, which shows surface changes over a short time period, is an excellent indicator of changes of the velocity and deformation pattern and can be termed the velocity ellipse. The areas subjected to the greatest changes during the 35 days of InSAR observation are located in the middle of active longwalls. The ERS SAR interferogram clearly displays the dynamics of the active slope of the subsidence trough.

Long-Term and Short-Term Subsidence in Densely Urbanized Areas: Municipality of Bytom

The municipality of Bytom is located in the northwestern part of the Upper Silesian Coal Basin. The town was settled in medieval times and now has 200 000 inhabitants. Bytom was rapidly developed in the 19th century when extensive coal mining was started and thus most of urban and communication infrastructure was established during that time. In medieval times, silver-ore mining from Triassic dolomites at depths of 60–200 m was started, and later in the 19th century lead and zinc ores were also included. Hard coal mining started in the 19th century and operates at depths of 100–800 m.

Such extensive and intensive mining activity results in huge terrain surface changes. The averaged subsidence has reached 12–15 m; locally, in the northern part outside of urbanized areas, the subsidence has reached 30 m (based on unpublished reports, courtesy of Bytom Mining Company). The densely urbanized center has subsided by up to 2.5 m. Within the area affected by ore mining, a sinkhole hazard is very common. Between 1956 and 1994, 53 major sinkholes (2–5 m diameter) have been recorded. The subsidence and associated horizontal stress has caused damage to buildings and infrastructure, and hydrological problems (over-flooding). Up until 1950 (before extensive exploitation under the town), 36% of the buildings had been damaged (Chudek and Sapicki 1984).

The densely urbanized center of Bytom enables the generation of coherent interferograms with a long temporal baseline. Interferograms from data acquired in 1995 (Figure 8) present the subsidence velocity pattern (more than 3.4 mm per day) due to coal mining under Bytom city center. Moreover, the velocity is often higher than the range of measurement with C-band SAR (Perski 2003).

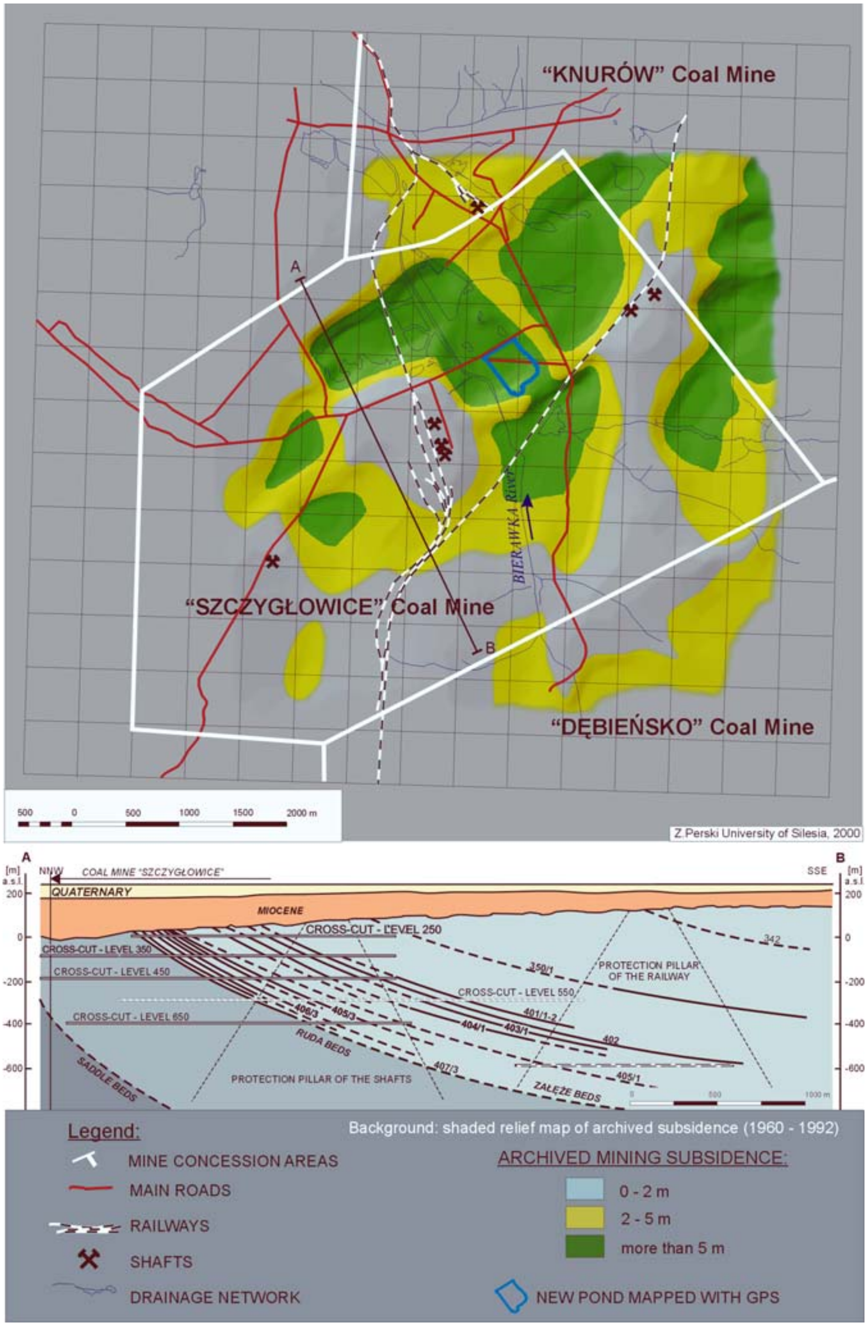

Figure 6. Map of archived subsidence in the Szczygłowice Coal Mine and geological cross-section A–B of the mine. Continuous black lines represent mined coal seams with seam numbers (Perski and Jura 2000).

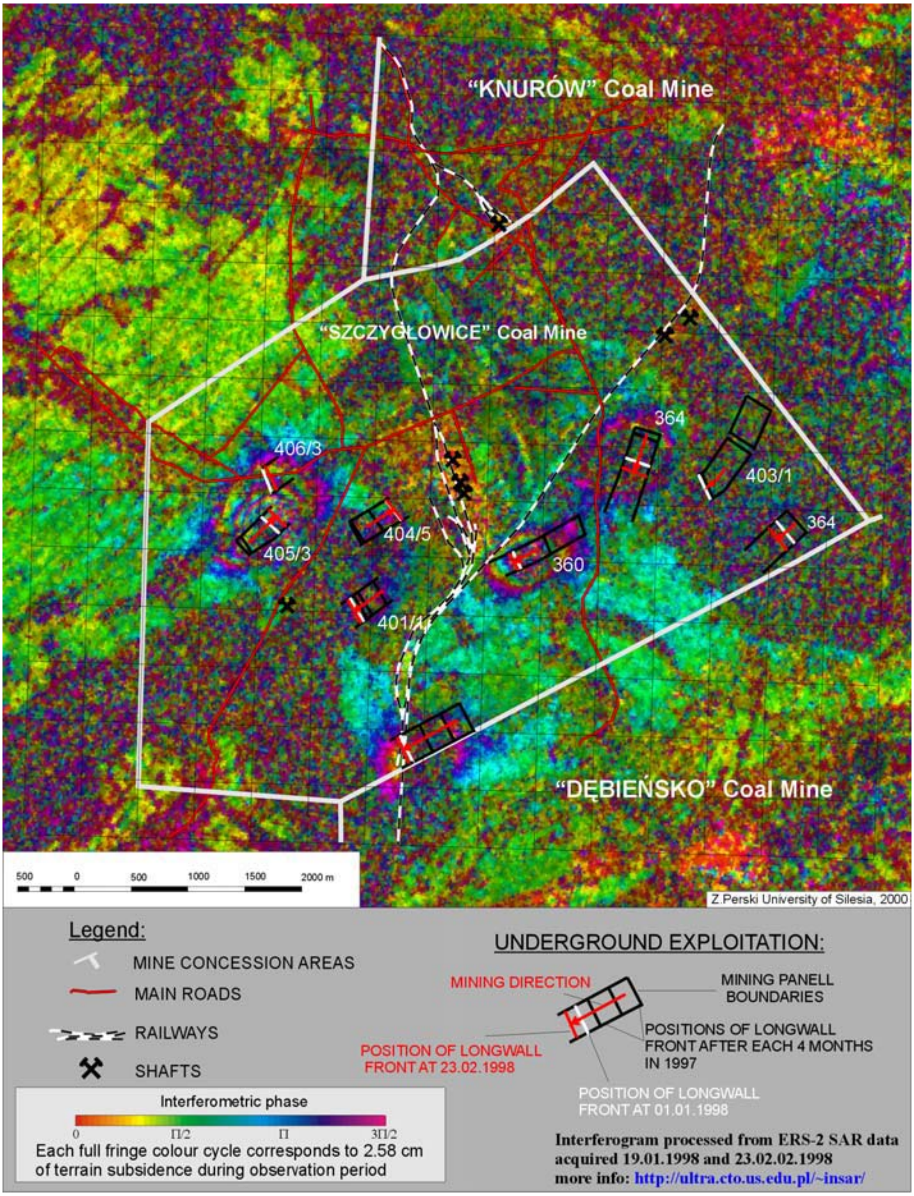

Figure 7. ERS SAR Interferogram of the Szczygłowice Coal Mine provided from couple acquired on 19.01.98 and 23.02.98. The interferometric fringes represent in color cycles rates of subsidence of up to 12 cm per 35 days. The presented interferogram is superimposed on the map of underground coal mining occurring during the same time period as ERS SAR data acquisition (Perski and Jura 2000).

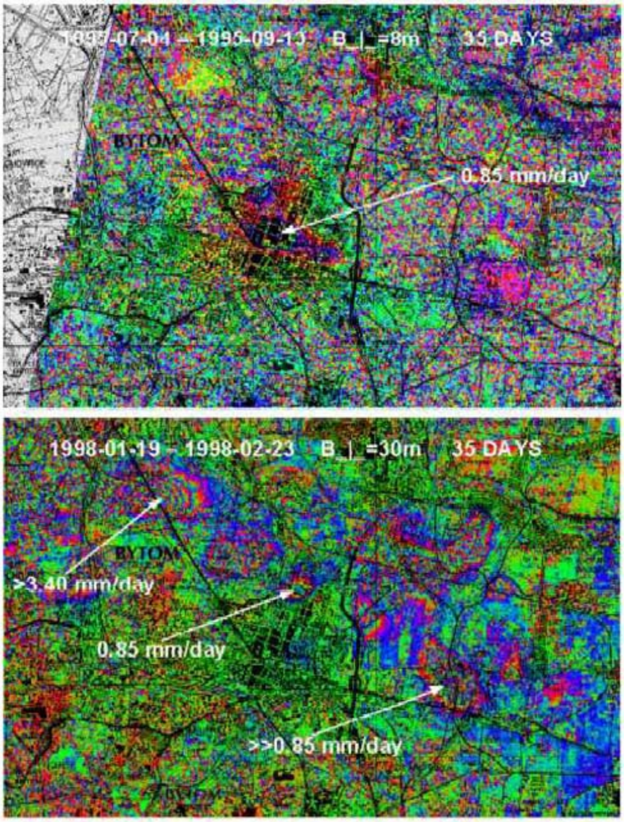

Figure 8. Thirty-five-day ERS SAR interferograms from the Bytom area (Perski and Jura 2003). SAR SLCI data courtesy of ESA.

In the case of a low rate of subsidence and high coherence of urban-area interferograms, short-term interferograms such as those of 35 days present unique information about the subsidence velocity pattern which has an extraordinary spatial quality. Such information about the shape and extent of subsided areas could be derived also from relatively low-quality interferograms where quantitative information is unavailable. The detailed extent of subsided areas is very difficult and expensive to measure using traditional leveling methods. The combination of terrestrial measurements of selected points and mapping of the extent of the subsided area seems to be the most efficient measurement method.

The traditional InSAR techniques have been extended in recent years to pixel-based approaches such as, for example, the Permanent Scatters (PS) method (Feretti et al. 1999). The comparison of two interferograms from 1995 and 1998 in Figure 8 shows how dynamically the subsidence pattern is changing in the case of underground mining. However, even with the PS technique the main problems related to decorrelations still remain. It is potentially advantageous to use alternate polarization (Perski 2003) and multi-frequency SAR data.

Interferograms of long temporal baselines present a much more reduced coherence. From many processed pairs, only three were suitable for analysis (Figure 9).

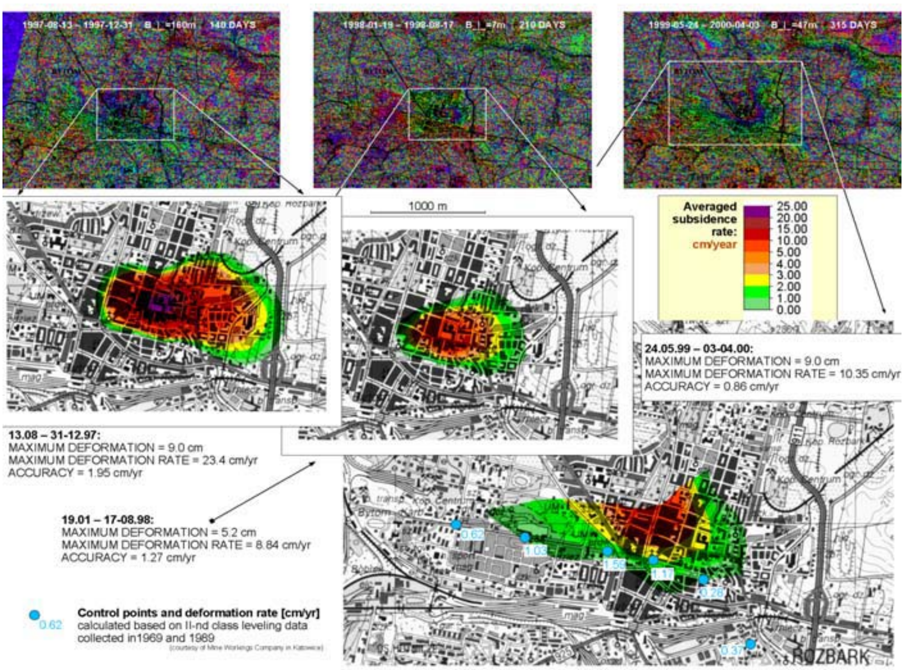

Figure 9. Long-term ERS SAR interferograms from the Bytom area and their interpretation (Perski and Jura 2003). SAR SLCI data courtesy of ESA.

With such a high subsidence velocity it was impossible to detect subsidence related directly to the long-term effects of mining (Perski 2003). The short-term interferogram from January 1998 (Figure 8) presents no subsidence in Bytom center. Long-term interferograms from the years 1997, 1998, and 1999 (Figure 9) show a slow movement of 10–20 cm per year related to more complex subsidence phenomena such as post-mining relaxation and reactivation of old abandoned cavities. Their similar shape and value prove that observed fringes on different independent interferograms are not related to atmospheric or other errors. Comparison with terrestrial leveling provided by Katowice Mine Surveying Company from second-class 1968 and 1989 measurements shows similar annual subsidence rates. Furthermore, the spatial differences of measured subsidence velocities along the profile are very similar to the spatial variances obtained on long-term interferograms. This phenomenon indicates the permanent character of the slow subsidence in the city center. However, in order to draw final conclusions more terrestrial data need to be analysed.

Terrain Deformation in Coal Mine Waste Dumping Areas in Upper Silesia

The Sosnica 1.6-square-kilometer waste dump includes 50 million t of waste rock containing mainly carboniferous siltstones and mudstones (Cempiel et al. 1998). The interferogram of this area from October 1992 shows an elongated set of fringes corresponding to a half-cycle interferometric phase (Perski 2001). The center of the fringes is decorrelated, probably as a result of an active waste deposition process. The order and number of fringes allows estimation of 1.8 cm of subsidence, probably caused by compaction of the waste material. An interferogram from data acquired in the autumn of 1993 documents the continuation of this process over a larger area (Figure 10).

Studies on deformations of mine waste areas may bring new data regarding the stability of such structures which are usually difficult and in many cases dangerous to measure using common methods. SAR interferometry allows also long-term monitoring of large waste areas for many years after the end of industrial activity, or occasional checks of the terrains known to be stable.

Subsidence Caused by Underground Copper-Ore Mining: Legnica–Głogów Copper Region

In the area of the Legnica–Głogów Copper Region (LGOM) there are seven mining areas, in which three mines are under exploitation The total mining area in the LGOM occupies a surface area of about 400 km^2. Within the range of ground movement caused by mining exploitation there exist two towns, Lubin and Polkowice, and about a dozen villages. The mining works conducted since 1960 have caused a subsidence area to occur; this subsidence is mainly generated by underground exploitation and by underground water pumping.

The degree of land subsidence in the LGOM over areas of intense exploitation (which is conducted mainly in a chamber–pillar exploitation system with roof fall), reaches average values from 2000 to 2600 mm. The maximum land subsidence was observed in the Polkowice II mining area and reached 3380 m (Popiołek 1998). Surveying and theoretical calculations indicate that the average rate of this type of land subsidence over exploitation areas does not exceed 1.25 mm per 24 hours and the maximum rate should not exceed 100% of the average value— 2.5 mm per 24 hours.

As a result of interferogram analysis, 26 dynamic slopes of subsidence troughs have been located (Figure 11). After fitting the interferogram to the local coordinate system, correlation analysis between interferogram and excavation areas was carried out (Krawczyk and Perski 2000). As a consequence of the analysis, the centers of 24 subsidence troughs are found to occur within the limits of exploitation, which was at its height in the fourth quarter of 1993 and the first quarter of 1994. The remaining two small areas of land subsidence were observed in the neighbourhood of abandoned workings. At OG Sieroszowice I, four dynamic subsidence troughs were observed: numbers 1, 2, 5, 7 (Figure 11). None of this subsidence exceeded 70 mm per 60 days. Over the researched period the subsidence involved an area of approximately 342.8 ha.

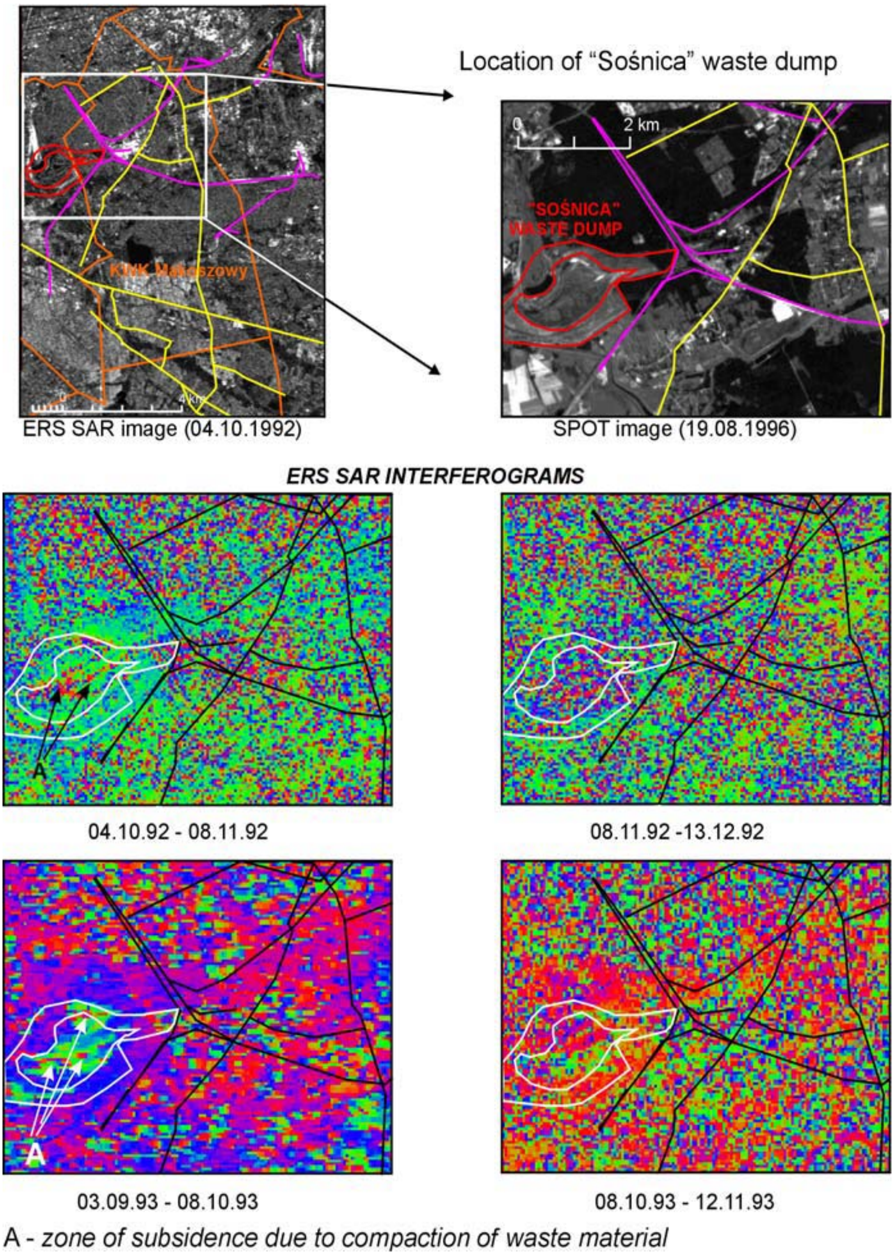

Figure 10. Interferometric image of the subsidence dynamics at the Sośnica waste dump.

Similar phenomena have been observed in the southwestern part of Upper Silesia on one of the largest mine-waste dumping areas, Koscielok, as a concentric set of fringes denoting 2.5 cm of subsidence stimulated also probably by mechanical compaction (Perski 2001).

In the area of OG Polkowice II, seven subsidence troughs have been observed: numbers 6, 13, 14, 20, 21, 22, and 12 (Figure 11). In this mining area the deepest dynamic subsidence trough is subsidence trough number 21; it reached a subsidence of approximately 110 mm over 60 days.

Detection of Surface Changes Associated with Opencast Mining

The presented study has been completed in the Jaworzno–Szczakowa sand pitting area in the Upper Silesian Region. It is the largest opencast sand mine in Upper Silesia. The interferograms show no fringes due to the very low coherence. However, some other features have been observed on the so-called interferometric signature image (Wegmuller et al. 1995). The interferometric signature is an RGB composition of coherence (red), averaged intensity of two SAR images (green), and intensity change of two SAR images (blue). The very dark, green–blue areas are located in the center of the mine (Figure 12). These characterize very low coherence and high changes in backscatter and can be interpreted as temporal changes caused by active sand excavation and machine operation. The yellow parts—high coherence and without changes in backscatter—represent temporarily stable zones within the pit, hence with no activity (Perski 2001).

ARCHIVED INSAR LIMITATIONS

Limitations Due to Decorrelation

Successful coherent interferogram generation depends on seasonal and weather conditions during and before SAR data acquisition. Usually, wet weather and dense vegetation cover significantly degrade coherence.

SAR data selection must thus be performed very carefully, taking into consideration detailed meteorological data. Typically, SAR image pairs with a temporal baseline longer than 70 days are incoherent. This limitation considerably decreases the number of data available for processing. In the moderate climatic zone of Central Europe there are many areas which are permanently inaccessible for InSAR observations (forests) and there are others that are temporarily inaccessible (arable lands).

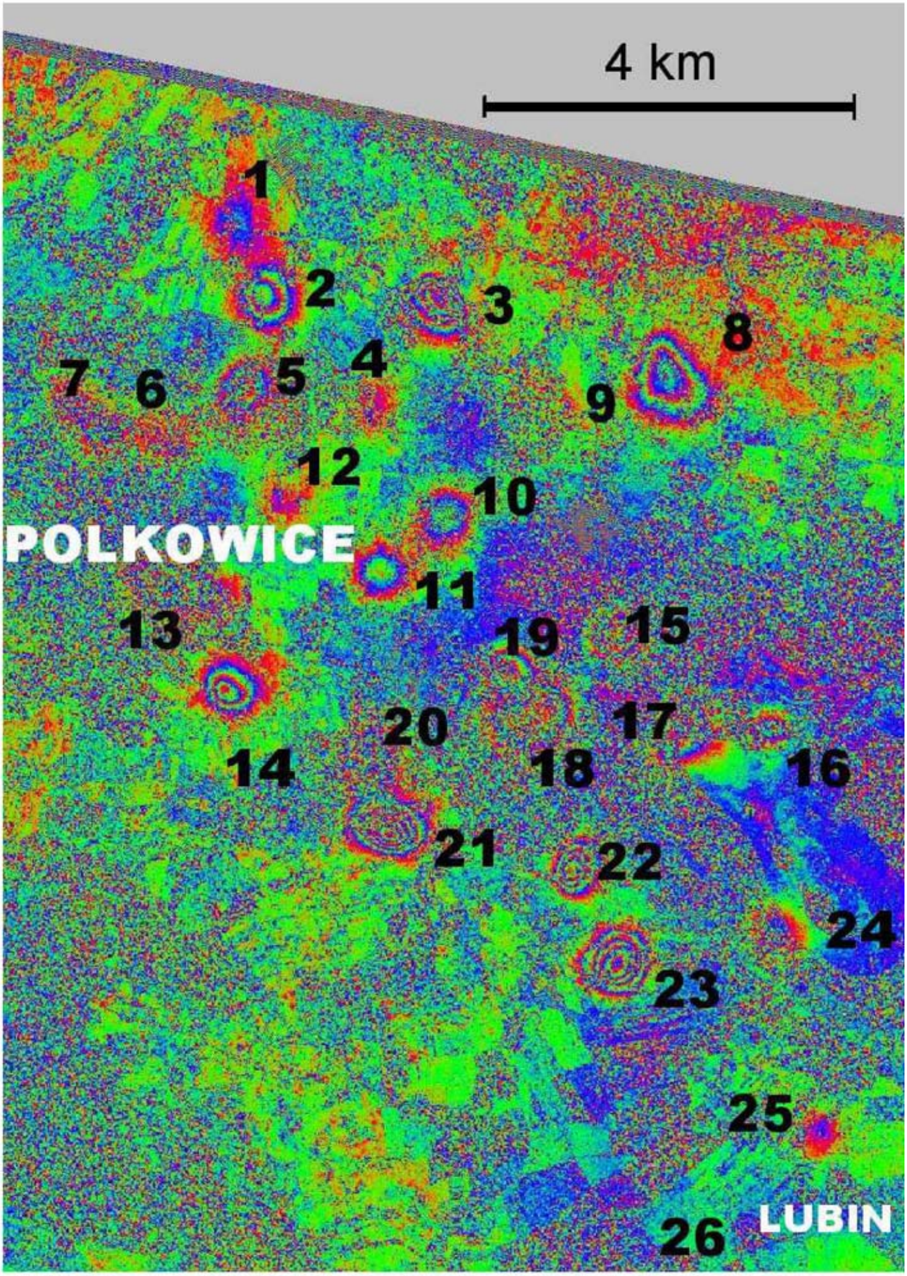

Figure 11. ERS-1 SAR interferogram of the Legnica–Glogow Copper mining areas (Krawczyk and Perski 2000). The ERS-1 SAR data were acquired on 10.01.94 and 11.03.1994. A description of the numbered subsidence areas represented by interferometric fringes is given in the text. ERS-1 SAR SLCI data courtesy of ESA.

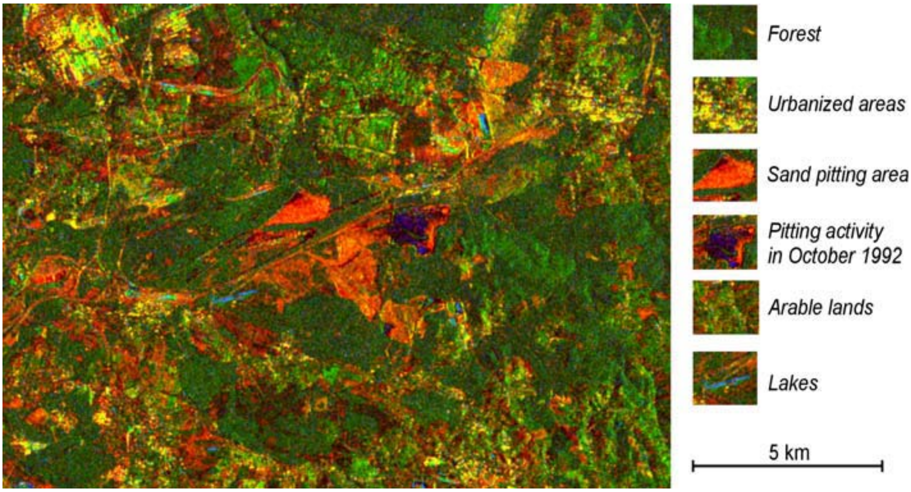

Figure 12. Interferometric signature composition of the Jaworzno–Szczakowa open-cast sand mine. Image generated from InSAR data from 04.10.92 and 08.11.92. ERS-1 SAR SLCI data courtesy of ESA.

Only man-made structures remain coherent over long time scales (Usai and Hanssen 1997). By applying very careful data selection according to meteorological data, it is possible to maximize coherence (Villasenor and Zebker 1992). Detailed analysis of the low-coherence areas on coherent interferograms from Upper Silesia shows that volume scattering is the most important factor causing decoherence (Perski 2003) in vegetated areas. This type of decorrelation takes place when the backscattering comes from targets with different elevations within the resolution cell (Fortuny et al. 1994). Volumetric scattering occurring for vegetation targets and decorrelation is caused by wavelength-order position changes of branches, leaves etc.

Limitations Due to ERS SAR Sensor Characteristics

During detailed analysis of interferograms from Bytom and other mining areas, the loss of the interferometric fringe signal due to extremely fast movement has been noted. If the increment of the slope angle of the subsidence trough during a period between SAR acquisitions of an interferogram is greater than several centimeters the fringe pattern will present the wrong value—too high a phase gradient with respect to spatial resolution. This happens because the areas affected by subsidence are relatively small (commonly 1 per 2 km) with respect to the typical 20-m spatial resolution of SAR interferograms (typical multilook factor 5 in the azimuth direction). In many cases the interferometric fringe of mine subsidence consists of dozens of pixels.

Taking into consideration C-band wavelength and multilook factor 5 as the critical value, the land subsidence could be defined as

$$w_{cr} = \frac{f_r}{d}$$

where f_r is a vertical displacement corresponding to one fringe; d is the distance between adjacent pixel centers of the multilook interferogram.

For ERS-1 and ERS 2, f_r = 3 cm and d = 20 m, and thus w_{cr} = 1.5 mm/m.

The value of w_{cr} may also be understood as the practical limit of InSAR measurements for changes in terrain inclination due to subsidence.

ACKNOWLEDGMENTS

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Note that all presented examples of images have been digitally processed and visualized at the Geological Visualization Laboratory of the Department of Fundamental Geology at the Faculty of Earth Sciences, University of Silesia. Source data in a single-look complex and precision image format are courtesy of the ESA (European Space Agency).

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THE U.S. NATIONAL GEOLOGIC MAP DATABASE PROJECT: OVERVIEW & PROGRESS*)

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Abstract:

The National Geologic Map Database (NGMDB) project continues to fulfill its mandate. Some of its accomplishments are specific and tangible, and others are more general in nature – for example, the NGMDB contributes to advancements in digital mapping techniques and database design by agencies in the United States and internationally. However, without extensive collaboration from enthusiastic and highly skilled members of the state geological surveys and the Geological Survey of Canada, these accomplishments would not have been possible. Highlights of the past year include: 1) the Geoscience Map Catalog now contains bibliographic records for more than 61,000 map products published by more than 270 organizations including the U.S. Geological Survey(USGS), 43 state geological surveys, universities, and scientific societies and organizations, 2) the Geologic Map Image Library has evolved from a concept to a prototype Web site that serves high-resolution images of nearly 1,000 geologic maps, 3) the project contributed significantly to evolution of the North American standard data model, science language, and data-interchange format, and to the cartographic standard for the U.S. Through discussions with ESRI, this data model may form the basis for their Geology Data Model for Arc Geodatabase. Internationally, NGMDB staff participated in "DIMAS", the map standards committee of the Commission for the Geological Map of the World, 4) the seventh annual Digital Mapping Techniques workshop was a success, bringing together 90 technical experts from 36 agencies, and 5) the third phase of the project – the design and implementation of an online, vector-map database – was reoriented mid-year, and began to focus on data input tools and standardized science language.

Keywords: Geoscience map catalogue, geologic map library, geodatabase, digital mapping techniques, vector map database, NGMDB

INTRODUCTION

This project provides an unusual if not unique opportunity to foster better relations and technical collaboration among all geological surveys in the nation. Given the nature of the issue – the creation and management of

S. Ostaficzuk (ed.), The Current Role of Geological Mapping in Geosciences, 245–277.

geoscience map information in digital format during a period of rapid technological evolution – collaboration is critically important. Perhaps more significant, these are changing times for all geological surveys – funding and staff seem to become more scarce each year – and through collaboration we can share our intellectual and computing resources and not “reinvent the wheel” within each agency.

Before describing the NGMDB components and progress, we wish to highlight the various mechanisms by which we define and accomplish our goals. Because advice, guidance, and technical collaboration are an integral part of this project, we discuss the project plan at numerous venues throughout the year. These include geoscience and related professional society meetings, the Digital Mapping Techniques workshop, and site visits to state geological surveys. Advice gathered at these venues serves to refine and, in some cases, to redirect the project’s goals. Comments from users, generally via our Web feedback form, also provide us with valuable perspectives, and have prompted us to make numerous modifications, especially to our Web interface design.

Because the NGMDB’s scope is so broad, its success relies on the many people and agencies that participate in its activities. Members of the committees and small working groups that advise and contribute to the project’s goals are listed in Appendix A. These committees are an important mechanism for coordinating with each agency, and they deserve noting:

1 - Digital Geologic Mapping Committee of the Association of American State Geologists (AASG) – charged with representing all state geological surveys in the NGMDB project, and with providing authoritative guidance to the project.

2 - Technical Advisory Committee – provides technical vision and guidance to the NGMDB, especially on the project’s Phase Three.

3 - Map Symbol Standards Committee – oversees the completion, and then the maintenance, of the Geologic Map Symbolization Standard, which will become a Federal standard endorsed by the Federal Geographic Data Committee.

4 - AASG/USGS Data Capture Working Group – coordinates the annual Digital Mapping Techniques workshop, and provides through an email listserver a forum for exchange of technical information.

5 - AASG/USGS Metadata Working Group – summarized issues related to creating metadata, and identified useful software tools.

6 - AASG/USGS Data Information Exchange Working Group – created technical guidance for map publication guidelines.

7 - AASG/USGS Data Model Working Group – defined a draft version of a standard geologic map data model.

8 - North American Data Model Steering Committee – succeeded the Data Model Working Group, and is developing a standard data model, science language, and data-interchange format for the North American geoscience community.

9 - NGDMB contact-persons – within each state geological survey, several people work with us on various project databases and activities.

BACKGROUND

The National Geologic Mapping Act of 1992 and its reauthorizations in 1997 and 1999 (PL106-148) require a National Geologic Map Database to be built by the USGS in cooperation with the AASG. This database is intended to serve as a "national archive" of standardized geoscience information for addressing societal issues and improving our base of scientific knowledge. The Mapping Act anticipates a broad spectrum of users including private citizens, professional geologists, engineers, land-use planners, and government officials. The Act requires the NGMDB to include these geoscience themes: geology, geophysics, geochemistry, paleontology, and geochronology.

In mid-1995, the general stipulations in the Geologic Mapping Act were addressed in the proposed NGMDB design and implementation plan developed by the USGS and AASG. Summaries of this plan are listed in Appendix B. Because of the mandate's broad scope, we proposed a phased, incremental design for the NGMDB. A phased approach has two benefits: 1) it enables us to identify the nature and quality of existing information and quickly serve it to the public; and 2) it gives us time to build consensus and expertise among the database designers in the state geological surveys and the USGS. Furthermore, it enables us to more effectively consider and respond to evolving technology and user needs. These phases, and our progress, are shown in Figure 1.

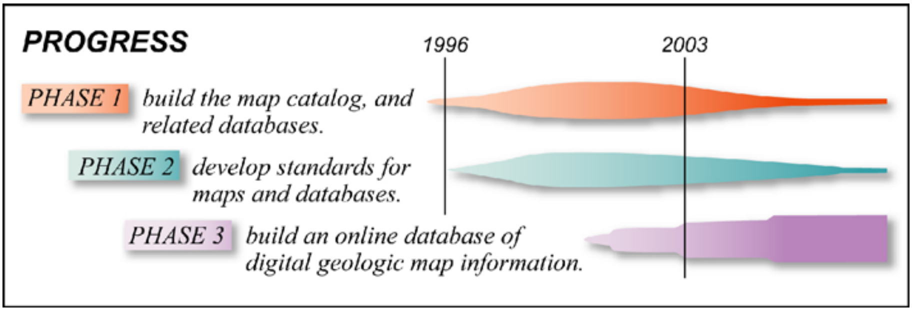

Figure 1. Diagram showing the three NGMDB Phases, and progress toward our goals (for example, documenting in the Geoscience Map Catalog all maps and related products for the United States and its territories and possessions).

In the first and most fundamental phase of the project, we are building a set of easy-to-use reference databases; for example, a comprehensive, searchable map catalog of all geoscience maps in the United States, whether in paper or digital format. The second phase of the project focuses on the development of standards and guidelines needed to improve the utility of digital maps. The third phase proposes to, in the long term, develop an online database of vector-based geologic map information at various scales and resolution.

In late 1995, work began on Phase One. The formation in mid-1996 of several AASG/USGS Standards Working Groups initiated work on Phase Two. The project opened its Web site to the public in January, 1997, as a prototype intended to solicit comments on the Map Catalog. At the Digital Mapping Techniques '98 through '03 workshops, a series of presentations and discussion sessions provided updates on the NGMDB and, specifically, on the activities of the Standards Working Groups. These progress reports are listed in Appendix B. This report summarizes accomplishments since the project's inception, and therefore repeats material from previous reports, but it focuses on activities since mid-2002. Additional and more current information may be found at the NGMDB project-information Web site, at:

http://ncgmp.usgs.gov/ngmdbproject

The searchable databases are available at:

http://ngmdb.usgs.gov

To submit general comments about project scope and direction, please address the authors directly. For technical comments on the databases or Web page design, please use our Web feedback form; this form is linked from many of our search pages (see "Your comments are welcome", at:

http://ngmdb.usgs.gov/

PHASE ONE

Through ongoing discussions with private companies, citizens, government officials, and research geologists, it is clear that first and foremost, we need to provide reference databases so that geoscience maps and descriptive information can be found and used. Many people want to better understand the geologic framework beneath their home, business, or town, and so we are building several databases that support general, "data-discovery" questions posed by citizens and researchers alike (Figure 2).

These reference databases are: 1) the Geoscience Map Catalog; 2) GEOLEX, the U.S. geologic names lexicon; 3) Geologic Mapping in Progress, which provides information for ongoing National Cooperative Geologic Mapping Program (NCGMP) mapping projects, prior to inclusion of their products in the Map Catalog; and 4) the prototype version of our Geologic Map Image Library – this new initiative is briefly described below, and in other papers in this volume. Plans for the prototype National Paleontology Database also are discussed below.

Figure 3 shows the number of people (actually, the number of unique IP addresses or computers) who have used the NGMDB, per month since it opened to the public in January, 1997. These numbers indicate that the site has become a useful resource. Additional increases in use are expected as the Map Catalog, Geolex, and Image Library become fully populated.

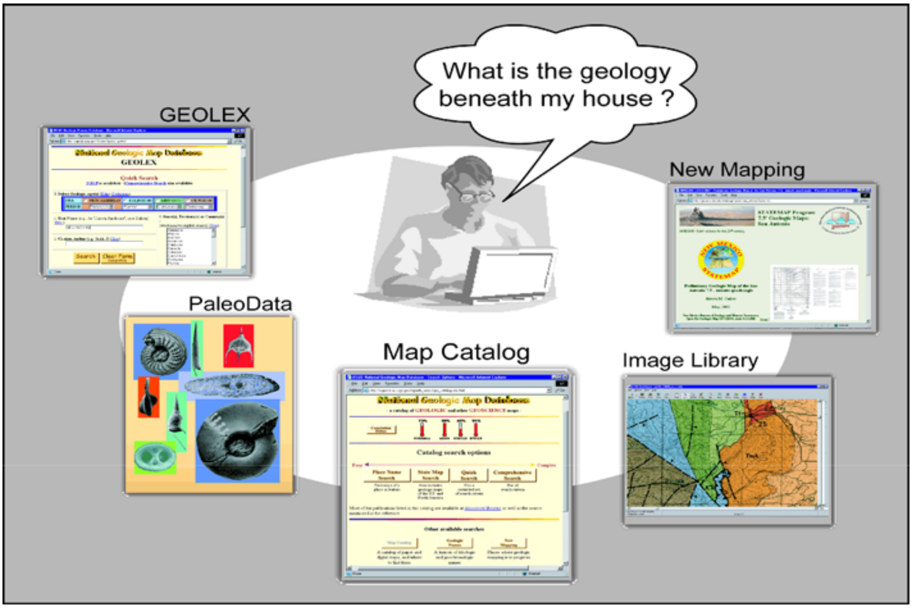

Figure 2. Many people want to know whether the geologic framework and the geoscience characteristics (for example, earthquake hazard, geochemistry) of an area have been studied and published. The reference databases built under NGMDB Phase One provide users with access to that information.

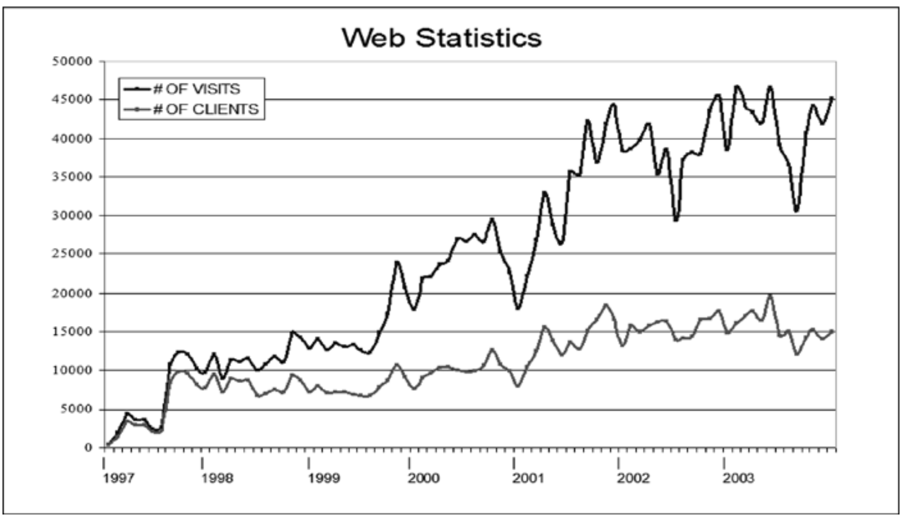

Figure 3. Web usage for the Geoscience Map Catalog, GEOLEX, and Mapping in Progress Databases. This diagram shows that the number of people (actually, the number of unique IP addresses or computers) using the NGMDB has gradually increased as these resource databases become more widely known; this usage trend is punctuated by sharp increases after essentially all USGS maps were entered into the Catalog and after many state geological surveys began to enter map records. The Catalog accounts for about 75-80% of user visits to the NGMDB site.

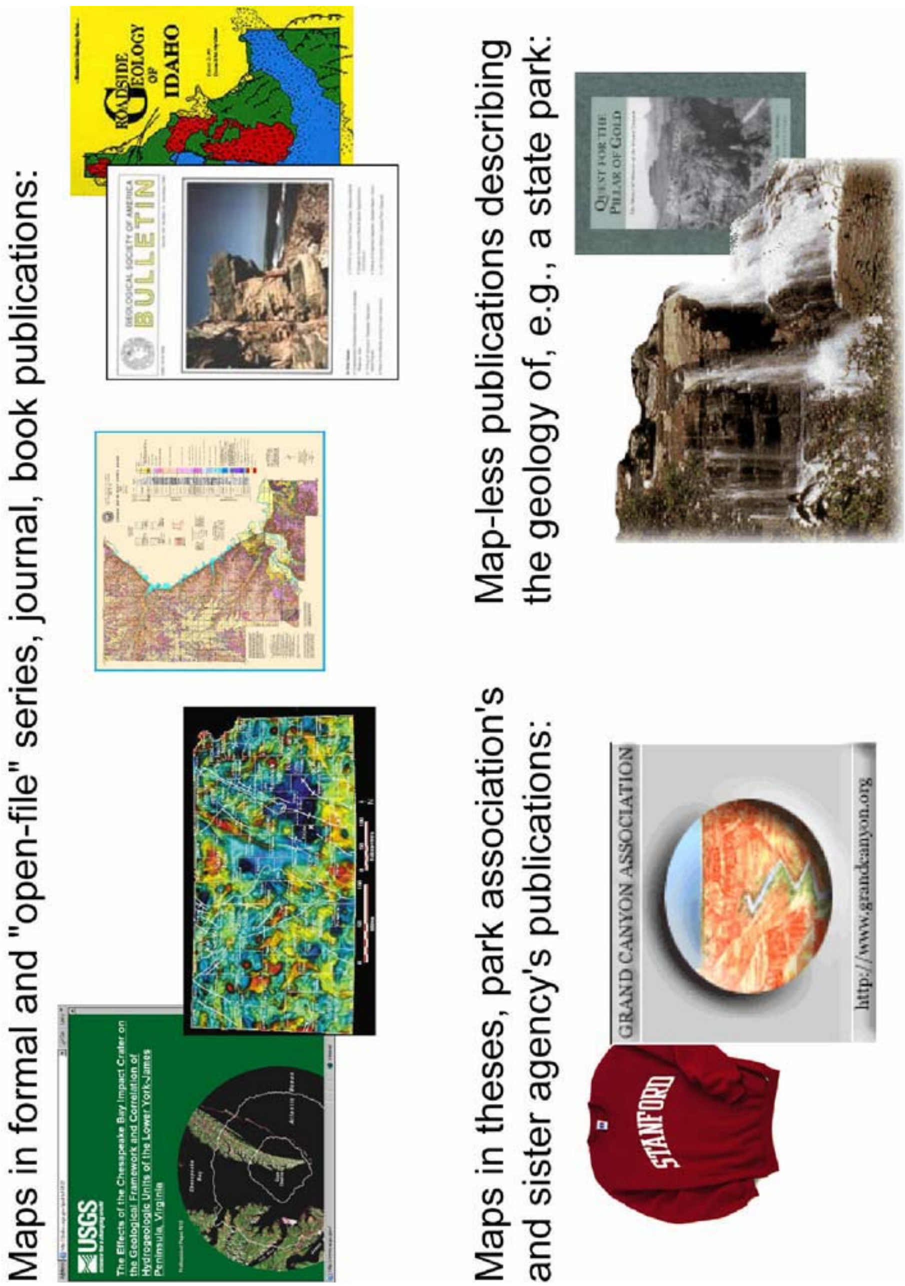

Figure 4. Bibliographic records in the Geoscience Map Catalog are drawn from a diverse group of more than 270 publishers.

The Geoscience Map Catalog

"I want to know if a map exists for an area, and where I can find it…"

Many organizations produce paper and digital geoscience maps and related products. Discovering whether a product exists for an area, and if so, where it can be purchased or obtained online, can be a time-consuming process. In the past, people found this information by contacting various agencies and institutions, and by conducting extensive library searches. To increase accessibility and use of these paper and digital products, we built the Geoscience Map Catalog as a comprehensive, searchable database of all maps and related products for the United States and its territories and possessions.

The Geoscience Map Catalog contains bibliographic records for more than 61,000 products from at least 270 publishers (see Appendix C or our most current list of publishers at:

http://ngmsvr.wr.usgs.gov/ngmdb/pub_series.html

Most of these products are from the USGS and 43 state geological surveys. Other publishers include state agencies, federal agencies, scientific societies, park associations, universities, and private companies. Products range from digital maps to books that don't contain maps but describe the geology of an area, and can be formal series products, open-file reports, or unpublished dissertations (Figure 4). Because there are many types of geoscience maps and related products, we categorize them by theme (Figure 5).

GEOLOGY	GEOPHYSICS	MARINE GEOLOGY	RESOURCES	HAZARDS
☐ Bedrock	☐ Magnetics	☐ Geophysics	☐ Metals	☐ Earthquakes
☐ Surficial	☐ Gravity	☐ Coastal	☐ Nonmetals	☐ Volcanoes
☐ Structure Contours	☐ Radiometrics	☐ GLORIA	☐ Petroleum	☐ Landslides
☐ Engineering	☐ Other	☐ Other	☐ Coal	☐ Environmental
☐ Other			☐ Other Energy	☐ Other
			☐ Water	
			☐ Other	
☐ GEOCHRONOLOGY	☐ PALEONTOLOGY	☐ GEOCHEMISTRY		☑ ALL THEMES

Figure 5. A portion of the Geoscience Map Catalog search page, showing the types of products included.

The Geoscience Map Catalog provides links to more than 1,300 published, downloadable products of the USGS and the state geological surveys. These links are established only to stable Web pages that provide the official copy-of-record for the publication – in the USGS, links are established only to the Publications Server and the NSDI Clearinghouse node.

Figure 6 shows how the Geoscience Map Catalog can be used to find particular products – upon searching it and identifying the needed product(s), the user is linked to the downloadable data and metadata, to a depository library, or to the appropriate organization for information about how to purchase the product. We address the diverse needs of our user audience through four search options.

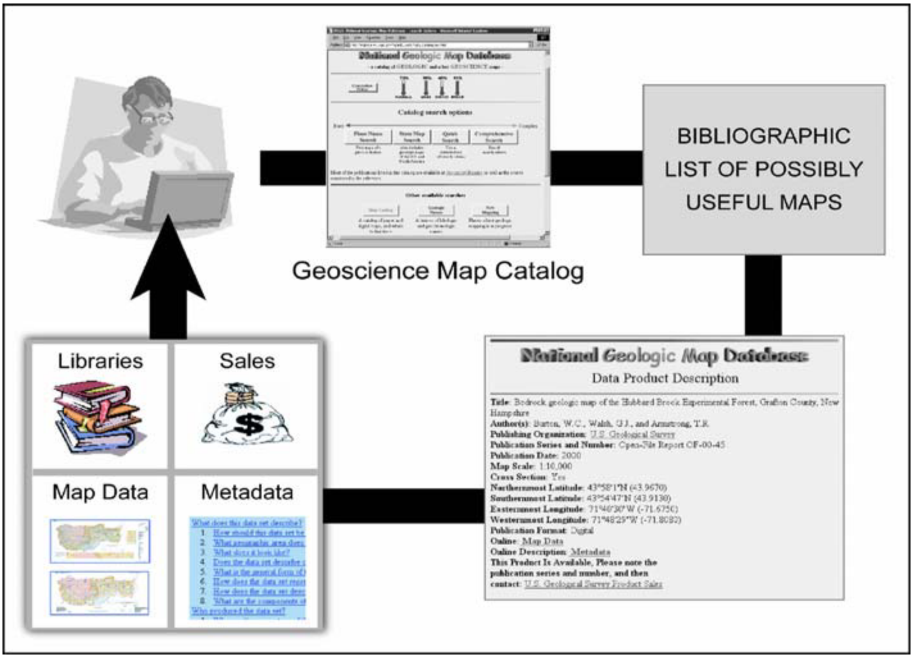

Figure 6. Diagram showing how a user navigates the Geoscience Map Catalog. Interested in knowing something about the geology of an area (such as the land beneath their house), the user queries the Catalog, which returns a hit list of possibly useful maps and related products. The user selects one of these and, from the Product Description Page, obtains further information and can then choose to buy the product, view and download it, inspect the metadata, or find it at a depository library.

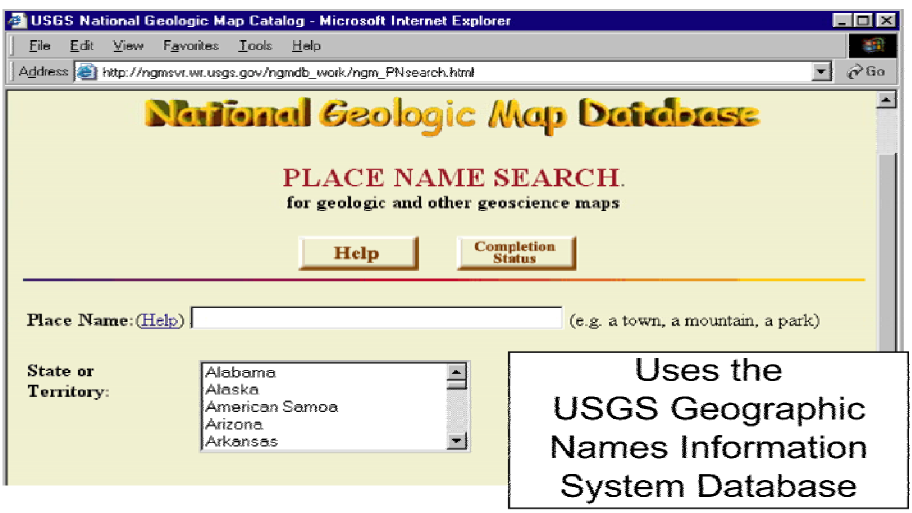

Figure 7. The first page of the Geoscience Map Catalog's Place Name Search.

The U.S. Geologic Names Lexicon ("GEOLEX")

"I want to know more about the geologic units shown on this map…"

This is the nation's lexicon of geologic nomenclature. GEOLEX contains information for more than 16,000 geologic units in the U.S. (Stamm and others, 2000). It is an excellent resource for finding significant publications that defined and described geologic units mapped in the U.S. These publications can be critically important in field studies, enabling students and mappers to compare these published descriptions with what they see in the field.

GEOLEX includes the content of the four geologic names databases on USGS Digital Data Series DDS-6 (Mac Lachlan and others, 1996). Before incorporating into GEOLEX, those databases were consolidated, revised, and error-corrected. Our work now focuses on:

1. Resolving the name conflicts found in the four databases of Mac Lachlan and others (1996). This is done by consulting publications, previous U.S. geologic names lexicons (listed in Appendix A of Stamm and others, 2000), and the records of the U.S. Geologic Names Committee (GNC),
2. Using the previous lexicons to incorporate type locality, publication history, geologic age, areal extent, and usage information for many central and western U.S. geologic units listed in Mac Lachlan and others (1996),
3. Adding geologic names not recorded in Mac Lachlan and others (1996) but found in the old USGS regional geologic names card catalogs (this is estimated to be 25% of all U.S. names), and
4. Adding geologic names approved by the state geological surveys but not recorded in GEOLEX.

Many state geological surveys have been registering new geologic names with the USGS for decades, and are encouraged to continue this practice. In order to promote standardized geologic nomenclature within the U.S., the GNC is being reconstituted. Formerly a committee that focused on nomenclature issues within the USGS, the new GNC will include members from each state geological survey (Figure 8). When a conflict arises, GNC members from the USGS and those states affected will resolve it, and any changes will be recorded in GEOLEX. Through this mechanism, we anticipate that GEOLEX will serve the entire U.S. geoscience community.

Geologic Mapping in Progress Database

"I see from the Map Catalog that a map hasn't been published for this area – is anyone mapping there now?"

Our Geologic Mapping in Progress Database provides users with information about current mapping activities (mostly at 1:24,000- and 1:100,000-scale, but at 1:63,360- and 1:250,000-scale in Alaska) that is funded by the National Cooperative Geologic Mapping Program. We are re-engineering and repopulating this database, and will be linking it directly to the state geological survey fact sheets and Web sites.

Geologic Map Image Library

"I want to see a picture of this geologic map, online…"

Through discussions with users, and from comments received via our Web feedback form, it became clear that many people are interested in viewing and/or obtaining maps "online." Interpretation of the phrase "providing maps online" varies widely -- to some people, it implies access to fully attributed vector-based map databases, whereas to other people, it implies access to map images. Regarding the vector-based map database, we address this large task in Phase Three, below. With the Image Library, we have begun to provide map images to users, as described in two papers in this volume. We hope this new initiative will further strengthen the cooperative relationship between the AASG and USGS.

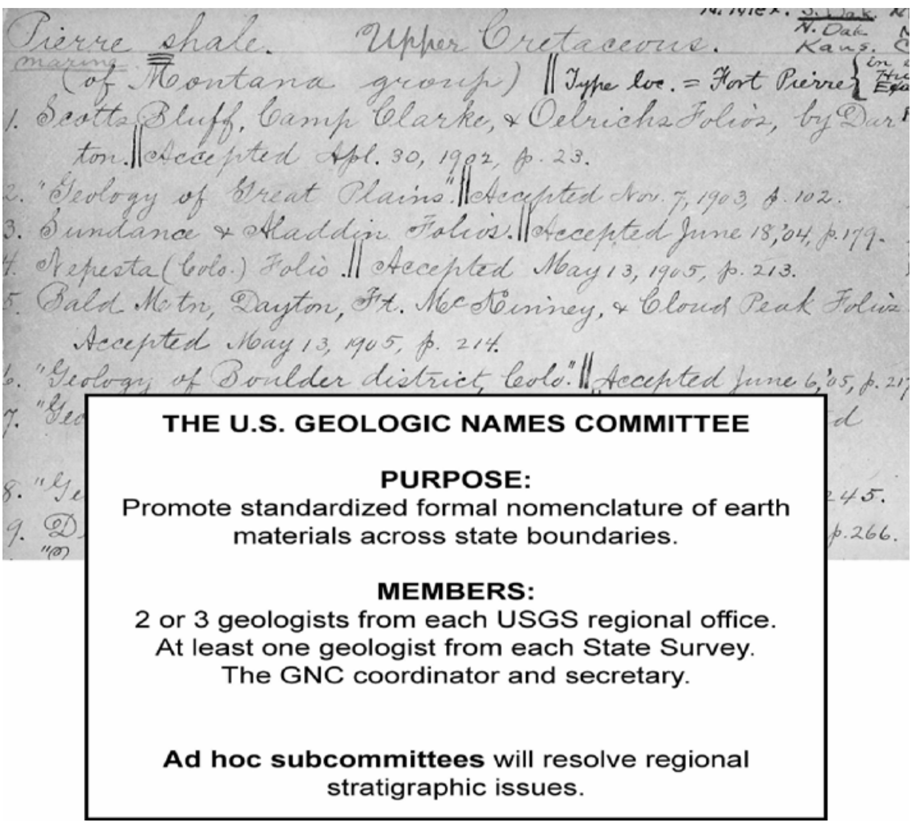

Figure 8. The purpose and membership of the reconstituted Geologic Names Committee. Background image is an index card from the files of the USGS Geologic Names Committee, ca. 1903, showing decisions recorded regarding the use of the Pierre Shale in the USGS Geologic Atlas of the United States folios.

Paleontology Database

"I want to know if there is any fossil data from this area…"

The NGMDB project has designed and is planning to develop a National Paleontology Database (see Wardlaw and others, 2001). Our general plan is to build prototypes of this database in areas where geologic mapping is underway, so that we can work with mapping projects to design a database useful to science as well as to the public. Plans for a prototype have been delayed somewhat, while we assess ways that the project might interact with the National Science Foundation's CHRONOS project (described in a paper by Wardlaw in that volume).

PHASE TWO

Phase Two focuses on development of standards and guidelines needed to assist the USGS and state geological surveys in efficiently producing digital geologic maps, in a more standardized and common format. Our profession encourages innovation and individual pursuit of science, and so the question may be posed – why do we need these standards? Clearly, standards should not impede science but instead should help us efficiently communicate our science to the public. The need for communication was perhaps best articulated by former USGS Director John Wesley Powell, while planning for the new Geologic Atlas of the United States:

"… the maps are designed not so much for the specialist as for the people, who justly look to the official geologist for a classification, nomenclature, and system of convention so simple and expressive as to render his work immediately [understandable]…" (Powell, 1888).

At that time, and throughout the early 20th century, Powell and others guided the USGS and the Nation's geoscientists toward a set of robust, practical standards for classifying geologic units and materials and representing them on maps. Those standards endured and evolved, and continue as basic guidelines for geologic mapping. Although today we commonly record in the field and laboratory far more complex information than during Powell's era, the necessity to provide it to the public in a standardized format remains unchanged. Newly evolving data formats and display techniques made feasible by computerization challenge us to revisit Powell's vision, and to develop standards and guidelines appropriate to today's technology and science.

In mid-1996, the NGMDB project and the AASG convened a meeting to identify the types of standards and guidelines that would improve the quality and utility of digital maps produced by the nation's geological surveys. From that meeting, Standards Working Groups were formed to address: 1) standard symbolization on geologic maps; 2) standard procedures for creating digital maps; 3) guidelines for publishing digital geologic maps; 4) documentation of methods and information via formal metadata; and 5) standard data structures and science terminology for geologic databases. The working group results will help provide a set of national standards to support public use of standard, seamless geologic map information for the entire country. In essence, Powell's pragmatic vision for the Geologic Atlas of the U.S. has been applied a century later to the National Geologic Map Database.

The tasks assigned to these Standards Working Groups are interrelated, as shown in Figure 9 – when in the field, a geologist makes observations and (often, provisionally) draws geologic features on a base map; at that time, the accuracy with which these features are located on the map can be estimated. Further, the information may be recorded digitally in the field; if so, it can be structured similar to, or compatible with, the map database's structure (the "data model" in this figure).

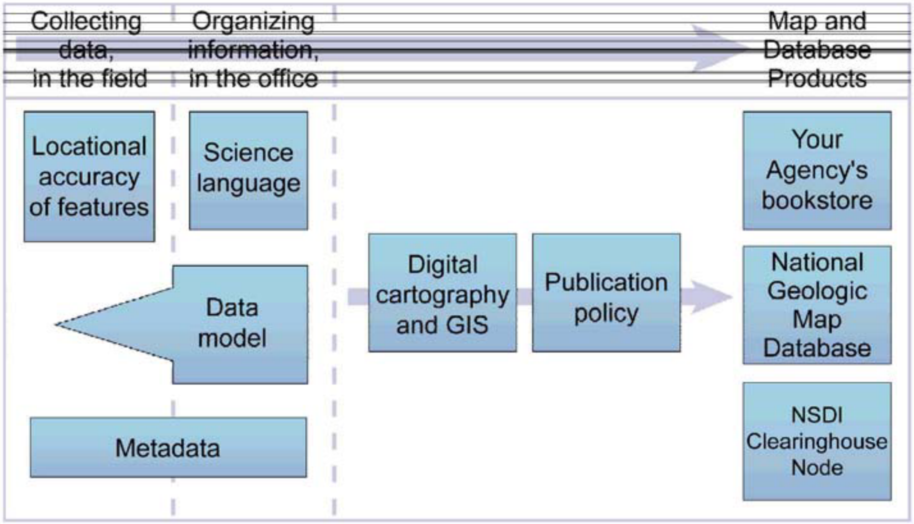

Figure 9. Diagram showing how the standards and guidelines under development by the NGMDB and related groups relate to the process of making a map.

Returning to the office, the geologist commonly organizes and interprets field observations and prepares for map production – descriptions may be standardized according to an agency or project-level terminology or "science language," the map data may be structured according to the standard data model implemented by the agency, and procedures may be documented with metadata both in the office and when gathering data in the field. The descriptive information then is combined with the feature location information in a GIS, and digital cartography is applied to create a map that is published according to agency policies. Finally, the map is released to the public and accessed through various mechanisms including the NGMDB.

As described below, since 1996 these Working Groups and their successor organizations have made significant progress toward developing some of the necessary standards and guidelines. General information about the Working Groups and details of their activities are available at http://ncgmp.usgs.gov/ngmdbproject/standards/. Working Group members are listed in Appendix A.

Internationally, the NGMDB participates in venues that help to develop and refine the U.S. standards. These venues also bring our work to the international community, thereby promoting greater standardization with other countries. Examples include:

1. Participation in "DIMAS", the map standards committee of the Commission for the Geological Map of the World (see article in this volume, and http://www.geology.cz/host/dimas.htm), and
2. Development of a map database and standards Clearinghouse

http://ncgmp.usgs.gov/intdb/

that is endorsed by the International Union of Geological Sciences' Commission for the Management and Application of Geoscience Information ("CGI", http://www.iugs.org/iugs/science/sci-cnfo.htm) and the International Association for Mathematical Geology (http://www.iamg.org/).

Geologic Map Symbolization

A draft standard for geologic map line and point symbology and map patterns and colors, published in a USGS Open-File Report in 1995, was reviewed in 1996 by the AASG, USGS, and Federal Geographic Data Committee (FGDC). It was revised by the NGMDB project team and members of the USGS Western Region Publications Group, and in late 1997 was circulated for internal review. The revised draft then was prepared as a proposed federal standard, for consideration by the FGDC. The draft was, in late 1999 through early 2000, considered and approved for public review by the FGDC and its Geologic Data Subcommittee. The document was released for public comment within the period May 19 through September 15, 2000, see the:

http://ncgmp.usgs.gov/fgdc_gds/mapsymb/

for the document and for information about the review process. This draft standard is described in some detail in Soller and Lindquist (2000). Based on public review comments, in 2002 a new section was added to the draft standard to address uncertainty in locational accuracy of map features. This section was presented for comment (Soller and others, 2002) and revised accordingly. With assistance from a Standing Committee to oversee resolution of review comments and long-term maintenance of the standard, the document is being prepared for submittal to FGDC, for final discussion and adoption as a Federal standard.

Digital Mapping

The Data Capture Working Group has coordinated seven annual "Digital Mapping Techniques" (DMT) workshops for state, federal, and Canadian geologists, cartographers, managers, and industry partners. These informal meetings serve as a forum for discussion and information-sharing, and have been quite successful. They have significantly helped the geoscience community converge on more standardized approaches for digital mapping and GIS analysis, and thus agencies have adopted new, more efficient techniques for digital map preparation, analysis, and production. In support of DMT workshops, an email listserver is maintained to facilitate the exchange of specific technical information.

The most recent DMT workshop, held in Millersville, Pennsylvania, and hosted by the Pennsylvania Geological Survey, was attended by 90 representatives of 36 state, federal, and Canadian agencies and private companies. Workshop proceedings are published (see Appendix B and

http://ncgmp.usgs.gov/ngmdbproject/standards/datacapt/).

Published copies of the proceedings may be obtained from David Soller or Thomas Berg.

Map Publication Requirements

Through the USGS Geologic Division Information Council, the NGMDB led development of the USGS policy "Publication Requirements for Digital Map Products" enacted May 24, 1999; see link under Map Publication Guidelines, at:

http://ncgmp.usgs.gov/ngmdbproject/standards/

A less USGS-specific version of this document was developed by the Data Information Exchange Working Group and presented for technical review at a special session of the Digital Mapping Techniques '99 workshop (Soller and others, 1999a). The revised document (entitled "Proposed Guidelines for Inclusion of Digital Map Products in the National Geologic Map Database") was reviewed by the AASG Digital Geologic Mapping Committee. In 2002, it was unanimously approved via an AASG resolution, and has been incorporated as a guideline for digital map product deliverables to the STATEMAP component of the National Cooperative Geologic Mapping Program, see link under Map Publication Guidelines, at:

http://ncgmp.usgs.gov/ngmdbproject/standards/

Among the geological surveys there are many approaches to determining authorship credit and citation format for geologic maps, digital geologic maps, and associated digital databases. It is prudent for agencies to adopt policies that preserve the relationship of the geologist-authors to their product, the map image, and to identify the appropriate authorship (if any) and/or credit for persons responsible for creating the database files. A summary of this issue and a proposed guideline was discussed at the Digital Mapping Techniques workshop in 2001 (Berquist and Soller, 2001).

Metadata

The Metadata Working Group developed its final report in 1998. The report provides guidance on the creation and management of well-structured formal metadata for digital maps, see:

http://ncgmp.usgs.gov/ngmdbproject/standards/metadata/metaWG.html

The report contains links to metadata-creation tools and general discussions of metadata concepts, see, for example, the metadata-creation tools, "Metadata in Plain Language," and other helpful information at:

http://geology.usgs.gov/tools/metadata/

Geologic Map Data Model

In early 1999, the Data Model Working Group had concluded its work with release of a draft version of a data model (Johnson and others, 1998). The Group then was succeeded by the North American Data Model Steering Committee (NADMSC)

http://geology.usgs.gov/dm/

state and USGS collaborators on the NGMDB continue to participate in this activity, helping to develop, refine, and test the North American Geologic Map Data Model ("NADM") and the standard science language that must accompany it.

This work recently has produced a significant accomplishment, the NADM Conceptual Data Model. This model is available for perusal and comment, at:

http://geology.usgs.gov/dm/steering/teams/design/NADM-C1.0/NADMC1_0.pdf

Information about other Committee activities is provided in two papers in this volume: 1) the development of a XML-based interchange format; and 2) the development of standard science language to describe the lithology of earth materials.

To provide templates for building GIS data, ESRI is designing ArcGIS data models for many industries and applications, see:

http://esri.com/software/arcgisdatamodels/index.html

Through discussions that involved the NGMDB, ESRI plans to structure the ArcGIS data model at least in part on concepts in the NADM Data Model.

PHASE THREE

Over the past few decades, significant advances in computer technology have begun to permit complex spatial information (especially vector-based) to be stored, managed, and analyzed for use by a growing number of geoscientists. At the beginning of the NGMDB project, we judged that computer-based mapping was not a sufficiently mature discipline to permit us to develop an online, vector-based map database. In particular, technology for display and query of complex spatial information on the Web was in its infancy, and hence was not seriously considered by the NGMDB project as a viable means to deliver information to the general public. However, there now exists sufficient digital geologic map data; sufficient convergence on standard data formats, data models, GIS and digital cartographic practices and field data capture techniques; and sufficient technological advances in Internet delivery of spatial information to warrant a research effort for a prototype, online vector-based map database.

Before beginning to design this database, project personnel held numerous discussions with geoscientists and the general public to gauge interest in an online database and to define its scope. Based on these discussions, it was clear that this database should be:

1. Bilt from edge-matched geologic maps at various scales;
2. Managed and accessed as a coherent body of map information, not just as a set of discrete map products;
3. Updated by mappers and/or a committee, "on the fly" when new information becomes available - it should be a “living” database;
4. Standardized, adhering to a standard data model with standard scientific terminology; and
5. Available to users via Internet browsers and common GIS tools.

This database will integrate with other databases developed under the NGMDB project. For example, a user accessing the online, vector-based map database might identify a map unit of interest, and then want to purchase or download the original published map product, or inquire about fossils found within that unit, or learn about the history of the geologic unit. Also, a user might access the Map Catalog and identify a map of interest, and be linked to the online map database in order to browse and query it.

Prototyping

The NGMDB project has begun a series of prototypes, to advance our understanding of the technical and management challenges to developing the operational system; an introduction is given in Soller and others (2000). In 1999, we outlined some basic requirements for the prototype and tested them using map data for the greater Yellowstone area of Wyoming and Montana (Wahl and others, 2000). The second prototype (Soller and others, 2001) was conducted in cooperation with the Kentucky Geological Survey. In this prototype, we demonstrated in a commercial database system (GE-Smallworld) how the geologic database could be analyzed over the Web in concert with local datasets. The data model for the second prototype is described in Soller and others, 2002, and was a significant contributor to the design of the new NADM Conceptual Data Model noted above.

Before proceeding further with plans for the publicly-accessible map database, we need to define a set of standardized terminology for the properties of earth materials (the science language). This science language must be sufficiently robust to accommodate terminology generated through today's field mapping, and terminology found in map unit descriptions on older and on smaller-scale maps, where descriptions tend to be highly generalized. Also, we need to collect enough standardized geologic map data to justify the cost of developing the database. Therefore, in our third prototype we will create map data with a standardized data model and science language, using available mapping in disparate field areas (central Arizona, northern Virginia, Kentucky, southern California, and the Greater Yellowstone Area; see Figure 10). To achieve this, we are writing data-entry software tools supported by entities for symbolizing the map on-screen and in print form.

What is a data model, and how does it apply to geologic maps?

A data model provides organization to the descriptive and spatial information that constitute a geologic map. The relations between a data model, science language, and the geologic map require some explanation. A data model may be highly conceptual, or it may describe the data structure for managing information within a specific hardware/software platform. In either case, it is a central construct because it addresses the database design for geologic maps in GIS format. In Figure 11, the data model is simplified to four locations, or "bins", where information can be stored, with each bin containing many database tables and fields:

1. Occurrence – this bin contains the spatial geometry for each geologic feature in a map database. For example, the map unit identifier and the coordinates that define the outline of a map unit are included here.
2. Descriptor – this bin contains the wealth of descriptive information for each feature that occurs in the map database. This can include the full map unit description and simple attributes such as dominant lithology, color, and the nature of bedding.

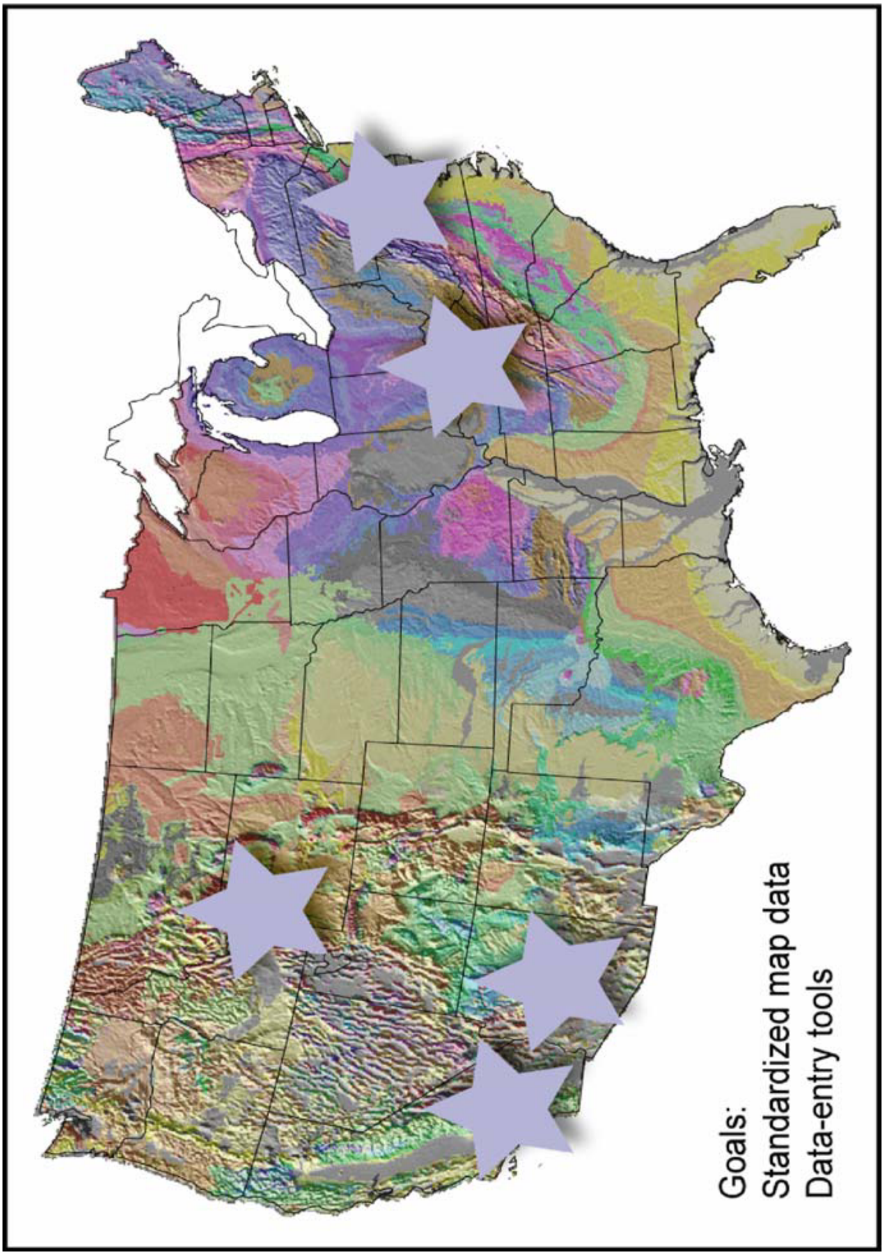

Figure 10. The goals of the current prototype are to: 1) create map data that has a standardized data model and science language, beginning with some national-scale maps and available mapping in disparate field areas shown above, and 2) create data-entry tools that are flexible and readily modified, enabling geologists to enter detailed, more standardized descriptive information.

3. Concept – this bin contains essential reference standards, such as geologic time scale(s) and science language. It also contains concepts and definitions essential for querying the database (for example, the concept that a rock can “intrude” another rock).
4. Symbol – this bin includes cartographic science language derived from the NADMSC.

Will the U.S. have a single standard data model and science language?

The NGMDB online map database is envisioned as a distributed system that will provide seamless access to, and display of, map data served by many agencies. If all agencies used the same science language and exactly the same data model, and if it were implemented on the same hardware and software platform, a functional system would be relatively easy to build. That, however, is not a realistic scenario. Each agency has a unique history, set of objectives, and budget that will dictate the nature of their map database. (It should be noted that not all geological surveys in the U.S. can now afford to build such a system.) A more realistic approach is to assume a heterogenous computing environment, and to build software that can translate data structure and science language from one agency’s system to another (Figure 11). This translation mechanism ensures “interoperability” between systems, and is the most realistic approach for the NGMDB.

To facilitate interoperability among systems, the NGMDB will define and maintain a set of reference standards (for data model, science language, time scale) based in part on those produced by the NADMSC. Interoperability software that enables disparate systems to appear to the user as a single system is being evaluated by groups including the NADMSC, NGMDB, and the National Science Foundation-funded GEON project. We anticipate collaborative research, especially with GEON, on XML-based “wrapper/mediator” technology to address these needs for the NGMDB. Through this technology, agencies should be able to correlate their unique data structure and scientific terminology to the reference standard, and the translator (presumably XML-based) will enable us to display the information to the user in a single view.

Extending the data model to include three-dimensional (3-D) map information

The data model was designed for the typical geologic map, which provides a two-dimensional representation of the geologic framework. On most geologic maps, this framework is expressed generally, in cross-sections and map unit descriptions. The data model can accommodate more detailed and location-specific 3-D information, although it has not yet been applied in this fashion.

Three-dimensional maps are readily managed in the data model, like a traditional geologic map (Figure 12). The 3-D geologic map information can be represented by various methods. The most traditional approach is vector-based stack-unit mapping, where a vertical stack of surface and subsurface geologic units are combined into a two-dimensional (2-D) map unit (Figure 13A, B). The stack-unit characterizes the vertical variations of physical properties in each 3-D map unit.

Map unit descriptions, whether on traditional 2-D geologic maps or vector-based stack-unit maps, apply to the entire unit. As a consequence, if a map unit's texture is described as "generally sandy, although fining to the east," the unit cannot be readily subdivided into areas that are sandy and those that are finer. This can be a limitation to users, especially when using the map for detailed studies. In contrast to vector-based stack-unit maps, voxel maps show every part of a geologic unit as a unique point known as a volume-pixel or voxel. Each voxel can have a unique set of attributes, therefore lateral and vertical variations in texture within the geologic unit can be described in great detail. Such information is difficult to collect at depth, and so in studies where this type of representation is needed, voxel attributes tend to be computed from a few point measurements within the geologic unit.

A third approach to 3-D mapping, raster-based stacked surfaces, offers a useful compromise between vector-based stack-unit and voxel-based mapping. In this approach, a set of 2-D elevation maps shows, in raster format, the surface of each buried geologic unit. These surfaces are in many cases rasterized from conventional, vector-based maps. Unlike the vector-based stack-unit map, they provide the opportunity to model the surface elevation and thickness of each unit, and to assign unique physical properties to each location on the unit's surface. Although not as detailed as a voxel representation, this approach requires less information and fewer assumptions about the 3-D variation of properties within the unit, and can be created using conventional GIS software such as ArcGIS. Lateral variations in a physical property such as texture can be recorded; this is informative for units such as alluvium, which may have distinct subenvironments with different characteristics (for example, coarser material in the main channel, and finer material in overbank areas and tributaries).

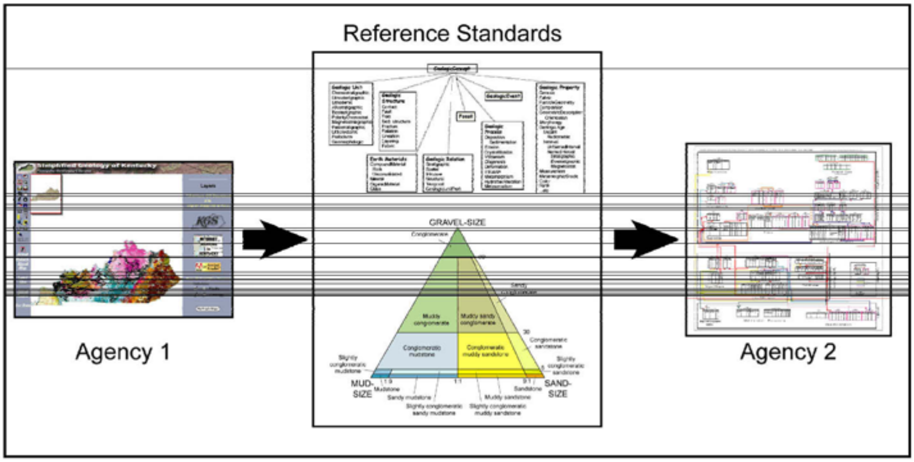

Figure 11. A single, monolithic system design shared by all agencies is unlikely. Rather, interoperability among the many agency databases linked together by the NGMDB database is the most logical design philosophy. In this diagram, we envision that map data from one agency (the Kentucky Geological Survey, http://www.uky.edu/KGS/) will be translated into reference standards (the data model and science language standards adopted by the NGMDB) and translated out to the criteria required by another agency (the Idaho Geological Survey's Geologic Map Data Model, http://www.idahogeology.org/Lab/datamodel.htm). This approach also could permit the NGMDB to coordinate the translation and display of multiple agency databases. In this diagram, the reference standards are represented by a schematic of the draft NGMDB data model (discussed in another paper in this volume) and an example of science language from Folk (1954, Figure 1a) showing a rock classification based on mud-sand-gravel content.

Raster-based stacked surfaces (and, by extension, voxel-based maps) can be represented in the data model, as shown in Fgure 13B. This raster-specific information can significantly improve the value of geologic data when applied to, for example, groundwater modeling. The 3-D geometry of the glacial aquifer shown in Figure 13B was provided to a private groundwater consortium in order to develop a regional groundwater flow model. The aquifer is composed of coarse sand and gravel in the main channel but is finer-grained in the tributaries because sediment dammed the margins of the main channel, causing lakes to form in tributaries. When the 3-D information was provided to the consortium, the authors did not have sufficient data to assign to the units any lateral variations in texture. As a result, the groundwater modelers had to assume a homogenous aquifer. Raster surfaces that showed lateral variations in sediment texture would have enabled the modelers to consider the heterogeneity that was known to exist within that aquifer.

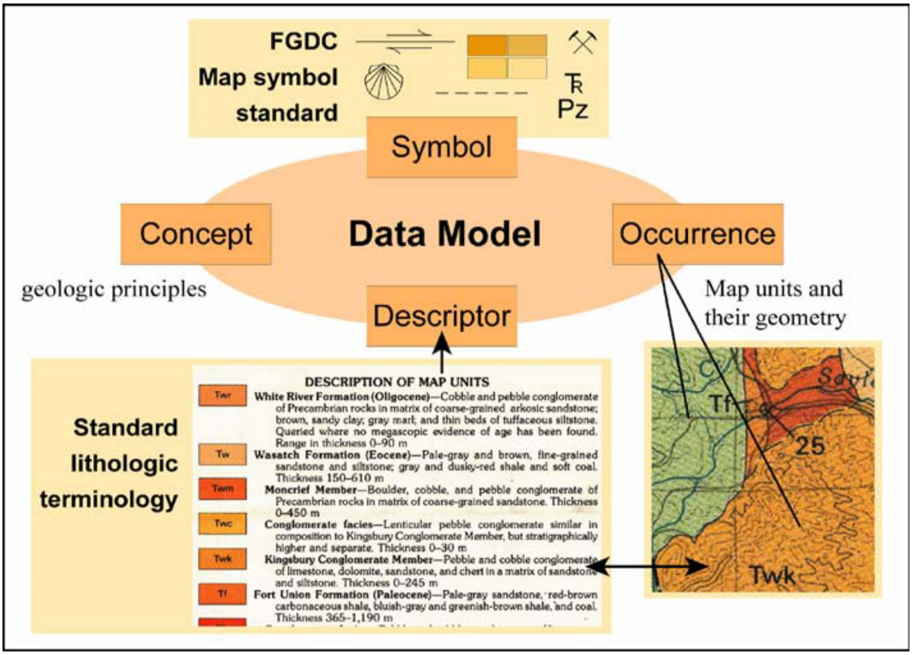

Figure 12. Simplified representation of the data model and its application to a typical, 2-D geologic map. The presence of a geologic unit on the map, referred to in the data model as an “occurrence” of that map unit, is described by: 1) its bounding contacts and faults, whose coordinates are stored as the unit’s “geometry”; and 2) its physical properties, which are stored as the unit’s “descriptors.”

National and regional map coverage

The online map database will be more useful if it includes some geologic map coverage for the entire nation. To that end, the NGMDB has supported compilation and GIS development of several regional maps (Figure 14). Most significant is the digital version of the “Geologic Map of North America”. This map is the final product of the Geological Society of America’s (GSA) Decade of North American Geology project. The NGMDB has provided funding and expertise for development of the digital files that will be used to print the map, in order to engage GSA in a plan to develop a database for the map. When compilation and review of the map has been completed, hopefully within the next year, we will propose a database design and begin to populate the digital files made available from cartographic production of the map. This work will be conducted in collaboration with GSA and interested national geological surveys. The other maps shown in figure 14 are published or in press, and we intend to process these for inclusion in the online map database.

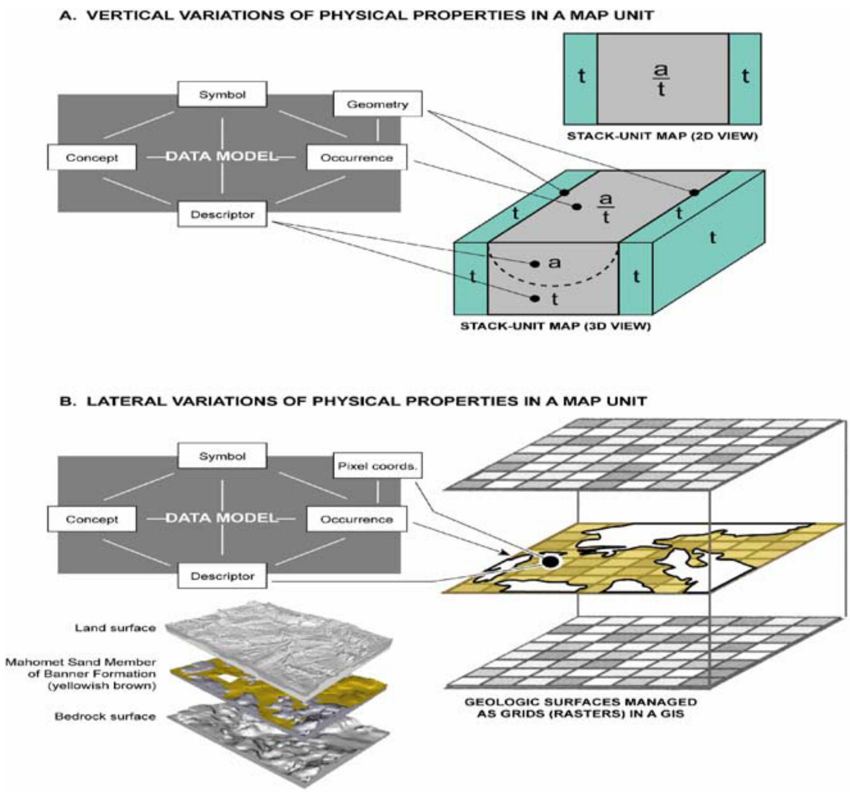

Figure 13. Approaches for representing three-dimensional map information, and for managing it in the data model.

A. Vector-based stack-unit maps depict the vertical succession of geologic units to a specified depth (here, the base of the block diagram). This mapping approach characterizes the vertical variations of physical properties in each 3-D map unit. In this example, an alluvial deposit (unit "a") overlies glacial till (unit "t"), and the stack-unit labeled "a/t" indicates that relationship, whereas the unit "t" indicates that glacial till extends down to the specified depth. In a manner similar to that shown in figure 11, the stack-unit's occurrence (the map unit's outcrop), geometry (the map unit's boundaries), and descriptors (the physical properties of the geologic units included in the stack-unit) are managed as they are for a typical 2-D geologic map.

B. Raster-based stacked surfaces depict the surface of each buried geologic unit, and can accommodate data on lateral variations of physical properties. In this example from Soller and others (1999b), the upper surface of each buried geologic unit was represented in raster format as an ArcInfo Grid file. The middle grid is the uppermost surface of an economically important aquifer, the Mahomet Sand, which fills a pre- and inter-glacial valley carved into the bedrock surface. Each geologic unit in raster format can be managed in the data model, in a manner not dissimilar from that shown for the stack-unit map. The Mahomet Sand is continuous in this area, and represents one occurrence of this unit in the data model. Each raster, or pixel, on the Mahomet Sand surface has a set of map coordinates that are recorded in a GIS (in the data model bin that is labeled "Pixel coordinates", which is the raster corollary of the "Geometry" bin for vector map data). Each pixel can have a unique set of descriptive information, such as surface elevation, unit thickness, lithology, transmissivity, etc.).

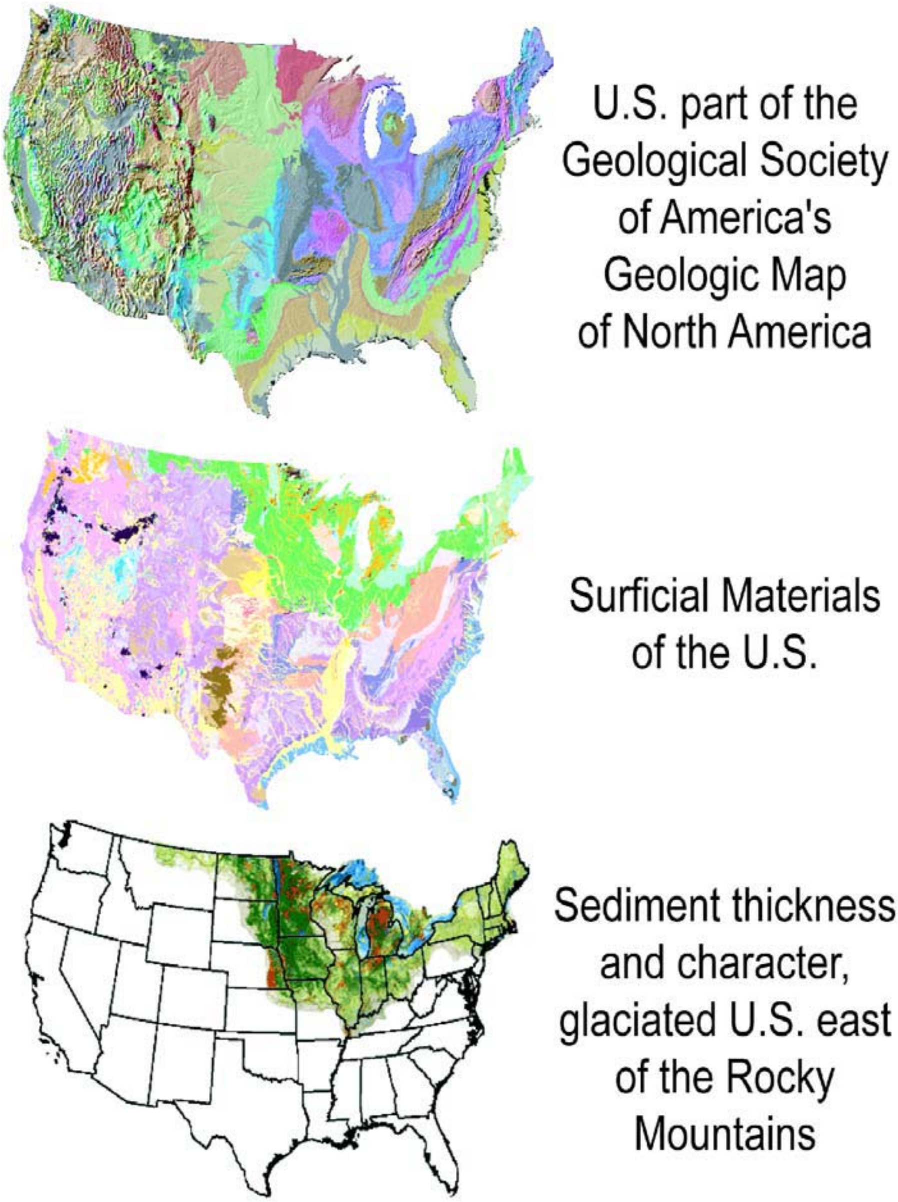

Figure 14. Regional maps whose compilation and/or GIS development is supported by the NGMDB. The uppermost map, the Geologic Map of North America, is discussed in the text. The center map is in press (Soller and Reheis, in press) and must be converted to a database. The database for the lower map is published (Soller and Packard, 1998) and will be adapted to the emerging NGMDB standards.

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REVIEW BY EARL BRABB

This superb article lays out a plan for nearly every conceivable situation involving the production and availability of digital geologic maps. The National Geologic Map Database Project began in 1995 to provide technical advice, standards, and an online database of geological information for North American state and federal agencies, scientific societies, park associations, universities, and the general public. The general scheme of the project is: (1) Build a catalog of geologic maps; (2) Develop standards for maps and databases; and (3) Build an online database of geologic information. Some measure of their success is that the map catalog has more than 61,000 products. Map standards have been drafted, reviewed, published in draft form, and are ready to be submitted as a standard for the United States. Nearly 1,000 geologic maps are already online. No one in North America who produces digital geologic maps can ignore this work.

The surprise to me is that hardly anyone in Europe or Asia seems aware of this work, in spite of the availability of published information since 1995. No one from Europe or Asia has attended an annual workshop, and only one author in this volume has cited one of the Project publications. The Project is now "working" (seriously?) with the Commission for the Geological Map of the World, the IUGS Commission for the Management and Application of Geoscience Information, and the International Association for Mathematical Geology, but involvement of European and Asian national and regional geological surveys is curiously lacking. All of us are headed for the digitization of geologic maps, like it or not, and we need to be aware of the accomplishments and failings of other organizations. This article opens the door to almost every aspect of the subject of digital geologic maps.

RESPONSE TO EARL BRABB'S COMMENTS:

The U.S. National Geologic Map Database project has been carefully planned to support the needs of geologists as well as other scientists and a host of users including public and private decisionmakers and the general public. Because our peers tend to be the most demanding and outspoken advisors and users, it is most gratifying to receive supportive comments from a geologist of Dr. Brabb’s stature. Designing and building our National Database has indeed been a difficult task, made easier only through alliances with colleagues in other geological surveys, who are facing the same technical, management, and funding challenges. Their moral support and ideas are gratefully acknowledged here, and I can only hope that I have adequately reciprocated.

It has become clear to me that communication, particularly the sharing of technical expertise and institutional experiences, is essential to the success of database projects such as this. To address Dr. Brabb’s question regarding the level of effort in the “working” relation between our U.S. National Geologic Map Database project and various international commissions – he correctly perceives that our interactions are not in-depth technical activities, but rather serve to promote general communication and to share results (for example, to provide information on North American progress on development of a conceptual model for geologic map databases, or to receive notice of useful geologic map cartographic standards in use by other geological surveys). Dr. Brabb closes by offering a challenge to the international geoscience community, to improve the level of detailed technical interaction – I emphatically agree that communication must be improved, in order to minimize costs and improve the utility of our databases. Mechanisms such as the U.S.'s "Digital Mapping Techniques" workshops and the IUGS Commission for the Management and Application of Geoscience Information serve to promote better communication among geological surveys, and I ask that we enthusiastically support these and similar venues. On behalf of my "digital mapping" colleagues in the United States, I cordially invite Dr. Brabb and other interested scientists to participate in our Digital Mapping Techniques workshops. Our map databases can only be improved through such interactions.

Dave Soller
September 30, 2004

APPENDIX A

Principal committees and people collaborating with the National Geologic Map Database project:
Digital Geologic Mapping Committee of the Association of American State Geologists: Tom Berg (Ohio Geological Survey and Committee Chair); Rick Allis (Utah Geological Survey); Lee Allison (Kansas Geological Survey); Larry Becker (Vermont Geological Survey); Rick Berquist (Virginia Division of Mineral Resources); Jim Cobb (Kentucky Geological Survey); Ian Duncan (Virginia Division of Mineral Resources); Rich Lively (Minnesota Geological Survey); Jay Parrish (Pennsylvania Geological Survey); Bill Shilts (Illinois State Geological Survey); Nick Tew (Alabama Geological Survey); Harvey Thorleifson (Minnesota Geological Survey).

Technical Advisory Committee: Boyan Brodaric (Geological Survey of Canada); David Collins (Kansas Geological Survey); Larry Freeman (Alaska Division of Geological & Geophysical Surveys); Jordan Hastings (University of California, Santa Barbara); Dan Nelson (Illinois State Geological Survey); Stephen Richard (Arizona Geological Survey); Jerry Weisenfluh (Kentucky Geological Survey).

Map Symbol Standards Committee: Dave Soller (U.S. Geological Survey and Committee Coordinator); Tom Berg (State Geologist, Ohio Geological Survey); Bob Hatcher (University of Tennessee, Knoxville); Mark Jirsa (Minnesota Geological Survey); Taryn Lindquist (U.S. Geological Survey); Jon Matti (U.S. Geological Survey); Jay Parrish (State Geologist, Pennsylvania Geological Survey); Jack Reed (U.S. Geological Survey); Steve Reynolds (Arizona State University); Byron Stone (U.S. Geological Survey).

AASG/USGS Data Capture Working Group: Dave Soller (U.S. Geological Survey and Group Chair); Warren Anderson (Kentucky Geological Survey); Rick Berquist (Virginia Geological Survey); Elizabeth Campbell (Virginia Division of Mineral Resources); Rob Krumm (Illinois State Geological Survey); Scott McCulloch (West Virginia Geological and Economic Survey); Gina Ross (Kansas Geological Survey); George Saucedo (California Geological Survey); Barb Stiff (Illinois State Geological Survey); Tom Whitfield (Pennylvania Geological Survey)

DMT Listserve: Maintained by Doug Behm, University of Alabama;

AASG/USGS Metadata Working Group: Peter Schweitzer (U.S. Geological Survey and Group Chair); Dan Nelson (Illinois State Geological Survey); Greg Hermann (New Jersey Geological Survey); Kate Barrett (Wisconsin Geological and Natural History Survey); Ron Wahl (U.S. Geological Survey);

AASG/USGS Data Information Exchange Working Group: Dave Soller (U.S. Geological Survey and Group Chair); Ron Hess (Nevada Bureau of Mines and Geology); Ian Duncan (Virginia Division of Mineral Resources); Gene Ellis (U.S. Geological Survey); Jim Giglierano (Iowa Geological Survey).

AASG/USGS Data Model Working Group: Gary Raines (U.S. Geological Survey and Group Chair); Boyan Brodaric (Geological Survey of Canada); Jim Cobb (Kentucky Geological Survey); Ralph Haugerud (U.S. Geological Survey); Greg Hermann (New Jersey Geological Survey); Bruce Johnson (U.S. Geological Survey); Jon Matti (U.S. Geological Survey); Jim McDonald (Ohio Geological Survey); Don McKay (Illinois State Geological Survey); Steve Schilling (U.S. Geological Survey); Randy Schumann (U.S. Geological Survey); Bill Shilts (Illinois State Geological Survey); Ron Wahl (U.S. Geological Survey);

North American Data Model Steering Committee: Dave Soller (U.S. Geological Survey and Committee Coordinator); Tom Berg (Ohio Geological Survey); Boyan Brodaric (Geological Survey of Canada and Chair of the Data Model Design Technical Team); Bruce Johnson (U.S. Geological Survey and Chair of the Data Interchange Technical Team); Murray Journeay (Geological Survey of Canada); Rob Krumm (Illinois State Geological Survey); Jonathan Matti (U.S. Geological Survey and Chair of the Science Language Technical Team) Scott McColloch (West Virginia Geological and Economic Survey); Steve Richard (Arizona Geological Survey); Peter Schweitzer (U.S. Geological Survey); Loudon Stanford (Idaho Geological Survey); Jerry Weisenfluh (Kentucky Geological Survey;

NGDMB contact-persons in each State geological survey

These people help the NGMDB with the Geoscience Map Catalog, GEOLEX, the Geologic Map Image Library, and the Mapping in Progress Database. Please see
<http://ncgmp.usgs.gov/ngmdbproje

APPENDIX B

List of progress reports on the National Geologic Map Database, and Proceedings of the Digital Mapping Techniques workshops.

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Soller, D.R., and Berg, T.M., 1998, Progress Toward Development of the National Geologic Map Database, in Soller, D.R., editor, Digital Mapping Techniques '98—Workshop proceedings: U.S. Geological Survey Open-file Report 98-487, p. 37-39, accessed at http://pubs.usgs.gov/openfile/of98-487/soller2.html.

Soller, D.R., and Berg. T.M., 1997, The National Geologic Map Database—A progress report: Geotimes, v. 42, no. 12, p. 29-31.

Soller, D.R., and Berg, T.M., 1995, Developing the National Geologic Map Database: Geotimes, v. 40, no. 6, p. 16-18.

APPENDIX C

List of publishers contained in the National Geologic Map Databases's Geoscience Map Catalog

Alabama Academy of Science; Alaska Division of Geological & Geophysical Surveys (1972-present); Alaska Division of Geological Survey (1970-72); Alaska Division of Mines and

Geology (1966-70); Alaska Division of Mines and Minerals (1959-66); Alaska Territorial Department of Mines (1959); American Association of Petroleum Geologists; American Geophysical Union; American Institute of Mining, Metallurgical, and Petroleum Engineers
Arizona Bureau of Geology and Mineral Technology; Arizona Bureau of Mines; Arizona Department of Water Resources; Arizona Geological Society; Arizona Geological Survey; Arizona Public Service; Arizona State University; Arkansas Geological Commission; Association of Engineering Geologists;

Baylor University; Bowling Green State University; Brigham Young University Department of Geology; British Columbia Ministry of Energy and Mines; California Division of Mines and Geology; California Institute of Technology;

California State University, Chico; California State University, Fresno; California State University, Humboldt; California State University, Long Beach; Canadian Hydrographic Service, Department of Fisheries and Oceans; Canyonlands Natural History Association; Colorado Geological Survey; Colorado School of Mines; Colorado State University; Columbia University Libraries; Columbia University School of Mines; Commonwealth of Virginia Department of Conservation and Economic Development; Confederated Tribes of the Colville Reservation; Connecticut Geological and Natural History Survey;

Dallas Geological Society; Delaware Geological Survey; Desert Research Institute; Dibblee Geological Foundation;

Eastern Washington University; Elsevier Science Environment Canada; Field Conference of Pennsylvania Geologists, Inc.; Florida Geological Survey;

Geodata International, Inc.; Geological Society of America; Geological Society of Nevada; Geological Society of Sacramento; Geological Survey Department, Jamaica; Geological Survey of Alabama; Geological Survey of Canada; Geological Survey of Michigan; Georgia Department of Natural Resources; Georgia Division of Mines, Mining, and Geology; Global Tectonics and Metallogeny; Grand Canyon Association; Great Plains Historical Association; GTR Mapping;

Hawaii Commission on Water Resource Management; Hawaii Division of Water and Land Development; Hawaii Institute of Geophysics and Planetology; Hawaii Water Authority;

Idaho Bureau of Mines and Geology; Idaho Geological Survey; Idaho State University; Illinois Basin Consortium; Illinois Oil and Gas Association; Illinois State Geological Survey; Indiana Department of Conservation; Indiana Department of Natural Resources; Indiana Geological Survey; Indiana University, Department of Geological Sciences; Institute of Food And Agricultural Sciences Service, University of Florida; Intergovernmental Resource Center, Clark County, Washington; Intermountain Association of Petroleum Geologists; IntraSearch, Inc; Iowa Geological Survey;

John Wiley and Sons Publishers; Joint Transportation Research Program, Purdue University/Indiana Department of Transportation;

Kansas Academy of Science; Kansas Geological Society; Kansas Geological Survey; Kentucky Department of Commerce; Kentucky Geological Survey;
Lincoln-DeVore Engineers and Geologists; Loma Linda University; Los Alamos National Laboratory; Louisiana Geological Survey;

Mackay School of Mines; Maine Geological Survey; Martel Laboratories, Inc.; Maryland Geological Survey; Massachusetts Institute of Technology; Medical Association of the State of Alabama; Memorial University of Newfoundland; Miami Geological Society; Miami University, Ohio; Michigan Department of Conservation; Michigan Department of Natural Resources; Mineral Resources Development, Inc.; Mines and Minerals (Scranton, PA); Minnesota Department of Natural Resources, Division of Waters; Minnesota Geological Survey; Missouri Division of Geology and Land Survey; Missouri Geological Survey; Missouri Geological Survey and Resource Assessment Division; Montana Bureau of Mines and Geology; Montclaire State College, NJ; Mountain Press Publishing Company; Museum of Northern Arizona;

National Academy of Sciences - National Research Council; National Well Water Association Nevada Bureau of Mines and Geology; Nevada Department of Conservation and Natural Resources; Nevada Division of Water Resources; Nevada Petroleum Society; New Hampshire Academy of Science; New Hampshire Department of Environmental Services; New Hampshire Department of Resources & Economic Development; New Hampshire State Planning and Development Commission; New Jersey Geological Survey; New Mexico Bureau of Geology and Mineral Resources; New Mexico Bureau of Mines and Mineral Resources; New Mexico Geological Society; New York Academy of Sciences; New York State Department of Environmental Conservation; New York State Geological Survey; New York State Museum; New York, Oswego County Planning Board; North Carolina Department of Natural Resources and Community Development; North Carolina Department of Transportation, Geotechnical Engineering Unit; North Carolina Division of Mineral Resources; North Carolina Geological Survey; North Dakota Geological Survey; Northern Arizona University; Northwest Scientific Association; Northwestern University;

Ohio Division of Geological Survey; Ohio Division of Shore Erosion (Ohio Division of Geological Survey); Ohio Geological Society; Ohio State University; Ohio University; Oklahoma Geological Survey; Oklahoma State University; Oregon Department of Geology and Mineral Industries; Oregon State University; Oxford University Press;

Paleontological Research Institution; Pennsylvania First Geological Survey (1836-1842); Pennsylvania Geological Survey; Pennsylvania Second Geological Survey (1874-1889); Pennsylvania State University; Pennsylvania Third Geological Survey (1899-1914); Petroleum Publishing Company; Portland State University Department of Geology; Primedia Business Magazines & Media; Princeton University; Puerto Rico Department of Public Works; Puerto Rico Division of Mineralogy and Geology; Puget Sound Power and Light Company; Purdue University; Purdue University Office of Agricultural Research Programs;

Rhode Island Geological Survey; Rice University; Rockwell International, Rockwell Hanford Operations, Energy System Group; Royal Bank of Canada, Oil and Gas Department;

San Diego State University; San Jose State University; Shannon & Wilson, Inc; Sigma Gamma Epsilon; Society of Economic Geologists; Society of Economic Paleontologists and Mineralogists; South Carolina Geological Survey; South Coast Geological Society, Inc.; South Dakota Academy of Science; South Dakota Geological Survey; Southern California Academy of Sciences; Southern Pacific Railroad; Springer-Verlag New York; Stanford University; State Geological Survey of Kansas; State of New Jersey Department of Conservation and Economic Development;

Tacoma-Pierce County Health Department; Tennessee Division of Geology; Terrascan Group Ltd., Lakewood, CO; Texas A&M University; Texas Christian University; Texas Tech University; TRW, Inc.; Tulane University;

U.S. Army Corps of Engineers; U.S. Atomic Energy Commission; U.S. Bureau of Mines; U.S. Bureau of Reclamation; U.S. Department of Agriculture, Forest Service; U.S. Department of Agriculture, Natural Resources Conservation Service; U.S. Department of Energy; U.S. Department of Energy, Grand Junction Office; U.S. Department of Energy, Morgantown Energy Technology Center; U.S. Department of Transportation, Federal Highway Administration, Indiana Division; U.S. Geological Survey; U.S. National Oceanic and Atmospheric Administration;

University of Alabama; University of Alaska, Fairbanks; University of Arizona; University of Arizona, Department of Geosciences; University of Arkansas; University of California; University of California, Davis; University of California, Los Angeles; University of California, Riverside; University of California, Santa Barbara; University of Chicago Press; University of Colorado, Boulder; University of Hawaii, Water Resources Research Center; University of Idaho; University of Illinois, Urbana-Champaign; University of Iowa; University of London; University of Missouri, Columbia; University of Missouri, Rolla; University of Nebraska Conservation and Survey Division; University of Nebraska, Lincoln; University of Nevada Las Vegas; University of Nevada, Reno; University of New Mexico; University of New Orleans; University of North Carolina at Chapel Hill; University of Oklahoma; University of Oregon; University of Puerto Rico; University of South Carolina; University of Texas at Austin, Bureau of Economic Geology; University of Texas, Austin; University of Texas, El Paso; University of Toledo; University of Tulsa; University of Utah; University of Utah Research Institute, Earth Science Laboratory Research Institute; University of Washington; University of Wisconsin; University of Wisconsin, Madison; University of Wisconsin, Milwaukee; University of Wyoming; Utah Department of Natural Resources and Energy; Utah Geological and Mineral Survey; Utah Geological and Mineralogical Survey; Utah Geological Association; Utah Geological Survey;

Vermont Department of Water Resource; Vermont Geological Survey; Virginia Division of Mineral Resources;

Washington Department of Conservation and Development; Washington Department of Ecology; Washington Division of Geology and Earth Resources; Washington Division of Mines and Geology; Washington Division of Water Resources; Washington Geological Survey; Washington State University; West Virginia Geological and Economic Survey; West Virginia Geological Survey; Western Michigan University Department of Geology; Willard Owens Associates, Inc.; Wisconsin Geological and Natural History Survey; Wright State University; Wyoming Geological Association; Wyoming State Geological Survey;

Yale University.

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