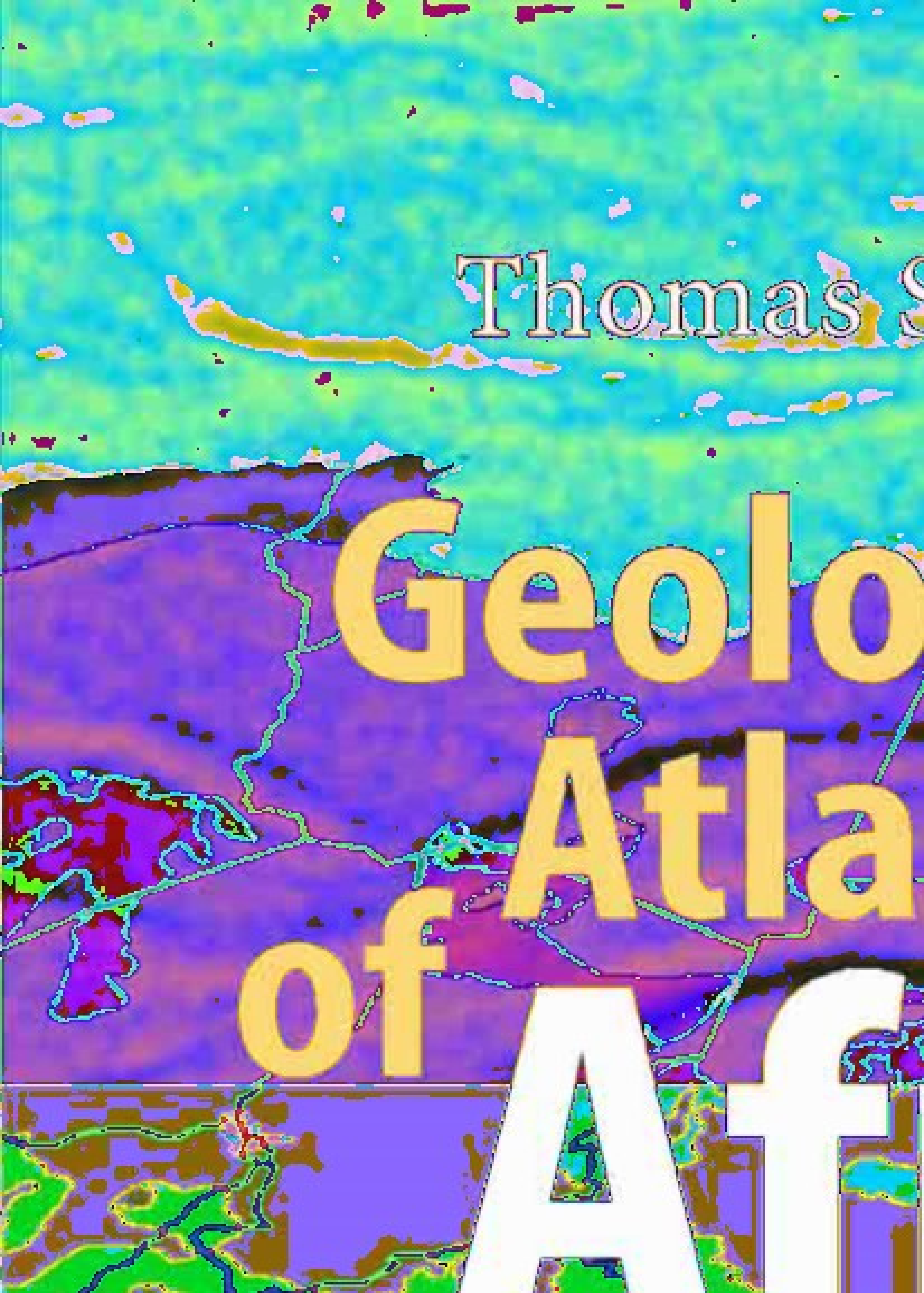
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Thomas Schlüter
Geological Atlas of Africa

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Geological Atlas of Africa

With Notes on Stratigraphy, Tectonics, Economic Geology, Geohazards and Geosites of Each Country

With contributions by Martin H. Trauth

With 249 Figures and a CD-ROM

Springer

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Preface

This atlas is intended primarily for anybody who is interested in basic geology of Africa. Its originality lies in the fact that the regional geology of each African nation or territory is reviewed country-wise by maps and text, a view normally not presented in textbooks of regional geology. It is my belief, that there has long been a need in universities and geological surveys, both in Africa and in the developed world, for summarizing geological maps and an accompanying basic text utilising the enormous fund of knowledge that has been accumulated since the beginning of geological research in Africa in the mid–19th century. I hope that, in part, the present atlas may satisfy this need.

The idea to compile the atlas resulted from my teaching experience at African universities for more than 20 years, and after I had witnessed that my colleagues there often had no access to geological overview maps, references and literature of other African countries, sometimes badly needed for teaching purposes. In western eyes Africa is often perceived only as a land of adventurers and explorers, but while Africa is undeniably diverse and different, it has never been a lost continent – only unfamiliar, underappreciated, misunderstood or forgotten. Anybody who has ever gone to Africa has taken a part of it away and left something behind. The results have not been always good, nor have they always been bad, but they have all gone into the mix that makes up the African society. The atlas is therefore intended to build capabilities and capacities at various places in Africa, so that the people there can later continue on their own with what I had begun.

The atlas is subdivided into four chapters centering on regional geological aspects of each African country or territory. The first chapter defines the scientific issues involved in the preparation of the atlas and provides some background for the arrangement of how the atlas was done. The second chapter is devoted to the history of geological mapping in Africa, necessary for a fuller appreciation of why this work in Africa is worth doing. Chapter 3 provides an executive summary on the stratigraphy and tectonics of Africa as a whole, i. e. in the context of no political boundaries. The main part of the atlas lies in Chapter 4, where in alphabetical order each African country or territory is presented by a digitized geological overview map and an accompanying text on its respective stratigraphy, tectonics, economic geology, geohazards and geosites. A short list of relevant references is also added. The atlas, essentially devoted to African geology, offers in a condensed way data on all aspects of current geoscientific issues that may in future contribute to the development of this continent.

Nairobi, February 2005 Thomas Schlüter

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Chapter 1

Aims and Concepts of the Atlas

1 Geological Maps

The production of a geological map of a certain area is a means of making understandable the geology of this area in a relatively simple way. On such a map different rock types or related groups of rocks are represented, and these are shown as having formed at various periods during the history of the Earth. Each of these rocks formed under, or has been affected by, a definite set of conditions. Some of the rocks that are exposed at the surface today must at one stage have been deep down in the crust. Other rock types are from old mountain chains or old volcanoes. Some of the rocks formed under cold, glacial conditions, others in deserts, some in swamps, and many obviously under the sea. It is the piecing together of all the available information about the rocks themselves that will provide a picture of the geological development of each particular country or territory in this atlas.

Mapping of any topic has a long history. The oldest maps were probably drawn on sand thousands of years ago, whereas the most recent kind of maps are being created via the World Wide Web and can be sent to someone's mobile phone. There is, however, an inherent problem of maps: they are short-lived and need to be updated regularly. The geological atlas of Africa is aimed at compiling, enriching and updating the geological information that already exists, but which is distributed in a scattered way and often not available.

Production of the here presented geological atlas of Africa had to cope with discrepancies and differences on the following aspects:

- *Level of detail*; meaning that there are differences of details in the maps used as sources.
- *Map scales*. Due to the format used for the atlas, comparatively small countries appear in a very different scale than those that are larger.
- *Harmonization of legends*. All the geological maps used as sources have different colours for particular rock units and different definitions of stratigraphic and tectonic terms. The Global Stratigraphic Chart of the International Commission on Stratigraphy (ICS), published jointly by the International Union of Geological Sciences (IUGS) and UNESCO in 2000, indicates the international terms of the stratigraphic units currently in use, their relative and absolute age, and the respective colours of each unit, which shall be adopted for geological maps. However, these principles were in practice not always applicable in the geological atlas of Africa. To compensate this, additionally for a better discrimination in the here presented overview maps often colours used by the United States Geological Survey (USGS) were also applied.

2 Accompanying Text

The atlas seeks to portray the geology of each African country or territory as a whole, therefore apart from the digitized maps an accompanying text is included, which specifically is related to the stratigraphy and tectonics, economic geology, geoenvironmental hazards and geosites of each particular country or territory. Due to the available data it has rarely been possible to provide details significant at a regional level, and almost never at a local level.

2.1 Stratigraphy and Tectonics

As the text of the atlas tries to describe the geology of each African country or territory, it is basically related to their stratigraphy and tectonics, thus by building up a chronological sequence of events or processes through geological time. Once the sequence and the structure of a certain area are known, also the sequence of events and processes can be determined. To do this effectively involves, however, utilizing information and principles from virtually all of the diverse branches of geology. This is provided in the accompanying text on stratigraphy and tectonics for each country or territory, but it has to be considered that there exists for each country or territory its own geological nomenclature, based on the limited regional occurrence of certain rock types (Burollet, 2004).

2.2 Economic Geology

The 52 independent nations and six other territories of continental Africa and adjacent islands considered in the atlas are home for about 850 million people (2004). For many of these countries mineral exploration and production constitute significant parts of their economies and remain keys to future economic growth. Africa is richly endowed with mineral reserves and ranks first or second in terms of concentration (20% to 80%) of world mineral reserves of bauxite, chromite, cobalt, coltan (columbite-tantalite), diamond, gold, manganese, phosphate rock, platinum-group metals (PGM), titanium minerals (rutile and ilmenite), vanadium, vermiculite and zirconium (Coakley & Mobbs, 1999).

Although the continent attracted significant investment in mineral development, particularly in the gas and oil sector, widespread civil wars, internal ethnic or political conflicts and refugee displacements continued to destabilize a number of African countries and constrained new investment in mineral exploration and development in many areas. Countries directly affected in 2003 included Algeria, Angola, Burundi, the Democratic Republic of Congo, the Republic of Congo, Eritrea, Ethiopia, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Nigeria, Rwanda, São Tomé and Principe, Sierra Leone, Somalia, Sudan, Uganda and Zimbabwe. Negative economic impacts that resulted from the burden of military assistance provided to different sides of the civil war in the Democratic Republic of Congo were also felt by Angola, Namibia, Rwanda, Uganda and Zimbabwe.

The long-term implication of the AIDS epidemic on the workforce presents another disincentive to foreign investment and economic development on the continent. In several southern African countries, from about 20 to 35% of the working age population are infected. AIDS is increasing the operating costs for the mining sector in many countries, where the social welfare and health-care costs of employees are absorbed by the mining companies (Smart, 2004).

International mineral exploration companies, in general, were cutting exploration expenditures over the last decade, some down to the minimum required to hold leases. Additionally, the lack of skilled labour remains a significant factor in the slow pace of mineral project development. The information on economic geology provided in the atlas is adopted from various informal sources and may not always be reflecting the last state of art of exploration and exploitation of the respective mineral resources.

2.3 Geoenvironmental Hazards

Although natural hazards and disasters seem to be inevitable, their catastrophic impact can be considerably reduced through various methods of pre-disaster planning and post-disaster reconstruction and rehabilitation. In many developing countries, characterized by heavy concentration of population, shanty towns, slums and marginal settlements, a natural hazard or disaster can lead to grave consequences even where its initial impact is not very severe. In this context the following distinctions have to be made for future planning exercises, and it is important to distinguish between hazards, disasters and emergencies: A *hazard* is a rare or extreme event or process in the natural or human environment that has the potential adversely to affect human life, property or activity to the extent of causing a disaster.

A *disaster* is the occurrence of a sudden or major misfortune, which disrupts the basic fabric and normal functioning of a society or community. An *emergency* is an extraordinary situation, in which people are unable to meet their basic survival needs, or there are serious and immediate threats to human life. Disasters and emergencies are therefore the consequences of hazards and may always be taken as the potential results of hazards. The following three categories reflect the types of hazards, which are considered and addressed in the atlas:

- Geophysical hazards, including earthquakes, landslides, volcanic eruptions and mudflows
- Environmental hazards, including erosion and desertification
- Geochemical hazards, including natural contamination of soils and human-made pollution by mining and other activities

Disaster management requires response, incident mapping, establishing priorities, developing action plans, and implementing the plan to protect lives, property and the environment. Mapping and information acquisition is therefore vital for disaster management. Preparation of risk maps is essential for planning effective preparedness and response measures. Available technologies such as GIS and Remote Sensing provide analysis of environmental factors for the identification of potential geohazards and disasters. A comprehensive inventory of the major geoenvironmental hazards of the African countries has not yet been made, and it is therefore aimed in the atlas that there should be more efforts directed towards the development of an integrated geographical information system amongst various governmental institutions and non-governmental agencies that will help to minimize the effects of hazards and disasters.

2.4 Geosites

Across the whole continent of Africa there are many examples of landscapes, rocks and fossils that provide key evidence of a particular moment or period in Earth history. Such Earth heritage sites are important for educating the general public in environmental matters. They also serve as tools for demonstrating sustainable development and for illustrating methods of site conservation as well as remembering that rocks, minerals, fossils, soils, landforms and activities like mining form an integral part of the natural world. However, it is only since 1996 that the International Union of Geological Sciences (IUGS) and UNESCO have been sponsoring the global GEOSITES project, which is aimed at compiling a global inventory of important geological sites of both scenic and scientific value.

Why is the preservation of geosites of importance? Firstly, in some instances the significance of certain sites for aesthetic or tourism reasons is obvious. There are numerous geosites, which could contribute to effective exploitation of geotourism, often in conjunction with ecotourism. The strategy employed to such sites involves close consultation with all communities in the vicinity of the respective geosite and is not only aimed at tourism and education, but also at sustainable improvement of the infrastructure of the people of this area. Geological heritage sites, properly managed, can generate employment and new economic activities, especially in regions in need of new or additional sources of income. Secondly, geosites are a medium of education, with regard to natural sciences, but also with respect to the mining industry and to history. This aspect involves such subjects as neoarchaeological and mining geological heritage. In Africa it is only South Africa, where an active community of geoconservationists has already provided an inventory of geosites in the country, which are examplary described and well-illustrated in the book of Viljoen and Reimold (1999).

3 Conclusions

As already outlined in the epilogue for the Gondwana 10 Symposium (Cape Town 1999) by Ashwal and De Wit (2000), much of the research work that currently takes place in Africa is done by non-Africans. The reasons for this are complex and involve sociological, political and financial elements. Africa as the focal area of Gondwana has apparently been rediscovered in recent years, and it is therefore vitally important that this interest and research effort from countries external to Africa is balanced against a growing interest from within the continent. Under ideal conditions, scientists from the first world should consider their counterparts in the south as full and equal colleagues, but this is often not the case. This is especially important in the acquisition, handling and sharing of large and frequently disparate datasets. Considerable responsibility also rests on the shoulders of geoscientists, who live in Africa, to communicate amongst themselves, not only to welcome colleagues from outside the borders of their countries, but also to maintain and enhance their passion for a collaborative effort in understanding this spectacular natural laboratory. It is therefore the aim of this atlas to contribute to capacity building and extended communication in African Earth Sciences, both within the continent and outside, and to initiate new research opportunities by providing a database of basic geological background information of this continent.

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Chapter 2

Early Geological Maps of Africa

William Smith (1769-1839), an English engineer and surveyor, began at the end of the 18th century to collect fossils from successive beds, which he had observed in the course of his journeys across England. He realized that each stratum could be recognized by the fossils found in it, and that the same succession of strata could be observed wherever the rocks concerned were found. In 1815 appeared as a result of his investigations the large geological map of England and Wales with an accompanying explanation. This is the earliest large-scale geological map of any extensive area or country (Winchester, 2001), although similar efforts had already been made since the late 18th century in Saxony by A. G. Werner (Wagenbreth, 1998). A preceding attempt of these early scientific geological maps should here, however, be mentioned, because of its origin in Africa: Undoubtedly existed in ancient Egypt a highly developed surveying and engineering system, but unfortunately almost no cartographic proof of it is known - except a map drawn on a papyrus, which is currently kept in the Museo Egizio in Turin. It was apparently prepared during the 19^{th} Dynasty under the reign of the Pharaoh Sethos I, together with his son Ramses II, who had to initiate new mining operations for gold in the Eastern Desert of Egypt, because the traditional nearer accessible supplies had been exhausted. One of these areas for exploration may have been in the Wadi Hammamat and is figured on the Turin Papyrus, exhibiting apart from topographic details also the occurrence of silver and gold bearing deposits (Bowen & Jux, 1987) (Fig. 1). It is therefore a kind of a geological map, surely the oldest known attempt to draw somehow geological units.

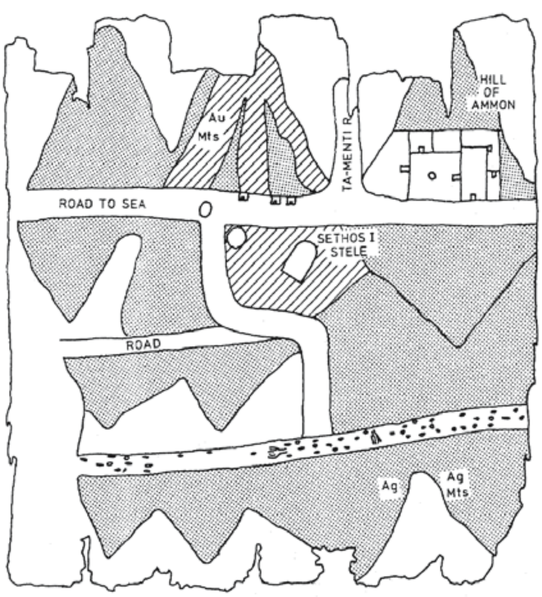

Fig. 1 Pharaonic map of gold mining areas in Wadi Hammamat, Eastern Desert, Egypt

The oldest scientific geological map of Africa originates also from Egypt and was already compiled by R. Russeger in 1842 (Fig. 2). The term “Nubian Sandstone”, which characterizes mainly continental and sandy deposits, and which is still in use today, is mentioned for the first time in this map. Until recently, this chronolithological unit was considered to be stratigraphically indivisible. Recent research has shown that these rock sequences comprise differentiated strata containing intercalations of marine sediments.

Fig. 2 Geological map of Egypt, published by Russeger (1842)

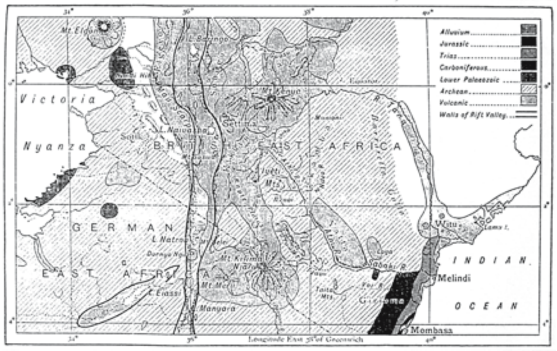

Fig. 3 Geological sketch map of the southern part of the Kenya Colony and the northern part of former German East Africa (from Gregory, 1896)

Geological maps have sometimes been produced without proper knowledge of the topography of the concerned area, as can be seen from the geological map published by Sadebeck (1872) on East Africa, in which the Great Lakes region of central eastern Africa is very poorly figured, but surely because the famous explorers like Livimgstone, Stanley, von Höhnel had not yet reported about their discoveries there. In 1880 the Scotsman Joseph J. Thompson presented in the journal Nature the first geological field account of a sector of the East African Rift System, that of Nyanza, in which he included three cross sections. As a result of his traverses Thompson postulated a zone of volcanism extending from the Cape to Ethiopia,roughly parallel to the Indian Ocean. From 1883 to 1886 the German naturalist Gustav A. Fischer mapped the rift grabens of southern Kenya and northern Tanzania. Notably is a detailed geological map at a scale 1:50,000, which he included in his 1884 publication. Less than 15 years later Gregory (1896) was already able to draw a rather comprehensive and exact picture of the geology of the Kenya Colony and the northern part of the then German East Africa (Schlüter, 2001) (Fig. 3). Similarly in the grade of accuracy has also the geological map of the Karoo Basin and adjacent areas in southern Africa been prepared (Rogers, 1905) (Fig. 4). The stratigraphic sequence of the Karoo System (or Supergroup as it is termed today), subdivided into Dwyka, Ecca, Beaufort and Stormberg Series, had already been established, and their paleoenvironment carefully evaluated.

There is, however, one aspect that was largely omitted by the pioneering geologists of the late 19th century almost up to the middle of the 20th century: The Precambrian basement comprises by far the largest share of rocks on the continent, but often the monotony of facies as well as the inability to date these formations sufficiently were probably the two striking reasons, why comparatively few publications on the Precambrian strata were published. Geologists of this time had no other tools than lithostratigraphic comparisons, which, of course, were not sufficient to correlate these formations precisely. Arthur Holmes (1890-1965), whose book "The Age of the Earth" had already appeared in 1913, was a scientist, who devoted a major portion of his career to the application of radioactivity in the solution of geological age dating. It is remarkable that his calculations and hence resulting definition of the Mozambique Orogenic Belt

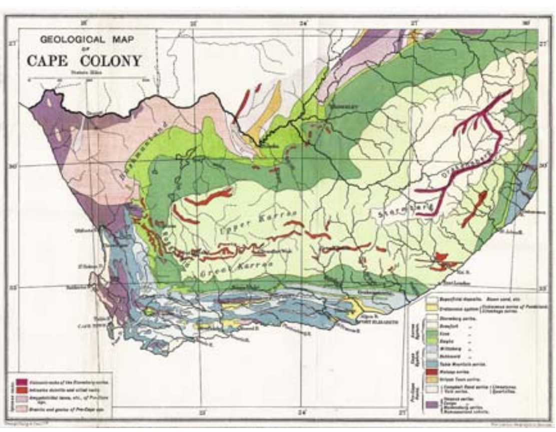

Fig. 4 Geological map of the Cape Colony (from Rogers, 1905)

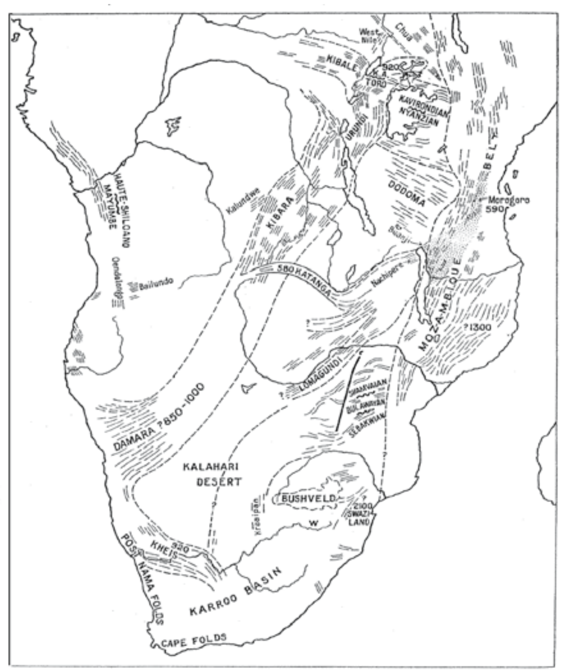

Fig. 5 Orogenic belts in southern and central Africa as proposed by Arthur Holmes in 1948 (Holmes 1951)

were based on less than 25 radiometric ages, when he gave his memorable address to the association of African Geological Surveys at the International Geological Congress in London in 1948 (Holmes, 1951). He provisionally dated the Mozambique Orogenic Belt to be approximately 1,300 Ma old, an age today indicative for the Kibaran Orogenic Belt, but at least much younger than the previously assumed Archean age. Therefore, when Holmes defined the Mozambique Orogenic Belt as extending from south of the Zambezi River to the extreme north of Kenya, Uganda and southern Ethiopia, the stratigraphic and structural map of equatorial and southern Africa received a new face (Fig. 5), which basically still holds today. In a compilation prepared by Arthur Holmes and Lucien Cahen (1912-1982), the latter being another father of Precambrian stratigraphy of Africa, in 1954, the number of radiometric ages in Africa had grown to approximately 100, and by 1956 the same authors were able to list about 300 ages. In their summarizing book "The Geochronology of Equatorial Africa", Cahen and Snelling (1966) considered more than 550 determinations. During the early fifties, the K:Ar and R:Sr methods had been established on a virtually routine basis, while the older U-Pb method had become even more firmly entrenched.

On the other hand it has to be pointed out that Cahen et al. (1984) in their famous and, currently probably most cited book on the Precambrian stratigraphy of Africa, are of the opinion that much of the former isotopic evidence is of relatively poor precision, and that the data obtained for the variation of initial 87Sr:86Sr ratios through place and time with respect to Africa will probably soon become only of historical interest. Accordingly, also the abundant U-Pb data achieved before 1984 should for similar reasons largely be ignored. Cahen et al. (1984) predict for future stratigraphic investigations isotopic variations of strontium, lead and neodymium, whereas they are skeptical about palaeomagnetic studies.

Publication of quarter degree sheet geological mapping at various scales began in Africa since the beginning of the 20th century, sometimes only in the 1930s, and was linked to the establishment of Geological Surveys in the respective countries. It was assumed that these institutions might provide sound and reliable geological maps as a basic prerequisite for the development of potential mineral resources. It was during the colonial administration also anticipated that private mining companies were not expected to take serious interests in initiating detailed mineral exploration projects before having at their disposal geological maps indicating the nature, distribution, composition and structural relationships of the various rocks in the respective areas. Geological maps were prepared predominantly in a scale 1:125,000, sometimes 1:100,000. Some geological maps with various aims in a smaller or a larger scale were sometimes also issued. Quarter degree sheet mapping of Africa has, however, never been completed, and it has to be pointed out that the advent of independence for most African countries in the 1960s and the cease of publication of geological maps from there are almost coincident. For example, although about 80% of Tanzania is now geologically mapped, only 116 of the foreseen 322 map sheets have yet been published, mostly because there are currently no sources for their printing available.

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Chapter 3

Tectonostratigraphic Synopsis

1 Introduction

Africa encompasses a land area of 30.3 million km^2, occupying about one-fifth of the land surface of the Earth. From a geological viewpoint it is a very old continent spanning at least 3,800Ma of the Earth' history. Practically the whole of the continent is underlain by Precambrian basement. Phanerozoic cover rocks are only of limited areal extent. The following executive summary on the stratigraphy and tectonics of Africa in a comprehensive context is mainly based and adopted from papers published by R. Key (1992), A. J. Boucot (1999) and A. B. Kampunzu & M. Popoff (1991).

The crystalline basement of Africa is composed of metasedimentary, meta-igneous and igneous rocks, which vary in age from Paleoarchean to Cenozoic times. Within the Precambrian crystalline blocks, granitic-gneissic greenstone belts of the Archean cratonic nuclei are surrounded by essentially Proterozoic orogenic provinces often referred to as mobile belts. Parts of the crystalline basement are igneous intrusions associated with anorogenic magmatism. The heterogeneous basement is extensively concealed beneath a variable thickness of diverse, essentially unmetamorphosed supracrustal cover rocks. These also vary in age. The oldest cover rocks are the Archean and Paleoproterozoic sedimentary and volcanic sequences capping the Kapvaal Craton: the Pongola, Witwatersrand, Ventersdorp, Transvaal-Griqualand West and Waterberg-Soutpansberg-Matsap Supergroups. The youngest cover sequences include the Cenozoic volcano-sedimentary deposits associated with rifting, notably within the East African Rift System, and the partly consolidated sediments, such as the Kalahari Supergroup, currently infilling the major crustal depressions.

2 Archean Cratonic Nuclei (Fig. 6)

2.1 General

Large parts of the Congo Craton and of the cratonic nuclei in western and northern Africa are covered mainly by unconsolidated Cenozoic deposits. This means that their geological histories and areal limits are imperfectly known. The western part of the southern African Archean province is also concealed by up to 200m of the Kalahari Supergroup, but geophysical studies and subsequent drilling operations have established its main geological components. Detailed geological mapping and geochronological studies have shown that all the Archean cratons have been reworked, at least marginally, during several Proterozoic orogenesis. The principal components of the Archean cratonic blocks (excluding the Limpopo Mobile Belt between the Kapvaal Craton and the Zimbabwe Craton) are predominantly low-grade greenstone belts, extensive areas of high-grade gneisses, granitic series including several phases of migmatites, and usually ending with anorogenig K-granites, and late minor intrusions.

2.2 Greenstone Belts

Two sequences of greenstone belts are generally recognized in the major cratonic nuclei except the Kapvaal Craton, which prematurely stabilized (at about 3,050Ma) prior to the formation of the second generation of belts. The oldest greenstones were laid down between about 3,550Ma and about 3,050Ma. They commonly have precursor gneiss foundations, which include definite metasedimentary components. Within these greenstone belts there are essentially single cycles from basal, mainly basic, volcanics with diagnostic high-MgO rocks (komatiites), upwards into clastic sediment-dominated sequences. They are best preserved on the Kaapval Craton and central parts of the Zimbabwe Craton. The Barberton Greenstone Belt in northeastern South Africa and Swaziland serves as an excellent example of the lithological content of the older belts. Unusually, the older volcanics of the Tanzania Craton, referred to the Nyanzian Group, may have a higher proportion, up to 75% of the volcanic pile, of andesites, although it is doubtful if the lower part of the Nyanzian is ever seen. The younger greenstone belts were laid down between about 2,800Ma and about 2,600Ma. They appear to be slightly older in the West African Craton relative to the central African cratons, although there was a minor development of greenstone belts on the Zimbabwe Craton at about 2,950Ma. All these belts again comprise single volcanic cycles from basal basic lavas up into more felsic pyroclastics. Both bimodal and calc-alkaline volcanic sequences are recognized. Bimodal assemblages are found in the basal parts of younger belts and contain abundant mafic and ultramafic rocks with minor felsic volcanics and cherts and very little andesitic material. Upper volcanics in younger belts have calc-alkaline affinities and vary from ultramafics through andesites to felsic rocks with associated greywackes. Mineral variations are used to distinguish up to six types of amphibolites (altered mafic volcanics). However, they have similar whole rock chemistries, which closely correspond to oceanic tholeiitic basalts.

Sedimentary sequences are important in the youngest greenstone belts, e. g. the Shamvaian Group on the Zimbabwe Craton, the Kambui Supergroup of West Africa, the Kavirondian Group of the Tanzania Craton, and the upper Congolian Group of the Congo Craton. The sediments consist of intercalated beds and lenses of chemical and clastic deposits, which form highly variable proportions of greenstone belts within individual cratons. Thus, although the average proportion of metasediments within the younger greenstone belts of the Zimbabwe Craton is about 15%, the Vumba Greenstone Belt contains minor metasediments, while the adjacent Tati Greenstone Belt has major metasedimentary formations. Typical metasediments in the greenstone belts are Algoma-type banded iron formations (BIF), marbles, calc-silicates, metaquartzites, coarse clastic rocks (conglomerates, arkoses, etc), aluminous shales, black shales, greywackes and reworked volcaniclastics. These show wide grain-size variations and are chemically varied. The ironstones have along-strike facies variations from chert-hematite/magnetite associations into carbonates and sulphides. Typical greenstone belt mineralizations are indicated by gold dissemination in the metavolcanics or concentration in fracture-controlled veins, or by volcanogenic base metal deposits. The greenstone belt terrains have distinctive hilly landscapes controlled by the varied bedrock.

Greenstone belts are least common in the Kaapvaal Craton, where only the oldest are represented, and most common within the Zimbabwe Craton and northern half of the Tanzania Craton. The belts are broadly linear throughout the West African Craton and are of higher metamorphic grade (up to granulite facies). Within other cratonic domains, the greenstone belts have only suffered greenschist facies metamorphism apart from marginal zones at amphibolite facies. It is possible that the high-grade West African greenstone belts represent disinterred basal remnants. The varied distribution of the greenstone belts of up to 20% by area of each craton, may be due to a combination of tectonic disruption and variable erosion. At deeper crustal levels granitoid rocks may dominate, especially if the greenstones are compressed within tight synclinal folds.

2.3 Granitic Series (Including Gneisses) and Late Minor Intrusions

Granites, roughly contemporaneous with spatially associated greenstone belts, are recognized in the main cratonic nuclei. Two main granitic series are recognized, one encompassing igneous activity between about 3,600Ma and about 3,100Ma, and the second between about 2,950Ma and 2,450Ma. The older series commenced with high-grade migmatites, which are certainly as old as the adjacent greenstone belts (e. g. the Ancient Gneiss Complex of Swaziland), or older as the basement in the central African cratons. Metasediments and orthogneisses are present in the early migmatites, which are recognized on all the cratonic nuclei. However, the succeeding intrusions have only been mapped and placed into a chronological order in the southern African cratons. Here various major synorogenic tonalitic and trondhemitic intrusives cut the early migmatites and older greenstone belts and were succeeded by anorogenic potassic granite plutons. The early sequence is repeated by the second granite series, characterized by calc-alkaline trends, which is much more widely recognized. The migmatites, which floor younger greenstones generally record ages of about 2,950Ma, or they are slightly younger. The succeeding granitoid intrusives generally show progressive increases in K_2O/Na_2O ratios from early tonalitic plutons to anorogenic potassic granites. These relatively sodic, early rocks underlie featureless plains, whereas the later G3 plutons form positive outcrop features, locally with a thick saprock. The relatively high potassium content and the abundance of quartz means that the saprock is not broken down into a thick soil cover. The emplacement of the potassic granites generally marks the end of the Archean orogenesis. This was a diachronous process, from about 3,050Ma (Kaapval Craton) to about 2,600Ma for the Zimbabwe Craton and about 2,450Ma for the central African cratons.

2.4 Tectonothermal Events

Complex vertically plunging structures dominate the early (3,600-3,200Ma) African cratonic areas. However, detailed studies of the younger Archean cratonic areas have revealed polyphase tectonothermal histories similar to those established for Phanerozoic orogenic belts. Regional folding produced nappes followed by static metamorphism and emplacement of tonalitic plutons into folded metasedimentary

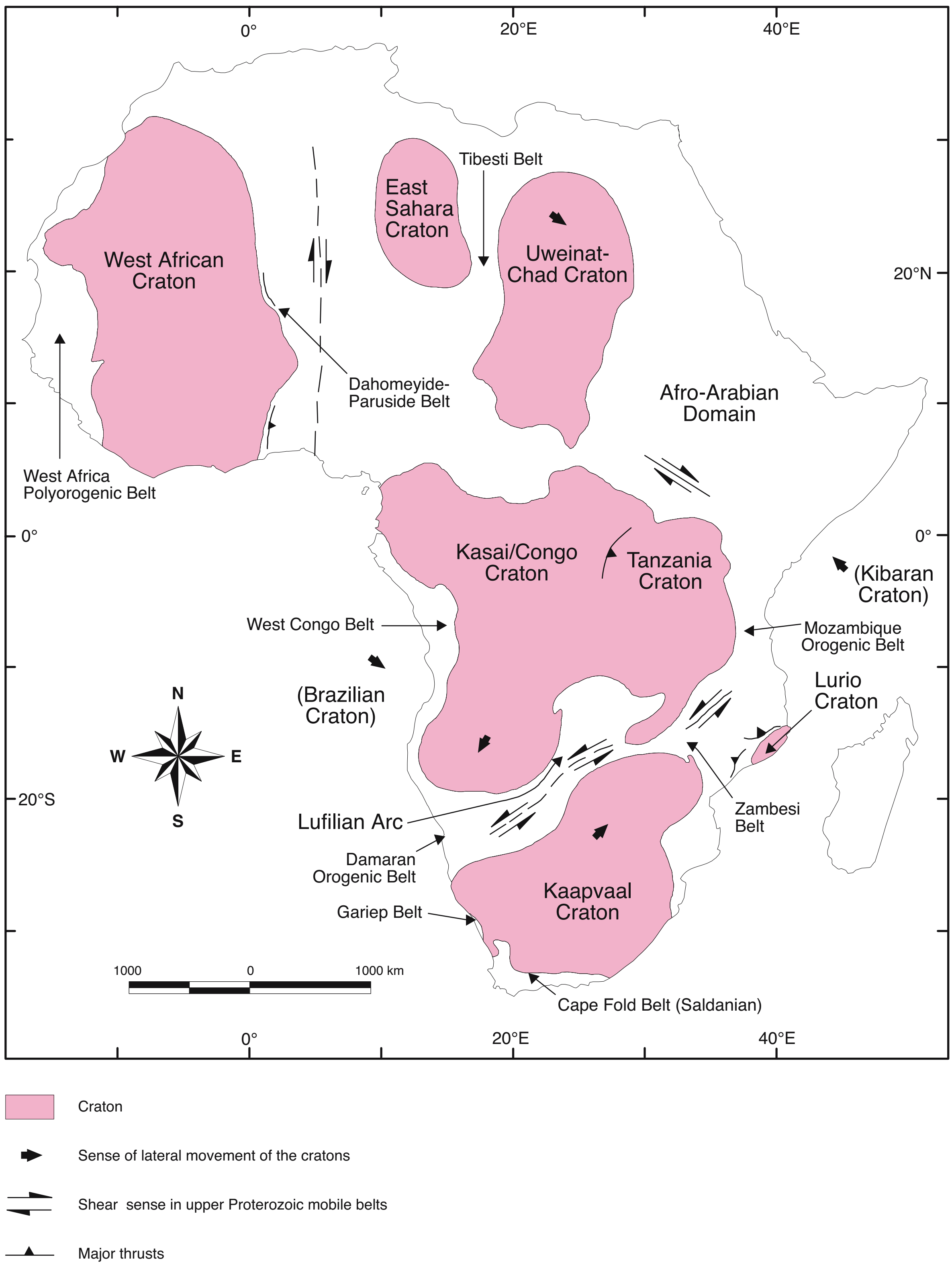

Fig. 6 Assumed extension of the Archean cratonic nuclei (after Key, 1992)

and metavolcanic rocks. After these early events the greenstone belts were isolated as relatively low-grade schist relics within higher-grade gneisses. Further ductile and subsequently brittle tectonothermal events were roughly contemporaneous with the final phase of the granite series. Although the final tectonothermal events were relatively weak compared to higher-grade earlier events they have a critical influence on groundwater storage. These late events generated open folds and crenulations in addition to brittle faults and fractures, which are locally important aquifers. Retrogressive metamorphism produced hydrous mineral phases, which made the host rock more susceptible to weathering. The average regolith thickness over the Zimbabwe Craton is about 18m, and is generally from 10 to 30m in West Africa.

Undoubtedly there were unique features to Archean geology caused by secular changes to the lithosphere. The older greenstone belts are thought to have originated above mantle plumes, due to the existence of hotter, thinner and more mobile crust within ensialic rifts. However, the recognition of the similarities of the geological histories of younger (post-3,200Ma) Archean cratons and Phanerozoic orogenic belts has generally led to uniformitarian interpretation of the older provinces. For example, the youngest greenstone belts are regarded as fragments of oceanic volcanic terrains accreted to continental nuclei during orogenesis. Consequently the development of the younger Archean cratons is often likened to that of younger orogenic provinces including the Proterozoic mobile belts recognized in Africa. Tankard et al. (1982) have described an evolutionary path from mobile belt to craton with gradual lateral growth of African continental crust throughout the Precambrian. Key (1992) assumes that this is probably an oversimplification as major disruption of the Archean cratonic blocks took place during the various Proterozoic orogenies and it is still unknown, how much continental crust was present by the end of the Archean.

Strike-slip shears and transcurrent faults, over 100 km in length, are characteristic features of modern lithospheric plates. Their existence indicates relative horizontal movement between adjacent competent crustal/lithospheric segments. Therefore the presence of Archean shears of comparable length can be used as evidence for large, coherent Archean crustal blocks. In Africa, the oldest of these mega-shears is found in the Limpopo Mobile Belt, where they have a maximum age of 3,000Ma. A logical follow-up of this argument is that the early greenstone belts of the Archean areas, which are older than the major shear zones, formed in environments devoid of large stable blocks of continental crust. Their generation cannot therefore be related to Wilson-cycle plate tectonic processes, but they may have originated above mantle plumes.

2.5 The Limpopo Mobile Belt

The Limpopo Mobile Belt trends in a WSW-ENE direction for about 690km with a maximum width of about 200km. It separates the Kapvaal and Zimbabwe Cratons and is dominated by high-grade gneisses and lacks the low-grade greenstone belts, tonalitic plutons and anorogenic potassic granite batholiths normally associated with Archean provinces. Orogenic development between about 3,200Ma and about 2,500Ma was dominated by differential (vertical/strike-slip) movement between the Kaapvaal Craton and the ancient central areas of the Zimbabwe Craton. The Limpopo Mobile Belt may be referred to as a linear buffer zone as typical for Proterozoic mobile belts. The Great Dyke in Zimbabwe (emplaced at about 2,450Ma) cuts across the Zimbabwe Craton-Limpopo Mobile Belt boundary to provide a minimum age for the stabilization of the southern Africa Archean Province.

3 Paleoproterozoic Basement Development (Fig. 7)

During this period in excess of two thirds of the present African continental crust was affected by a similar sequence of events to those recorded from the Archean cratonic nuclei. However, controversy remains with regard to the proportion of Archean material adjacent to the nuclei in the surrounding Paleoproterozoic provinces. This is due mainly to a lack of detailed geological and geochronological knowledge of the Paleoproterozoic provinces, together with poor exposure in many areas, notably northern Africa. However, an increasing amount of isotopic data does imply that a significant amount of new crustal material was introduced around the Archean cratonic cores.

Low-grade supracrustal sequences are more widely preserved than in the Archean cratons. The oldest supracrustals are clastic metasediments derived from Archean cratons during the long period of uplift and weathering at the beginning of the Proterozoic. They include the altered quartzites, pelites and banded ironstones of the Luiza Supergroup of equatorial Africa and the Oendolongo System of southern

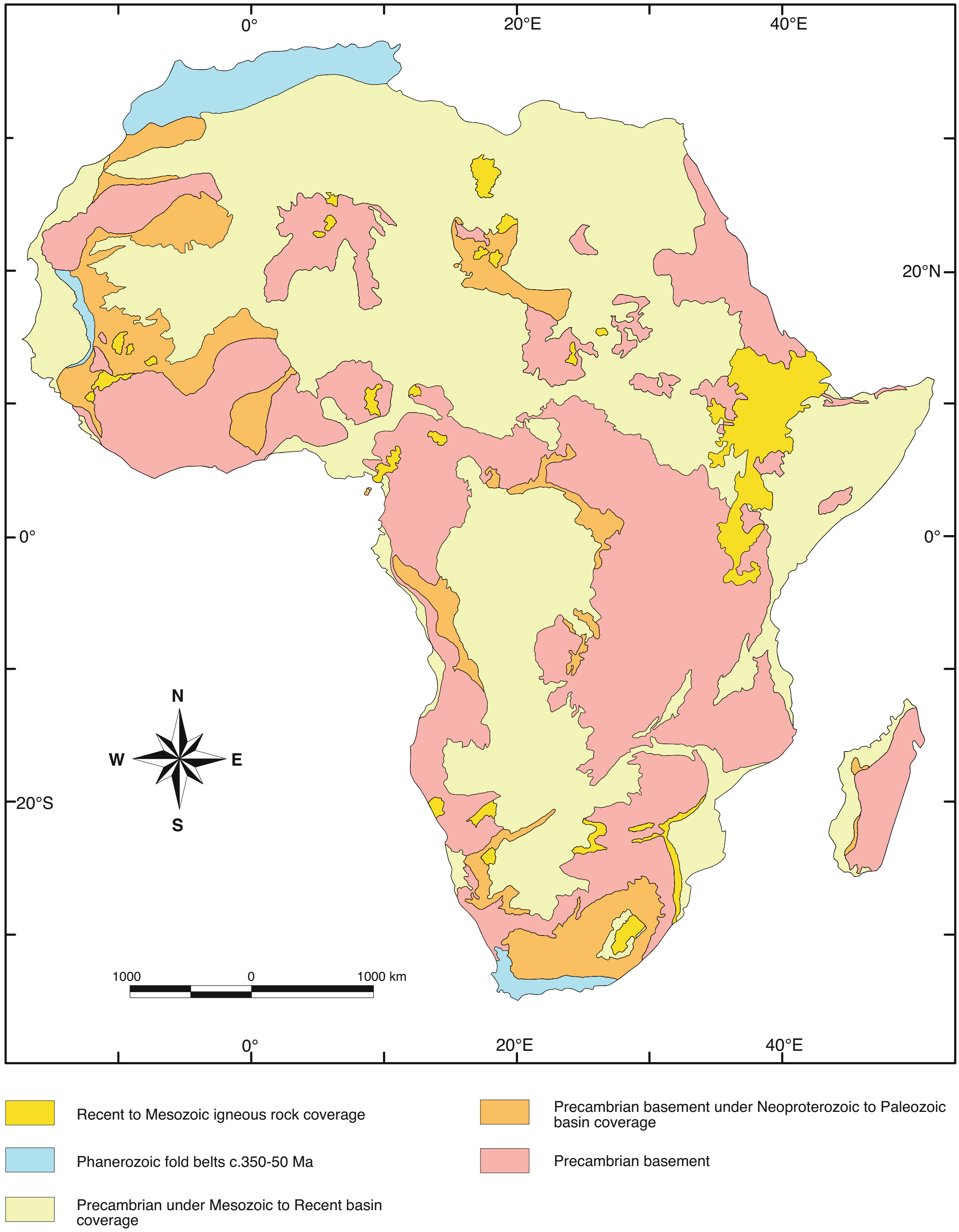

Fig. 7 Exposure of Precambrian rocks, partly under younger coverage (after Key, 1992)

Angola, which is dominated by metaconglomerates. The main supracrustal sequences in the 2,250-1,950Ma orogenic belts are lithologically similar to those of the Archean greenstone belts. These include the Birrimian Supergroup in West Africa (up to 15,000m thick in Ghana), the Mporokoso Group (up to 5,000m thick) of the Bangweulu Block, and the Buganda-Toro Supergroup in eastern equatorial Africa locally interpreted from geochemical evidence, as accreted slabs of ocean crust. The Birrimian Supergroup is characterized in Ghana by five parallel, evenly spaced, several hundred kilometre-long volcanic belts, separated by basins with folded volcaniclastic and clastic sediments as well as granitoids. A lower, thick sequence dominated by alternating phyllites and greywackes with associated slates, schists and tuffs is overlain by a group of volcanics with minor sedimentary intercalations. Basic lavas and associated intrusives, and less common acidic lavas and pyroclastics, comprise the Upper Birrimian Group. The erosion of the Birrimian volcanics and sedments produced the Tarkwaian Group sediments, which were deposited in long narrow intramontane grabens, which formed by rifting in the central portions of all five Birrimian volcanic belts.

Associated with the supracrustals is a wide range of intrusions. Alkaline granite series, featuring early large syntectonic plutons are recognized within the main orogens. These include major granodiorites and potassic granites occupying antiformal zones between synforms defined by Birrimian supracrustals in the Baoule-Mossi Province of West Africa. The large gabbro-anorthosite complexes of southern Angola were also emplaced in the earliest orogenic stages. Migmatites appear to have Proterozoic sedimentary/volcanic rock and Archean components - most easily recognized in marginal zones of the Archean cratonic nuclei. Post-tectonic igneous activity in the orogenic belts is principally restricted to relatively small intrusions of mixed composition. However, contemporaneous anorogenic magmatism is important within the stable Archean provinces. Both the Great Dyke and the Bushveld Igneous Complex were emplaced during Paleoproterozoic times. Dolerite dyke swarms such as the Mashonaland dolerites of central Africa are another distinctive facet of anorogenic magmatism.

As wide a range of tectonic styles is shown in the Paleoproterozoic Eburnian provinces as in the Archean cratons. Some have similar sequences of events to the early cratons with initial ductile elements (Folds and shears) defining regional structural trends, e. g. the SSW-NNE grain of the Baoule-Mossi Province defined by the major synforms in the supracrustal relics. Other areas record major strike-slip movements between bounding cratons. The most impressive structures in all the Eburnian provinces are steeply dipping, brittle fractures (in the intrusives) and faults. The largest faults can be traced for several hundred kilometres, notably in the Tuareg Shield. These faults may have originated as ductile shears of sutures during the early orogenic history, with repeated subsequent movement to include late brittle faulting. The faults tend to be parallel to the regional trend of the orogenic provinces, e. g. N-S to NE-SW within the Baoule-Mossi domain.

The pre-existing stable Archean provinces must have had a profound influence on the evolution of the Eburnian belts of Africa. It is thought that the Paleoproterozoic provinces resulted from either full Wilson-cycle orogenesis, involving collision of separate, relatively small Archean cratons, or ensialic disruption of a single large craton (Kröner, 1981). Post-orogenic gravitational collapse and extension of continental crust thickened by tectonic and/or magmatic processes may have produced some mid-Proterozoic sedimentary basins.

4 Mesoproterozoic Basement Development (Fig. 7)

Orogenic activity was not as widespread as during the preceding period. Two major orogens are recognized: the linear Kibaran Belt of central western Africa and the arcuate Namaqua Province of southern Africa. The Namaqua Province comprises the Namaqua Belt of South Africa, the Choma-Kaloma Block and possibly the NE-SW trending Irumide Belt of central southern Africa. The younger, E-W trending Zambesi Belt separates the Choma-Kaloma Block from the Irumide Block. Elsewhere in Africa, less well documented orogenesis took place in the Mozambique Orogenic Belt. All three provinces are polycyclic with superimposed Pan-African events (complete orogenic cycles).

A large proportion of the Kibaran Belt comprises metasediments, which likely exceed 10,000m in total thickness. The supracrustals are dominated by clastic metasediments with major metaquartzite formations. Less common are limestones and greenstones (basic metavolcanics). Metamorphic grade is generally low within this base-metal mineralized belt. Intrusives include early granitic gneiss complexes as well as

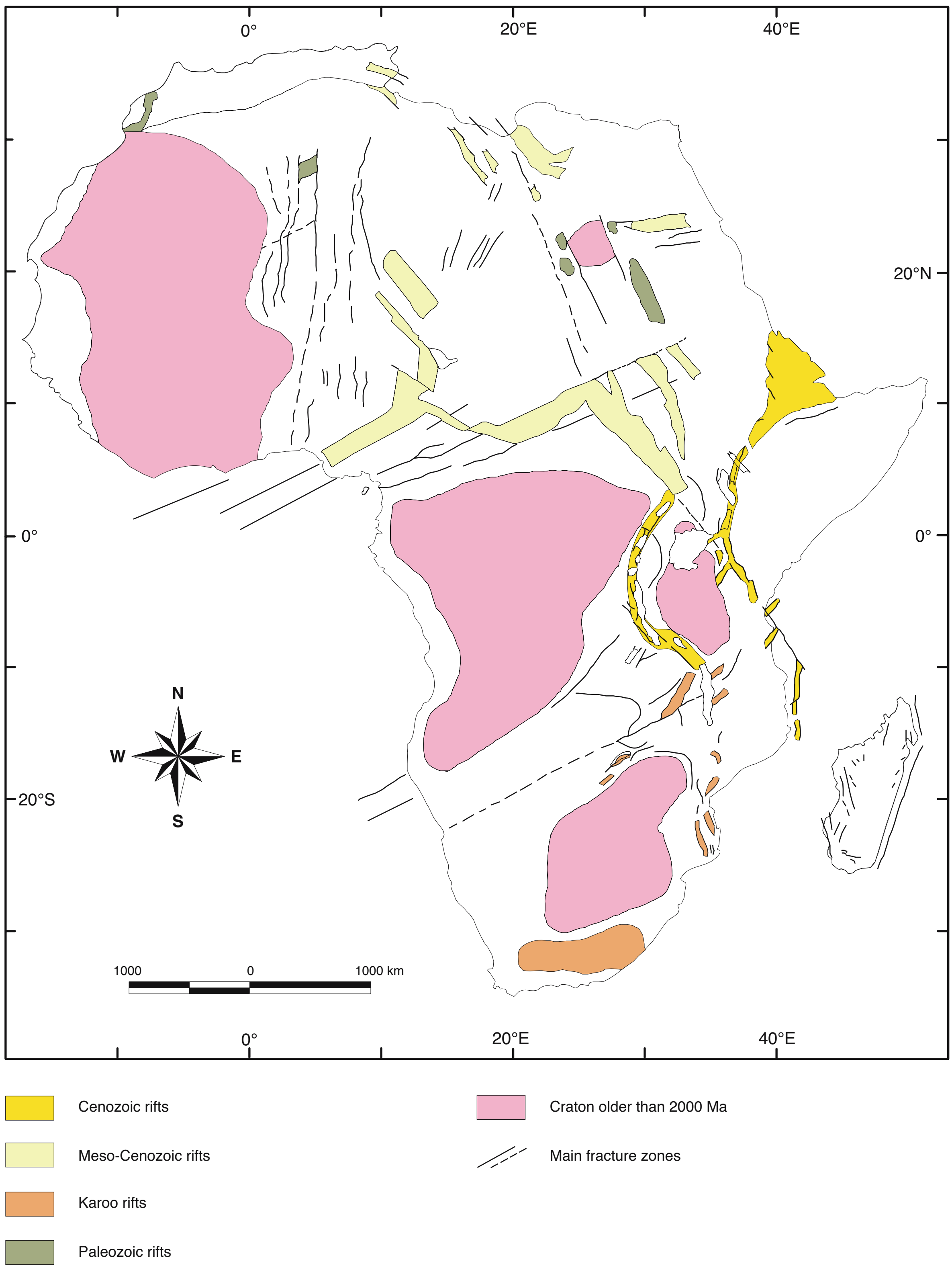

Fig. 8 Main rift structures (after Kampunzu & Popoff 1991)

composite granitoids such as the Choma-Kaloma Batholith of Zambia.

The Namaqua Province is lithologically more varied with tectonic interleaving of basement gneisses, supracrustals and syntectonic sheet-like intrusions all cut by discordant post-tectonic minor intrusions. In this respect it resembles the older Proterozoic crystalline basement provinces. Variable, greenschist to granulite facies, metamorphism associated with tectonic disruption further complicated the lithological diversity. The province is extensively mantled by Neoproterozoic to Recent deposits. The Irumide Belt in Zambia generally consists of coarse clastic metasediments (Muva Supergroup) with possible felsic metavolcanics. In a western foreland zone these overlie the granitoid Bangweulu Block. Further east in Malawi a thicker cover sequence is dominated by metapelites with local carbonates and amphibolite (metagabbro) sheets. These sheets, at least in part, represent altered intrusions and not ophiolite slices. In Malawi, and possibly parts of Zambia, the metasediments are volumetrically subordinate to early granitoid intrusives.

There is geochronological evidence for a Mesoproterozoic basement to the more widespread Neoproterozoic sediments and volcanics in the Mozambique Orogenic Belt from Mozambique, Malawi, Tanzania and Kenya. This basement records a 1,100-1,200Ma old high-grade tectonothermal event. In central Kenya it is dominated by massive migmatites, but a more extensive and varied lithological sequence is described from Mozambique. Here, four separate supracrustal sequences have been tectonically interleaved and cut by various granitoid batholiths. The oldest supracrustal formation comprises gneisses and migmatites derived from calc-alkaline volcanics. The younger units are mixed sequences of fine-grained metasediments and metavolcanics, which include disrupted ophiolites. The granitoid batholiths, which are locally porphyritic, are individually up to 500km^2 in area and form about 25% of the orogenic belt.

Two main periods of polycyclic tectonothermal activity have been defined in the main Mesoproterozoic orogenic provinces. During both periods the earliest major structures are fold and thrust belts, implying compression across the orogens. Ductile shears penetrate through the cover rocks into a crystalline basement, which largely controlled the style of deformation. The associated metamorphism locally reached the granulite facies. Subsequent events produced more upright folds and shear zones with large strike-slip movement, e. g. 200km of dextral displacement across the Gordonia Subprovince in the Namaqua Province. Contemporaneous strike-slip faulting in adjacent reactivated older belts compensated for shortening in the main orogens, e. g. major NW-SE sinistral strike-slip faulting in the Ubendian Belt during oblique compression across the Irumide Belt.

The recognition of uplifted blocks of basement in the Kibaran Belt influenced early models for the evolution of the Mesoproterozoic mobile belts as ensialic rifts along intracratonic zones of crustal weakness. However, subsequent detailed structural studies in southern and central Africa indicate that the orogenies also involved considerable crustal shortening. Their stepwise evolution comprised:

1. Crustal extension.
2. Crustal shortening to produce fold and thrust belts, which tectonically interlayered sedimentary and volcanic supracrustal rocks and some sialic basement.
3. Post-collision strike-slip faulting, upright folding and retrogressive metamorphism
4. Uplift and erosion to commence the next orogenic cycle (of Neoproterozoic) in parts superimposed on all the Mesoproterozoic belts.

5 Neoproterozoic Basement Development (Fig. 7)

By the end of the Neoproterozoic period almost all of the present African continent had formed, and it has remained a stable cratonic area after polyorogenic activity in well defined belts. Cahen et al. (1984) record widespread tectonothermal activity in the orogenic belts at about 950Ma, 785Ma, 720Ma, 685-660Ma and from 600 to 450Ma. Four major lithological components are variably present in the main orogenic belts, as follows.

Clastic and chemical sedimentary rocks with important fluvio-glacial deposits and stromatolitic limestones (e. g. in the Voltaian and Togo Belt of West Africa, the Limestone and Quartzite Group of Morocco and the Damar metasediments of Namibia). In some cases these rocks are at very low metamorphic grades and should not strictly be regarded as part of the crystalline basement.

Volcanic rocks either as minor intercalations in thick sedimentary sequences or as important volcano-sedimentary provinces tectonically interleaved with the sedimentary sequences. The major volcanic assemblages include the disrupted island arc/ ophiolite sequences found in northeastern and

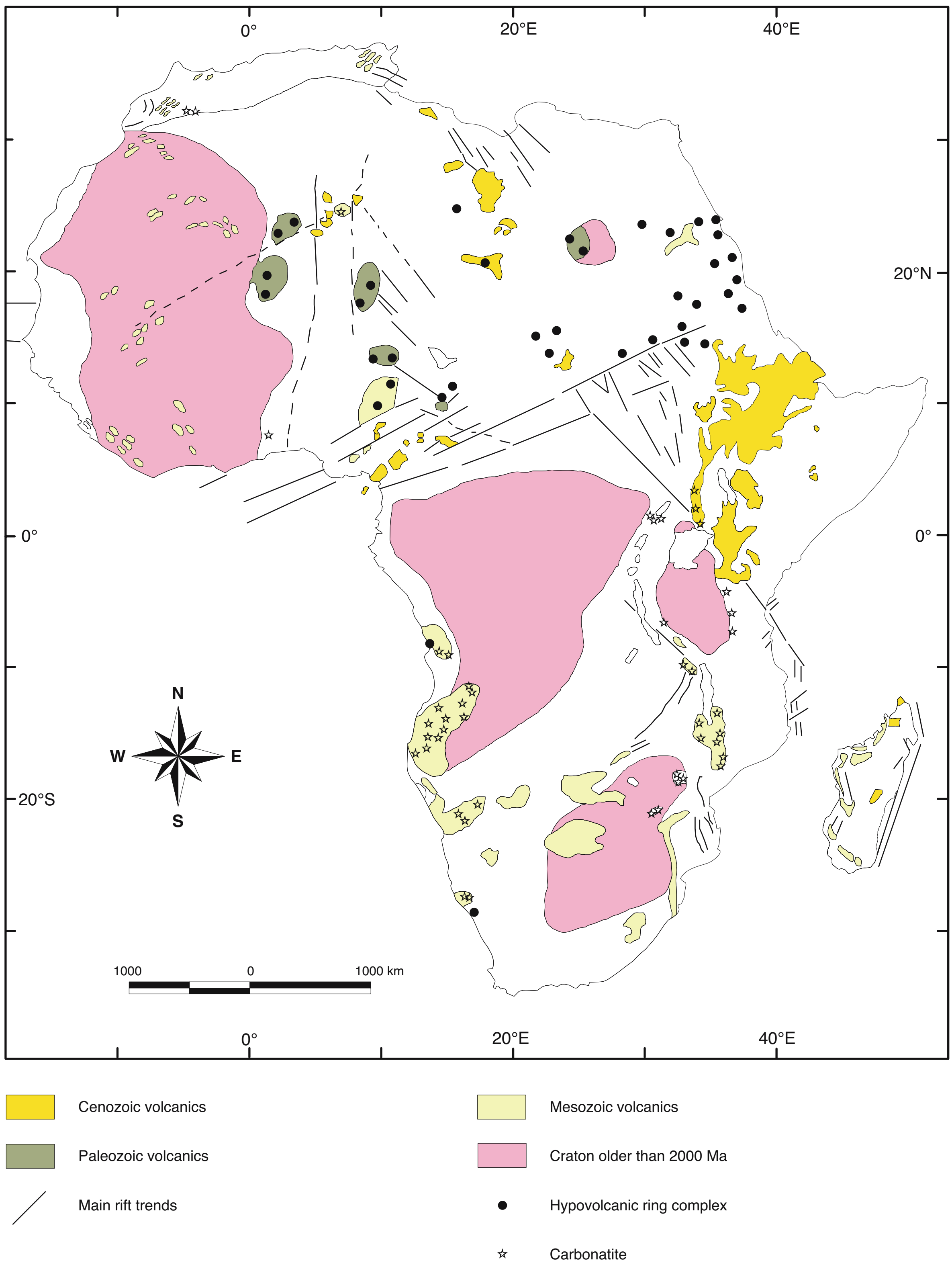

Fig. 9 Main magmatic events (after Kampunzu & Popoff, 1991)

northwestern Africa. Alkaline and calc-alkaline volcanic assemblages up to several thousand metres thick are recorded.

Intrusive rocks of the alkaline and calc-alkaline granitoid series including syn- and post-orogenic intusions. The major batholiths are mostly granodioritic, e. g. the early granodiorites of the Mozambique Orogenic Belt in Kenya. Major pegmatites are common, e. g. the Khan Pegmatite of Namibia, as are post-tectonic dolerite dykes and sheets (West Africa, Egypt).

Older basement inliers occur as crystalline foundations at low tectonic levels or tectonically interleaved within cover sequences (all high-grade orogenic belts). For instance, the Mukogodo Migmatite in central Kenya is exposed in the cores of relatively late antiformal structures. There was widespread tectonic reworking of the marginal parts of the cratonic areas.

Metamorphic grade is variable within single Neoproterozoic orogens. For example, a range from greenschist to granulite facies assemblage occurs in the Mozambique Orogenic Belt of equatorial eastern Africa and in the Tibesti Belt of northern Africa. The Neoproterozoic sequences of northeastern Africa are generally at low metamorphic grades, whereas contemporaneous rocks further south in the Mozambique Orogenic Belt are in the amphibolite or granulite facies. Both terrains are related to the same oblique continent-continent collision. Eroded root zones of the orogen are presently exposed in the Mozambique Belt. Lower grade, higher level parts preserving major slivers of oceanic crust crop out in northeastern Africa, indicating a lateral change in tectonic style along the orogen. Major strike-slip faulting took place in the northeast. Consequently it is futile to generalize with regard to the lithological make-up of the Neoproterozoic orogenic belts of Africa.

The cover sequences of the orogenic belts can be traced onto the cratonic forelands, where they are not metamorphosed and are not part of the crystalline basement, e. g. the Voltaian Supergroup and the Rokel River Group of West Africa. Contemporaneous anorogenic magmatism (e. g. within the cratonic foreland to the Pharusian Belt of northern Africa) and major ductile or brittle shearing, such as the Chuan shear zones of the Tanzania Craton including the Aswa shear zone in Uganda, are also recorded within the cratonic areas between the Neoproterozoic orogens. On the cratons, the intrusions are only of local importance, but the shear zones can be traced for up to several hundred kilometres.

All recent authors interpret the development of the Neoproterozoic orogenic belts in terms of Wilson-cycle plate tectonic processes. Four stages are identified, which may be repeated within a single orogen, as follows.

1. Rifting. Initial extension of continental crust (older cratonic areas) with either complete disruption to generate oceanic crust or intraplate, locally transtensional aulacogens (failed rift arms). Some aulacogens are formed by reactivation of old crustal fractures by the new stress fields, e. g. the Katangan Supergroup. Remnants of the newly formed oceanic crust are recognized, both in low- and high-grade terrains, over the whole of Africa.
2. Subduction and initial collision. Initial basin closure with accretion of successive volcano-sedimentary assemblages onto the cratonic forelands are well documented from northeastern Africa. Major tectono-thermal activity gave rise to thrust and fold belts and accompanying magmatism.
3. Collision between the cratonic fragments. Continuing tectono-thermal activity and magmatism extend into the cratonic forelands. Major strike-slip zones within the orogens are aligned subparallel to the trends of the orogens, e. g. in the Trans Sahara Belt.
4. Post-collision cooling and uplift. Recorded by mineral ages within the orogens and the cratonic blocks. During this period there was a change from subduction-related to within-plate magmatism.

6 Phanerozoic Development

6.1 General

Africa lay at the centre of Gondwana at the close of the Precambrian. The Pan-African orogeny had joined other continents to its eastern and western margins. Throughout most of the Paleozoic times North Africa occupied the southern seaboard of the Iapetus Ocean, whereas southern Africa was bordered by a shelf sea to the south. After the Iapetus Ocean closed during mid-Devonian times and the Hercynian orogeny had brought together in Late Carboniferous the remaining northern continental blocks into the Pangea Supercontinent, Africa assumed an even more interior location, in which position it remained until Mesozoic to Cenozoic times, when Pangea fragmented and each continent went its separate way.

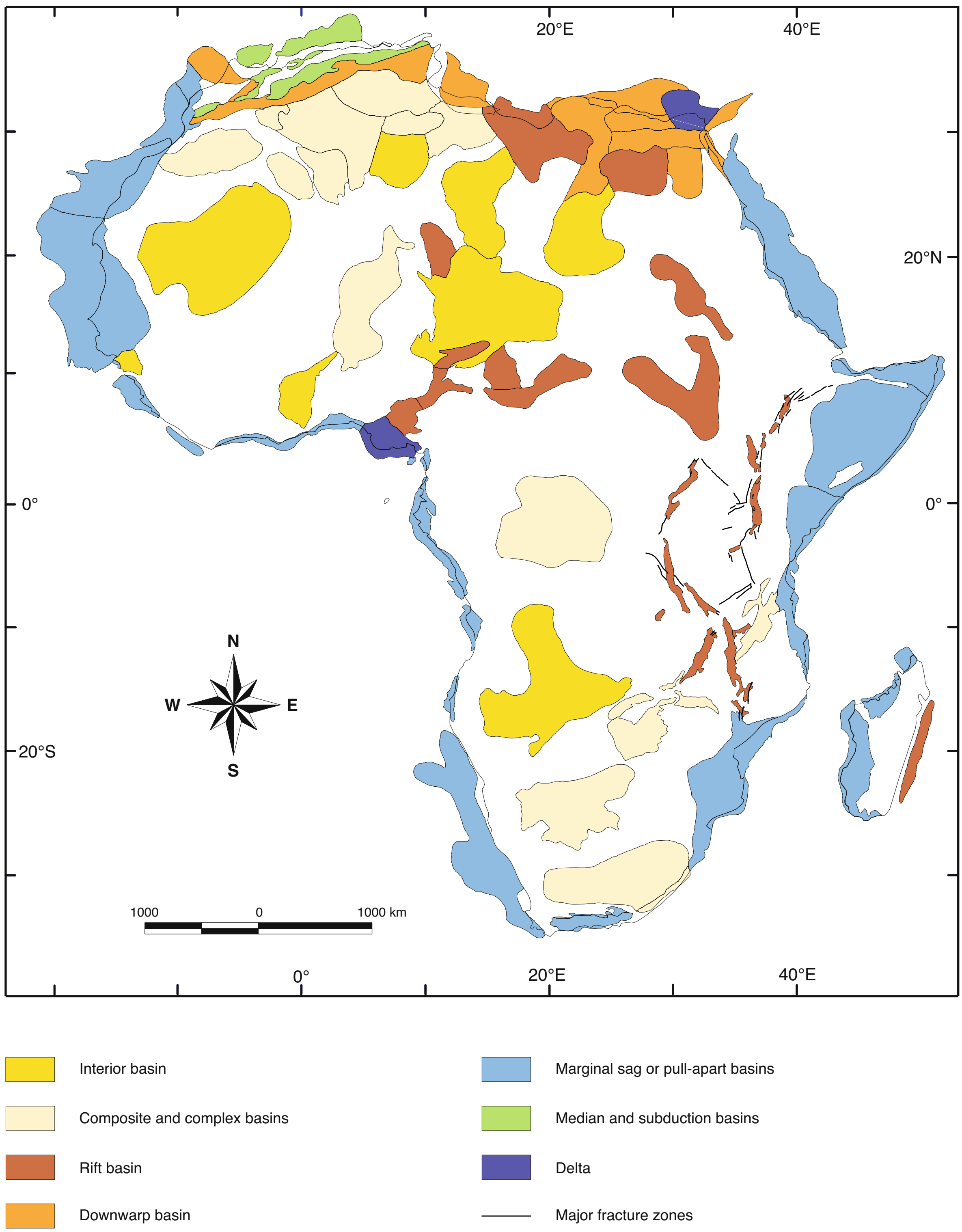

Fig. 10 Various types of sedimentary basins (after Clifford, 1986)

6.2 Orogenic Activity

The final throes of the Neoproterozoic orogenesis persisted into the lower Paleozoic until about 425Ma. Anorogenic granitoid magmatism and uplift were widespread in the mobile belts. Low-grade tectono-thermal activity was mostly localized, although epithermal alteration was ubiquitous in the orogens, facilitating subsequent weathering processes. Renewed major orogenesis in well-defined fold-thrust belts was confined to the southernmost tip and northwestern coastal zone of Africa. Elsewhere in Africa essentially unmetamorphosed major Phanerozoic basins form important components of the cover.

The beginning of Paleozoic orogenesis in northwestern Africa is marked by extrusion of alkaline volcanics at about 560Ma. Cover sequences of clastic and chemical sediments with volcanics, cut by relatively minor granitoid intrusives, were deformed during the Caledonian-Hercynian tectono-thermal activity. This produced mountainous fold-thrust belts cut by major wrench faults. The orogeny is a product of the interaction between the North Atlantic and African Plates. Major extensional faults and rift-related magmatism during the Triassic and Jurassic preceded the Alpine orogenesis in the extreme north.

Inliers of older metasediments and a granite basement are locally present along the mountainous coastal strip, the Cape fold belt, which strikes roughly E-W across the southern tip of the continent. A predominantly sedimentary cover of the Middle Paleozoic Cape Supergroup and overlying mixed Karoo Supergroup dominates this late Hercynian fold-thrust belt, which heralded the break-up of Pangaea.

6.3 Anorogenic Magmatism

Phanerozoic anorogenic magmatism is widespread and generally linked to major faulting and rifting associated with the break-up of Gondwana and subsequently since the Mesozoic with the development of the East African Rift System. Two major suites of intrusives are recognized as well as the new oceanic crust generated in the Afar area of the East African Rift System. These are the alkaline granitoid ring complexes and basic dykes and sheets.

The alkaline ring complexes are generally sited within the Neoproterozoic mobile belts. Their emplacement is related to uplift during reactivation of the major shears and transcurrent faults during fragmentation of Gondwana. Individual complexes are up to about 100km in length, but mostly from 1 to 30km in diameter. They tend to form positive topographic features despite extensive epithermal alterations.

The basic, commonly tholeiitic, dykes and sills are concentrated in areas that remained as stable cratons during the Neoproterozoic in contrast to the granitoid intrusions. The dyke swarms preferentially weather to control present drainage networks and consequently have important groundwater implications. Kimberlite pipes are another small-scale manifestation of anorogenic magmatism.

6.4 Phanerozoic Rifts and Associated Magmatism (Fig. 8 and 9)

In contrast with the Archean cratonic areas, where only kimberlite bodies are common, the successive Proterozoic mobile belts have been the sites of Phanerozoic brittle tectonics and magmatism since the end of the Pan-African Orogeny. For instance, the western branch of the East African Rift System reworked the Paleoproterozoic NW-SE trending Ubendian suture zone along the southern Lake Tanganyika region; it also cut across the Mesoproterozoic Kibaran structural trends in the northern Lake Tanganyika-Lake Kivu regions and possibly the Neoproterozoic Mozambique Belt in Lake Malawi. In western Africa, the N-S trending Pan-African suture and decollement zones, still active up to Cambrian times, were mobilized during the Paleozoic east of the West African Craton. Later on, during the Mesozoic, the Mesozoic African Rift System also reworked the NE-SW trending Pan-African ductile shear zones, which accommodated the last stages of the collision between the West African and the San Francisco-Congo Cratons.

Depending on the extensional stress applied to an individual domain, the old crustal to lithospheric discontinuities together with some neo-fractures acted as normal to oblique faults and transfer faults, observed respectively as perpendicular, oblique and parallel to the vertical sigma 1 - sigma 3 principal stress planes. In Mesozoic times, Africa was cross-cut by major transfer fault systems (Fig. 8). In the earliest rift stages, for instance clearly illustrated in the western branch of the East African Rift System, and also in the Benue Trough, the magmatic provinces are mainly located at the junction of the major fracture systems (Fig. 9). Later on, these rift faults imprinted the continental marginal fracture zones, whereas transfer faults with their initial offset induced transform fault zones when in contact with an oceanic crust.

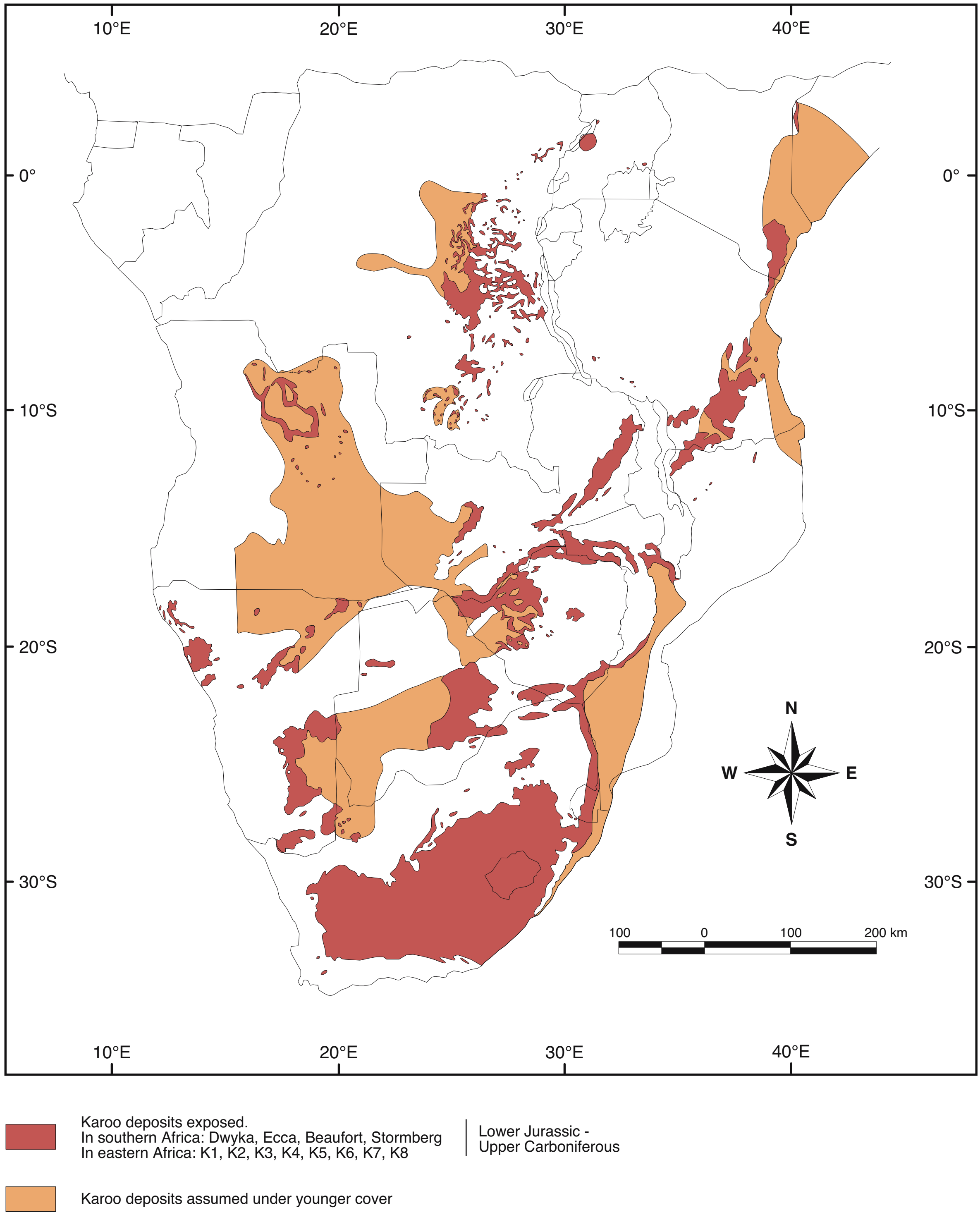

Fig. 11 Deposits of the Karoo Supergroup in southern and eastern Africa (after Schlüter et al., 1993)

6.5 Sedimentary Basins (Fig. 10)

African sedimentary basins can be grouped into four main types (Clifford, 1986):

1. Divergent passive marginal basins
2. Intracratonic sag basins
3. Intracratonic fracture basins or rifts
4. Cratonic foreland basins

Fig. 10 shows the distribution of these primary types of sedimentary basins, and the secondary or modified basins, all of which cover about half of the continent. Depending on their structural location and on the dominant depositional process, the passive or marginal sag basins have been further classified as wrench, deltaic sag, and fold belts. This classification has also been determined by their stage in the Wilson Cycle: rifting, drifting and sagging, and subduction and continental collision. Only two parts of Africa were marginally involved in Phanerozoic collision tectonics. Northwest Africa comprising the Moroccan Hercynide foreland and thrust belt and the Mesozoic to Cenozoic Atlas and Rif Alpine orogenic systems with thin-skinned thrust belts, and the Early Paleozoic Cape Fold Belt in South Africa, were affected by Phanerozoic orogenies. The basins in the rest of the continent are at the first two stages in the plate tectonic process. Paleozoic intracratonic sag basins constitute the Saharan platform, which extends from Mauritania and Morocco in the west to Egypt and Sudan in the east. In sub-Saharan Africa the Congo, Okawango and Etosha intracratonic sag basins, although containing Precambrian to Phanerozoic sediments, subsided mainly in Karoo times (Late Carboniferous to Early Jurassic).

6.6 Phanerozoic Marine Cover Sequences

There is a well-developed Early Cambrian sequence known, ranging from northern Africa to the Middle East and overlying an extensive Proterozoic sequence unlike anything else in other parts of Africa, but no Middle Cambrian and virtually no Late Cambrian exists, suggesting a disconformity generated by uplift associated with a late phase of the Pan-African orogenesis. Cambrian fossils are very rare in southern Africa, being known only from the Nama Group and from some archaeocyathid-bearing cobbles present in the Permo-Carboniferous Dwyka Group. North Africa has widespread marine Ordovician rocks, mostly indicating a cool environment, except during the Ashgill, which features warm water carbonate rocks and fossils. In other parts of the continent Ordovician body fossils are absent, except for the Late Ordovician of the Table Mountain Group, where articulate brachiopods and trilobites are found. Fossiliferous Silurian, particularly graptolitic facies, is widespread in North Africa and Arabia, unlike anything in southern Africa. Silurian rocks are also known from the Bove Basin in Guinea, West Africa, but no further to the northwest. Marine palynomorphs of Silurian age were recovered at Elmina, near Takoradi, in Ghana. The Devonian in North Africa is lithologically as well as faunally very distinct from southern Africa, with Devonian Old World Realm faunas being present from Morocco to Libya and Arabia. Early Devonian brachiopods are known from Guinea and adjacent southeastern Senegal. Devonian rocks occur also near Accra in Ghana. In South Africa the Bokkeveld Group has yielded various marine fossils of Devonian age, whereas from the Carboniferous only the Dwyka Group in the Kalahari and the Great Karoo Basins are represented by thin marine sequences. Lower Carboniferous (Mississippian) marine fossils are present near Takoradi in Ghana and in Morocco. The Permian has yielded some localities of marine deposits in southern Africa but less in North Africa (Boucot, 1999). Triassic marine fossils are unrecognized in all the coastal basins of Africa. The Jurassic and Cretaceous of Madagascar, East and Northeast Africa widely contain a Tethyan type fauna of various Mollusca, Echinodermata, Brachiopoda, Foraminifera, etc. All marine fossil-bearing strata of Cenozoic age in Africa point to rather warm water conditions.

6.7 Karoo Supergroup (Fig. 11)

The Late Carboniferous to Early Jurassic period in sub-Saharan Africa is represented by widespread non-marine strata, belonging to the Karoo Supergroup (Fig. 11) (Schlüter et al., 1993). The term “Karoo” is entrenched in African geological literature, being used in a generic sense for tectonically and climatically controlled continental sequences ranging from Late Carboniferous to Early Jurassic. A typical Karoo succession comprises from base to top tillites, coal-measures, fan-deltaic clastic wedges, which interfinger with lacustrine deposits, fluvial and eolian beds, and finally extensive basalt flows. Karoo basins are of three types: The main Karoo Basin, which extends in an E-W direction across southern Africa, and subsided as a foreland basin because of prolonged regional compression and uplift in the Cape Fold Belt. Outside the Karoo foreland basin are shallow broad intracratonic sag basins to the west. These sag basins are known in South Africa, Botswana, Namibia, Angola, the Democratic Republic of Congo and Gabon. The third and eastern group of Karoo basins are represented by narrow grabens and half-grabens or troughs, which occur in eastern and southeastern Africa, e. g. in Tanzania, Kenya, Uganda, Zambia, Zimbabwe and Madagascar. These Karoo troughs resulted from a long period of regional crustal extension, which proceeded the fragmentation of Gondwana in the Late Jurassic to Early Cretaceous.

The type area for the Karoo Supergroup is in southeastern South Africa, where nearly horizontal continental sandstones and shales are exposed, intersected by dolerite sheets and dykes. Here, four major lithostratigraphic units record the broad spectrum of depositional environments. The glaciogenic Dwyka Group is succeeded by the coal-bearing alluvial to flyschoid clastics of the Ecca Group, which in turn is overlain by deltaic wedges of the Beaufort Group, that pass upward into fluviatile and eolian deposits (Molteno, Elliot and Clarens Formations). Voluminous outpourings of Drakensberg basaltic lavas in the Jurassic, generally referred to the Stormberg Group, ended the Karoo depositional cycle.

6.8 Interior Sag Basins (Fig. 10)

Mesozoic to Cenozoic interior sag basins are mostly located in sub-Saharan Africa, including the Iullemeden, Congo, Okawango, Etosha and Kalahari Basins. Sedimentation in these basins, for the most part, was under continental conditions, and was not profoundly influenced by rifting either.

6.9 Quaternary

The term Quaternary was first applied in Europe in the mid-18th century to alluvial and superficial deposits, which sometimes yielded artifacts as a characteristic element. It was therefore separated from the preceding Tertiary. The Quaternary was later defined to include deposits with a fauna and flora that has living representatives. The most widely adopted concept of the Quaternary was however the fact that during this period extensive and frequent glaciations occurred. Climatic cooling in intervals on a global scale apparently coincided with the establishment of desert conditions in the Sahara, although a desert area in northern Africa may have existed periodically since at least the early Miocene. Generally, as on the other continents, severe oscillations in climate and vegetation were also experienced in Africa during the Quaternary. Over the past 1Ma in particular, vegetational belts contracted and expanded in response to changes in temperature and moisture that were possibly tied to Milankovich cycles (Behrensmeyer et al., 1992). However, the extent, phase and duration of arid to moist changes in Africa evidently are not perfectly correlated with glacial to interglacial environments of Eurasia, and varied extensively from region to region. Synchroneity of climatic change through the African continent was complicated by variations in atmospheric and oceanic circulation patterns. Thus, no general climatic-chronological framework similar to the glacial-interglacial framework of Europe has yet been worked out for Africa.

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Chapter 4

Review of Countries and Territories

Algeria

1 General

Area: 2,381,741 km²
Population: 30,200,000 (2001 estimate)

2 Summary of Geology

Algeria's geology can be subdivided into three contrasting tectono-stratigraphic domains: The West African Craton generally consists of a Precambrian granitized basement and its surrounding Neoproterozoic mobile belts, forming the larger central, southern and western part of the country. The eastern limit of the West African Craton borders to the Tuareg shield, which comprises the Hoggar region and its southwestern and southeastern prolongations, the Adrar des Iforas and the Aïr, respectively. This region has been mostly affected by the Pan-African tectono-thermal event. In the north, beginning from Tangier in Morocco via northern Algeria to Tunis in Tunisia, a folded chain extends over the entire length of the Maghreb. This belt is part of the Alpine chain, with its features more resembling the Betic and Apenine segments of the Alpine unit. The Algerian part of the latter belt is also known as the Tellian chain.

3 Stratigraphy and Tectonics

In Algeria, the West African Craton crops out in the Reguibat Shield in the northwest of the country. The Reguibat shield may be subdivided into two main parts, of which only the eastern is represented in Algeria: The so-called Archean Shield in the west exhibits major metamorphism of very high grade and an abundance of migmatites and ferruginous quartzites. The main structural feature is a migmatitic core 300 km in diameter, where gneiss septa are still present. Ages older than 2,500 Ma are dominant. The so-called Eburnean Shield as central and eastern part of the Reguibat Shield yields mostly ages not older than 2,000 Ma and is broken up by several faults, the number of which increases from west to east. Intrusive granites in the west and volcanic formations in the east predominate. In Algeria the Yetti Series, consisting of volcano-sedimentary rocks, acid and basic lavas and pyroclastic products is part of the Reguibat Shield. These rocks were affected by several generations of folds, of which the earliest, isoclinal and coeval with low-grade metamorphism, developed before the emplacement of Eburnian granitoids, i. e. about 2,150 Ma ago. The Akilet Deilel Series lies unconformably on the Yetti Series and is made up of predominantly detrital deposits with, at their top, volcanic rocks of calc-alkaline geochemical affinity emplaced in a continental margin setting. The metamorphism is weak, or even non-existent. It is followed by the emplacement, between 1,950 and 1,755 Ma, of a granitoid suite, at first calc-alkaline with pink granites at Erg Afrout, and then alkaline with granites at Bir Moghrein. At the end of this episode, the shield was stabilized. It is unaffected by the Pan-African orogeny that developed around its rim. Its cover terrains are tabular and horizontal.

The eastern boundary of the West African Craton is defined by the Pan-African Trans-Saharan Belt, which has been interpreted as a collision belt formed during a Wilson cycle. N-S trending geological domains predominate in the Tuareg Shield of central southern Algeria. High-grade Archean terranes occur for instance in the In Ouzzal-Iforas part of the Western Tuareg Shield, and possibly in the Oumelalen-Temasent area of the Eastern Tuareg Shield of the Hoggar (Ahaggar) mountains. The In Ouzzal-Iforas domain is a narrow elongate submeridional block occupying the full width of the Tanezrouft-Adrar zone and thinning towards the Mali-Algerian border and then re-appearing in a westerly displaced block, which widens to the south through the Adrar des Iforas area. Archean granulites in this region were later affected by the Paleoproterozoic Eburnean orogeny, during which they underwent low-grade metamorphism. The In Ouzzal granulite complex consists of a range of aluminous metapelites, banded magnetite quartzites, leptynites and marbles commonly associated with norites and lenses of pyrigarnite and Iherzolite. Grey gneisses and associated potassium augen-gneisses are the oldest rocks in the region, dated at 3,480 Ma. Interstratified within the metasediments of the In Ouzzal granulite complex are lenticular bodies of orthopyroxene-sillimanite granulites. These rocks have undergone high-grade metamorphism between 3,300 and 2,900 Ma and were later affected by low-grade metamorphism during the Paleoproterozoic Eburnean orogeny, during which additional granulites were formed in this region. Shelf sedimentation is recorded in the northwestern Hoggar mountains in Ahnet at the end of the Eburnean orogeny. Mesoproterozoic ages were dated from various sites in the eastern and western Hoggar mountains, but the main tectono-thermal events in this region occurred

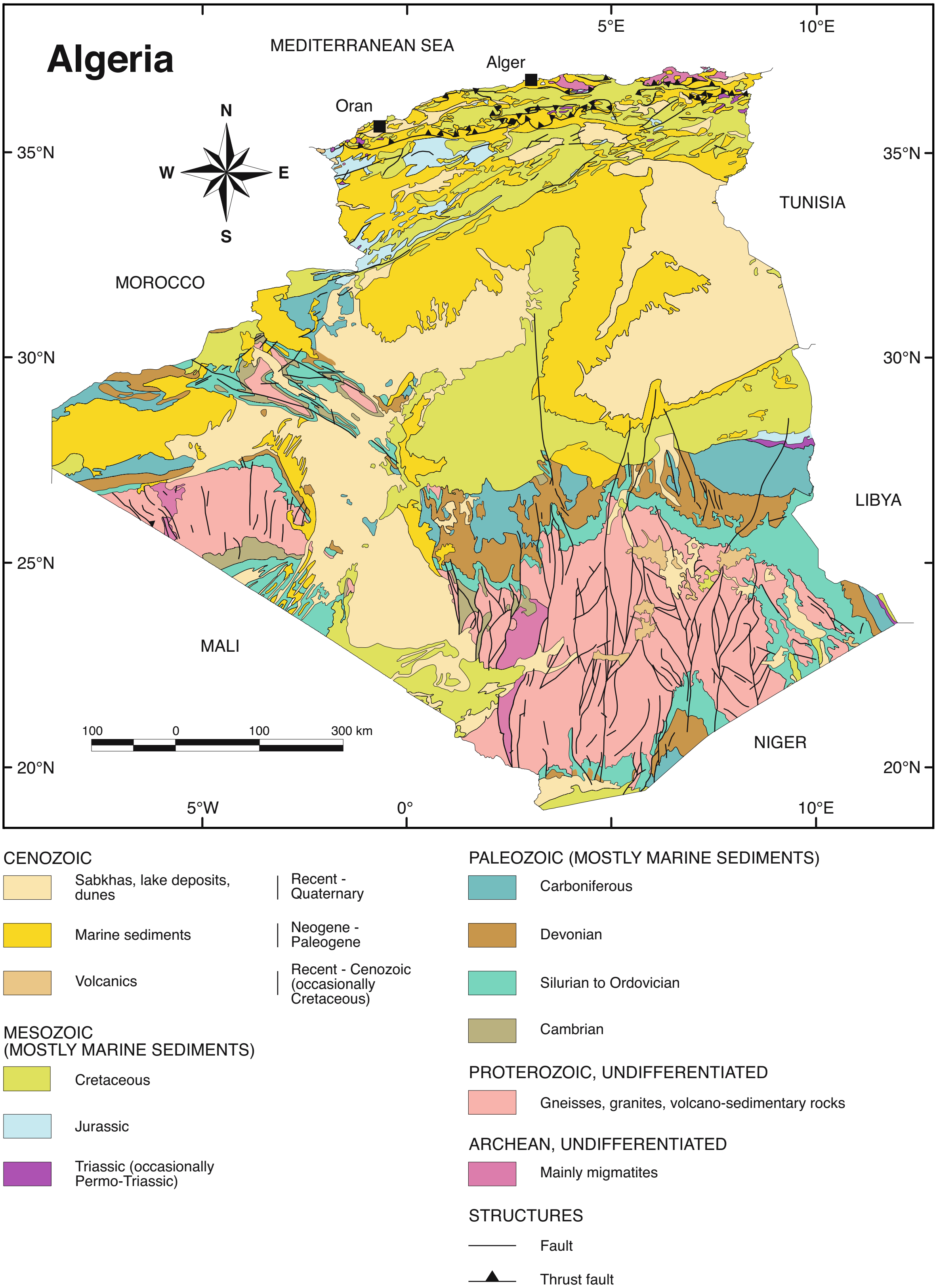

Fig. 12 Geological overview of Algeria (modified after Fabre et al, 1978)

during the Pan-African orogeny.

In the northwest of the Hoggar mountains, a series known as "Green Succession", made up of thick greywackes with fragments of volcanic origin, lies through a probable angular discordance and a basal tillite onto Mesoproterozoic quartzites. The tillite also contains fragments of the basic and ultrabasic rocks that recut the stromatolitic shelf deposit. Above a calc-alkaline rhyo-dacite volcanism developed characteristic of an active continental margin. In different areas of the Hoggar mountains and the Adrar des Iforas, the magmatic rocks have ages of crystallization ranging from 800 to 630 Ma. The rocks older than 600 Ma are deformed by an initially gently dipping foliation, formed during tangential movements of great amplitude and followed by transcurrent movements along steeply dipping major shear zones. During this Pan-African deformation, the metamorphic conditions evolved from medium- to high-pressure towards lower pressure/high temperature. The effects of the Pan-African tectonics differ from one area to another in the Hoggar mountains and various structural zones can be distinguished:

In the eastern Hoggar mountains, the Djanet-Tafassasset terrain is a unit of metapelitic and greywacke-type rocks with lenses of marbles and metagabbros, involved in steeply dipping N-S trending structures. Their metamorphism is in the greenschist and amphibolite facies. The age of a late-kinematic granite has yielded 730 Ma. In the west, the Tiririne Formation corresponds to the molasse of this belt and is made up of clays and limestones, followed by coarse detritus of eastern provenance, and finally by detrital but mature sedimentary rocks. Basic magmatic rocks, dated at 660 Ma, are commonly intrusive into the Tiririne Formation. The polycyclic Hoggar terrain shows three petrographic facies, known as a quartzo-feldspathic gneisses and granitoids facies, a highly metamorphic metasedimentary (quartzites and marbles) facies, corresponding to the so-called Suggarian chain, and a slightly metamorphic volcanic and volcano-sedimentary facies, corresponding to the Pharusian chain, which consists of two successive cycles separated by a major discordance. The first, or Pharusian I, starts with the deposition of shelf sediments of the Timessalarsine succession, in which voluminous magmatism in a rift-type environment led to the emplacement of basic and ultrabasic rocks within the succession. Subsequently it was affected by recumbent isoclinal folds before the intrusion of calc-alkaline granitoids dated at about 870Ma.

Fig. 13 Paleozoic sandstone formations east of Djanet, Tassili Mountains

The Pharusian II begins with the deposition of the Amded Formation containing fragments of the TimessalarsineFormation, and is overlain by the Irrelouchem volcanic rocks dated at about 680Ma. The whole succession is recut by calc-alkaline granitoids. These Pharusian II episodes are characteristic of an active margin environment. In its western part, the Pharusian chain consists of Archean and Eburnean cores, covered by Mesoproterozoic quartzites and Neoproterozoic stromatolitic carbonates and a volcano-detrital succession known as "Green Series". The Tilemsi zone in the west of the Tuareg shield corresponds to an island arc currently about 100km wide at outcrop. Various types of intrusive rocks occur, from banded tholeiitic gabbros and gabbro-norites dated at about 710 Ma, to calc-alkaline granodiorites at about 635 Ma.

Paleozoic rocks underlie most of Algeria. These outcrop along a NNW-SSE uplifted zone that runs along the Ougarta ranges through the Touat and Bled-el-Mass anticlinorium; in the adjoining Bechar Basin to the northeast; along the northern margins of Yetti Eglab of the Reguibat Shield; and also form a girdle around the Tuareg Shield with the Annet and Tassili N'Ajjer being the largest Paleozoic exposures. Between the uplifted zones of central Algeria extensive Paleozoic sequences fill great depressions, the largest of which are the Bechar-Timimoun (Erg Occidental) Basin, the Ghadames (Rhadames or Erg Oriental) Basin, the Illizi (Polignac) Basin, and the Ahnet Basin. The Bechar-Timimoun Basin contains an almost complete marine succession of Cambrian to mid-Carboniferous strata. The Ghadames Basin occupies northwestern Libya and extends into eastern Algeria, where Cambrian to Carboniferous marine strata are widespread, but major unconformities caused by Caledonian and Hercynian movements occur. The Illizi Basin is also filled with Cambrian to Upper Carboniferous marine strata.

The tectonic style of the Algerian atlas, with broad synclinal basins and narrow anticlinal pinches, is similar to that of the Moroccan atlas. The folds, with axial strike N45°E, are oblique to the general N60°E trend of the Atlas. These folds are seldom symmetrical and, as in Morocco, the anticlines grade into stretch-thrusts at depth. The faults are well expressed throughout the domain. Contemporary E-W faults of the Atlasic phase display a dextral component. Most of these structures developed before or during the Middle Eocene. Triassic salt extrusions are frequently encountered. Their emplacement is Atlasic, but some are younger and have affected the Miocene. The highly fractured Zibane zone is the narrowest part of the Algerian Atlas.

The sedimentary sequences of the Tellian chain in northern Algeria, which is part of the almost circum-western-Mediterranean Alpine chain, were deposited on a Hercynian or locally older basement, that makes up a significant part of the internal zones of the chain. This basement crops out in northern Algeria in the Greater and Lesser Kabylia massifs. It is in the former mainly composed of gneisses, schists and a sedimentary sequence, which has been dated as Lower Paleozoic because of very weak metamorphism. Sometimes a calcareous Lower to Middle Devonian has been recorded, containing a volcano-sedimentary complex in its upper part. The Lesser Kabylian basement is overthrust towards the south and southeast onto flysch sediments. Crystalline rocks are present, including sometimes peridotites. A whole succession of transgressive and discordant formations on top of the Kabylian basement consists of detrital sediments of Oligocene to Miocene age. This unit is mainly conglomeratic with marls and silexites. It is overlain by an olistostrome of Burdigalian age, resulting from probably subaqueous deposition of materials derived from the Mauretanian, then the Massylian and finally the Numidian flysch units. It is usually composed of flaky pelites and sometimes micro-brecciated sandstones at the base. The Calcareous chain (or Dorsale) is the cover of the Greater Kabylian massif, detached from its basement and split into allochthonous units. A succession ranging from Carboniferous to Oligocene has been observed. An additional set of allochthonous units consisting of deep-sea turbidite deposits can be distinguished, which are known as the Mauretanian nappe, the Massylian nappe and the Numidian nappe. They are located at the southern edge of the Calcareous chain and to the north of the ancient terrains. Deformation of the Tellian chain begun during Cretaceous, followed by an intensive phase in end-Eocene, known as "Pyrenean". Late deformation has affected the Oligocene-Miocene deposits of the Kabylian massifs and has been assigned as a compressive phase at the end of the Miocene.

4 Economic Geology

The production of hydrocarbons is still by far the leading mineral sector, accounting for the bulk of export earnings of Algeria. The Government's mineral industry fosters a diverse but rather modest production of metals.

The bulk of Algeria's iron ore output was extracted from the Ouenza Mine in the east of the country, where the hematite ore is ranging from 53-60% iron content. Iron ore is also mined at Bou Khadra south of Ouenza. Two lead-zinc ore deposits occur in the Oued Amizour mountain region, but most lead-zinc mining operations are still artisanal. The El Abed Mine near the Algerian-Moroccan border has yielded a production averaging between 10,000 to 15,000 mt/a of zinc concentrates. Algeria is a significant world producer of mercury, supplying about 10% of the world's output.

Algeria is among the world's major Paleozoic oil and gas provinces. Two well-known large fields are the Hassi Messaoud oil field with estimated reserves of 8 billion barrels, and the Hassi R'Mel gas field with estimated reserves of 50 trillion cubic feet of gas and 2 billion barrels of crude oil. The bulk of Algerian hydrocarbons is deposited in the Bechar-Timimoun Basin and in the Illizi and Ghadames Basins. Most of these occurrences are structural traps, which are linked to Caledonian and Hercynian movements. In

Fig. 14 Oil fields at Hassi Messaoud

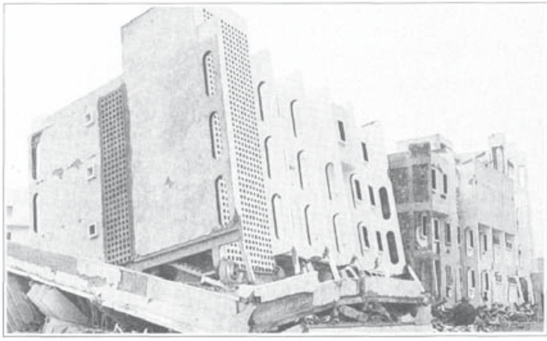

Fig. 15 Houses hit by the earthquake of 10 October 1980 in the Oued Cheliff region, northern Algeria, in which about 2,600 people lost their lives and nearly 300,000 were left homeless

their order of importance, the productive reservoirs in Algeria are in Cambro-Ordovician, basal Triassic, Devonian and Carboniferous sandstones. Generally the oil and gas fields are located in anticlines, faulted anticlines or domes. The sealing beds include Triassic to Lower Jurassic evaporitic sequences, Carboniferous and probably Devonian shales. The major source rocks were probably the widespread, organic-rich Silurian shales.

5 Geohazards

Earthquakes occur frequently in northern Algeria and have caused many human fatalities as well as the loss of infrastructure and property (Fig. 15).

Pollution of aquifers and the surface environment due to the exploration of hydrocarbons is evident.

6 Geosites

An inventory of potential geosites has never been made, but many places deserve due to their scenic beauty and/or geological significance increased protection, especially in the mountainous regions of the Sahara (Fig. 16 and 17).

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Fig. 16 Assekrem black volcanic peaks in the central Hoggar Mountains at sunset

Fig. 17 Gigantic dunes near tha oasis Ouargla, central Algeria

Angola

1 General

Area: 1,246,700 km^2
Population: 10,145,000 (July 2000 estimate)

2 Summary of Geology

Rocks of possibly Neoarchean age outcrop in the northeast of Angola belonging to the Kasai Craton. In the west the country is underlain by Paleoproterozoic, Mesoproterozoic and Neoproterozoic rocks of various composition, among them tillites at the base of the Neoproterozoic Bembe System, which are followed by stromatolitic and oolitic limestones. Sedimentary and volcanic rocks of the Karoo Supergroup occur in the northern central part of the country. In the coastal basin the Precambrian basement is directly overlain by a thick sequence of Mesozoic to Cenozoic marine sediments. The eastern part of Angola is largely covered by sands and related deposits of the Kalahari Group.

3 Stratigraphy and Tectonics

The oldest formations known in Angola are from the northeast, corresponding to those more completely studied in Kasai (Democratic Republic of Congo) and have been affected by metamorphic episodes corresponding to the so-called Musefu and Moyo episodes of Kasai, both being of Neoarchean age. Isolated Archean rocks are also exposed in some places in the basement of western Angola, for example at Malanje, Dondo and south of the River Cuanza near Cariango, where Archean assemblages show E-W and NE-SW trends and comprise enderbites, charnockites, kinzigites and granulite gneisses. South of Nova Lisboa the volcano-sedimentary Jamba Group is also of Archean age. Complex greenstone belts of Paleoproterozoic age are present in the southern central part of the country. It has been concluded (Cahen et al., 1984) that an orogeny affected most of this region at about 2.15 Ga, during which the main metamorphism, granitization and deformation took place, followed by extensive late- and post-tectonic, and anorogenic granitic intrusions and volcanic activity between 2.05 and 1.75 to 1.65 Ga. Low initial Sr isotope ratios in the homogeneous regional granites of southern Angola suggest the addition of juvenile crustal material. The West Congolian mobile belt extends for over 1,300 km from Gabon southwards through the Republic of Congo, the Democratic Republic of Congo, to northern Angola. It contains three structural zones, which are from east to west the external zone with sub-horizontal strata, the median folded zone and the internal zone consisting of intrusive and pre-west basement rocks. The older rocks in the internal zone are the Mayumbian and the Zadinian Supergroups, representing the infilling of a Kibaran-age continental rift, which was deformed and thrust eastwards during the Pan-African orogeny in the West Congolian. The external and median zones contain the West Congolian Supergroup, a sequence of low-grade metasediments. Because of its elongate basin geometry, the occurrence of high-energy debris flow deposits (mixtites), red beds and basic volcanics in its lower part, sedimentation has been assumed to have started in a fault-bounded continental rift, probably at around 1.1 Ga.

Sediments of Paleozoic to Mesozoic age are mainly preserved in the northern central to northwestern geological depression, called Cassanje Graben. These magmatic and sedimentary rocks are related to the Karoo Supergroup. During this period magmatic activities caused the emplacement of diverse sub-volcanic to volcanic bodies, including kimberlites, carbonatites, basalts, dolerites, syenites, trachytes and phonolites. The kimberlite and carbonatite bodies are located along a major trend line, which transects Angola diagonally from southwest to northeast.

The western margins of Angola are covered by Cretaceous to Pleistocene marine sediments. Considerable information has been gathered on these basins from borehole data during oil-exploration both off- and on-shore (Fig. 19). These basins are from north to south: The Congo, the Kwanza and the Namib marine coastal basins, which started with their development during Lower Cretaceous times.

In Angola three types of Tertiary to Quaternary rocks can be distinguished, forming the youngest geological units of the country. These are Quaternary alluvial and colluvial deposits, Tertiary to Quaternary continental sediments of the Kalahari Group, and early Tertiary laterite residues. Nearly half of Angola is covered by these sedimentary rock types. The Kalahari Group consists mainly of sand and quartzitic sandstones. In the central and eastern part of Angola the lateritic residue forms the substratum of the Kalahari Group. Quaternary alluvial and colluvial deposits in the form of sands, clay, rubbles and gravels occur mainly in depressions and/or river valleys.

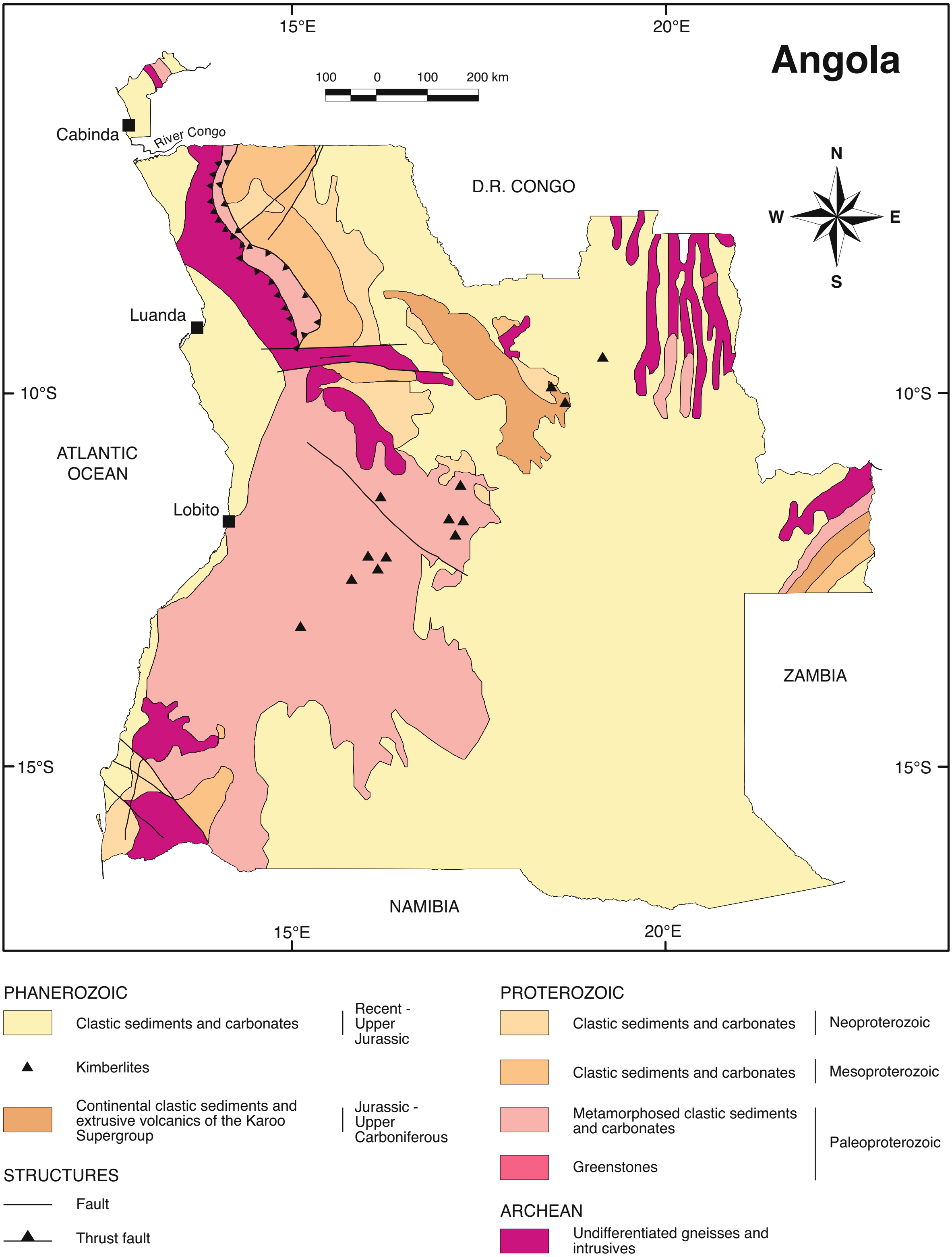

Fig. 18 Geological overview of Angola (modified after Araujo et al., 1998)

4 Economic Geology

Angola has a considerable mineral wealth. The petroleum industry still dominates the Angolan economy. Exploration of fuels is mostly done in near shore zones, defined as being less than 150 m in depth. These occupy a 20- to 50-km-wide strip along the entire Angolan coast. Paralleling the shallow water concessions are several deep water concessions, defined as occupying depths from 150 to about 600 m, of which not all are yet being exploited.

Diamonds are the most important mineral resource after oil, occurring in kimberlites and a variety of placer deposits. At least 700 kimberlites are known, of varying size and shape. The diamond grade increases with depth. The kimberlites are aligned along a NE-SW trend, which extends into the Democratic Republic of Congo. Most of the alluvial diamonds are produced from the erosion of Cretaceous kimberlites. The richest fields are located in Lunda Norte in the northeast of the country (Fig. 20). About 90% of the gold produced in Angola originates from the Maiombe area in Cabinda and is mainly alluvial. These deposits are related to greenstone belts of either Neoarchean or Paleoproterozoic age. Nickel, chrome and platinum occurrences have been reported from southwestern Angola. These occurrences are associated with mafic-ultramafic complexes. Iron was produced at the Cassinga mine near surface, from high-grade ore (50-60% Fe) of a deposit of Banded Iron Formation (BIF). A number of small manganese deposits are located near Lucala, Cuanza Norte and the Malanje provinces. Others are scattered all over the country, but economically less significant. These deposits are related to laterisation and the carbonatite complexes. Angolan copper occurrences are related to Neoproterozoic ore bodies and Cretaceous

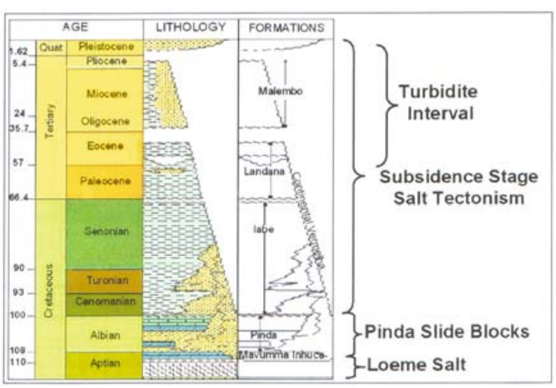

Fig. 19 Stratigraphic column offshore of Cabinda, where hydrocarbon source rocks were discovered in the Iabe, Landana and Malembo Formations

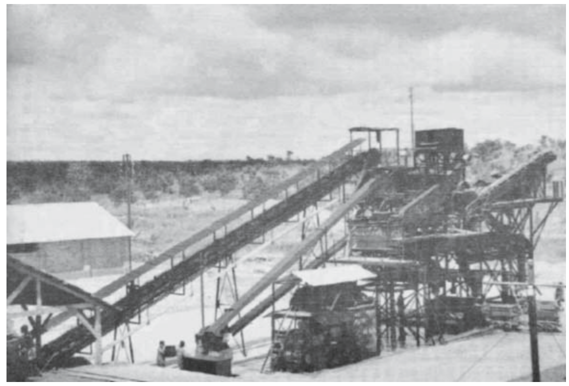

Fig. 20 A diamond-washing plant in the Kasai Basin in northeastern Angola (1964)

sedimentary basins, but production of copper came to a halt already in 1963. Silver and cobalt were by-products. Vanadium was produced from the Lueca and Kinzo mines in the 1950s, resembling in deposition the polymetallic Tsumeb ore body in Namibia. Low grade, sub-economic uranium deposits, associated with carbonatites, phosphates and pegmatites, occur in the Cabinda and Zaire provinces.

In the Lunge-Bunge area in Moxico, lignite occurrences in seams of 3 m, with overburden of 4-6 m, have been reported, which, however, are apparently not of economically significant value. Other lignite occurrences have been reported from the Cretaceous Kwanza basin. Angola is a producer and exporter of good quality dimension stone, especially red and black granite. Extensive exploration for phosphates led to the discovery of significant reserves of phosphates within the Tertiary-Cretaceous marine sediments. The major deposits are in the Cabinda and Zaire provinces. Kaolin was mined on a small scale in the early 1970s from deposits in Bengo, Huila, Huambo, Bie and Uige provinces. Despite the abundance of limestones, sands, sandstones and clays in Angola's marine coastal basins, their production has been low.

5 Geohazards

An inventory has not yet been made. Mining activities have caused pollution of aquifers and on the surface. Environmental problems apply for the offshore exploration of hydrocarbons.

6 Geosites

An inventory has not yet been made, but this large country offers many sites of scenic beauty, which are currently under consideration (Fig. 21).

Fig. 21 The Braganca Falls in northwestern Angola

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Benin

1 General

Area: 112.620 km^2
Population: 6,396,000 (July 2000 estimate)

2 Summary of Geology

The geology of Benin is comprised of two different domains, separated by a line almost parallel to the 7th latitude. The northern region is dominated by crystalline rocks of the Neoproterozoic Dahomeyide Orogen, whereas the southern region consists of sedimentary rocks ranging from Recent to Cretaceous age. In the northeastern part of the country alluvial rocks of Neogene age are predominating.

3 Stratigraphy and Tectonics

Crystalline rocks in Benin and Togo are generally considered as belonging to the Dahomeyide Orogen, which is located along the southeastern margin of the West African Craton. The following rock types have been recognized within this fold belt: metasandstones, schists, metasilexites, metasiltstones, metaconglomerates, metatillites, carbonate rocks or marbles, ultramafic rocks, metajaspillites, metahematites, quartzites, quartz schists, micaschists, gneisses, migmatites, amphibolites, granites, charnockites, eclogites, metabasalts, calc-silicate rocks and pyroxenites. Contrasting lithological associations are present in different parts of the orogen and, from west to east, six lithotectonic zones or terranes have been recognized, of which three or four are recorded in Benin. The rocks of Zone 1 border the West African Craton and constitute the external units of the Dahomeyide Orogen, named as Buem and Atacora (= Togo Group) structural units. The Buem Group comprises from bottom to top shales and sandstones, dolomites and limestones, with an important conglomerate generally regarded as a tillite, and a volcanic unit with basalts, dolerites and some rhyolites. It is structurally overlaying the Togo Group, which is characterized by over 300m of thick quartzites separated by pelites, the quartzites being locally accompanied by ironstones. Zone 2 is a narrow tract characterized by a high positive gravity anomaly. Its basic and ultrabasic rocks are believed to represent either mantle diapirs or remnants of a paleo-oceanic crust with characteristics of an ophiolithic complex. Zone 3 is made up predominantly of migmatites, gneisses, syenites, granites, micaschists, marbles, quartzites and amphibolites. Zone 4 is characterized by the presence of several N-NE to S-SW trending schist belts surrounded by a gneissic-migmatitic complex. There is an uneven distribution of available radiometric data within the Dahomeyide Orogen, which is best dated in Zones 4 to 6. Zone 1 indicates a signature of Pan-African tectonothermal activity. For Zone 2 in northwestern Benin a Kibaran activity has been recorded, but Pan-African ages are also evidenced in other parts of the region. Geochronological data on granites, orthogneisses, migmatites and granulite facies rocks of Zone 3 suggest that these rocks have been affected by three orogenic events, including phases of the Eburnean, Kibaran and Pan-African activities. Ages obtained from granitic rocks of Zone 4 (and 5) indicate predominantly Pan-African activities.

Outcropping in the northwestern part of the country are the sediments of the Voltaian Supergroup, ranging from Paleozoic to Neoproterozoic times. The Voltaian Supergroup has been divided into three groups. The lowest comprises sandstones, quartzites and shales with a maximum thickness of 600m. The middle Voltaian or Oti Group, with a thickness of about 1600m, lies unconformably on the lower Voltaian with conglomerates, interpreted as tillites, at the base, followed by shales, sandstones, limestones and dolomites. The upper Voltaian or Obosum Group is a molasse unit.

The Neogene formations are best developed in the coastal region and mostly represented by lagoonal and alluvial deposits. Alluvials are, however, also well developed along the major rivers within the Proterozoic terranes.

4 Economic Geology

Gold mineralisation is known from conglomerates in quartzites of the Togo Group in northwestern Benin. Alluvial and eluvial indices of rutile are very abundant in an elongated area extending from Kolkonde in the north to Basila in the south. A number of geochemical anomalies indicating the occurrence of nickel, copper, chromium and cobalt have been detected in the region of Goumpare, east of Parakou. Limestone is found in the Oueme District in the south, with reserves estimated at 123 million tons of limestone suitable for manufacturing of cement and lime, and 33 million tons of sandy limestone suitable for the use as ballast.

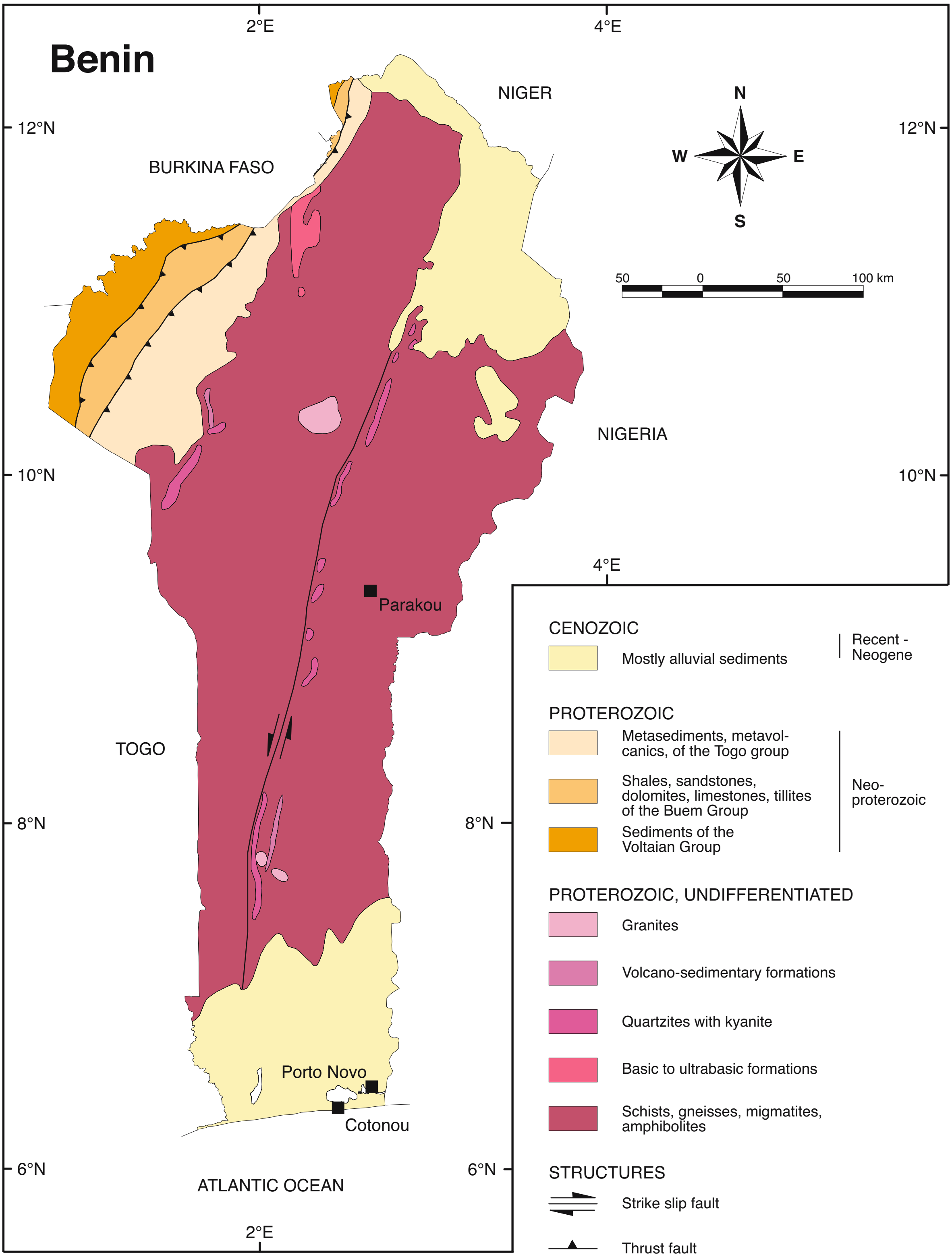

Fig. 22 Geological overview of Benin (modified after Anonymous, 1972, and Affaton et al., 1990)

Fig. 23 Lacustrine village in the Ganvie Lagoon, coastal Benin

Less important occurrences of uranium and iron ore were also detected.

Benin has since the 1990s produced some crude oil, which mostly came from the Seme Field, about 15km south of Cotonou. Further onshore exploration is still continuing, and the potential for the development of significant additional reserves of oil and natural gas is high.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made, but the coastal lagoon of Ganvie exhibits both cultural and geoscientific aspects of heritage to be preserved (Fig. 23).

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Botswana

1 General

Area: 581,730 km^2
Population: 1,576,000 (July 2000 estimate)

2 Summary of Geology

Rocks of Archean age predominate in the east and southeast of Botswana. Proterozoic orogenic belts, mostly concealed beneath Karoo rocks, young progressively westwards away from the Archean rocks. Karoo strata deposited within the Kalahari Basin underlie central Botswana, whereas in the north and northwest rocks of Meso- and Neoproterozoic age occur.

3 Stratigraphy and Tectonics

The northwestern part of the Archean Kaapval Craton extends into southeastern Botswana, where gneissic granitoids with associated metasedimentary and metavolcanic rocks are intruded by the Modipe Gabbro as well as by the Gaborone and Mmathete Granites. There is a partial cover of Archean supracrustal rocks of the Lobatse and Lower Transvaal Group. The western margin of these Archean rocks is concealed beneath a cover of Karoo rocks and Kalahari sediments. The same applies for the Archean Zimbabwe Craton and the Paleoproterozoic Limpopo Mobile Belt in the east of the country, which are both lithologically similar to the Kapvaal Craton but differ in their structural styles and in timing of major thermal events. The following rock units have been found in these terranes: migmatites, porphyric granites, metasedimentary rocks, amphibolites, meta-intrusive rocks, gabbroic anorthosites and gneissic granites. In northwestern Botswana folded rocks of unknown age possibly form a cover sequence over the southern part of the Congo Craton.

From Paleoproterozoic times, major episodes of sedimentation, major centres of magmatism and major deformation belts have been recorded in Botswana. The preserved areas of sedimentation and magmatism are both within the Archean crustal elements as well as in the bounding orogenic belts. Within the Archean plates, there is a spatial association of Paleoproterozoic sedimentation and magmatism, where the sediments represent proximal deposits from the eroded magmatic rocks. The about 2,000Ma old Kheis Belt defines the western margin of the Kapvaal Craton, whereas its northern margin is partly represented by the Mahalapye Complex of similar age. It remains unclear what happened in the central and western zones of the Limpopo Belt during the Paleoproterozoic. The Magondi Belt has been traced into northern Botswana to define the western edge of the Zimbabwe Craton. The Kubu Island Granite was emplaced at about 2,000Ma into Archean crust towards the southeastern edge of the Magondi Belt, where it continues into the western zone of the Limpopo Belt. To the northwest the Magondi Belt is bounded by the Mesoproterozoic northwest Botswana Rift and the inland arm of the Neoproterozoic Damara Belt.

An accurately defined northeasterly trending Mesoproterozoic rift structure has been evidenced in Botswana, within which there was bimodal volcanism and associated sedimentation. The southeastern margin of the rift is preserved as a reactivated Paleoproterozoic thrust zone, the Kalahari Suture Zone. Rifting continued into the Neoproterozoic as the Ghanzi Group sediments were laid down in a rifted basin. The present northwestern edge of the northwest Botswana Rift is defined by a major Damaran thrust zone. The northwest Botswana Rift links the central African intracratonic Irumide and Kibaran Belts to the Namaqua, Natal, Falkland, Haag, Maud and southern Mozambique Belts.

Neoproterozoic rocks occur mostly in northwestern Botswana and belong to the Damara Belt, of which the Ghanzi Group along the northeasterly striking Ghanzi Ridge exhibits three different siliciclastic formations. The intensity of folding and related thrusting within the Damara Belt increases towards the northwest. The Passarge Basin is infilled with very weakly folded Ghanzi Group strata, whereas the Nosop/Ncojane Basin further to the south has flat-lying Nama Group sediments above Ghanzi Group rocks. Low-grade siliciclastic metasediments with associated limestones and felsites of the Okwa Group are exposed in the Okwa Valley. The sequence is also of Neoproterozoic age or even younger (Ramokate et al., 2000). Essentially unexposed but well defined due to recent airborne magnetic surveys are four rock units within the inland branch of the Damara Belt in Ngamiland, which are probably also of Neoproterozoic age.

The Karoo strata of Botswana can be subdivided into five stratigraphical units (Smith, 1984). The basal Dwyka Group comprises all the glacial deposits, which were laid down from Late Carboniferous until

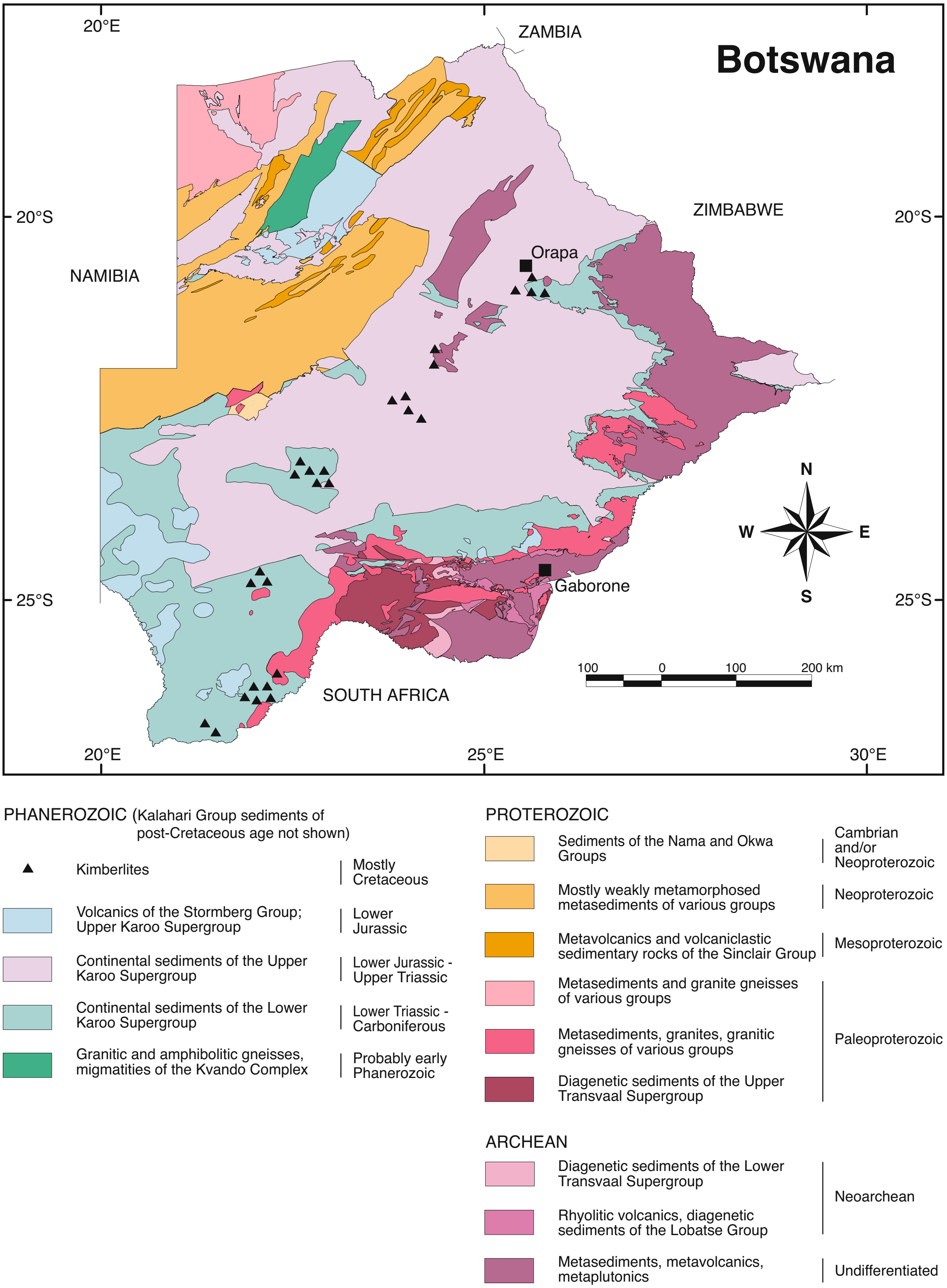

Fig. 24 Geological overview of Botswana (modified after Key & Ayres, 2000)

Early Permian. Its main outcrop is in the south in the Mabuasehube to Middlepits region. There are smaller exposures in the Mmamabula and Palapye areas. The Ecca Group sediments of Permian age have a huge outcrop area in southwestern Botswana. Further to the east exposures of Ecca Group strata occur around the fringes of the Kalahari and Tuli Basins. The Kule Formation of the Beaufort Group (Permo-Triassic in age) is widespread in Botswana with large outcrop areas in the southwest. There was regional uplift within the Kalahari Basin at this time to account for the major unconformities recognised at the base and top of the Kule Formation. The Lebung Group sediments were laid down during Triassic and early Jurassic. In Botswana these sediments are interleaved with basal flood basalt flows, which extruded at about 180Ma. The flood basalts cover the central and northern parts of the Kalahari Basin, the Tuli Basin, and are also preserved in grabens in the Maun area. Numerous and large dolerite sheets intrude the Karoo mainly along the Ecca/Beaufort unconformity in southwest Botswana. Similar dolerites occur also in northwestern Botswana.

More than 200 kimberlites are known from Botswana, which are predominantly of Cretaceous age. However, the exceptionally diamondiferous Jwaneng pipe is Permian in age. The Kalahari Group sediments of post-Cretaceous age infill an inland depression in central-southern Africa, which was initiated at the end of the Cretaceous by the break-up of Gondwana. Major deposition took place since the end of the Miocene in the centre of southern Africa. Terrestrial as well as fresh water sediments are present in the Kalahari Group of Botswana. The Okavango River in northern Botswana is currently depositing deltaic sediments. Despite their large spatial coverage, the Kalahari Group sediments are generally less than 180m in total thickness.

Fig. 26 Reconstruction of the fossilized crater lake (maar) of Orapa in eastern Botswana, which has yielded the richest insect and plant bearing taphocenosis of middle Cretaceous in Africa

Fig. 25 The Orapa diamond mine in eastern Botswana, one of three in Botswana providing the country with its most important source of revenue

4 Economic Geology

Diamondiferous kimberlite pipes have largely contributed to the prosperous economy of Botswana (Fig. 25). Other mining commodities include copper-nickel (from the Selebi Phikwe mining complex), gold (near Francistown) and minor occurrences of iron, platinum and soda ash. Estimated reserves of coal are about 17 billion tons.

6 Geosites

A formal inventory of potential geosites has not yet been made, but the middle Cretaceous maar lake deposit of the Orapa kimberlite pipe north of Gaborone with its unique floral and faunal components must be considered for this purpose (Fig.26).

Fig. 27 Salty crust on the dried out surface of Lake Makgadikgadi in northwestern Botswana

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Burkina Faso

1 General

Area: 274,200 km²
Population: 11,946,000 (July 2000 estimate)

2 Summary of Geology

Burkina Faso is predominantly underlain by rocks of the Guinea Rise, which borders the Gulf of Guinea and extends from Sierra Leone in the west to Ghana in the east. The rise is generally characterized by granitic gneisses, and north to northeasterly trending belts of metasediments and metavolcanics.

3 Stratigraphy and Tectonics

The oldest rocks in Burkina Faso are pre-Birrimian migmatites, gneisses and amphibolites underlying the Birrimian rocks. In southwestern Burkina Faso the Birrimian deposits can often be divided, similarly as in neigbouring Ghana, between predominantly clastic (flysch) formations and volcano-clastic formations. However, whereas in Ghana sedimentological features clearly indicate that the former are older than the latter, in Burkina Faso the opposite sequence has generally been favoured. The clastic sequence consists of intensely deformed pelitic and psammitic metasediments. There are three major Birrimian greenstone belts in the south and the west of the country, in which volcano-sedimentary sequences are dominant, and a fourth in the central and northeastern regions, besides numerous other smaller greenstone belts, which are found throughout the country. Granites and granodiorites occupy the spaces in between the greenstone belts. Proterozoic conglomerates and sandstones of the Tarkwaian Group rest unconformably on Birrimian rocks around Essakane in the NE of Burkina Faso. The margins of a large sedimentary basin of Neoproterozoic to Ordovician age emerge at the western border of Burkina Faso. These rocks consist of basal sandstones with overlying shales and dolomites, sometimes carrying bauxite mineralizations.

4 Economic Geology

Gold occurrences are widespread and found throughout the Birrimian formations as mineralization related to quartz veins and stockwork, disseminations and the alluvial concentrations in Quaternary or recent river gravels. Gold occurrences have been described from the following seven districts: 1. Poura, about 180km SW of Ouagadougou, with reserves estimated to be 1.45Mt at 11.3g/t; 2. Dori-Yalago, in the NE between Pissila and Dori; 3. Aribinda District, in the extreme N; 4. Dossi-Kiere District, about 150km east of Bobo-Dioulasso; 5. Essakane in the extreme northeast; 6. Yako-Kaya-Ouahigouya District, about 100km north of Ouagadougou; 7. Kwademen, about 30km southwest of Koudougo west of Ouagadougou. Alluvial diamonds have been found, but so far no major discoveries were made. Besides gold, the country's most significant mineral resources are the Perkoa zinc (about 120km west of Ouagadougou) and the Tambao manganese (about 300km northeast of Ouagadougou) deposits. Three low grade copper deposits have been investigated, but none is presently mined. Numerous small deposits of bauxite have been discovered, but none has been mined to date. There are several phosphate deposits in the southeast of Burkina Faso, concentrated in the Pendjari Series of sedimentary rocks. Reserves are believed to be in the order of 30Mt of ore.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

7 References

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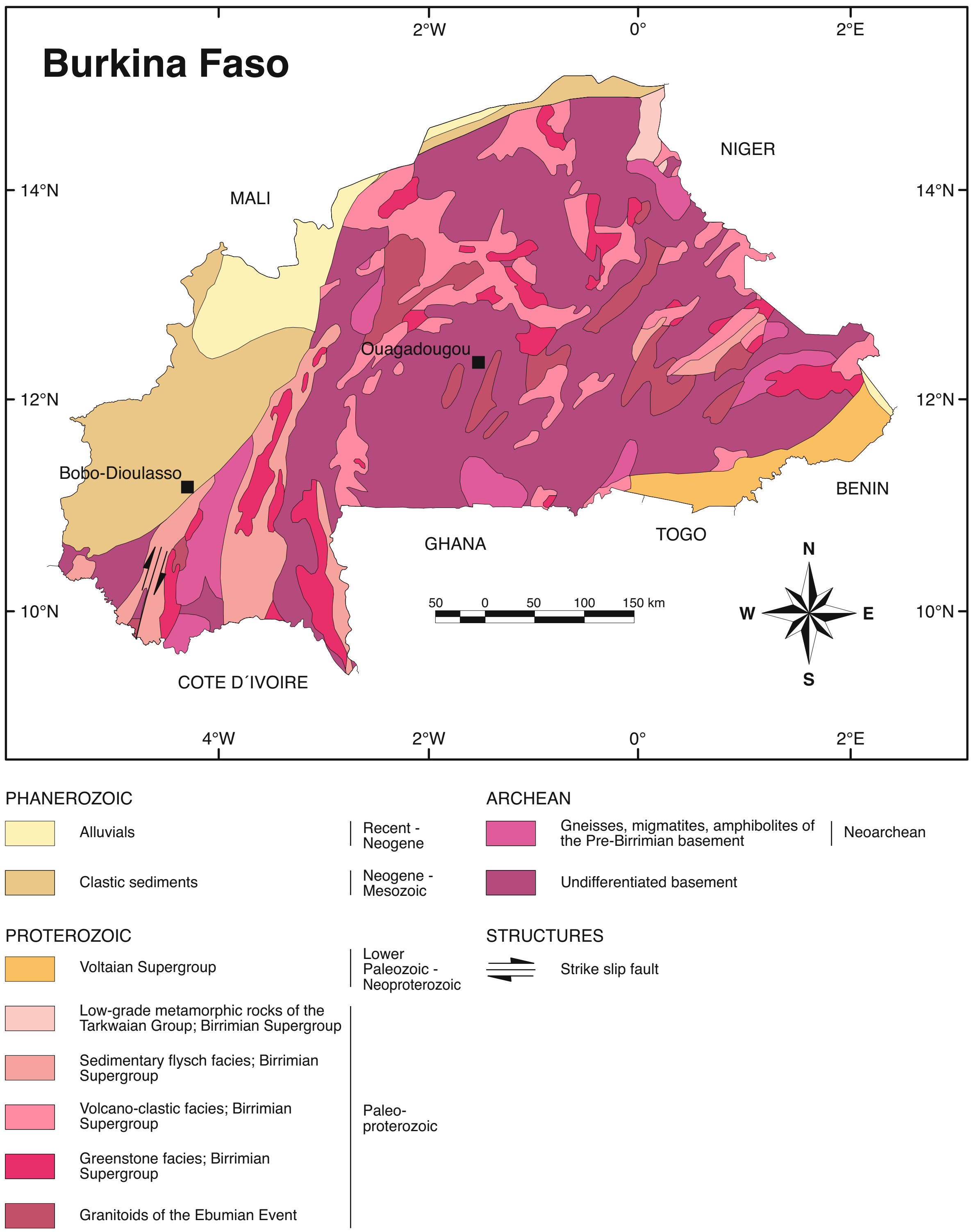

Fig. 28 Geological overview of Burkina Faso (modified after Bessoles, 1977)

Burundi

1 General

Area: 27,830km^2
Population: 6,055,000 (July 2000 estimate)

2 Summary of Geology

Burundi's geology is mostly made up of rocks belonging to the Mesoproterozoic Kibaran Belt, which is here termed as Burundian Supergroup, and of the Neoproterozoic Malagarasian Supergroup, which is equivalent to the Bukoban System in northwestern Tanzania. Tertiary and Quaternary sediments fill parts of the Western Rift at the northern tip of Lake Tanganyika.

3 Stratigraphy

Rocks of Archean age in Burundi were subjected to retrogressive metamorphism in the greenschist facies and subsequent deformation during the Ubendian orogeny in Paleoproterozoic times. The Kazigwe amphibolite facies complex resulted from mylonitization and retrogressive metamorphism of the Archean Kikuka gneiss complex in southwestern Burundi.

Rocks belonging to the Mesoproterozoic Kibaran Belt are widespread in Burundi and are locally termed as Burundian Supergroup. Generally, the Burundian Supergroup is subdivided into three units. The base of the lower Burundian consists of a quartzitic sequence, which overlies directly the Archean basement. The upper part of this unit contains locally a tuff horizon of intermediate composition. It is overlain by schists of considerable thickness, whose lower part consists of graphitic schists, which are interbedded with quartzitic horizons of minor importance. Higher up, the quartzitic horizons are interbedded with grey schists, sometimes containing volcanic intercalations. The middle Burundian begins with a sequence of quartzites overlain by schists and green phyllites, which are particularly well-represented in the western part of the country, and which in this region contain basic volcanic intercalations overlain by acidic volcanic horizons. These pelitic key horizons are overlain by black graphitic and ferrugenetic schists, which progress gradually towards the upper Burundian. The upper Burundian is generally characterized by poorly sorted sediments, containing often arenites. Within these arenites occur numerous lenticular conglomeratic bands. Frequently present is an intraformational conglomerate near the base of this formation, which is characterized by the presence of ferruginous lenses. The rocks of the Burundian Supergroup are intruded by granites, and along a 350km long narrow zone by mafic and ultramafic intrusions.

Neoproterozoic rocks in Burundi are represented by the Malagarasian Supergroup, which is equivalent to the Bukoban System of adjacent Tanzania. The contact between the Neoproterozoic Malagarasian Supergroup and the underlying Burundian sedimentary rocks belonging to the Kibaran Belt in the west or to the Archaen craton in the east is either unconformable or faulted. The relatively flat-lying and unmetamorphosed Neoproterozoic formations of southeastern Burundi are composed of epicontinental sediments associated with basic igneous rocks. The Malagarasian Supergroup of Burundi with an overall thickness of about 2000m has been subdivided into the following five units: The lowest group is the Kavumwe Group, whose sediments were accumulated in local basins, consisting of quartzites, sandstones, argillaceous sandstones and shales. The following Nkoma Group consists of conglomerates, quartzites and sandstones. The following Musindozi Group contains dolomitic limestones, calcareous shales, lavas, sandstones, quatzites and conglomerates. In the following Mosso Group silicified dolomitic limestones and lavas have been recorded. The top of the Malagarasian Supergroup is represented by the Kibago Group, which is characterized by sandstones, quartzites, shales and a basal conglomerate. An ensialic and intracratonic geodynamic evolution for this part of central Africa is more likely than the development of a Neoproterozoic orogenic belt. A system of conjugate strike-slip sedimentary basins located along the southeastern border of the Kibaran Belt and linked to a late evolution of this belt indicates that the Malagarasian (and Bukoban) sediments may be interpreted as the molasse of the Kibaran Belt.

Mostly Neogene sediments fill parts of the Western Rift at the northern tip of Lake Tanganyika and along various rivers.

4 Tectonics

In central Burundi a fault system crosscuts the Kibaran Belt and gives rise to an almost N-S trending corridor, which is known as the N-S accident. It has been assumed that the N-S accident is either representing

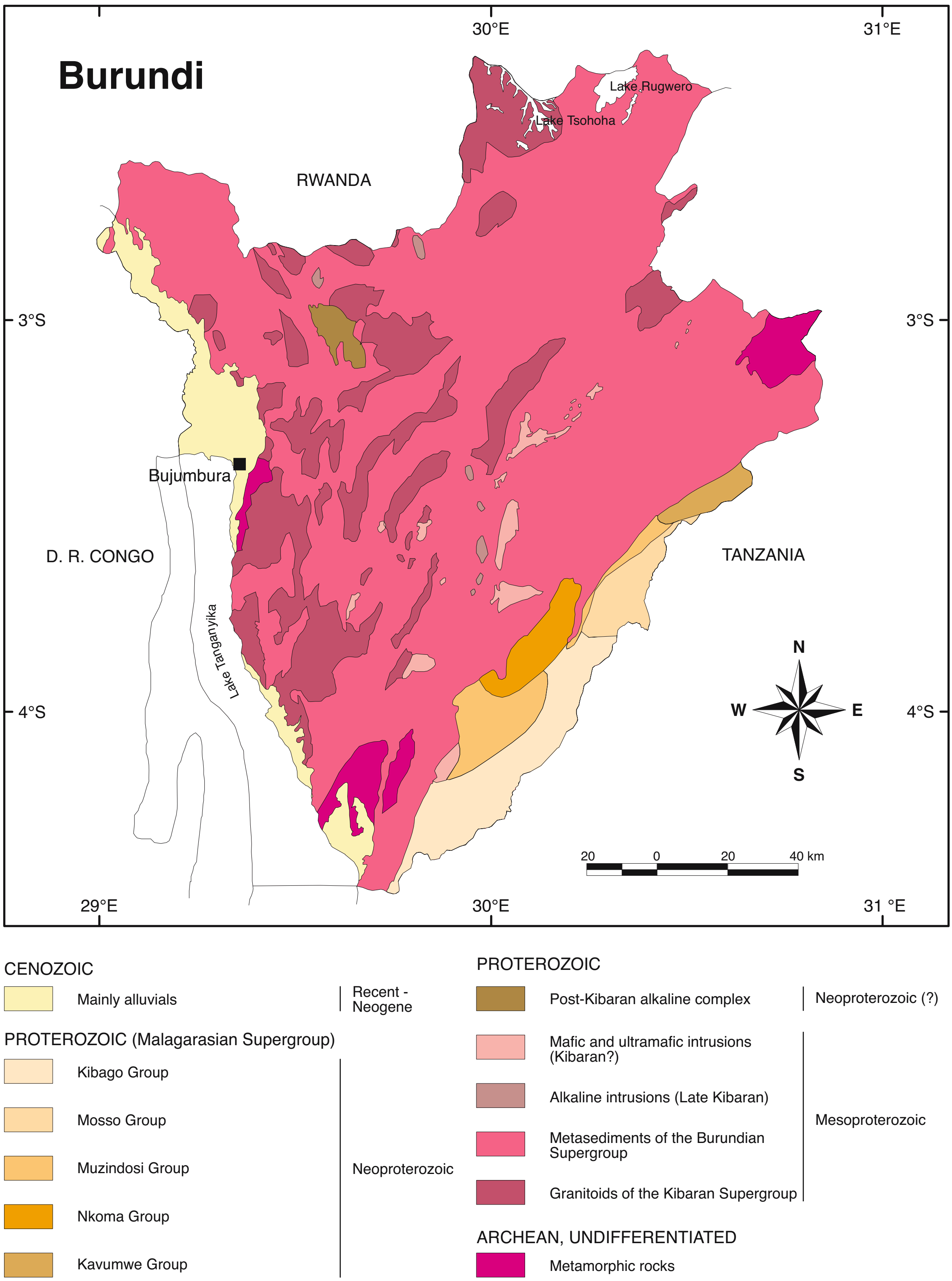

Fig. 29 Geological overview of Burundi (modified after Deblond, 1990)

a late Kibaran suture, or a late Kibaran lateral strike-slip deformation, which culminated in a major shear zone.

5 Economic Geology

Although minerals are of considerable interest in this small, but densely populated country for many years, even in the most productive years they contributed for less than 1% to the GDP. Mineral production, starting in the 1920‘s, has included gold, tin, tungsten, rare earths, columbium-tantalum and peat, as well as various construction materials. During the past 30 years, nickel, vanadium and phosphate deposits, in many cases associated with precious and other valuable minerals, attracted some attention, as did oil and gas possibilities. However, lack of infrastructure, especially reasonable-cost transportation, and also the ongoing or dormant civil war since the early 1990‘s, were the major obstacles to development.

Gold lodes in quartzites at a number of sites near Muyinga, 120km northeast of Bujumbura, were evaluated since 1989. Alluvial gold deposits in the northwest were studied in the early 1990‘s. Nickel laterite deposits near Musongati, about 90km southeast of Bujumbura, may yield 30,000mt/a of ore for production. Tin ore, or cassiterite, production by private companies on an artisanal level has started again in 1987 after a lapse of eight years. The location is in the north-central area near the border to Rwanda.

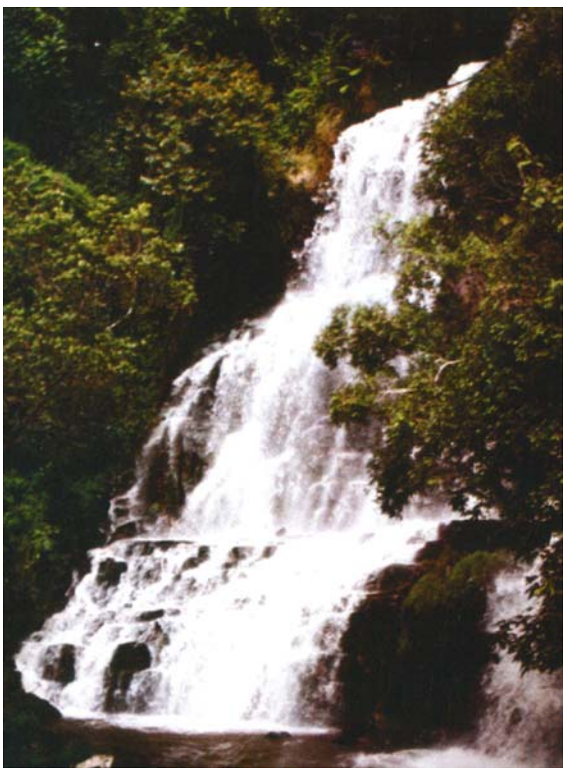

Fig. 30 Karera Falls in southern Burundi.

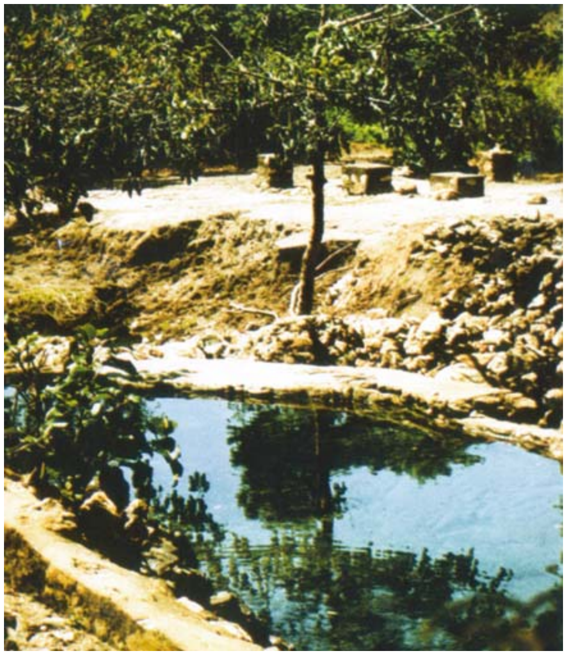

Fig. 31 Thermal springs at Muhweza in southern Burundi

6 Geohazards

An inventory has not yet been made.

7 Geosites

A formal inventory has not yet been made, but this mountainous country exhibits many places of scenic beauty (Fig. 30 and 31).

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Cameroon

1 General

Area: 475,440km²
Population: 15,422,000 (July 2000 estimate)

2 Summary of Geology

Cameroon is underlain by Precambrian rocks, Cretaceous sediments and Cenozoic sedimentary and volcanic formations. Large parts of the Precambrian are undifferentiated gneisses and migmatites. Meso- and Neoproterozoic rocks are exposed in the southeast of the country. Cretaceous sediments overly the Precambrian basement. In northern Cameroon the sedimentary facies of the Cretaceous is mainly continental, while the Cretaceous in the coastal area is mainly marine. A zone of young volcanic extrusives cross Cameroon in northeastern direction. This line probably follows a major ancient structural zone.

3 Stratigraphy

The basement rocks can be divided into two stratigraphic units, the Congo Craton in the south and the Central African Mobile Zone (CAMZ) in the north. The Congo Craton is of Archean age and covers large parts of southern Cameroon where it is known as the Ntem Group (Ndéléc and Nsifa, 1987). Its principal rock types are gneiss, granite and charnockite. The CAMZ is a domain of remobilized Precambrian terrain including igneous and metamorphic rocks of Pan-African age (Vail, 1989). Generally, most parts of the CAMZ consist of mica schists, plagioclase bearing and micaceous gneisses, and migmatites intruded by quartz, diorite and granodiorites. The basement is overlain in some places by Lower Paleozoic volcanic and younger sedimentary formations, e. g. the Mangbei, Douala and Rio-del-Rey Basins (Moreau et al., 1987).

Cenozoic magmatic rock types in Cameroon can be divided into two major units: Ring complexes range in diameter from 1 to 10km and are often associated with the Cameroon Volcanic Line (CVL), comprising a variety of rock types including syenites and granites. Their age of 66 to 30 Ma suggests that there was an overlap in activity with the extrusive centre of volcanism. The ring complexes probably represent deeply eroded remnants of older volcanoes that were intruded into the granitic and metamorphic Precambrian Basement and into early Tertiary sediments. More than 60 of these sub-volcanic ring complexes are known in Cameroon (Moreau et al., 1987), referred to as the "Granites Ultimes", extending over a distance of about 1,000km and being parallel to the NE-SW alignment of the CVL. The continental volcanism of the CVL is characterized by a 1,600km long Y-shaped chain of Tertiary to Recent, generally alkaline volcanoes, that stretch from the Atlantic Island of Pagalu through the Gulf of Guinea into the interior of western Africa. Mt Cameroon is the southernmost volcano of the continental sector of the CVL and the only volcano along the line that has recorded eruptions within the last two centuries. However, the numerous cones and craters dotted throughout the line are clear evidence of sub-recent volcanic activity. These volcanic centres differ in size, age and lithology, their lavas generally evolving from mildly alkaline basalts towards trachyte and rhyolite.

Fig. 32 Mt Cameroon seen from Victoria Bay

Fig. 33 Volcanic plugs at Rumsiki/Kapsiki in the Mandara Mountains in northwestern Cameroon

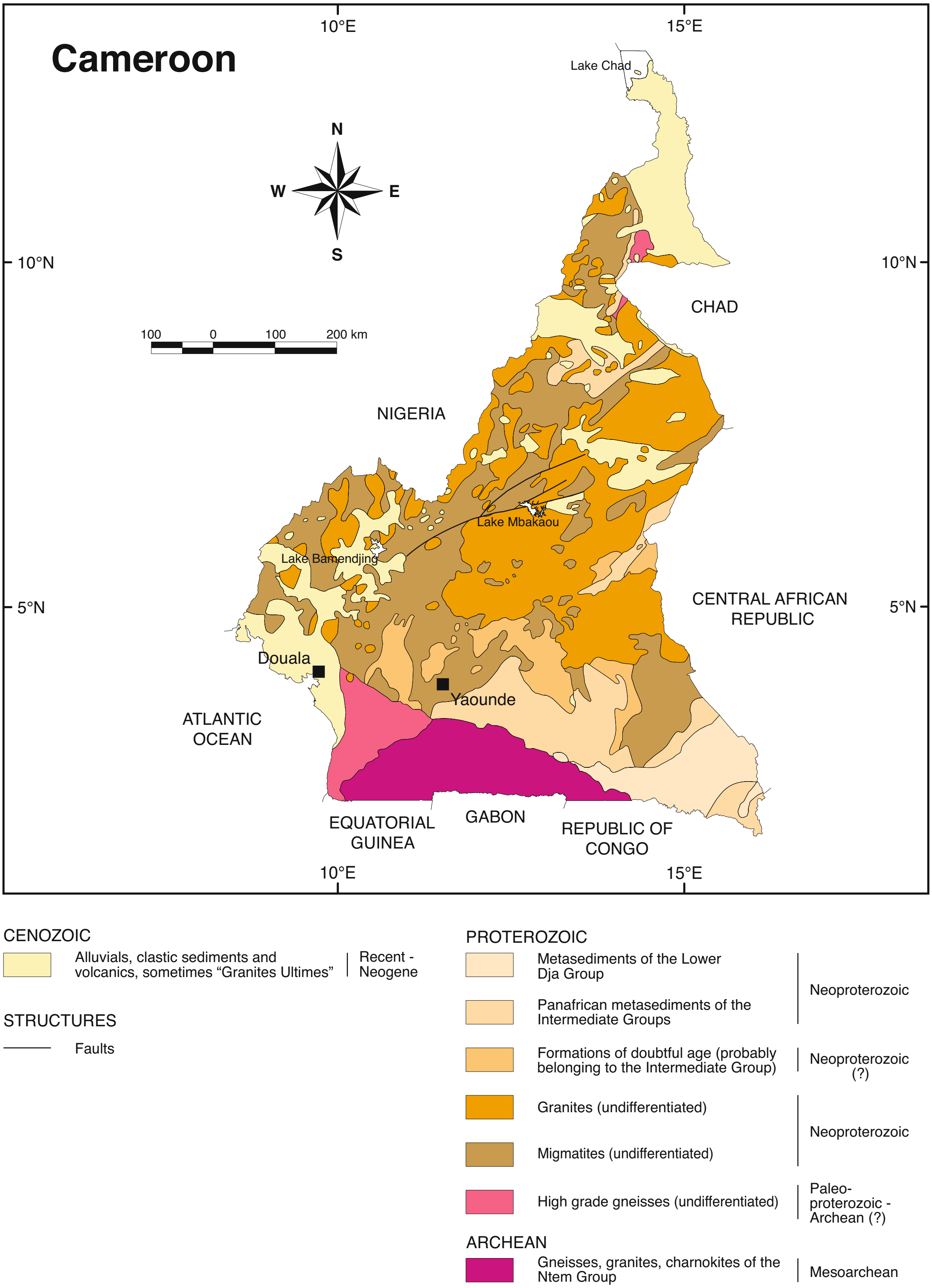

Fig. 34 Geological overview of Cameroon (modified after Elangwe, 1979)

Sedimentary rocks are restricted to the southwestern and northern parts of the country. In SW Cameroon, the oldest sedimentary rocks are massive cross-bedded sandstones and conglomerates of the Mudeck Formation of probable Lower Cretaceous age, which rests unconformably on the crystalline basement. The sandstones are overlain by fossiliferous shales of early Turonian age.

The Douala and Rio-del-Rey offshore basins are typical passive margin basins that originated during the opening of the equatorial Atlantic Ocean. They formed one continuous sedimentary basin that stretched from Nigeria to southern Cameroon from Cretaceous to Miocene times. The Lake Chad Basin in the north is covered by Quaternary to Recent sediments. Alluvial and colluvial materials of Holocene age predominate in the flood plains of large rivers.

4 Tectonics

The CAMZ is transected in central Cameroon by major faults of the Foumban Shear Zone. The orientation of the former continuous Cretaceous equatorial Atlantic Ocean Basin was controlled by normal faults, whereas the northern part of the Douala Basin is characterised by a series of NNE-SSW strike-slip faults. These faults were probably formed during the volcanic activity that separated the basin into the recent Douala and Rio-del-Rey Basins. The CVL is partly superimposed upon a preexisting fracture zone, the Central African Shear Zone (CASZ), which cuts across a major post-Cretaceous uplift, the Adamawa Uplift. To the north lies the Benue Trough and to the south the Foumban Shear Zone, both of which are major tectonic features.

5 Economic Geology

Diamonds are associated with Cretaceous fluvio-lacustrine formations of the “Séries de Carnot” close to the border with the Central African Republic and exploited by using artisanal methods. Gold indices are across the whole country, especially in the crystalline basement and the epimetamorphic sequences. Highest concentrations are in the east, essentially along the borders with the Central African Republic and Chad. Cassiterite is found in a small deposit at Mayo Darlé in NW Cameroon. Nickel and Cobalt of economic concentration occur east of Lomie in an area of about 80km^2. Rutile was exploited till 1957 near Yaounde, where mica-bearing schists are outcropping. Bauxite occurs in two larger deposits in the Ngaoundal and Minim-Martap Complex in the south of the country and near Fongo-Tongo in the west. Two iron deposits with grades of 30-40% Fe are known in Cameroon, in the southwest at Mbalam and near the coast at Kribi. Limestone is exploited at Figuil for a local cement manufacturing plant, whereas marble occurs in northern Cameroon near Bidzar. A pozzolana quarry is mined in the north at the Djoungo quarry. Petroleum is produced along the coast north of Victoria and off-shore in the Mokoko-Abana Oilfield. Gas reserves currently undergo feasibility studies.

Fig. 35 The western granitic margin of Lake Nyos

Fig. 36 Degassing of CO2 in Lake Nyos

Fig. 37 Water falls over basalt of the Sanage River in the Adamana Plateau in northwestern Cameroon

6 Geohazards

Mt Cameroon, the only active volcano in the continental sector of the CVL, has erupted seven times in the 20th century (1909, 1922, 1954, 1959, 1982, 1999 and 2000). Generally, only minor fatalities such as the destruction of forest and plantations through lava flows have been recorded. The highest geoenvironmental risk in Cameroon are, however, crater lakes that have been found to contain very high accumulations of volcanic gases, principally carbon dioxide. Two of these lakes have been sites of toxic gas emissions: Lake Monoun in 1984 (37 deaths) and the largest natural gas disaster ever recorded at Lake Nyos with about 1700 deaths. Since then degassing pipes have been installed with the aim to reduce the risk of oversaturation of the lake with gas.

Earthquakes are in Cameroon mostly confined to the Mt Cameroon region, though additionally, there are some linear zones of activity within the NE-SW trend of the CVL. Regions with large mass movements are located on the predominantly rugged slopes of the various volcanic mountains, due to their topography, heavy rainfall and large scale deforestation.

7 Geosites

A formal inventory of potential geosites has not yet been made, but the country exhibits many places of scenic beauty, for instance in the CVL.

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Canary Islands (Spain)

1 General

Area: 7 major islands covering about 7,500 km^2
Population: 1,592,000 (1995)

2 Summary of Geology

Pre-Tertiary submarine volcanism rose out of the Canary Islands oceanic floor and is related to a first period of opening of the meso-Atlantic rift, and later to the sporadic activity of deep fractures, similarly as with other passive continental margins. The islands are therefore made up of rocks of various types and alternating deposits of pyroclastics, lavas, intrusives, extrusives, marine and terrestrial sediments.

3 Stratigraphy and Tectonics

The eastern Canary Islands exhibit continental affinities, both in nature of their crustal type and in the source of their Mesozoic sediment relics. The western Canary Islands show a crust of oceanic type, pre-Quaternary sediments are lacking or doubtful and volcanism is predominant. The central islands are transitional and diastrophism has apparently played a greater role than elsewhere, a critical zone where stresses have tectonic significance. To a degree, the islands represent independent volcanic edifices, yet as they all lie within the 3,000m isobath. As in all islands magmatism is associated with basal fracturing, there is some common linkage between them.

The oldest rocks occur on Fuerteventura, being dated as Cretaceous. These rocks are folded and faulted, and their deformation has either been related to the emplacement of the basal complex or to distant echoes of the Alpine orogeny in the Moroccan Atlas. Separation from Africa is presumed to have occurred in Early Tertiary. On Fuerteventura isotopic ages have yielded 35Ma for the basement complex. The pre-Miocene history of most islands cannot as yet be too clearly deciphered, because basement complexes are not evident in all islands, but with the exception of Hierro - a product of Pliocene times - all islands appear to date from Early Tertiary, perhaps back to Jurassic for Fuerteventura and possibly Lanzarote. Over a period of about 20Ma events can be traced, such as volcanism, submarine and subaerial effusions, explosive episodes, marine and terrestrial sedimentation, extensive periods of denudation, positive and negative movements of the islands of volcano-tectonic and isostatic origins and eustatic fluctuations. From east to west the islands are becoming younger.

Interspersed with the constructive phases there have been repeated periods of denudation, some of relatively long duration, stripping away volcanics and sedimentary rocks, and upon these planed-off areas fresh volcanism has formed, thus creating many unconformable relationships within the sequences. The petrologic succession shows, according to the different islands, detrital sedimentation from a possibly African source, marine sedimentation with limestones chiefly, terrestrial deposition of fluvial and aeolian origin, submarine and subaerial volcanism of lavas and pyroclastics, plutonic intrusions as dykes, sills, irregular bodies, quiet effusions and explosive outbursts causing interlayering, volcanism from central vents, from fissures and adventitious cones. Well into Recent times positive and negative movements of the islands are noted. Volcanism extends into historic times, for instance in 1971 on La Palma.

4 Economic Geology

The mining industry has no economic significance on the Canary Islands. Basic and ultrabasic rocks have been unsuccessfully investigated for copper content. Black sands on Hierro may form an ore rich in magnetite or Ti-magnetite.

Various rocks are quarried for building purposes. Clays are used in pottery and tile manufacture, pozzulana, foraminiferal sands and clays in cement manufacture, limestone for the production of lime. Lapilli are spread over fields, particularly in the drier islands of Lanzarote and Fuerteventura, to lower evaporation and promote water condensation. In these two islands also salt is evaporated from sea waters.

The utilization of geothermal energy, with special reference to Lanzarote, is currently under investigation. In the western region of this island the Basaltic Series IV lava flows have yielded temperatures of between 16° to 350°C over an area of some 200km^2. In Gran Canaria are thermal springs varying in temperatures from 21° to 26°C, and in Tenerife with 20.8°C.

5 Geohazards

An inventory of potential geohazards has not yet been made.

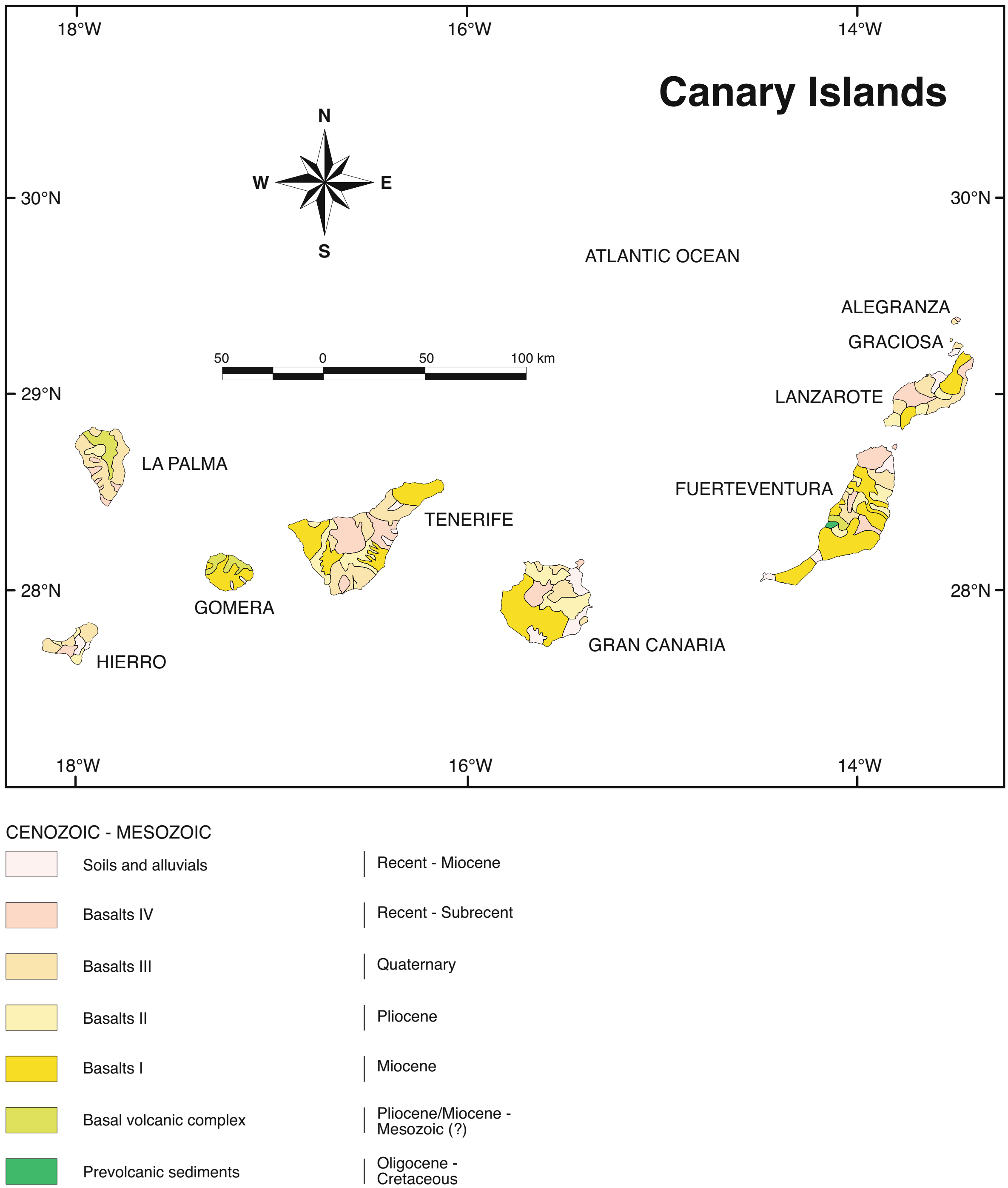

Fig. 38 Geological overview of the Canary Islands (modified after Mitchell-Thomé, 1976 and Rothe, 1996)

Fig. 39 Miocene calcareous arenites with fossilized ostrich eggs and terrestrial gastropods at Orzala on Lanzarote (from Rothe, 1996)

Fig. 40 A fossilized ostrich egg in calcareous arenites at Orzola on Lanzarote (from Rothe, 1996)

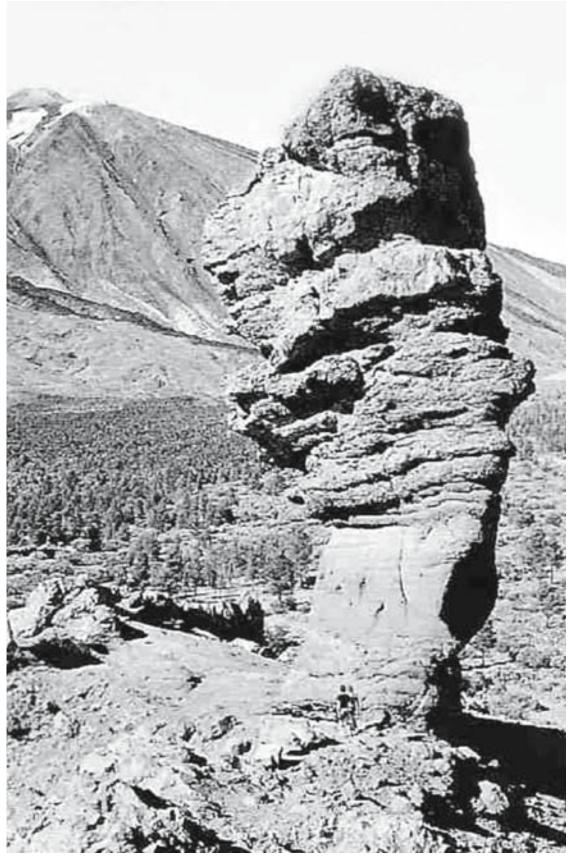

Fig. 41 The Roques de Garcia, eroded pyroclasts of the Canadas Series, on Tenerife. In the background is Pico de Teide (from Rothe, 1996)

6 Geosites

The Canary Islands are known as tourist destinations, due to their climate and their scenic beauty. There exist geological guides, in which most potential geosites are described in detail (Rothe, 1996) (Fig. 39 - 41).

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Cape Verde

1 General

Area: 4,033 km²
Population: 401,000 (July 2000 estimate)

2 Summary of Geology

The Republic of Cape Verde, located some 500km west of the coast of Senegal in the Atlantic Ocean, consists of 12 islands, 9 of which are inhabited. They are made up mostly of Tertiary and younger volcanics.

3 Stratigraphy and Tectonics

The oldest rocks of the Cape Verde Archipelago occur in Maio, from where aptychi (i. e. shell remains of ammonites) were collected, which have been assigned to an Upper Jurassic or Neocomian age (Mitchell-Thomé, 1976). It is not clear if other Cretaceous deposits occur on the archipelago, for instance in Sao Nicolau, Sao Vicente, Maio, Sao Tiago and Ilheus Secos. Another stratigraphic uncertainty refers to the Paleogene. The greatest number of fossils has been collected from the Neogene of Sao Nicolau, indicating a Helvetian and Tortonian age. Raised beaches of Pleistocene age have been determined for several islands, whilst Holocene is represented by active dunes, marine terraces, coastal river alluvium, scree deposits, etc.

The islands of Cape Verde represent a within-plate archipelago located in the central Atlantic Ocean. They are remnants of Tertiary volcanism, generated by a mantle plume and related to the Mid-Atlantic Rift environment. The main current volcanic activity is centred underneath the Fogo-Bravo region. Lithologically they consist mostly of basalt, but few oceanic Mg-rich carbonatites also occur (Le Bas, 1980). Recent volcanic formations from Santo Antão Island, the northwestern island of the archipelego, were summarized by Silva et al. (2004), indicating the latest volcanic activities at about 0.09 Ma.

4 Economic Geology

The products of a very and mostly traditional mining activity on the Cape Verde islands are salt, pozzolana salt, gypsum, kaolin, limestone and building materials. The only mineral of some interest is pozzolana, some of which was exported to Portugal in the past. A small lime operation exists on the island of Boa Vista.

5 Geohazards

At least 26 volcanic eruptions have been reported since the 15th century from Fogo Island, indicating that the strongest impacts on the landscape and human settlement there resulted from volcanic products. The last two eruptions occurred in 1951 and 1995, causing the following geoenvironmental hazards: rapid lava flows, volcanic vent reactivation, emission of bombs, ashes and gas emanations. Fogo is apparently the only island with active volcanism within historic times.

6 Geosites

An inventory has not yet been made.

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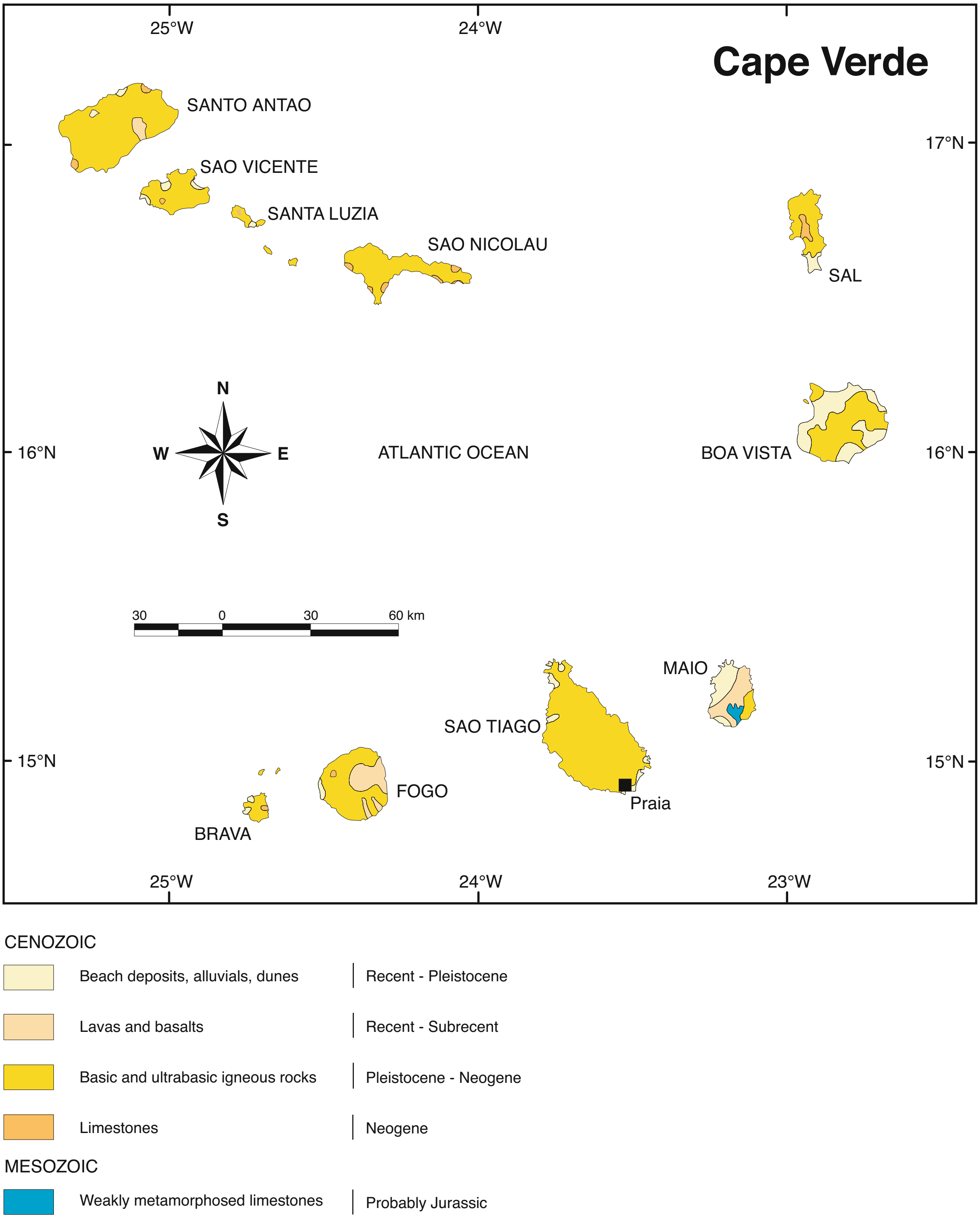

Fig. 42 Geological overview of Cape Verde (modified after Mitchell-Thomé, 1976)

Central African Republic

1 General

Area: 622,984km²
Population: 3,513,000 (July 2000 estimate)

2 Summary of Geology

Approximately 60% of the Central African Republic are underlain by rocks of Archean and Proterozoic age. Parts of the western and central areas of the country are covered by probably Paleozoic glaciogene sediments and flat-lying Cretaceous sandstones.

3 Stratigraphy and Tectonics

The Precambrian strata of the Central African Republic can be subdivided into two major units: The lower "Granitic-Gneissic Complex" is mainly made of gneisses, gneissic-migmatitic, granitic and amphibolitic rocks, probably of Neoarchean age. This unit has been described as a greenstone belt (Cahen et al., 1984) and was subdivided into the Bandas Belt and the Dekoa Belt, which originally possibly belonged to the same entity, whereas they are presently separated by Proterozoic sequences. The complex is often intruded by doleritic dykes as well as by late granitoid batholiths of Neoproterozoic age. Highly metamorphosed formations, at the granulite facies, form large complexes in the central part of the country. The upper "Schisto-Quartzitic Complex" is characterized by quartzitic and schistose rocks, probably of Neoproterozoic age. This unit is often folded, but weakly or not metamorphosed. Mica schists, quartzites and dolomitic limestone indicate a sedimentary origin. Quartzites are more common in the central part of the country, whereas mica schists are found in the east. The Schisto-Quatzitic Complex is also intruded by basic rocks, which are generally sheared.

Probable Paleozoic sequences include the Mambere Formation in the west, and the Kombele Formation in the east, which are apparently of glaciogenic origin. These are separated from probably Cretaceous fluviatile sequences by a discontinuity, which corresponds to a stratigraphic unconformity. These sub-horizontal sandy/conglomeratic units cover more than 85,000km² and are known in the northeast as the Mouka-Ouadda Sandstone Formation, and in the southwest as the Carnot-Berberati Sandstone Formation. Rocks of Cenozoic age, especially of Eocene, occur in the southwest of the country, known as Bambio Sandstone Formation and forming there plateaux. As it is typical in the intertropical zone and particularly in peneplains, significant chemical alteration of the surface rocks occurred during Quaternary, sometimes reaching a thickness of up to 40m.

4 Economic Geology

The mineral potential of the Central African Republic has not yet been systematically evaluated, but may be large. The mining industry is mostly based on the production and export of diamonds. To date, diamonds are mined exclusively in Quaternary alluvial deposits, by diving or by gravel extraction from river beds, as well as by mining of the lower terraces of rivers, in the river basins crossing the sandstone formations of Carnot-Berberati in the southwest and of Mouka-Ouadda in the northeast. Some diamonds are also found in the Precambrian sandstone of Kette. Gold is associated with ultrabasic rocks of the greenstone belts, and is concentrated in secondary vein deposits. It is generally mined in placer deposits. In addition to diamonds and gold, iron ore deposits (BIF) occur near Bogoin, copper deposits at Ngade and tin deposits at Yalinga. At Bakouma, an uraniferous phosphate deposit was discovered, but the currently low uranium price, combined with infrastructure, mining and processing difficulties, has delayed opening of the planned mine. Lignite occurrences at Nzako and limestone deposits at Babassa play only locally a role in the mining sector.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

7 References

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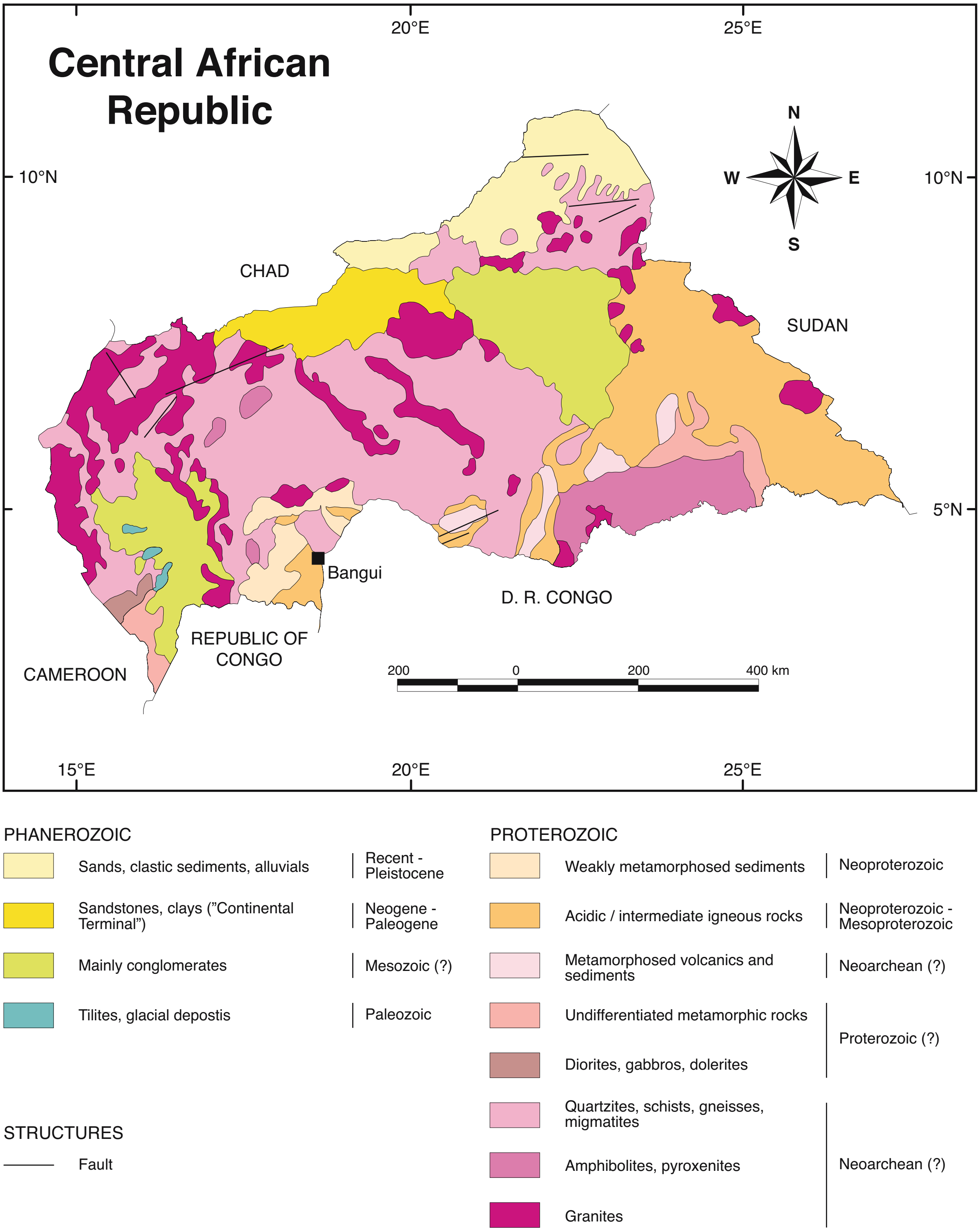

Fig. 43 Geological overview of the Central African Republic (modified after Malibangar et al., 2001)

Chad

1 General

Area: 1,284,000 km²
Population: 8,425,000 (July 2000 estimate)

2 Summary of Geology

The geology of Chad is characterized by Precambrian and younger sediments surrounding the central Chad Basin. Precambrian rocks occur in the Tibesti Mountains in the north and the eastern part of the country. Lower Paleozoic sandstone sequences in the Kufra Basin in the northeast (at the border with Libya and Sudan) are overlain by Nubian sandstones. The Lower Cretaceous is made up of continental clastic rocks, whereas the Upper Cretaceous includes marine sediments. Tertiary continental sediments cover parts of southern Chad. The Neogene Chad Formation comprises lacustrine sediments in large parts of the Chad Basin.

3 Stratigraphy and Tectonics

Along the border between Libya and Chad there is an impressive area of some of the highest mountains in the Sahara, known as the Tibesti highlands (Fig.44). The tallest peaks are Cenozoic volcanoes, which in places directly overlie basement rocks, which are often completely surrounded and overlapped by flat-lying sediments. Much of this platform cover, especially on the western, southern and eastern flanks in northern Chad, is made up of continental Cambrian to Ordovician sandstones (Fig. 46) resting with marked unconformity on the Precambrian rocks. The latter have been divided into two units, separated by an unconformity and basal conglomerate, which differ in degree of metamorphism, but which are both highly folded and intruded by granitic rocks. The older sequence, known as Tibestian I, is made up of highly metamorphosed sedimentary and intercalated basic volcanic rocks, such as mica schists, micaceous quartzites, hornblende schists, amphibolites and pyroxenites. They are intruded by synorogenic granodiorites and folded on NNE axes. Due to their style of folding and facies they may be age-equivalent to the Paleoproterozoic Suggarian event in the eastern Hoggar Mountains. The upper unit, known as Tibestian II, covers a much larger area and is composed of alternating quartzites and arkoses with slates and rhyolitic lavas. The rocks are

Fig. 44 Eroded granite in the northern Tibesti Mountains

in a low grade of metamorphism, but are affected by syn- and late-orogenic calc-alkali and alkali granites, the latter associated with pegmatites containing wolfram and tin. Isotopic measurements have yielded age determinations ranging from Neoproterozoic to early Paleozoic times.

There is a large area of basement rocks exposed in eastern Chad, which extends across the Sudan border into the Darfur Province. The dominant rock types are granitic gneisses, quartzo-feldspathic, graphitic and pelitic schists, whereas calcareous and volcanic rocks are rare. The folding is usually on NE axes, and many of the rocks are in amphibolite grade of regional metamorphism. There are many late-orogenic granitic batholiths cutting the schists and gneisses, in which quartz veins and pegmatites are developed in places and tin and wolfram mineralization occurs. Intrusive granitoids have yielded ages ranging from 590-570Ma.

Precambrian rocks affected probably by the Pan-African tectono-thermal event occur also in the southeast of the country close to the border with Cameroon in the Guera Massif and the Lam Mountains.

The Erdis Basin of Chad is an extension of the larger Kufra Basin, which is known from southeastern Libya, southwestern Egypt and northwestern Sudan. It is made up of a sequence of Paleozoic rocks ranging in the Kufra Basin from Cambrian to Carboniferous times. The Chad Basin refers to a group of NW-SE trending buried rifts in western central Chad and southeastern Niger. These buried rifts are beneath a mantle of Quaternary desert dunes. The sequence, up to 4,000m thick, begins with Permo-Triassic to Early Cretaceous non-marine strata of fluviatile and lacustrine origin, which belong to the "Continental Intercalaire" Group, which is overlain by Cenomanian

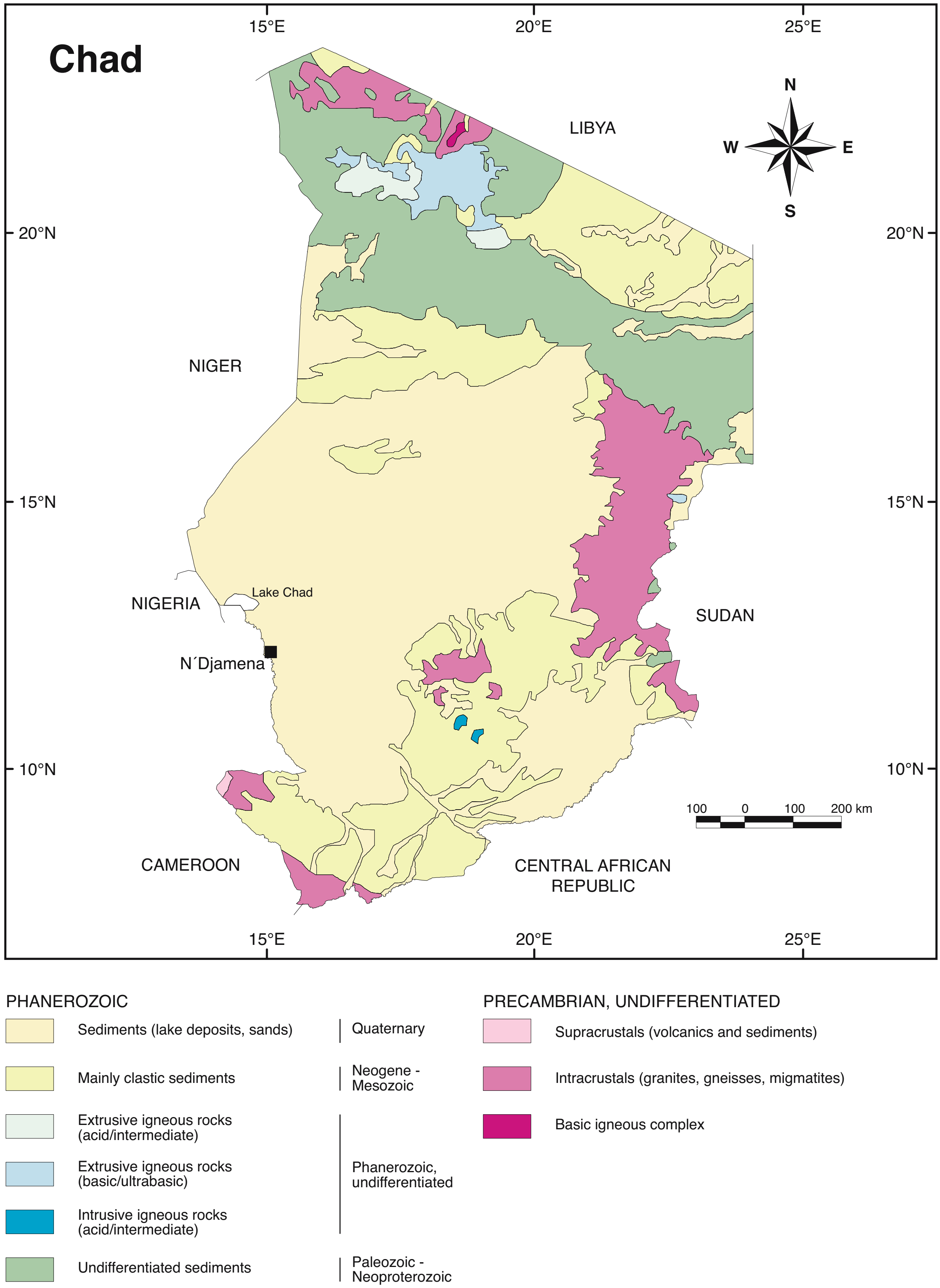

Fig. 45 Geological overview of Chad (modified after Wolff,1964)

Fig. 46 Paleozoic sediments overlain by shield volcanoes of the Tarso Abeki in the Tibesti Mountains

Fig. 48 The shore of Lake Chad

to Coniacian marine shales and carbonates. The Upper Cretaceous is a clastic sequence with gypsiferous, glauconitic and fossiliferous shales still recording marine influence up to the Santonian and Campanian. Tertiary non-marine beds resting unconformably on Maastrichtian to Paleocene continental sandstones with oolitic iron-stones, belong to the "Continental Terminal".

In the Tibesti Mountains, Phanerozoic sediments are overlain by shield volcanoes and explosive volcanic centres. Here basaltic and acidic ignimbritic eruptive rocks are predominant, with hot springs indicating recent activity (Fig. 47).

4 Economic Geology

Currently Chad possesses virtually no mineral industry. Underdevelopment characterizes Chad's mining sector since independence in 1960, although a variety of minerals have been reported to occur in Chad. Columbium-tantalum, tin, tungsten and uranium are associated with granites and pegmatites of the Aouzou region and Tibesti mountain region of northern Chad. Indications of bauxite, chromium, copper, iron, lead, nickel, titanium and zinc have been reported. Historically, artisanal exploitation of alluvial gold has been reported near Pala in southern Chad.

Fig. 47 Volcano Ehi Mousgou about 70km southeast of the oasis Bardai

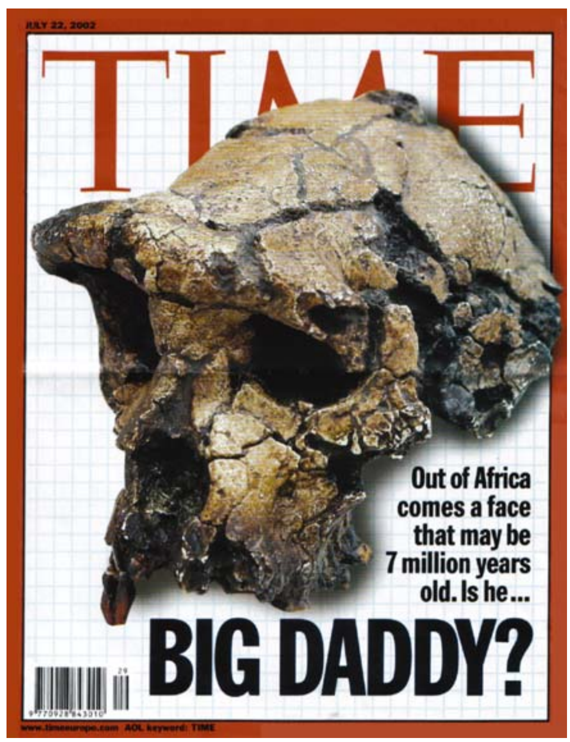

Fig. 49 *Sahelanthropus*, the oldest known hominid, on the cover of Time Magazine (July 2002)

Fig 50 The discovery site of *Sahelanthropus Tchadensis*

Crude oil was discovered in Chad in 1974 at Sedigi, north of Lake Chad, approximately 300km from N'Djamena. The oil reserves are estimated of about 10.5M barrels. Natron is extracted north of the Lake Chad region by the local population (Fig. 48). Salt is extracted from the salt lakes in northern Chad. Construction materials in the form of aggregates are extracted from a quarry located south of Lake Chad along with clay, limestone and sand.

5 Geoenvironmental Hazards

An inventory has not yet been made.

6 Geosites

An inventory of potential sites has not yet been made. However, one of the most spectacular paleoanthropological discoveries of recent times was made in the Djurab Desert of northern Chad, when a team of Chadian and French scientists in 2001 found an almost completely preserved hominid skull (*Sahelanthropus tchadensis*), which was dated at about 7Ma and therefore represents the oldest known remains of our ancestors (Fig. 49 and 50).

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The Comoros (Mayotte is still under French administration)

1 General

Area: Altogether 2,033 km^2 (Grand Comore [Ngazidja], Moheli [Mwali] and Anjouan [Ndzuani] make up the State of The Comoros, the fourth island, Mayotte [Maore], is still under French administration)
Population: 578,000 (July 2000 estimate)

2 Summary of Geology

The archipelago of the Comoros is located at the northern tip of the Mozambique Channel in the Indian Ocean, halfway between the coasts of Madagascar and the African continent. It comprises four major islands of volcanic origin aligned to a NW-SE trending axis. The volcanic chain of the Comoros apparently represents a “hot spot trace”.

3 Stratigraphy and Tectonics

The Mozambique Channel in the Indian Ocean constitutes a region of particular complexity within the geodynamique framework of polyphase tectonics during the dislocation of the Malagarasian microcontinent from Gondwana. The principal steps of the structural development include during the period ranging from Permian to Lower Jurassic a NE-SW trending Karoo rifting and from Middle Jurassic to Lower Cretaceous the formation of oceanic basins along the N-S trending Davie Ridge. The age of the volcanics of the Comoros increase eastward, from Grand Comore (0.01Ma) to Moheli (5.0Ma), to Anjouan (3.9Ma) and Mayotte (7.7Ma), indicating that the volcanic chain of the Comoros represents a “hot spot trace” produced as the Somali plate moved over a mantle source.

The lavas are primarily undersaturated alkali olivine basalts. Phonolitic and small volumes of trachytic lavas have also been reported. The volcanic rocks have been differentiated into the “Phase volcanique superieure, intermediaire et inferieure”. In all phases, basaltic lavas prevail. Scorias and puzzolanic tuffs have been reported from Grand Comore, Moheli and Anjouan. Phonolitic and trachytic rocks are known from Mayotte.

4 Economic Geology

The mineral industry of the Comoros is limited to the production of local building materials from mainly volcanic rocks. The mining of corals for the production of lime from coral debris is in use but also limited.

5 Geohazards

Karthala is an active volcano on Grand Comore, which erupted several times since earliest reliable records in 1857. A volcanological observatory in the capital of Moroni is concerned with risk assessment of potential eruptions.The use of the primary coral reefs as a construction material is problematical due to environmental impacts.

6 Geosites

The Comoros are tourist destinations and therefore exhibit a number of potential geosites (mostly volcanoligal), both of geological significance and scenic beauty (Fig. 51).

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Fig. 51 Crater lake at Karthala on Grand Comore (from Bachèlery & Coudray, 1993)

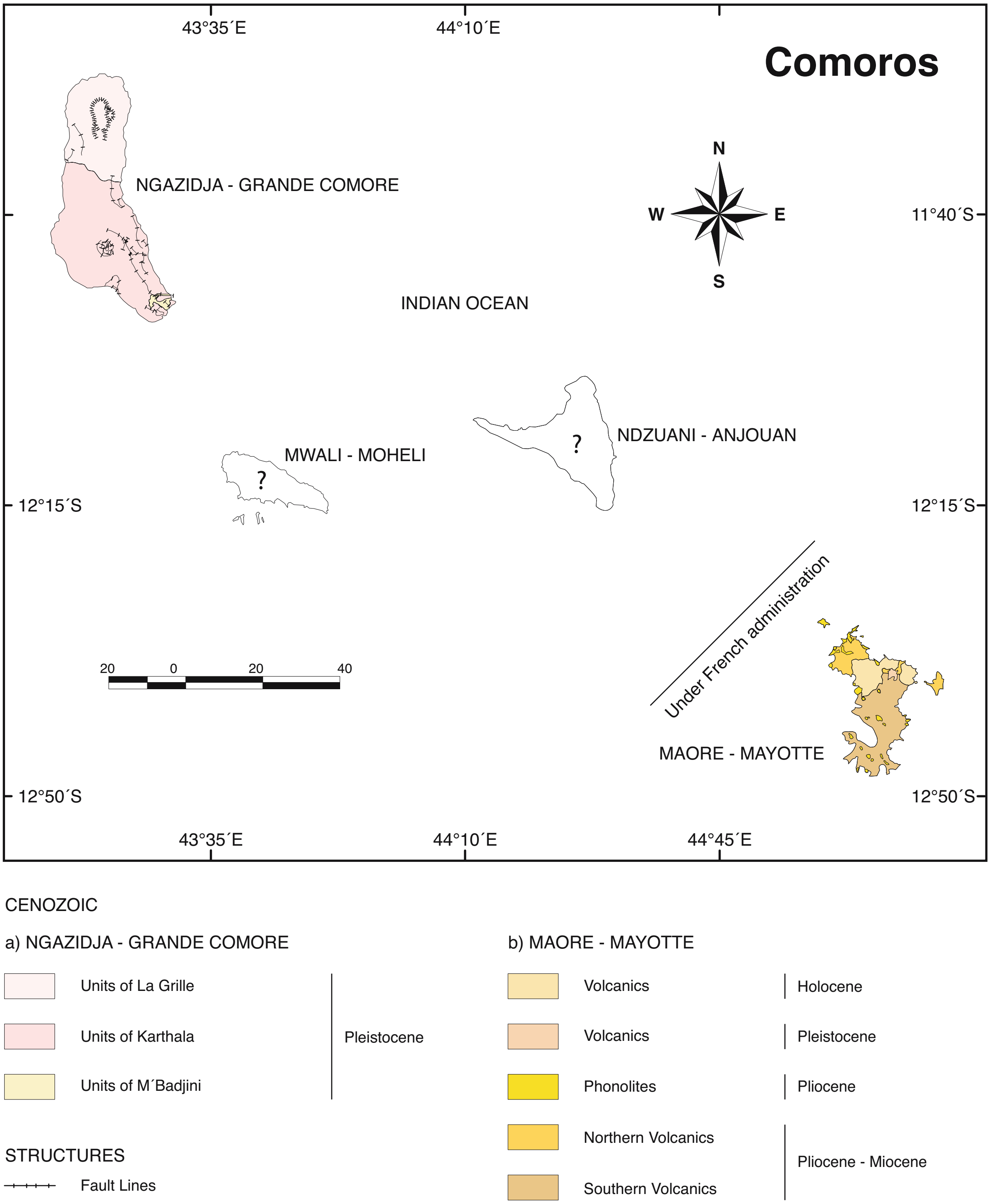

Fig. 52 Geological overview of the Comoros (modified after Bachelery & Coudray, 1993, and Stieltjes, 1988), except Mwali-Moheli and Ndzuani-Anjouan.
Source maps for Mwali-Moheli and Ndzuani-Anjouan were not available

Democratic Republic of Congo (DRC)

1 General

Area: 2,345,410km^2
Population: 51,965,000 (July 2000 estimate)

2 Summary of Geology

The Congo Basin, made up largely of Mesozoic to Cenozoic and Recent sediments, occupies large parts of the centre and west of the country. It is surrounded by more or less elevated Precambrian ridges: to the west by the Atlantic Rise, to the north by the Uganda to Central African Republic mobile belts and to the south by the Kasai and northeastern Angola Shield. Tabular volcano-sedimentary deposits of Pan-African age encircle the inner margins of the basin. The southeast of the country is underlain by the Pan-African Lufilian Arc. Along the eastern part, at the border to the Western Rift of the East African Rift System, occur numerous Tertiary to Recent volcanoes and some carbonatites.

3 Stratigraphy and Tectonics

Archean terranes are exposed in three principal parts of the Congo Craton in equatorial Africa. In the southwestern part it is the Kasai and northeastern Angola Shield, in the northwest it is a broad basement comprising the foreland of the younger West Congolian mobile belt, and in the northeast occur granite-greenstone terranes, which extend into the neighbouring countries of the Central African Republic, Uganda and Sudan.

In the region of the Kasai and northeastern Angola Shield ancient metamorphic basement is exposed, which is bounded at about 4° south by a fault. In the east the Archean terrane is bounded by the Katangan System, while Phanerozoic rocks cover the southern and western ends of the shield. Most of the Kasai and northeastern Angola Shield is underlain by poorly exposed gneisses and migmatites. The oldest rocks, dated at about 3,400Ma, are the Upper Luanyi granite gneisses with pegmatites of amphibolite facies. These are separated from the adjacent Kanda Kanda grey tonalites and granodiorite gneisses by inferred faults. The Kanda Kanda gneisses contain diffuse lenses of alaskite gneisses, which are hololeucocratic pink rocks that probably formed near the limit of granulite facies metamorphism or as intrusions, which originated from the nearby charnockitic rocks, the Kasai-Lomami gabbro-norite and charnockitic assemblage. Although their exact ages are unknown, the Kanda Kanda gneisses have been estimated to range between 3,400-2,820Ma. The Kasai-Lomami gabbro-norite and charnockitic assemblage comprises two rock suites: There is a mafic unit (gabbro, norite, amphibolites and anorthosites), which originally comprised a heterogeneous sequence of hypabyssal intrusives or effusive magmatic rocks and deep-seated intrusives, which have undergone granulite facies metamorphism. The second unit is an acidic assemblage comprising dark gneisses of charnockitic-enderbitic composition and aluminous granulites, both of which probably had partially sedimentary precursors. The acidic part of the Kasai-Lomami assemblage contains metadolerite dykes. Both the mafic and the acidic components contain grano-clastic textures and cataclastic deformations, which reflect granulite facies metamorphism (or charnockitization) and regional deformation respectively. These events are dated at about 2,800Ma.

The northwestern part of the Congo Craton is a broad basement upward, which constitutes the foreland of the younger West Congolian mobile belt of Pan-African age. It extends as a vast granitoid assemblage known as the Chaillu Massif from the Republic of Congo, the Democratic Republic of Congo, through Gabon, where it is mostly concealed beneath Neoproterozoic supracrustals, to southern Cameroon. The Chaillu Massif shows a N-S foliation and contains two generations of granitoids: grey granodioritic to quartz dioritic biotite or biotite-amphibolite types, and pink, mostly potassic migmatites, which occur as veins cutting the grey granitoids. Within the granitoids, schists and greenstones exist as septa, which have not been completely transformed by granitization. The Chaillu Massif granitoids have been dated at about 2,700Ma, thus the engulfed schists and greenstones are apparently older.

In the northeastern part of the Congo Craton Archean gneisses and granite-greenstone terranes are widely distributed and extend into the adjacent territories of the Central African Republic, western Uganda and southern Sudan. In this vast region Archean rocks comprise the following major three assemblages: old basement gneisses, which have yielded ages of about 3,500Ma and are known as Bomu and West Nile Gneissic Complexes; scattered greenstone belts known as the Ganguan Greenstone Belt in the west and as the Kibalian Greenstone Belt

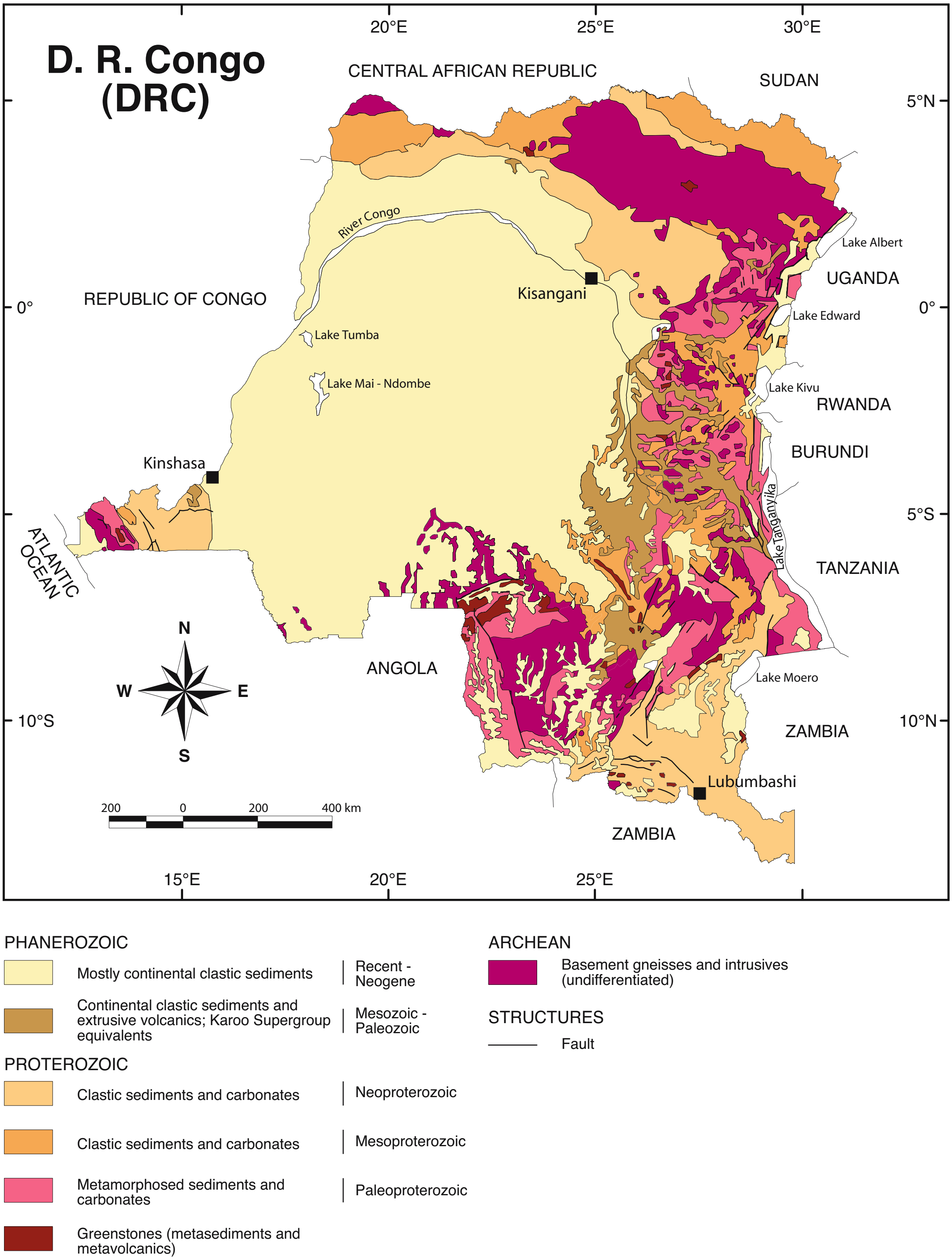

Fig. 53 Geological overview of D. R. Congo (modified after Lepersonne, 1974)

in the east, both of which represent two periods of greenstone emplacement between 3,200-2,600Ma; and two main generations of granitoids emplaced at about 2,900-2,700Ma. The Bomu Gneissic Complex is exposed around the confluence of the Bomu and Uele Rivers at the border between the Democratic Republic of Congo and the Central African Republic. Several gneissic assemblages, the Bomu, Bereme, Nzangi and Monga gneisses constitute the basement complex in this region. The largest are the Bomu amphibolite-pyroxene gneisses occupying a synformal structure in the northern Democratic Republic of Congo. The Bomu gneisses are schistose and garnetiferous and have undergone retrograde metamorphism. They also contain massive and banded tonalitic and monazonitic granitoids. The geological history of these gneisses began with the deposition of probably oceanic precursors of the Bomu gneisses at about 3,500Ma, followed by high-grade tectono-thermal activity and finally the intrusion of tonalites at about 3,410Ma. The so-called West Nile Gneissic Complex includes several basement gneisses, which are poorly exposed from the West Nile Province in northwestern Uganda and the northeastern part of the Democratic Republic of Congo, through southern Sudan into the Central African Republic.

Granulite rocks known as pre-Watian assemblage in this region contain charnockitic dolerite dykes and are characterized by isoclinal folds with vertical axial planes trending E or ENE. Before they were deformed and intruded by dolerite dykes, the parent rocks of these granulites were probably of volcano-sedimentary origin. These parent rocks were metamorphosed at greater crustal depths to granulite facies during the Watian tectono-thermal event at about 2,900Ma. Charnockites developed during this stage. The Watian event was probably followed by the formation of volcano-sedimentary rocks, which were later metamorphosed into the so-called Western Grey Gneisses Group comprising well-layered gneissic rocks and predominantly composed of upper amphibolite facies biotite-hornblende gneiss with microcline. The Western Grey gneisses exhibit NE-plunging folds with steep axial planes and are assigned to the Aruan tectono-thermal event at about 2,680Ma. In the northeastern part of the Democratic Republic of Congo occur also the so-called Eastern Grey Gneisses, which are of low metamorphic grade. The Ganguan Greenstone Belt occurs in several exposures mainly east of the Bomu-Uele confluence. Lithologically it comprises from bottom to top sericite quartzites and quartz phyllites, quartz-poor talc schists, sericite schists, chlorite schists and phyllites. The Ganguan greenstones are dated at about 3,200Ma, but were affected by tectono-thermal activities at about 2,980Ma. Although the Kibalian Greenstone Belt is exposed in several isolated belts and is separated by the Upper Congo Granitoid Massif, it probably represents only one continuous greenstone belt, which has been subdivided into an eastern facies and a western facies. The eastern facies shows a predominance of mafic to intermediate volcanics, while the western facies contains mostly banded iron formations and less mafic rocks. The Kibalian Greenstone Belt is further subdivided into a regionally more extensive lower Kibalian with an age of about 2,890Ma and an upper Kibalian dated at about 2,500Ma. An island arc tectonic setting has been proposed as a model to explain the Kibalian greenstones, some of which are believed to be of oceanic crust origin. Granitoids are the most extensive rocks in the northeastern Congo Craton, representing mostly orthogneisses, which were derived from reworking of monzonite granites and tonalites. There are two generations of granitoids: the first generation is dated at about 2,840Ma and consists of tonalites with diorites and granodiorites. The second group, which is dated at about 2,460Ma, is the most abundant and consists of medium-to-coarse-grained quartz monzonites, which intrude the first generation.

The Lufilian Arc comprises a zone of Neoproterozoic rocks in northern central Zambia and the Katanga (Shaba) Province in the Democratic Republic of Congo. Formed initially within a major zone of intra-continental extension, the Lufilian Arc developed its present fold and thrust belt character during the development of the transcontinental Damara-Lufilian-Zambezi Orogen. This complex orogenic system separates the Congo, Bangweulu and Kalahari Cratons, overprinting the 1,300-1,100Ma old Kibaran and Irumide orogenies. Isolated by the Mwembeshi Shear Zone the Lufilian Arc components in the Democratic Republic of Congo are also known as Katanga Orogen. Starting from about 875Ma, up to 10,000m of Katangan sediments were deposited within a system of linked, differentially-subsiding rift basins and subsequent sag basins. Differences in the original rift morphology and subsequent tectonic evolution of the Lufilian Arc accounts for the stratigraphic variations between regions and structural domains in the orogenic belt. In Katanga, the base of the otherwise in Zambia thick Roan Supergroup is generally not seen. This sequence is here assumed by the presence of significant intraformational breccias, representing tectonic stacking of north-thrusted sheets. The Roan Supergroup is unconformably overlain by carbonaceous shales, iron formations and pyroclastics of the Mwashya Group. Within the Katangan-Zambian copper belt, the Upper Roan Supergroup and the Mwashya Group sediments contain significant volumes of irregular sill-like amphibolitic gabbros. The overlying Lower and Upper parts of the Kundelungu Supergroup have both glacial sequences at their bases, terminated by cap carbonates. The Katangan sediments were deformed and metamorphosed to green schist and amphibolite grade during Pan-African times.

Tabular cratonic sedimentary formations rest on the Congo Craton along its margin, representing the remnants of a once flat-lying Pan-African cover, which is equivalent to the deformed successions in the craton-encircling Pan-African mobile belts. The basal parts of the Pan-African cratonic cover contain Kibaran molasse, while the upper part includes Pan-African molasse. Only very few radiometric ages are available, but stratigraphic correlations are based on stromatolites and acritarchs. On the southeastern part of the Congo Craton is the Mbuyi Mayi Supergroup, which is made up of conglomerates, quartzites, siltstones, shales and dolomitic shales, sometimes containing stromatolitic carbonates. The northern tabular sequence is known as the Lindian Supergroup, which lies north and northeast of Kisangani. It consists of the Ituri Group at the base, which is a typical epicontinental orthoquartzite -carbonate assemblage deposited under stable shallow marine conditions with stromatolites. The Aruwumi Group at the top comprises in ascending order quartzites of fluvial and aeolian origin, marine or lagoonal limestones, euxinic shales and finally a thick deltaic arkosic sequence. Between the Congo and Tanzania Cratons patchy tabular outcrops belong to the Itombwe Supergroup, the equivalent of the Bukoban or Malagarasian Supergroups to the east. The Mpioka and Inkisi Groups are the foreland tabular sequences of the West Congolian Orogen.

The Congo Basin is a broad downwarp centred on the Congo Craton and contains Karoo, Late Jurassic to Early Cretaceous fluviatile and lacustrine deposits and an Upper Cretaceous non-marine succession. The Lualaba and the Kamina Series constitute the Late Jurassic to Early Cretaceous sequence, while the Kwanga Series represents the Upper Cretaceous succession, rich in freshwater fishes, ostracodes and palynomorphs. Diamond-bearing gravels and conglomerates occur at the base of the Kwango Series, suggesting the intrusion of kimberlitic pipes in Early Cretaceous.

Fig. 54 Open-cast copper mine in Shaba Province (1984).

Volcanism in the Western Rift of the East African Rift System commenced contemporaneously with, or shortly after volcanism began in the Kenyan Rift. The oldest basalts, dated at about 14Ma, form a foundation to the Virunga Massif east of the present rift. These fissure basalts are of transitional alkalinity, and are overlain by alkaline basalts ranging in age from 13 to 9Ma. In Late Pliocene times (ca. 3Ma), a change in tectonic style to NE-SW fracturing was accompanied by a fundamental change in volcanism. Potassic, highly undersaturated lavas now erupted along a zone transverse to the rift, building up a chain of large central volcanoes. Most, if not all, of these volcanoes evolved through a stage of having a semi-permanent lava lake, the two youngest being the Nyiragongo and Nyamulagira volcanoes.

4 Economic Geology

The overall decline of the Democratic Republic of Congo‘s mining industry continued since the outbreak of the civil war drastically and has led to a virtual collapse of the metal mining sector of the country.

Fig. 55 Open-cast copper mine in Shaba Province (1993).

The copperbelt of Katanga and Zambia within the Lufilian Arc holds more than half of the world‘s reserves of cobalt deposits and about 12% of the world‘s copper reserves. Of the 4.8 million tonnes of cobalt metal reserves in the copperbelt, the Democratic Republic of Congo has the largest share, with about 3.1 million tonnes. The copperbelt is a polymetallic metallogenic province, the major types being stratiform, vein and skarn, in which the dominant deposits are Cu-Co and Zn-Pb sulphides, Cl oxides and noble metals (<fig. 54 and 55).

Gold production has fallen considerably over the years, largely owing to obsolete equipment. Auriferous deposits exist mainly in the east of the country and currently some rehabilitation activities are underway.

The output of zinc was a byproduct of the Kipushi Mine in the Katangan copperbelt near Lubumbashi. The mine was closed in 1993, but feasibility studies suggest a reopening aimed at a production of 200,000t/y of zinc. It was also a major source of germanium. 200 tonnes of tin were yearly produced at Sominki in the east of the country till the early 1990s, but current production data are not available.

The metallic ore of columbite-tantalite, sometimes better known as coltan, is found in major quantities in the eastern part of the Democratic Republic of Congo. When refined, coltan becomes metallic tantalum, a heat-resistent powder that can hold a high electrical charge. These properties have made it in the last decade a vital and strategic element in creating capacitors, the electronic elements that control current flow inside miniature circuit boards. Tantalum capacitors are used in almost all cell phones, laptops, pagers and many other electronics. Thus the price for coltan has skyrocket to as much as 400US$/kg in recent years. The path that coltan takes to get from central Africa to the world market is highly a convoluted one, with legitimate or artisanal mining operations often being confused with rebel operations.

The Kisenge manganese deposit has not been mined since the late 1970s, when the civil war in Angola closed the Benguela railroad, Kisenge‘s principal export route.

Diamond production comes mainly from mining operations in Mbuji-Mayi in the Kasai Province, but the alluvial deposits there are nearing exhaustion. It is assumed that more than one third of the country‘s diamond production, worth about 300m US$, are smuggled out each year. However, the fight of Unita rebel troops in Angola across the Angola/DRC border into diamond producing areas in Kasai was disruptive to artisanal mining activities.

Coal production from the Luena Mine was significantly reduced as a result of ethnic conflicts in the Shaba Province and the reduced demand from Gécamines plants. No data are available on the current production of hydrocarbons.

5 Geohazards

Mining operations have caused pollution in the aquifers and the surface environment especially in the Katanga Province, but no data are available.

The last eruption of the volcano Nyiragongo in

Fig. 56 Lava burns in a street of Goma Town, eastern DRC, from the eruption of Nyiragongo Volcano, January 2002.

Fig. 57 The house and compound of the WHO in Goma Town in a mass of lava flow from Nyiragongo Volcano, January 2002.

Fig. 58 Refugees from Goma seek shelter after the lava flow of Nyirangongo Volcano in January 2002.

January 2002 in the east of the country led to the death of at least 45 people in the town of Goma, about 20km away from a fresh plume near the top of the 3,470m volcano, when a river of molten lava poured from there into the town and then into Lake Kivu (Fig. 56-58).

6 Geosites

A formal inventory has not yet been made, but the DRC offers many places of geoscientic interest, for instance in the East the chain of the Virunga Volcanoes (Fig. 59 - 61).

Fig. 59 Lava fountains in the crater lake of Nyiragongo Volcano, eastern DRC, 23 July 1982 (from Krafft, 1990).

Fig. 60 An entombed skeleton of an elephant in the lava flow of Nyiragongo Volcano, eastern DRC (from Krafft, 1990).

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Fig. 61 "Staircase of Venus" Falls at Mt Hoyo, eastern DRC.

Republic of Congo

1 General

Area: 342,000km²
Population: 2,831,000 (July 2000 estimate)

2 Summary of Geology

The Republic of Congo is in the northwest and the southern central part mostly underlain by Precambrian rocks of Archean to Neoproterozoic age. The east of the country is covered by Quaternary alluvial sediments of the Congo Basin. The coastal basin is made up of Cretaceous to Quaternary marine sediments and bounded to Precambrian rocks of the Mayombe Supergroup.

3 Stratigraphy and Tectonics

The northwestern part of the Congo Craton comprises a broad basement upward, which constitutes the foreland of the younger West Congolian mobile belt. It extends as a vast granitoid massif known as the Chaillu Massif in the southern central Republic of Congo, through Gabon, where it is mostly concealed beneath Neoproterozoic supracrustals, to southern Cameroon. The Chaillu Massif shows a N-S foliation and contains two generations of granitoids, grey granodioritic to quartz dioritic biotite or biotite-amphibolite types, and pink, mostly potassic migmatites, which occur as veins cutting the grey granitoids. Within the granitoids schists and greenstones exist as septa, which have not been completely transformed by granitization. At Mayoko occurs a relict greenstone belt, which consists of sub-vertical banded iron-formations, amphibolites, pyroxeno-amphibolites and biotite gneisses. Another relict greenstone belt occurs at Zanago, which consists of N-S trending, deeply dipping banded iron-formations (BIF), amphibolite-bearing quartzites, amphibolites with residual pyroxenites and a small mass of dunite. The Chaillu granitoids have been dated at about 2,700Ma, the schists and greenstones engulfed by the granitoids must therefore be older.

The Sembe-Ouesso Group crops out in the northwestern Republic of Congo and in adjacent territories of Gabon and Cameroon. It lies below a mixtite and comprises in ascending order quartzites, arkoses, conglomerates, phyllites, quartzites, shales, phyllites, calc-shales, dolomites and quartzites. The age of the Sembe-Ouesso Group has been assigned by Cahen et al. to the Neoproterozoic, whereas Vicat et al. a Paleoproterozoic age have indicated.

The West Congolian mobile belt extends for over 1,300km from Gabon southwards through the southwest of the Republic of Congo, the west of the Democratic Republic of Congo, to northeastern Angola. It contains from east to west three structural zones: the external zone with sub-horizontal strata; the median folded zone; and the internal zone to the west. The external and median zones comprise the West Congolian Supergroup, for which a Neoproterozoic age has been assigned. The rocks in the internal zone are older and belong to the Mayombe Supergroup. Throughout most of the West Congolian Orogen the Mayombe Supergroup unconformably overlies post-Eburnean Mesoproterozoic metasediments and metavolcanics. Its age falls between that of the underlying Kimezian Supergroup, which was affected by the Eburnean Orogeny at about 2,000Ma, and the age of the Mativa granite, which was dated at about 1,020Ma. According to Porada (1989) the Mayombe Supergroup represents the infilling of a Kibaran-age continental rift, which was deformed and thrust eastwards during Pan-African times onto the West Congolian Orogen. The Mayombe Supergroup is usually subdivided into two distinct units: The lower is mainly volcanic and volcano-sedimentary, whereas the upper is entirely sedimentary.

The West Congolian Supergroup has been subdivided, from base up, into the Sansikwa Group, the Haut Shiloango Group, the Schisto-Calcaire Group, and the Mpioka and Inkisi Groups. Two horizons of pebbly schists or mixtites, formerly considered as glacial deposits, but now interpreted as mud flows, separate the Sansikwa Group from the Haut Shiloango Group, and the latter from the Schisto-Calcaire Group. The Sansikwa Group is mostly a clastic sequence with subordinate carbonates; the Haut Shiloango Group contains mainly argillites; the Schisto-Calcaire Group marks the predominance of carbonate deposition, which was followed by deposition of terrigenous sediments. The Mpioka Group overlies the Schisto-Calcaire Group unconformably with conglomeratic units comprising angular limestones and chert clasts, which fill depressions and shallow synclines in the underlying carbonates. The Mpioka Group is unconformably overlain by the Inkisi Group, which comprises conglomeratic arenaceous and pelitic red beds. The Mpioka and Inkisi Groups are considered to be molasse deposits laid down after the first orogenic episode of the West Congolian belt, which has been dated at about 735Ma.

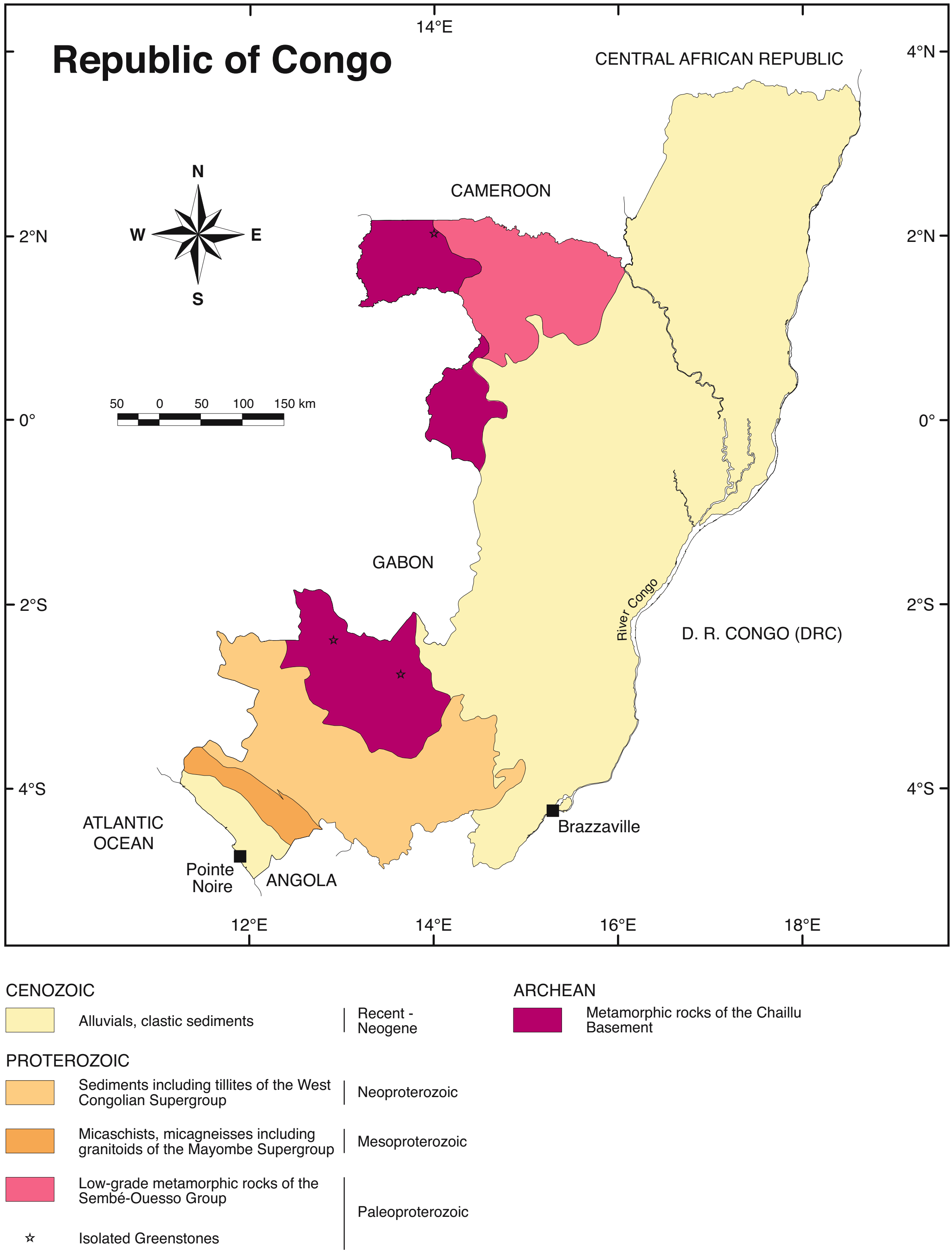

Fig. 62 Geological overview of the Republic of Congo (modified after Vicat et al., 1992)

4 Economic Geology

The Republic of Congo is a major crude oil producer in sub-Saharan Africa, and this commodity remains the mainstay of the Congolese economy, providing about 50% of the Government's revenue and 90% of export earnings. Almost all the oil is drilled offshore.

Two major base metal deposits occur in the M'Fouati region, about 290km west of Brazzaville. The two deposits, Djenguile and Yanga-Koubenza, are rich in copper, lead and zinc. Some small base metal mining operations in the area still persist, which geologically belong to the West Congolian Supergroup. Other potential deposits in this unit and in the Paleoproterozoic Mayombe Supergroup include gold, tin and wolfram, niobium and tantalum, uranium, manganese, titanium, nickel and chromium, and thorium, all of which have been recorded at least as geochemical anomalies. Gold, uranium, titanium, copper, niobium and tantalum may also occur in the Paleoproterozoic Sembe-Ouesso Group. Diamonds are known to occur as placers in the Bikosi conglomerates of probable Lower Cretaceous age. Gem-quality and industrial-grade diamonds are in minor quantities exploited and exported. The Archean Caillu Massif yields numerous deposits of gold, which are related to amphibolites. Iron ore is part of the frequent itabirites (BIF) in the Caillu Massif, but no commercial production exists.

The Republic of Congo has considerable resources of sedimentary phosphates, which are forming a string of outcrops extending over 50km along the coast. Known larger deposits occur at Holle and at Sintou Kola, about 50km away from Pointe Noire. Phosphate nodules of Neoproterozoic age have been found near Comba, 110km west of Brazzaville.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

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Djibouti

1 General

Area: 23,200 km²
Population: 643,000 (Estimate January 2002)

2 Summary of Geology

Djibouti lies on the narrow gulf linking the Red Sea to the Gulf of Aden. The country is formed of a triangular depression, which is caused by the collision of the general tectonic trends of the Great Rift Valleys of East Africa. These run N-S and NW-SE and have created a complex fragmented relief, composed of high blocks and subsidence zones, in which there are sometimes lakes, e. g. Lake Assal being 174m below sea level. Most of the country is composed of Cenozoic sedimentary and volcanic rocks.

3 Stratigraphy

Djibouti is framed by the Ethiopean Highland in the west, the Somali Plateau in the south and the Danakil Horst in the east. Its northern part is occupied by the Danakil Depression, a branch of the Red Sea. To the west, the area consists of highly disturbed basement overlain by unfolded Mesozoic strata. Within the Afar Depression, Neogene sediments lie unconformably on pre-Tertiary formations. In them, older limnic-fluviatile beds are succeeded by marine deposits. The whole sequence thickens towards the centre of the depression. These basin fillings constitute the Danakil Formation and indicate a major phase of rift faulting before and during their accumulation. Their extensions on both flanks of the depression reflect the structural borders of the Danakil Graben. Evaporites occupy its deepest part, which was down-faulted or opened by major rift movements in the Pliocene. Quaternary rifting determined the present topography and was succeeded by a marine invasion. Its sediments make up the Zariga Formation and gave radiocarbon ages of 25,000 to 34,000 years. The deepest part of the low is concealed under the Afrera Formation with a radiocarbon age of 5,800 years. This frames several lakes.

In northern Djibouti, rifting accompanied strong volcanic activity, so that extensive basalt flows intercalate and locally underlie the Danakil Formation. The Afar basalts gave K-Ar ages ranging from Miocene to Pliocene. In the southern part of the Danakil Graben, the late Tertiary sedimentary basin fillings are replaced by these plateau-forming basalt flows. They are succeeded by scoriaceous alkali-olivine-basalts, of which the differentiated lavas formed huge volcanoes parallel to the rift structures. In fact, the Central Volcanic Range, which delineates the middle part of the Danakil Graben, is still active. The Afar triangle cannot be considered as the formation of recent sea-floor spreading on land, because oceanic magma has not been found outside the Danakil region. Since the Early Pleistocene, coastal uplifts can be correlated with successive alluvial deposits.

4 Tectonics

During the Pliocene and Early Pleistocene, the Red Sea-Gulf of the Aden area opened. This event coincided with an uplift of the southern prolongation of the Danakil Horst. At the same time, uplifts and basins developed. Plate tectonic analysis of the Afar triple junction gave integrated extension rates for the Ethiopean rift valley of between 1 and 3mm annually. In the Afar Depression, where the Ethiopean Rift meets the Red Sea and the Gulf of Aden, earthquake epicentres concentrate along peripheral block faults, but there are too few fault plane solutions to allow any inferences regarding motions.

5 Economic Geology

Mineral production is an insignificant component in the economy of Djibouti. Solar-evaporated sea salt, limestone and calcined lime are produced. A potential for marble, granite, gypsum and perlite has been reported. Investigations for geothermal energy for electric power generation are underway.

Fig. 63 A line of volcanoes offshore Djibouti continues under the sea

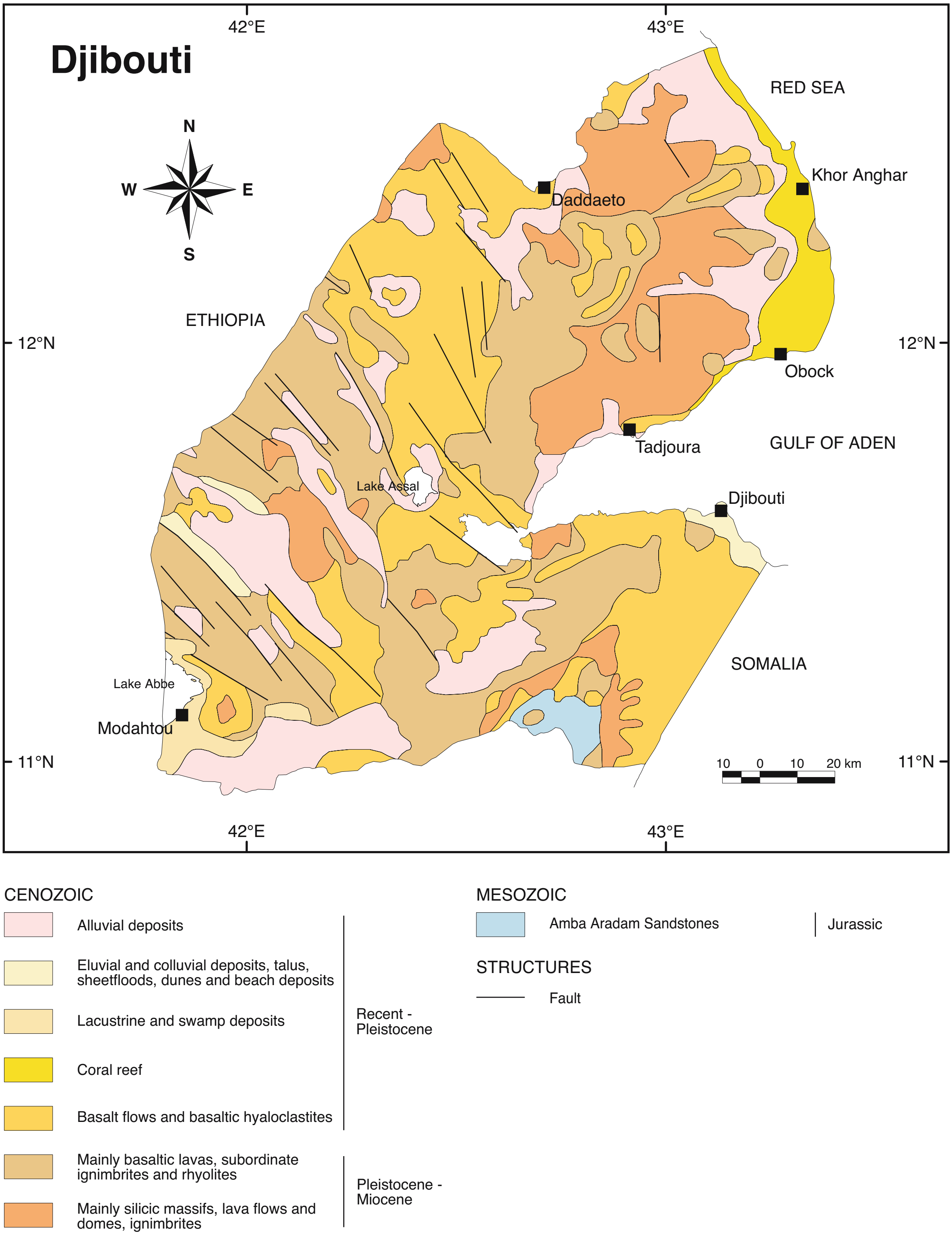

Fig. 64 Geological overview of Djibouti (modified after Merla et al, 1973)

Fig. 65 Raised reefs along coastal Djibouti, being either the result of geological upheavel or of a drop in sea level

Fig. 66 Fresh lava flows already broken in the highly active Afar depression

6 Geohazards

Earthquakes and volcanic eruptions are potential geoenvironmental hazards.

7 Geosites

An inventory has not yet been made, but the triple junction of the East African Rift System is of extreme geological interest and scenic beauty (Fig. 63, 65 - 67).

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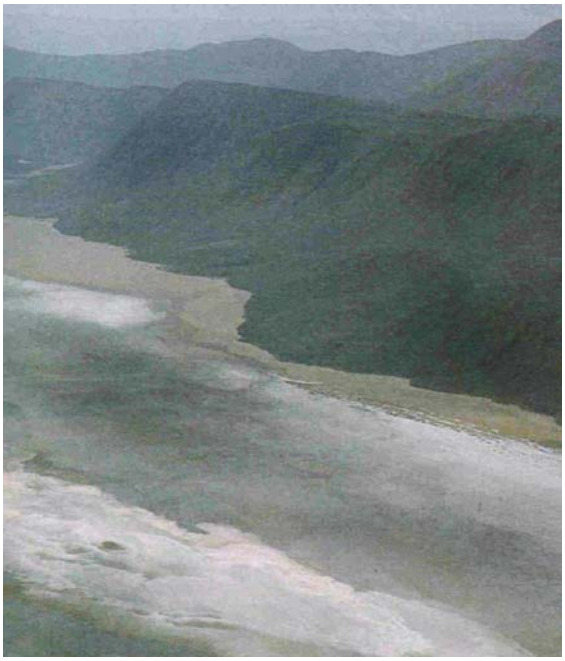


Fig. 67 Triple junction area of the three arms of the East African Rift Valley in Djibouti

Egypt

1 General

Area: 997,739 km²
Population: 65,700,000 (Estimate 2001)

2 Summary of Geology

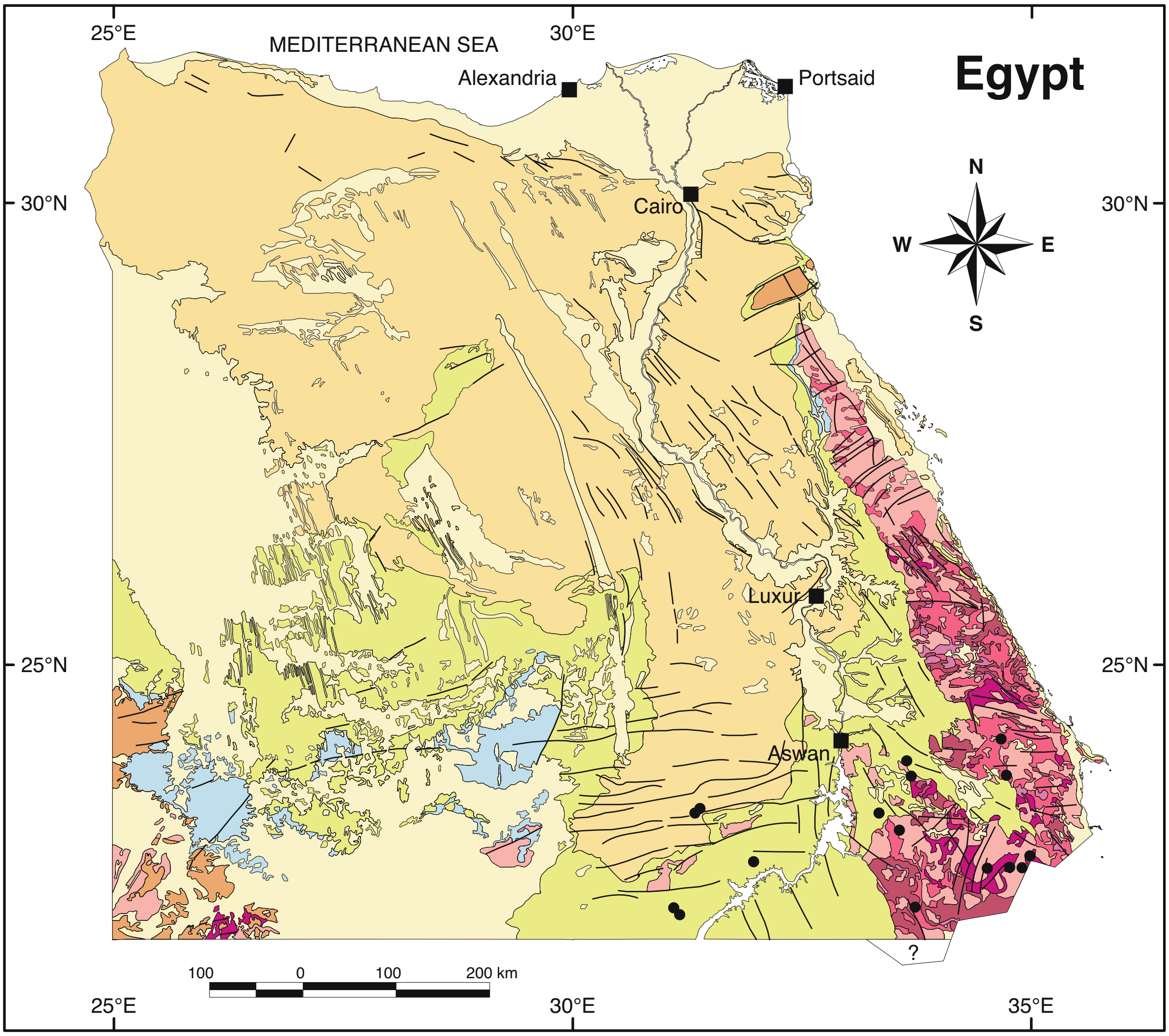
The oldest rocks in Egypt occur as isolated Archean to Proterozoic inliers in the Western Desert, whereas the Egyptian part of the Arabian-Nubian Shield along the coastal Red Sea region is made up of Neoproterozoic Pan-African rocks. Paleozoic sediments often mantle the basement rocks. After a sedimentary hiatus due to the Hercynian orogeny Cretaceous sediments are well exposed in various parts of the country. The Cenozoic history is characterized by transgressions and regressions and their respective sediment types.

3 Stratigraphy and Tectonics

Much of northeastern Africa is mantled by thick sedimentary strata of Phanerozoic age, which form a generally undeformed cover to a deep crystalline basement. The older rocks are well exposed in eastern Egypt and Sudan, where they comprise part of the Arabian-Nubian Shield. Further into the interior of northeastern Africa they appear as isolated inliers, for instance the Uweinat inlier across the borders of Egypt, Libya and Sudan. The Uweinat inlier is also significant because it has provided the oldest ages from anywhere in northeast Africa: Granulite facies rocks in this area have yielded an average age of about 2,900Ma. No younger ages than about 1,800Ma have been obtained there, thus indicating the tectonic stability of the Uweinat inlier since that time. It is therefore probable that this region is to be considered part of a craton from thence on.

Till to date, no pre-Pan-African rocks have been identified in other regions of Egypt. The basement rocks in the Eastern Desert of Egypt can be subdivided from base to top into the Meatiq Group, the Abu Ziran Group and the Hammamat Group, all of Neoproterozoic age. The Meatiq Group comprises old crystalline basement outcropping in gneiss domes. These probably evolved in a mainly compressional tectonic environment during Neoproterozoic times and exhibit many of the basic structural and lithological characteristics of metamorphic core complexes of the Cordilleran type. They comprise an anticline with low dipping foliation and unidirectional mineral-slickenside lineation. The core comprises granitic gneisses conformably overlain by a heterogeneous and isoclinically folded mylonitic material, which predates the doming event. This grades up into low-grade ophiolitic rocks. The area lies in the foreland fold and thrust belt of a continental margin origin. Ophiolites outcrop along the thrust between the Meatiq infrastructure and the imbricated Abu Ziran nappe. Calc-alkaline magmatism occurred along two upwards and is associated with gold mineralization. The Abu Ziran Group comprises ophiolites overlain by metasediments, pyroclastics and local intermediate volcanics with island arc characteristics. The Hammamat Group includes molasse-type clastics and the penecoeval Dokhan volcanics of andesitic to rhyolitic composition, these being equivalent to plutonic, syn- to late-tectonic calc-alkaline granites. The clastics are up to 5,000m thick, of Late Pan-African age and exposed in the coastel mountains of the Eastern Desert. There are four lithofacies, which are conglomerate, pebbly sandstone, sandstone and siltstone, respectively. The interrelationships suggest alluvial fan-braided stream deposition within several small-sized basins. The interbedding of conglomerate and thick siltstone units indicate the direct interdigitating of fans with playas or lake sediments. Discontinuous siltstone units are interpreted as cut-off channel deposits within braided streams. Debris flow sedimentation is not exhibited. Palaeomagnetic directions have been identified at several sites in the Dokhan volcanics and also from two dike swarms intruding the late orogenic (younger) granites. The reported Rb-Sr ages for the Dokhan volcanics range from 660 to 603Ma. The dike swarms range from 530 to 480Ma in age. The Abu Zawal area is approximately 150km northeast of Luxor and is composed of a sequence of igneous and metamorphic rocks of Neoproterozoic age. The least radioactivity is associated with basic metavolcanics and the highest values relate to late orogenic plutonites, whereas the granodiorites possess a moderate level of radioactivity.

Post-Hercynian structural realignments and resultant E-W trending structures in the Saharan platform determined the major depocentres until the disintegration of Pangaea in Jurassic to Cretaceous times created new structural trends. During the Mesozoic Egypt consisted of two main structural provinces, an unstable shelf to the north with complex NE-SW transcurrent faults and fault-bounded basins



CENOZOIC

	Sand dunes, sabkhas, Nile deposits - cultivated, Wadi and playa deposits, beach and corals, calcarenite bars	Quarternary
	Marine and nonmarine deposits: clastics, carbonates, gypsum; locally basalt-dolerite dykes	Tertiary

MESOZOIC

●	Ring complexes (mostly alkaline syenites)	
	Clastics, phosphate and carbonate rocks	Cretaceous
	Marine and fluviomarine beds, clastics	Jurassic

PALEOZOIC

	Mostly clastic	Paleozoic, undifferentiated

PRECAMBRIAN

	Granitoids (syn- to posttectonic); slightly metamorphosed clastics of the Hammat Group; slightly metamorphosed volcanics of the Dokhan Group; locally gabbros and Post-Hammat Group (felsites, porphyries)
	Metagabbro-Diorite-Complex (tectonised, uralitised); Geosynclinal Metavolcanics (regionally metamorphosed felsic to basaltic effusives and pyroclastic rocks)
	Serpentinite (sepentinites, talc carbonates and related rocks)
	Geosynclinal Metasediments (including hornblende-biotite and chlorite schists meta-greywacke, meta-mudstones, phyllites, slates, conglomerates)
	Mig'if-Hafafit Gneisses and Migmatites (psammitic hornblende and biotite gneisses and migmatites)
?	Source map not available

STRUCTURES

——	Fault

Fig. 68 Geological overview of Egypt (modified after Anonymous, 1981)

and horsts, and a stable shelf to the south. The stable shelf was covered by mostly Paleozoic to Mesozoic continental deposits and was intermittently overlapped by shallow seas, which encroached from the north. Major intracratonic basins lie in Egypt's unstable shelf, among which are the Dakhla Basin, the Misaha Trough and the Abyad Basin.

Paleozoic rocks unconformably overlie the Precambrian basement in the Gilf Kebir and Jebel Uweinat regions in southwestern Egypt. Ordovician sandstones containing abundant Skolithos and the indicative Cruziana rouaulti were found in the Jebel Uweinat area just above the basement palaeorelief. The Gilf Kebir region contains 400m of thick-bedded Silurian sandstones resting on the basement and containing Cruziana and Arthrophycus horizons. It composes the southeastern Abu Ras Plateau as well as its southern foreland. Cross-bedded sandstones up to 70m thick may be assigned to the Devonian, sometimes containing plant detritus. Carboniferous deposits are up to 100m thick and consist mainly of marine shales and siltstones with fine-grained sandstones having fluvial beds in the upper part. The eastern Gilf Kebir region is also composed to a great extent of Paleozoic strata. The upper limits of the Carboniferous are vaguely exposed and the Paleozoic/Mesozoic interval is not yet defined in the whole area. There has been a long sedimentary hiatus due to the Hercynian orogeny. Nevertheless, the western and eastern Gilf Kebir region essentially comprise Paleozoic rocks mantled to the north and northeast by Mesozoic deposits. Well exposed in this area is the colourful Abu Ballas Formation framing the plunging Gilf Kebir region on its northeasterly trend towards Abu Tartur. The age of this clayey and fossiliferous formation, containing one of the few lagerstaetten of fossil insects in Africa, is assigned to the Lower Cretaceous. Periodic transgressions of the Neo-Tethys ocean spread across the Saharan platform, reaching its climax in Cenomanian to Turonian times when a seaway was formed up to the Gulf of Guinea. Continental Late Jurassic to Cretaceous strata, generally referred to as the "Nubian Sandstone" or "Continental Intercalaire" accumulated over most of North Africa as far as southern Algeria. Now regarded as the Nubian depositional cycle, rather than a formal lithostratigraphic unit, these fluvial and deltaic sandstones were deposited by northward prograding fluvial systems. They intertongue northward with nearshore marine sediments, which contain carbonates and phosphatic beds in Egypt. Northwesterly tilt of the northern Saharan platform towards the Tethys region continued during Late Cretaceous and was accompanied by NNW-SSE rifting forming the Dakhla basin. Maximum Tertiary marine transgression occurred during the Paleocene and extended as far south as the Sudan. In Egypt, where the unstable shelf had developed folds in Late Cretaceous and Early Tertiary times, there was a thinner sedimentary cover in that region than in the stable shelf, where epeirogenic downwarps had created deeper depocentres. The Paleocene is represented by the Dakhla Shale, the Tarawan Shale and the lower part of the Esna Shale, while Eocene strata are mostly carbonates containing larger foraminifers such as Nummulites and Alveolina. The Oligocene was deposited under predominantly continental conditions with fluviatile sediments occurring in the south. In the northern shelf facies accumulated clays and minor carbonates. Along the escarpments of the Fayum depression a unique mammalian fauna is associated with silicified logs in fluvial point bar and floodplain deposits of the Jebel Quatrani Formation. The break-up of the Arabian-Nubian Shield during the Neogene dramatically affected the structural and palaeogeographical framework of Egypt. After the Gulf of Suez and the Red Sea grabens opened in the Early Miocene, a marine transgression spread over large areas of northern Egypt. Marine deltaic clays and fluvio-marine deposits accumulated in northern Egypt. During a late Early Miocene regression the Gulf of Suez was isolated from the Mediterranean Sea, and evaporites formed in the Gulf of Suez, later extending into the Red Sea. Arid conditions began in Late Miocene, in the course of which thick evaporitic sequences accumulated, possibly leading to a temporarily dry-up of the Mediterranean Sea (Messinian Event).

4 Economic Geology

The mineral industry is generally only a minor contributor to the Egyptian economy. The only exception is perhaps the petroleum production and its export revenues.

Gold and copper mineralisation exist in Egyt, but are not of sufficient grade to be economically viable (although gold had already been mined during Pharaonic times, Fig.1). In the Bahariya Oasis in the Western Desert occur large iron deposits, and the railway linking the mine there with the steelworks at Helwan near Cairo was rehabilitated in the early 1990s, thus enabling the expansion of the previous production capacity. Black sand placers containing the heavy minerals ilmenite, hematite, magnetite, zircon, garnet and monazite occur in Quaternary beach sands,

Fig. 69 Oasis Bahariya with outcropping sediments of Cretaceous and Tertiary age yielding bone beds with various vertebrates

sand dunes and sabkhas along the Mediterranean coast. A coastal sabkha is a geomorphological feature that is flooded occasionally and is produced by offshore deposition and sediment accumulation from the landward site.

Phosphate rock continued to be the major non-fuel mineral product of Egypt, but production has fluctuated since the mid-1980s. Production came principally from the East and West Sebaiya Mines on the River Nile, south of Luxor. Additional production is located adjacent to the Red Sea port of Safaga. Phosphate mining has also commenced at Abu Tartur in southern Egypt, where apparently the largest deposits occur.

Oil wells in the Gulf of Suez account for about 90% of the Egyptian petroleum production. Crude oil has also been discovered at Baddredin in the Western Desert.

Fig. 70 The Aswan Dam ponding Lake Nasser in southern Egypt

5 Geohazards

A comprehensive inventory of the various geoenvironmental hazards in Egypt has not yet been made. Air pollution in suburban Cairo caused by particulate emissions of cement fines may preclude further cement industry development in the near future.

6 Geosites

Many potential sites exist, but a comprehensive inventory has not yet been made. Many sites in the Saharan desert are especially of scenic beauty. Bone Beds containing Cretaceous tetrapods occur for instance in the Bahariya Oasis (Fig. 69 and 70).

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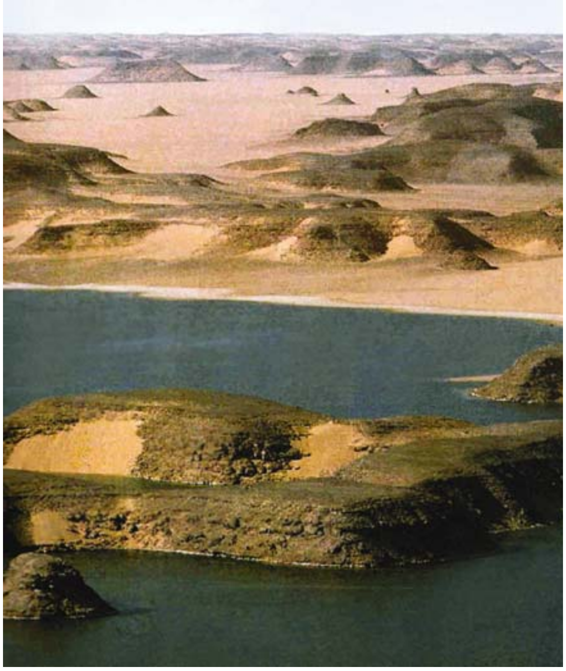

Fig. 71 The artificial Lake Nasser between Aswan and Abu Simbel

Equatorial Guinea

1 General

Area: 28,051 km²
Population: 474,000 (July 2000 estimate)

2 Summary of Geology

Precambrian metamorphic sequences underlie most of the central and eastern mainland of Equatorial Guinea, sometimes also being called Rio Muni. Mesozoic, Neogene and Quaternary sediments are exposed along its coastal and western zone. The Atlantic Ocean islands of Pagalú (= Annobon) and Bioko are part of the Cameroon Volcanic Line (CVL) and of volcanic origin.

3 Stratigraphy

Three stratigraphically and lithologically different units can be observed in this part of the Archean Congo Craton of Equatorial Guinea: a basal gneissic complex, a greenstone terrane and an undifferentiated granitoid complex. The basal complex consists of granulitc gneisses of charnockitic character and some gabbros. The granulitic gneisses were formed during the Liberian tectono-thermal event (about 2.8Ga), and were rejuvenated during the Eburnean orogeny (about 2.1Ga). The greenstone terrane is made-up of metavolcanics and volcaniclastics, which locally reach amphibolite facies. Quartzitc schists, garnitiferous mica schists, biotite schists and amphibolites are distinguished. The granitoid complex is formed by intrusive rocks ranging from granite to diorite. Most granitoids intrude the gneisses and the greenstones, but some to be part of the basal gneiss complex, i. e. at least two different stages of intrusion exist.

The Eastern Gabon and Douala Basins, which underlay the coastal lowlands, are filled with Meso- and Cenozoic successions accumulated during the Atlantic rifting event as well as its later evolution towards a passive margin.

Pagalú (=Annobon) (17km²) is the southernmost island of the Gulf of Guinea within the Cameroon Volcanic Line and is the top of a 5300m high strato-volcano, which is built on the oceanic crust and reaches an altitude of 813m asl. The volcano was progressively built: 1. Submarine volcanism produced palagonitic breccia, which crops out around the island; 2. Basaltic flow pile covered the major part of the island. The oldest flow has been dated 18.4Ma. Numerous dykes related to the following period intersect the pile and have been dated as 5.3Ma. A large pyroclastic cone was built upon the layered basaltic flows; 3. Trachytic plugs cut the cone and have been dated as 3.9Ma; 4. More recently, the volcano erupted to the north about 2.6Ma and to the south on the very small island of Tortuga. The lava series developed a potassic alkaline trend with basanites, hawaiites, tristanites and trachytes.

The island of Bioko (previously Fernando Poo) (2,017 km²) rests upon the continental shelf about 40km southwest of the coast of Cameroon. It consists of three amalgamated strato-volcanoes. Pico Santa Isabel occupies the northern part of the island and is the highest volcano reaching an altitude of 3008m. Pico Biao (San Joaquim) and Pico San Carlos volcanoes are adjacent and form the southern part of the island. Pico Biao has a small crater (0.4km diameter) occupied by a lake; Pico San Carlos has a large caldera (2.5km diameter). Numerous fresh pyroclastic cones, mostly on Pico Santa Isabel and between this volcano and Pico Biao testify to recent activity. Historical eruptions have been reported in 1898, 1903 and 1923. The ages of the dated lavas are not older than 1.1Ma, thus the island is probably of similar age as neighbouring Mt Cameroon. Only basaltic lavas are known on the island. They are picrites (with abundant peridotite nodules), alkali basalts, hawaiites, and rare kaersutite-bearing mugearites. All the lavas with a differentiation index less than 35 are nepheline normative. The picrites contain large olivine xenocrysts (with >2750ppm Ni) and some basalts contain large centimetric augite xencrysts (ith >3000ppm Cr, 50ppm Co and 35ppm Sc). The xenocrysts have been considered as mantle melting residua and the basaltic lavas, which contain these xenocrysts, as closely related representative of primitive magma.

4 Tectonics

Pre-, syn- and post-rift tectono-sedimentary units can be distinguished during the Meso- and Cenozoic formation of the Atlantic rifting event towards a passive margin. NE-SW and E-W trending intracratonic basins accumulated since the Miocene.

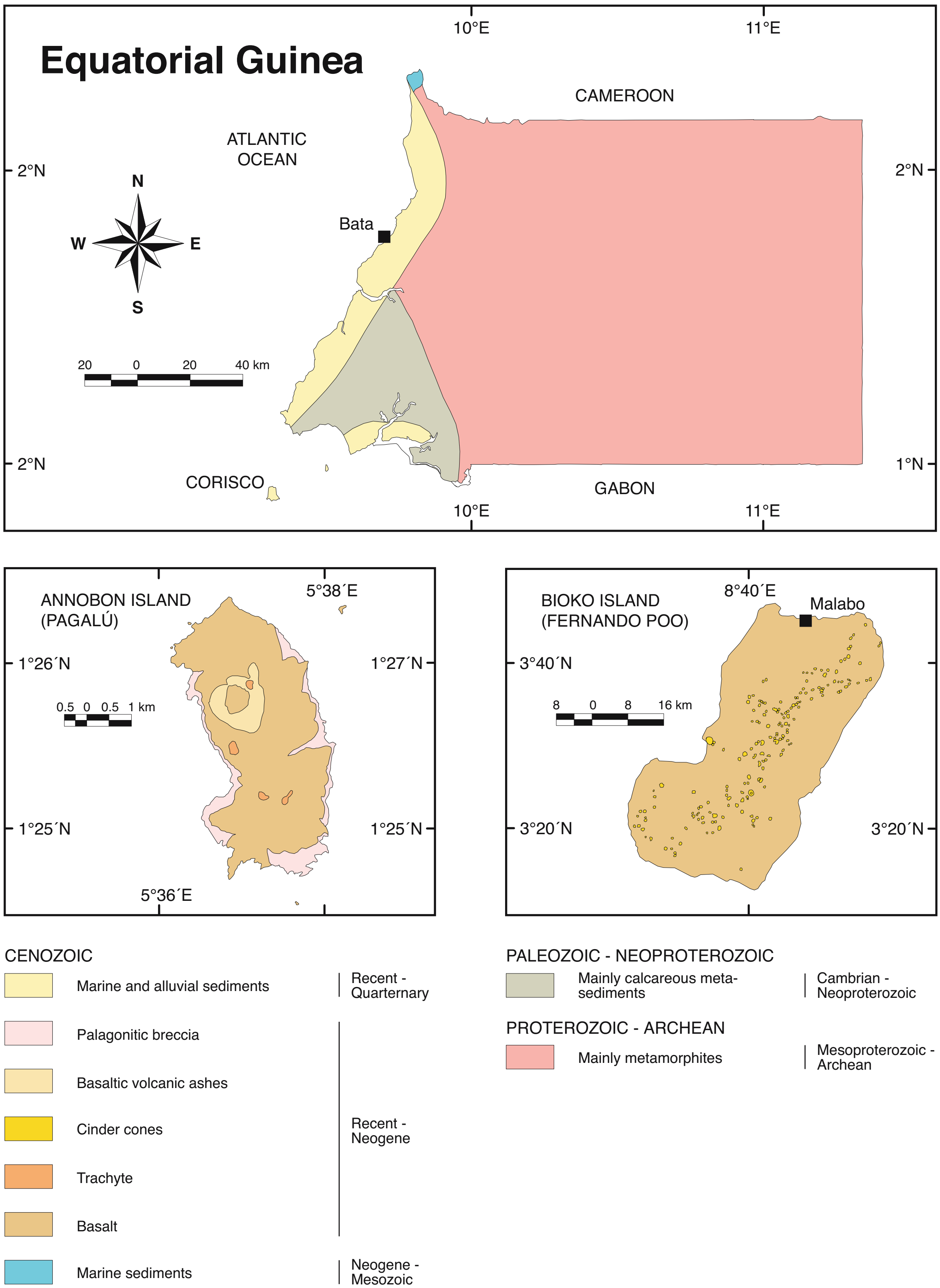

Fig. 72 Geological overview of Equatorial Guinea (modified after various sources)

5 Economic Geology

Equatorial Guina has no significant mineral industry. Artisanal alluvial gold mining takes place in some rivers draining Precambrian rocks of Rio Muni. Recently discovered oil and natural gas fields have made Equatorial Guinea the fourth-largest oil exporting country in Africa and contributed much to its GDP and revenues.

6 Geohazards

Possible volcanic eruptions on the islands of Bioko and Pagalú are a limited potential geoenvironmental hazard.

7 Geosites

An inventory has not yet been made.

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Eritrea

1 General

Area: 121,320 km^2
Population: 4,136,000 (July 2000 estimate)

2 Summary of Geology

Eritrea is underlain by Neoproterozoic terranes and Tertiary to Recent volcanic rocks. Marine sediments of Mesozoic to Recent age are exposed in the coastal area of the country along the Red Sea.

3 Stratigraphy and Tectonics

All the Precambrian rocks occurring in Eritrea have been involved in the Pan-African orogeny. Sometimes structures of the Precambrian rocks show interesting relationships to the Neogene rift structures: Basement foliation in northern Eritrea, west of the Red Sea Ethiopian plateau, generally dips steeply westwards, whilst east of the escarpment, on the Red Sea plains, the foliation dips gently eastwards.

Mesozoic sediments were severely deformed in the present Danakil and Aysha horsts. Near the northern end of the Danakil horst two separate quadrants of ringed intrusions have been observed, which are possibly related to Tertiary granites from the Afar margins.

Numerous thin and localized basaltic flows are found in the Miocene sediments of the Red Sea coast. Pliocene welded tuffs were formed prior to the main phase of rifting, which now displaces them in some magnificently exposed sections. The so-called Aden Series basalts range in age from Pliocene to Holocene and occur regardless on either floor or rim of river canyons. The basalts were probably extruded contemporaneously with the major Pleistocene phase of uplifting and rift faulting. Cones composed of pantelleric and comendic lavas, welded tuffs and pumice flows, known as the Aden Series silics, are aligned along the central fault zone of the rift, but occur also at Asmara. Their age is ranging from Pleistocene to Holocene.

Mesozoic limestones are found east of the Danakil depression, in the Danakil Alps. Most of the Tertiary sediments along coastal Eritrea comprise marine limestones. Large reserves of Neogene evaporites including halites, gypsum and potassium salts exist in the Dallol depression located in Ethiopia and Eritrea. Quaternary gypsum deposits occur along the coast.

Fig. 73 Escarpment south of Asmara.

4 Economic Geology

Political tension between Eritrea and Ethiopia after the war continued and eliminated most mineral exploration and production activity in southern Eritrea. In the late 1990s about 500kg of gold were produced annually from various, but generally small-scale concessions. Other mineral occurrences in Eritrea include asbestos, barite, copper, feldspar, iron, kaolin, lead, marble, nickel, potash, sylvite and zinc.

5 Geohazards

An inventory has not yet been made. Critical remarks on mining are presented in the National Environmental Management Plan for Eritrea (1995), especially concerning gold mining and the use of mercury.

6 Geosites

An inventory has not yet been made. The National Environmental Management Plan for Eritrea (1995) is among various topics also concerned with the natural heritage and biological diversity of the country, but no geosites are considered.

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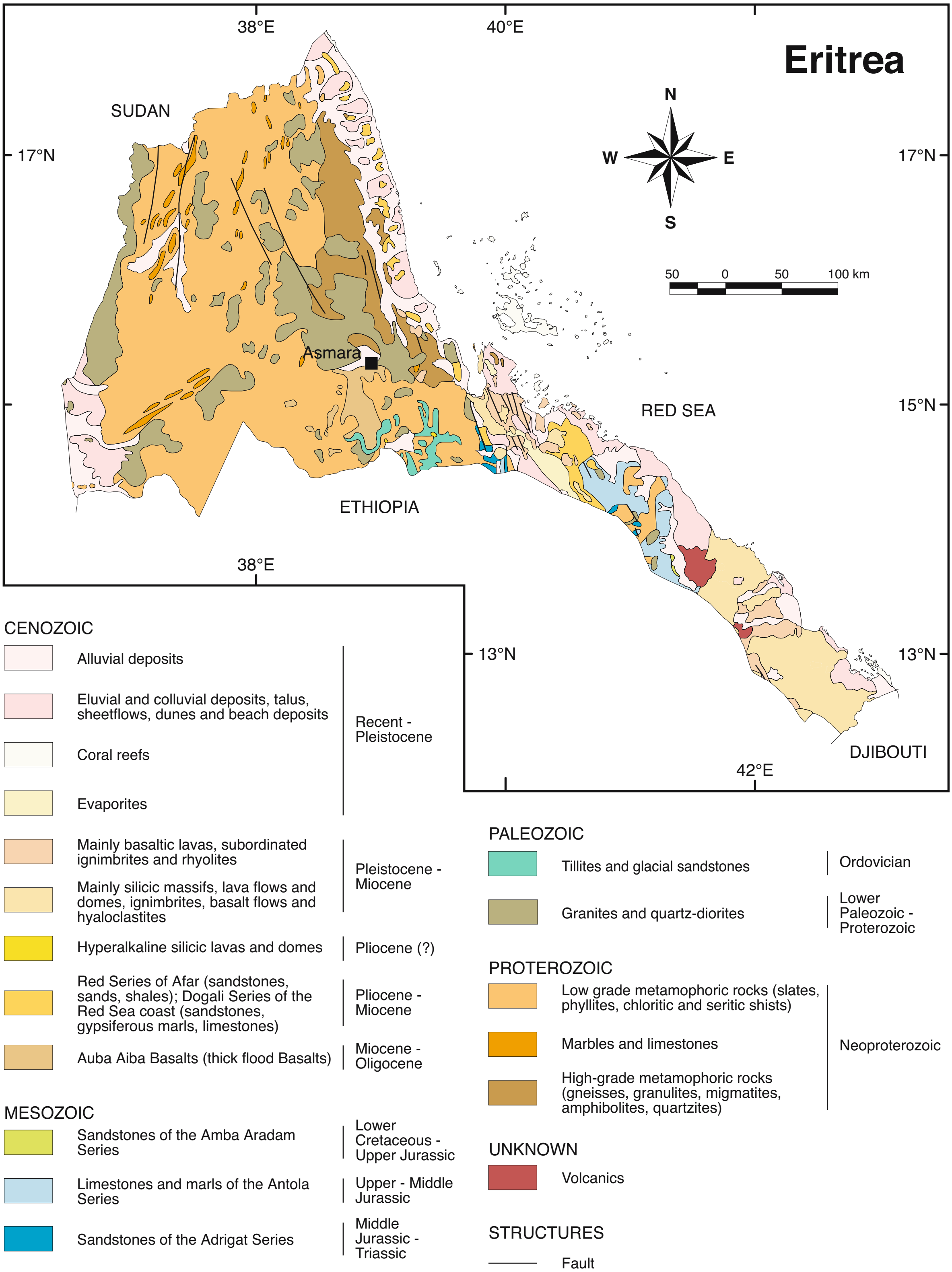

Fig. 74 Geological overview of Eritrea (modified after Merla et al., 1973)

Ethiopia

1 General

Area: 1,127,127 km²
Population: 64,117,000 (July 2000 estimate)

2 Summary of Geology

Rocks of Precambrian age underlie large parts of northern and western Ethiopia and smaller areas in the south and east of the country. Ethiopia lies at the northern tip of the continental part of the East African Rift System. Voluminous piles of mainly Cenozoic volcanic rocks occur in large parts of western Ethiopia. Mesozoic and Cenozoic sediments occupy the eastern part of the country. The rift valley is covered with relatively young lacustrine sediments and volcanics.

3 Stratigraphy and Tectonics

The Precambrian geology of Ethiopia is still little known. A generalized tectonostratigraphic classification suggests the occurrence of three major units: A Lower Complex of presumable Archean rocks, a Middle Complex of presumable Paleo- and Mesoproterozoic rocks, and an Upper Complex of presumable Neoproterozoic rocks. However, most of the Precambrian rocks of Ethiopia have apparently been involved in the Pan-African orogeny. Also the structural geology of the Ethiopian basement is very poorly known. Gently NE-SW pitching broad anticlines and synclines affect the low-grade schists of southwestern Tigray, but tighter folding with nappe development has been observed further north in Eritrea. Both folding and granitic intrusions in the Precambrian of northern and western Ethiopia tend to be cut discordantly by the final regional foliation. The over-all trend of basement foliation, from the Kenya border to the Red Sea, is roughly meridional, but a notable virgation to an ENE-WSW trend occurs in Tigray. Foliation strike is so frequently discordant to the later rift structures, that it can be emphasized that the pattern of the Ethiopian rift system has been imposed on the crust in spite of the basement structural grain.

Peneplaned basement rocks are unconformably overlain by Mesozoic marine sandstones, shales, gypsum and limestones, except where the Mesozoic sea failed to reach into the west and southwest of Ethiopia. Structural deformation of the Mesozoic rocks is of considerable importance in elucidating the early evolution of the East African Rift System. Subsiding troughs in the northern section of the main Ethiopian rift caused excessive thicknesses of sediments to accumulate, particularly during Upper Jurassic and Cretaceous times. Downwarping of the trough margins was accompanied by minor spilitic and basaltic volcanism. Deep basins filled with Mesozoic sediments are also known where no subsequent rift structures have developed. For instance in the Ogaden more than 3,000m of Jurassic to Cretaceous sediments have accumulated in narrow, fault-bounded basins over depressed basement. Monoclinal warping and minor faulting along E-W axes were affecting the Jurassic sediments of Tigray during deposition. These tectonic lines were again active during a N-S compression along the proto-rift system, at the end of the Mesozoic. The Mesozoic sediments were gently folded by this compression over the present plateau region, but were severely deformed within the proto-rift system.

Volcanic rocks are more extensively developed in Ethiopia than anywhere else in the East African Rift System. This occurrence coincides with the highest degree of uplift, though the periods of maximum volcanism and maximum uplift did not coincide. The Ethiopian volcanics are most thickly developed in the central region of the country, and along a N-S axis situated immediately west of the rift system. The volcanics are typically alkaline. The oldest post-basement volcanic rocks are alkali basalts and trachybasalts interbedded in the Mesozoic sediments of the Ogaden. Such lavas are not known from west of the rift system. The first major volcanic episode, and also the largest of the Cenozoic in Ethiopia, was the extrusion of the Trap Series fissure basalts during Paleocene to Oligocene times. The series is appreciably younger in southern than in central Ethiopia. On the plateaux the basalts lie unconformably on the Mesozoic strata, a strong though gently angled unconformity separating the two series. The Trap Series basalts thicken from a few hundred metres on the plateaux, to over 2,000m at the plateau-rift margins. Strong downwarping of the proto-rift troughs was occurring simultaneously with fissure basalt extrusion, and it is therefore probable that the sites of the fissures, and aligned centres, lay along the zone of most severe warping. There is also evidence, from northern Tigray, that E-W tectonic lines were controlling development of the Trap Series. The Trap Series can be traced right across the plateau-rift margin of northern Shoa to southern Wallo, but proof that the series extends beneath the rift floor is

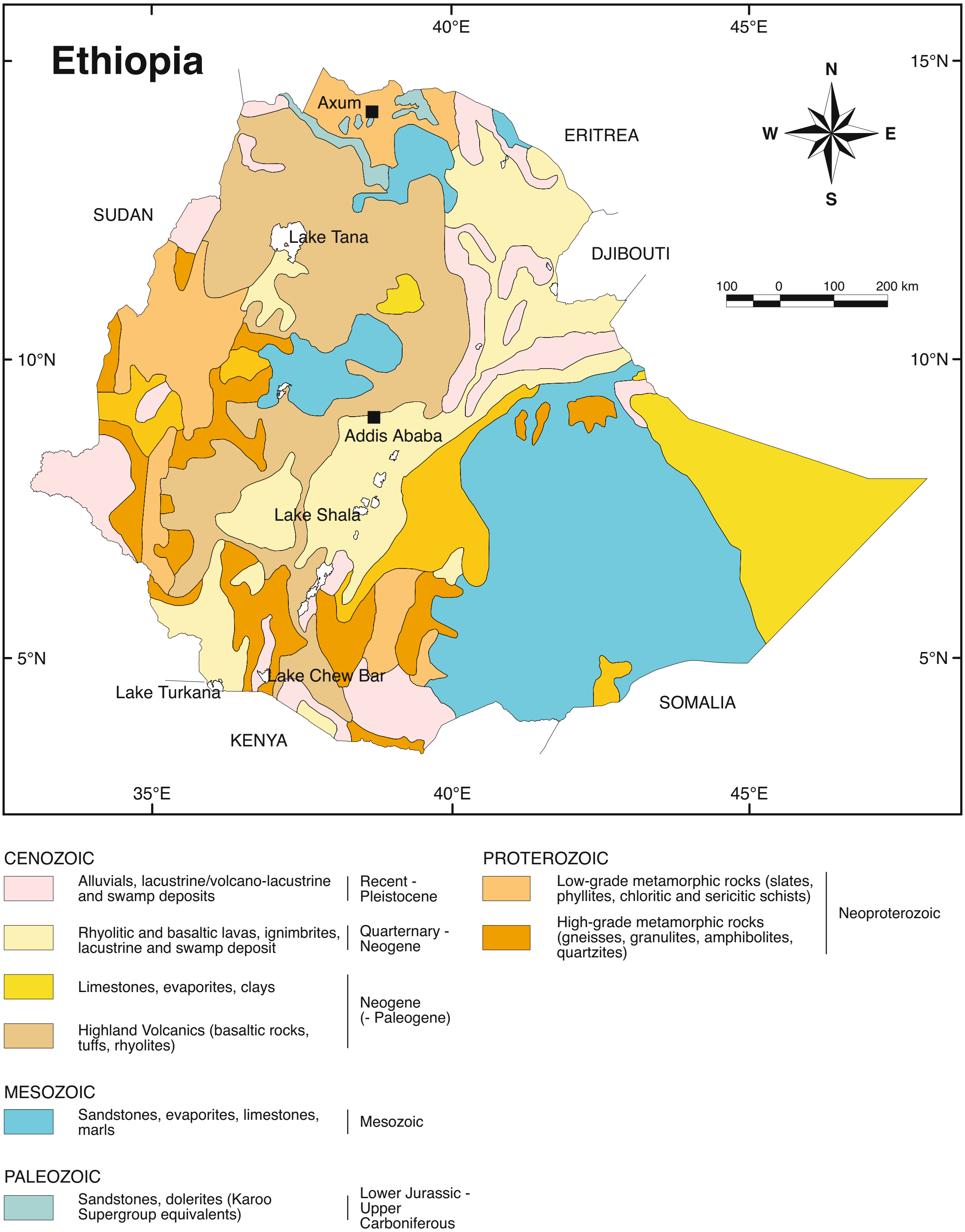

Fig. 75 Geological overview of Ethiopia (modified after Merla et al., 1973)

still lacking. Local unconformities within the Trap Series are not considered to justify its subdivision into an older, Ashanghi Group, and a younger, Magdala Group, a single series of flood basalts now being recognized over the whole of Ethiopia. The basalts are alkaline and typically oxidized. Large central-type shield volcanoes began to build up in the plateau interior during the Early Miocene. The lavas are chiefly alkali olivine basalts, but rare peralkaline silicic lavas and minor intrusions also occur. The largest of these centres forms the Simien Mountains of Beghemder. The basalts were very fluid and extended considerable distances north into Eritrea. The relation of the Shield group basalts to the older Trap Series basalts has not yet been elucidated. Dyke swarms in the Shield Group basalts indicate closely contemporaneous tensional strain during basalt extrusion. Strain acted both E-W (producing rift-trend dykes and sheets) and N-S (producing E-W dykes parallel to major tectonic lines of this trend). The rare silicic dykes trend N-S. Basaltic activity during the latter part of the Miocene was relatively minor. Over much of southern and central Ethiopia, violent silicic eruptions covered large areas of the plateaux and most of the proto-rift with flows of welded pantelleric tuffs. These ignimbrites are now preserved over an area of more than 150,000km^2. The welded tuffs are thickest at the margin of the rift system suggesting eruption from aligned centres or fissures closely paralleling the rift. The Pliocene welded tuffs were formed prior to the main phase of rift faulting, which now displaces them in some magnificently exposed sections. On the plateaux another series of plugs, bosses and domes of medium-grained intermediate lavas occurs, which tend to be peralkaline, for example the solvsbergite-tinguaites of Adua-Axum. Some N-S alignments of lavas are known, for example in western central Ethiopia, but E-W alignments are more significant, as at Adua-Axum. Feldspathoidal lavas have revealed a striking concentration on E-W tectonic lines, suspected to be transcurrent faults. Furthermore, not a single feldspathoidal lava occurring within the rift system is known, suggesting a fundamental difference between the silicic lavas of the plateaux and the rift. The rift lavas are always persilicic.

Three important tectonic units can be distinguished in the Ethiopian part of the East African Rift System: the plateaux, the rift margins (including rift horsts) and the rift floor. Although being physiographic in description, these terms reflect strongly the underlying Cenozoic tectonics. Whilst extensive areas of the Ethiopian plateaux exhibit a sub-horizontal succession of flood basalts and Mesozoic sediments upon the basement, other regions show a severe deformation, for instance the Mesozoic sediment-filled troughs of the Ogaden, the west-downwarped flood basalts of Jimma, and the Lake Tana deposits in the centre of the Ethiopian plateau. The term rift-margin can be defined in terms of physiography as the strip between the flat rift-floor and the escarpment of the high plateau. The margins of the main Ethiopian rift continue southwards from Afar via some strong cross-rift dislocations. These dislocations give the rift an apparent NE-SW orientation, but in fact the structural trend remains NNE-SSW. The cross-rift dislocations intersecting with major E-W plateau faults account for the Addis Ababa rift embayment. South of Addis Ababa, faulting of opposite throw to the main rift escarpment faults produces a marginal graben below Mt. Guraghe, but is not quite strong enough to do so in an upwarped zone east of Lakes Zway and Langano. The average width of the main Ethiopian rift is about 70km. The eastern escarpment is usually more strongly developed than the western escarpment. In some cases the western escarpment is hidden by Pliocene and Quaternary welded-tuff centres. The main Ethiopian rift splits into two branches south from the Lake Margherita basin, the branches being separated by the Amaro Horst. This horst is composed of basement rocks, which have been uplifted a total of 2,500m from the rift floor. Some of the uplift of this N-S 60 by 10km block has been effected in the Quaternary. The rift faulting dies out south of latitude 5°N, but resumes further west in the Lake Stephanie rift. The rift floor in Ethiopia is dominated by a narrow, 3-15km wide belt of intense, fresh faulting, which is usually axial to the rift. This belt, termed the Wonji Fault Belt, is a crustal zone of active tension, and has been traced for about 1,100km along the Ethiopian rift system. The Wonji Fault Belt is characterized by short, curvilinear faults of normal type, by tensional fissures, and by both basaltic and silicic volcanism.

4 Economic Geology

Mineral production remains a minor factor in Ethiopia's economy. Gold is the principal revenue-earning mineral commodity, whereas construction materials continue to be the most significant mineral commodity both in value and in quantity. A variety of other minerals are produced and many more known to occur in deposits of potentially economic size and grade.

Gold occurs in the Adola District, about 350km south-southeast of Addis Ababa, where quartzitic beds are forming a well-developed horizon assumed to be the source of the Adola placers. The paragenesis of this deposit (Au, Fe, Cu, Pb, Zn sulphides, Ag, Pb

Fig. 76 Artisanal gold panning in northern Ethiopia near Axum

tellurides, etc.) along with its position in a sequence rich in amphibolites, suggests an origin of the ore probably bound to submarine volcanic activity.

5 Geohazards

An inventory has not yet been made. Artisanal gold mining is often operated by using mercury.

6 Geosites

An inventory of potential geosites is currently in progress (Metaseria et al., 2004). Several Neogene deposits within the rift valley are famous for paleoanthropological discoveries, best known is the Australopithecine "Lucy" (*Australopithecus afarensis*) from the Afar badlands of Hadar (Fig. 77). The rift valley often exhibits extraordinary scenic beauty (Fig. 78 - 83).

Fig. 77 The famous skeleton of *Australopithecus afarensis*, popularly known as "Lucy", from the Afar region in northern Ethiopia

Fig. 78 An extinct volcano with a crater lake in the Danakil depression in northern Ethiopia

Fig. 79 The Danakil depression in northern Ethiopia

Fig. 80 A river bed in the Danakil depression in northern Ethiopia

Fig. 81 A volcanic plug in the central Ethiopian Highlands

Fig. 83 Lake Hayk in central Ethiopia

Fig. 82 Stromatolites at the shore of Lake Ahengi in central Ethiopia

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Gabon

1 General

Area: 267,667 km²
Population: 1,208,000 (July 2000 estimate)

2 Summary of Geology

Gabon is located at the northwestern margin of the Congo Craton. Three major stratigraphic units can be distinguished: the Archean basement and the Proterozoic sediments, which together cover about 75% of the country, and the Phanerozoic sedimentary cover, which is essentially of Cretaceous age or younger.

3 Stratigraphy and Tectonics

The oldest rocks of the country form part of the Archean cratonic basement of Gabon, the Republic of Congo, Cameroon and Equatorial Guinea. In Gabon, this basement is traditionally separated into the southern Chaillu Massif and the North Gabon Massif. The Chaillu Massif is dominated by granitoid rocks, which have given ages of 2,800-2,600Ma. The granitoid rocks represent a typical Archean cratonic assemblage of foliated quartz diorite-tonalite-granodiorite suites, with later more potassic rocks of monzonitic, granitic and syenitic compositions. A large charnockitic body has been mapped in the south. Supracrustal remnants are rare, with few extensive greenstones developed. Such rocks are restricted to pods and lenses of amphibolite, metaquartzite and mica schist. The North Gabon Massif appears to show more variation than the Chaillu Masif and includes the Monts de Crystal and Mitzic regions (adjacent to the Ntem granulites of southern Cameroon), where granulites and charnockites of varying composition are typical. The granitoid terrane in the south, which is a continuation of the Chaillu Massif, contains a large number of relatively small greenstone belts dominated by itabirites and iron-rich quartzites and schists.

Paleoproterozoic rocks consist of the about 2,000Ma old Franceville Supergroup in the eastern central part of the country and the Ogooué orogenic belt in the centre-west. The Franceville Supergroup comprises a thick pile of predominantly sedimentary rocks, which were deposited in three main basins, across which the stratigraphic succession appears to be fairly constant. The syn-Franceville N = Goutou Volcanic Complex has been dated at about 2,150Ma, thus indicating an age for the lower part of the succession. To the east of the Franceville Supergroup, the Ogooué orogenic belt comprises a number of thrust nappes of highly defored medium- to high-grade metasedimentary and metavolcanic rocks (the Ogooué Supergroup), that have been considered to be broadly coeval with the Franceville Supergroup. The belt contains a number of remobilised basement domes. In the southwestern part of the country, the Mayombe-Nyanga terrane comprises medium- to high-grade Paleoproterozoic basement rocks (including the Lambaréné migmatite belt), and metasedimentary rocks of the Doussa Supergroup, along with post-tectonic granites dated at about 1,900Ma.

The Mesoproterozoic geology of Gabon appears to be restricted to the rocks of the Mayombe Supergroup in the Mayombe-Nyanga terrane and a suite of post-Franceville dolerite dykes emplaced at about 970Ma. In the western part of the country, the Neoproterozoic (Pan-African) West Congolian Supergroup is exposed in two regions, the de la Noya and Nyanga Basins, which both contain thick low-grade, deformed, volcano-sedimentary sequences, which are typical of the Pan-African belts of southern Africa. A small carbonatite was emplaced at about 669Ma in the Lambaréné region.

The Phanerozoic sedimentary cover in the coastal region is either observed to be in pericratonic (Batéké Plateau in southeast Gabon) or intracratonic relationship with the Precambrian units. The coastal sedimentary basin is split into two unequal parts by the horst of the Lambaréné-Chincoua basement rocks and was formed during Lower Cretaceous. The interior or eastern basin, located east of the horst, consists mainly of continental and lacustrine sedimentary sequences ranging from Upper Paleozoic to middle Cretaceous. The Atlantic or western basin consists of mostly marine sedimentary sequences of middle Cretaceous to Quaternary age. The Batéké plateau sequence is comprised of Tertiary continental facies and lies unconformable on the Proterozoic formations.

4 Economic Geology

Gabon‘s economy is largely dependent on its mineral industry, whereby the petroleum sector will still continue to be dominant for many years. The Atlantic or western sedimentary basin, which extends offshore along the coast at least as far as Sao Tomé, is the source of Gabon‘s oil production. Favourable trapping

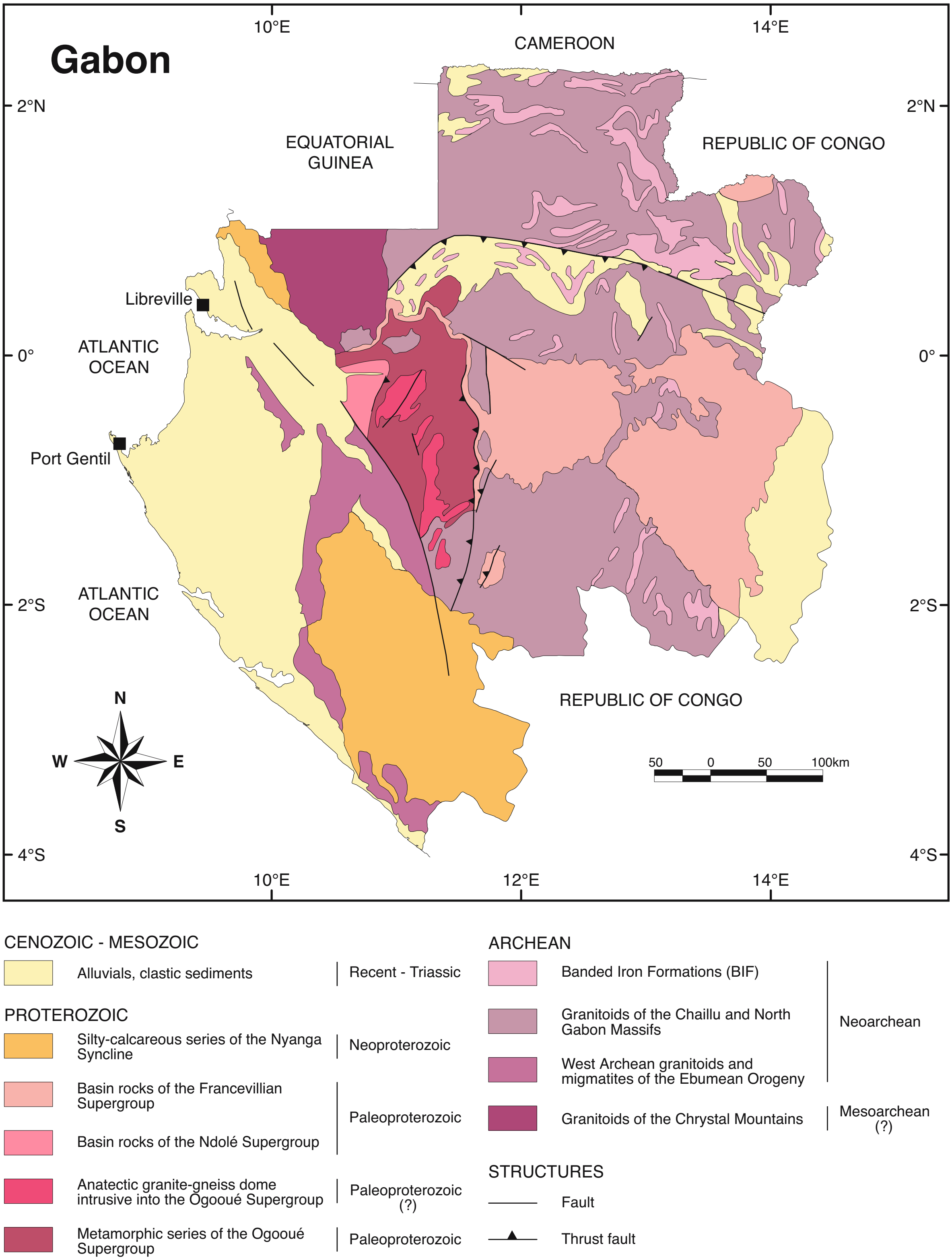

Fig. 84 Geological overview of Gabon (modified after Prian et al., 1991)

structures include faults related to the opening up of the Atlantic Ocean and salt diapirs. Gabon‘s largest oilfield, the Rabi-Kounga Field, onshore about 100km north of Gamba, was discovered in 1985 and began production in 1989. Increased drilling and seismic activity will likely lead to further discoveries and increased petroleum production.

The non-fuel mining sector is dominated by manganese and uranium mining. Manganese ore occurs on residual Lower Proterozoic deposits in southeast Gabon near Mounana. Deposits of uranium are also located in the Mounana area, in sandstones of the western margin of the continental Franceville Basin. Gold-bearing rivers are numerous and mostly located on top of metamorphosed Precambrian rocks. Almost all gold produced in Gabon comes from alluvial deposits. Also diamonds appear to be quite widespread in Gabon. They have been mined in the Makongonio area in the south and to a lesser extend in the Mitzic region in the north of the country. Several iron-bearing areas have been identified in the Makokou-Mékambo region in the north, which originated from the alteration of itabirites (BIF). Less important commodities include baryte from Dourekiki, west of Tchibanga, and a phosphate/niobium deposit at Mabounié, east of Lambaréné. Indices for lead, zinc, tantalite, potash, dolomitic limestone, talc and ornamental rocks have also been identified, but no follow-up work has yet been undertaken.

Fig. 85 Karstification in the Leconi Canyon in Gabon

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

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The Gambia

1 General

Area: 11,300 km²
Population: 1,367,000 (July 2000 estimate)

2 Summary of Geology

The Republic of Gambia is bordering the Atlantic Ocean and completely surrounded by Senegal, being confined to the valley of the Gambia River, thus it is entirely underlain by Cenozoic rocks of alluvial, fluvial marine and coastal beach sediments.

3 Stratigraphy and Tectonics

Stratigraphically, The Gambia is underlain by sedimentary rocks deposited in a regional basin related to the opening of the Atlantic Ocean. The oldest strata of the country, which is confined to the valley of the Gambia River, are Tertiary rocks of Oligocene, Miocene or Pliocene age known as the Continental Terminal Series and made up of sands, sandstones, silts, clays and kaolinitic claystones. These occur mostly in the west and centre of the country. Pleistocene ironstone crusts consisting of iron oxides, gravels, sands, silts and clay matrices predominate in the east of the country as well as Pleistocene alluvium, which is made up of undivided sands, silts and clays. Holocene deposits consist of marine and coastal sands, silts, clays and salts, sometimes with organic intercalations. The Holocene deposits are found along the Gambia River including its tributaries and close to the sea.

Fig. 86 Aerial view of the Gambia estuary. Banjul lies on a hooked sandspit in the far end (from Buckle, 1997)

4 Economic Geology

It has been assumed that there might be some potential for the discovery of oil in the basin. Several thousand km of seismic surveys have been run over the last decades, and a few petroleum exploration wells, all unsuccessful, were drilled.

In the 1950s, titaniferous beach sands were mined. The heavy-mineral concentrates average 70.2% ilmenite, 15.9% zircon, 3.3% rutile and 10.6% gangue minerals. There are also undocumented quantities of building and construction materials. The Gambia's significant glass sand deposits have yet to be exploited.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

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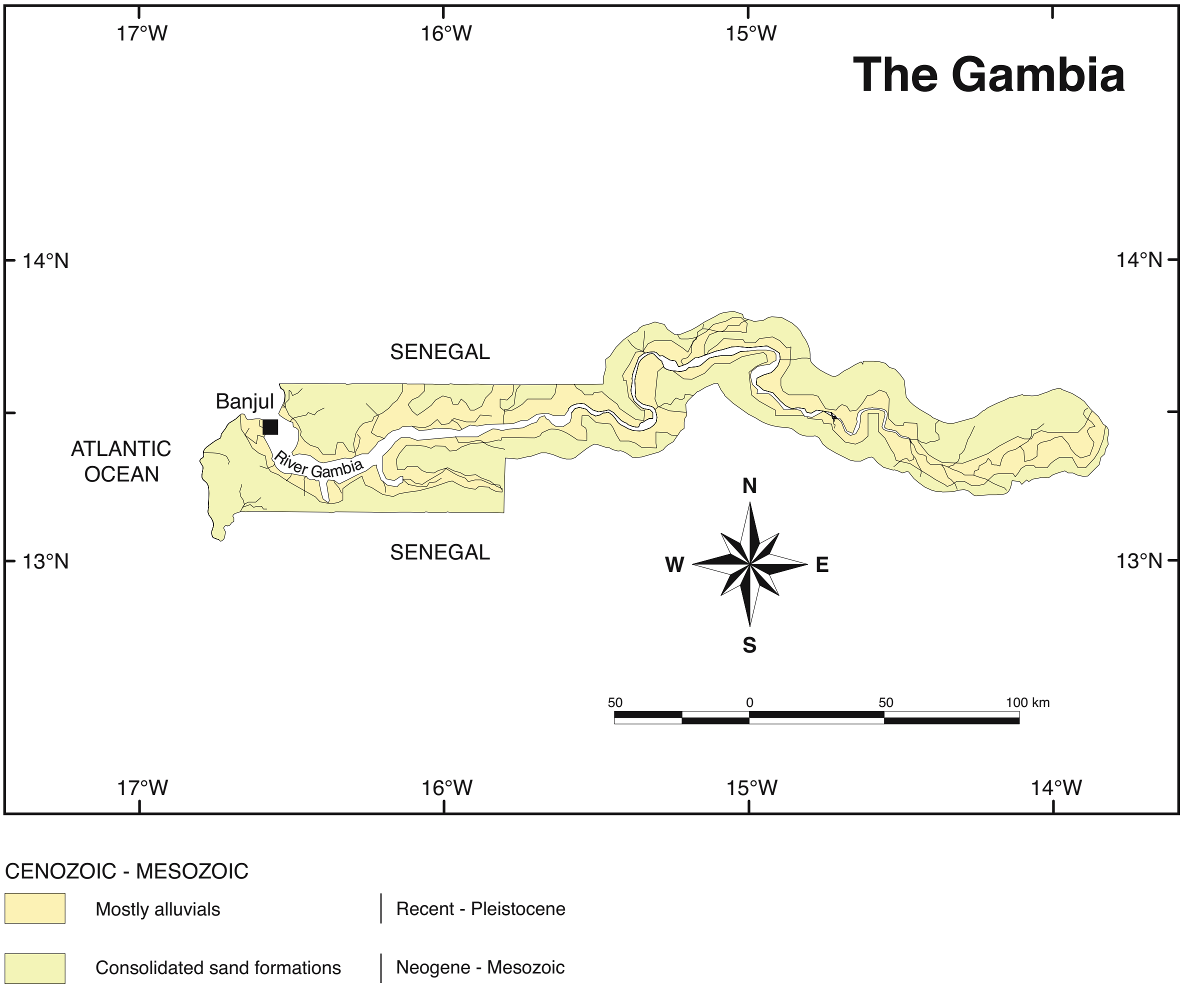

Fig. 87 Geological overview of The Gambia (modified after Russel & Whyte, 1988)

Ghana

1 General

Area: 238,540 km²
Population: 19,534,000 (July 2000 estimate)

2 Summary of Geology

Geologically, Ghana can be subdivided into three different major units: Paleoproterozoic rocks predominate in the southwestern and northwestern part of the country, whereas gneisses and supracrustal rocks of mostly Neoproterozoic age occur in the southeast and east of the country. Flat-lying shelf/marine sediments of very late Precambrian to Paleozoic age are found in the central and northeastern part of the country. Mostly Cenozoic sediments occur in a small strip along the coast.

3 Stratigraphy and Tectonics

Most Paleoproterozoic strata in West Africa can be assigned to the Birrimian Supergroup, which is largely subdivided into a sedimentary succession, consisting of phyllites, tuffs and greywackes, overlain by conglomerates, sandstones and shales, and a volcanic succession of tholeiitic affinity. These two units were originally defined as Lower and Upper Birrimian, respectively. It has, however, been demonstrated that the Lower and Upper Birimian rocks represent a coeval sequence, in which the volcanoclastic assemblage is emplaced as a series of evenly spaced volcanic belts. These volcanic belts are several hundred kilometres long and consist mainly of low-grade metamorphic tholeiitic lavas. From south to north they are named Kibi-Winiba Belt, Ashanti Belt, Asankrangwa Belt, Sefwi Belt, Bole-Navrongo Belt and Lawra Belt. Apart from the most northern Lawra belt they all trend in a NE-SW direction. These belts are separated by basins containing chiefly isoclinally folded dacitic, volcaniclastic and argillitic sediments as well as granitoids. In the transition zone between the volcanic belts and the sedimentary basins crop out cherts, manganiferous horizons, carbonates and C-rich sediments, considered as typical exhalative facies. After their emplacement, the Birrimian lavas and sediments were folded during the Eburnean tectonothermal event, intruded by various types of granitoids, uplifted and eroded. The erosional products were deposited as sediments of the Tarkwaian Group in a long and narrow intramontane graben, representing a gently folded molassic sequence, which was formed due to rifting. Intruded into the Birrimian Supergroup are large masses of granites and granodiorites of Cape Coast type, which occur as batholiths in the central portion of the Birrimian sedimentary basins, and of Winneba type, which has an Archean sialic precursor. Smaller masses of granites called Dixcove type form an unfoliated intrusion into the volcanic belt. The rare Bongo potassic granitoids are post-Tarkwaian in age and mainly found in the northern part of the country.

The Neoproterozoic Pan-African mobile belt terrane of eastern and southeastern Ghana consists of the Dahomeyan System, comprising mafic and felsic gneisses, the Togo Series with quartzite, shale and minor serpentinite, and the Buem Group, which consists of shales, sandstones, basaltic to trachytic lavas and volcanoclastics.

Sedimentary rocks of the Volta Basin can be subdivided into the following three units: The Bombouaka Supergroup, the Pendjari (or Oti) Supergroup and the Tamale Supergroup. These represent slightly different stratigraphic divisions than the lower, middle and upper Voltaian subdivisions previously used in Ghana. The Bombouaka Supergroup has a thickness of about 1000m and comprises dominantly sandstones and soft clay-siliceous sediments. The Pendjari (or Oti) Supergroup has an average thickness of about 2,500m and rests with an erosional unconformity, partly of glacial origin, on various Bombouaka rocks, or directly on crystalline basement. Predominant rock types at the base include an association of tillite-dolomitic limestone with baryte-silixite, and in the upper part rhythmic argillites and siltstones. The Tamale Supergroup has a thickness of about 500m and is made up in its lower part of clays and siltstones, and in its upper part of sandy, coarser continental rocks. This supergroup represents a typical foreland molasse basin. Age determinations indicated for the Bombouaka Supergroup 1,100-700Ma, and for the Pendjari (or Oti) Supergroup 700-600Ma, whereas the age of the Tamale Supergroup is controversial. Sometimes it is assigned to the upper Neoproterozoic to basal Cambrian, or sometimes to the Lower Paleozoic, and thus could be time equivalent to the Sekondian and Accraian Series developed along the Atlantic coast of Ghana.

Phanerozoic rock units at several places along the coast include the Early or Middle Devonian Accraian Series, the Middle Devonian to Lower

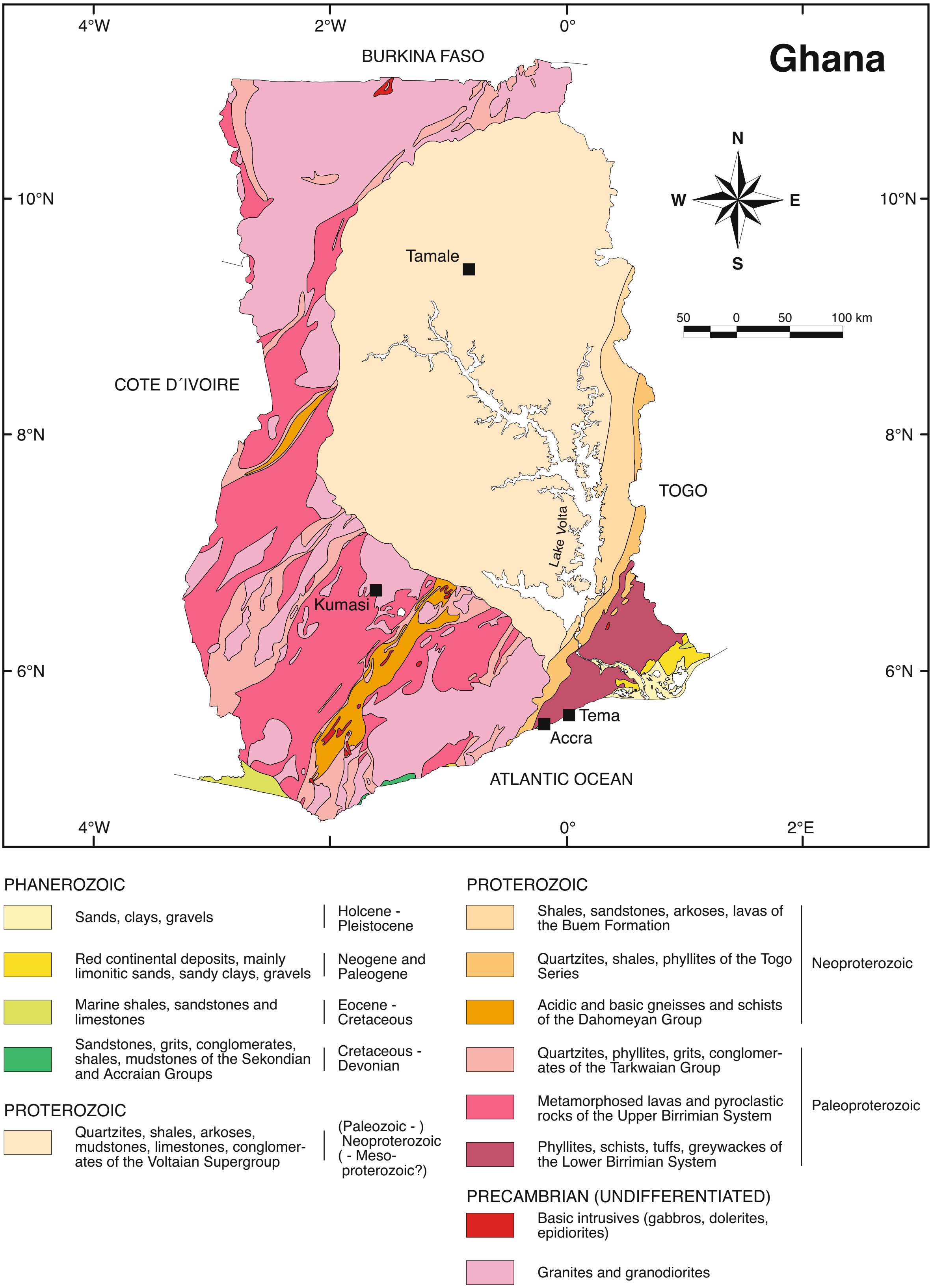

Fig. 88 Geological overview of Ghana (modified after Anonymous, 1989)

Fig. 89 The 113m high rock-fill dam at Akosombo in the Volta Gorge of southern Ghana, holding back an artificial lake of 8482 km² (1964)

Cretaceous Sekondian Series, the Upper Jurassic to Lower Cretaceous Amisian Group, the Upper Cretaceous Apollonian Group, and Tertiary to Recent unconsolidated, marine, lagoonal and fluvial deposits.

4 Economic Geology

Gold deposits are economically by far the most important mineral type in Ghana. Past cumulated production is estimated to be in excess of 1500t Au. Five important types of gold mineralisation occur: 1. Steeply dipping quartz veins with native Au in shear zones at Birrimian belt/basin boundaries; 2. Disseminated sulphide bodies, spatially, though not necessarily genetically in association with the shear zones, and quartz veins, with auriferous arsenopyrite as major host of gold; 3. Disseminated and stockwerk mineralisation in late-kinematic

Fig. 90 The heap of a gold mine in the Ashanti region

Fig. 91 A pit for artisanal gold mining in the Ashanti Region

"basin-type" granitoids; 4. Modified paleoplacer-mineralisation in quartz-pebble conglomerates of the Tarkwaian Group, carrying, besides gold, detrital and reconstituted magnetite and hematite; 5. Alluvial gold concentrations in Recent and subrecent river gravels (Fig. 90 - 93).

Considerable diamond deposits are recovered from river gravels in the eastern and central region. No kimberlites have been reported. Bauxite, derived from weathering of Paleoproterozoic phyllites, is mined in the Aswaro area of the western region. Manganese ore in the form of manganese oxides and carbonates is mined at Nsuta in the western region. Traces of chromite, asbestos, andalusite, barite, mica, nepheline syenite, cassiterite, columbite, monazite, beryl, spodumen, molybdenite and on-shore alluvial ilmenite and rutile have been identified but hardly been followed up. Small-scale production of sand, gravel and other construction minerals is widespread. Several small clay and kaolin deposits are worked for bricks and/or ceramic products.

Fig. 92 Chutes for liquid clayey gold mud used in artisanal mining in the Ashanti region

Fig. 93 The siphon of a liquid gold mud delivering chute in the Ashanti region

5 Geohazards

Major geoenvironmental hazards were created by the pollution of surface waters and aquifers through gold mining activities.

6 Geosites

An inventory has not yet been made, but the Bosumtwi Meteorite Impact Crater near Kumasi has been proposed by Reimold (1999), who complained that the touristic value of the site was not recognized by the Ghanaian geologists.

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Guinea

1 General

Area: 245,857 km²
Population: 7,670,000 (2001 estimate)

2 Summary of Geology

Major parts of Guinea are underlain by Precambrian rocks, which form the southern portion of the West African Craton. The eastern two-third of the country are dominated by rocks of the Kenema-Man domain and the Paleoproterozoic Birrimian System. Neoproterozoic and Paleozoic sediments with a basal tillite and overlying sandstones, marls and quartzites form wide parts of northern Guinea. Along the coast occurs a strip of Neogene marine and alluvial sediments.

3 Stratigraphy

Crystalline basement rocks in the western part of the Rokelide Orogen are placed in the Forecariah Group, which is considered to range from Neoarchean (2,700Ma) to Paleoproterozoic (2,000Ma) age. The Forecariah Group is composed of a variety of gneisses, schists, migmatites and mylonites metamorphosed to amphibolite and granulie facies. It is subdivided into the Kissi Kissi Formation, the Forecariah Formation, the Mahera Formation and the Kounsouta Formation. The Ouankifondi Group has been considered to be distinct from the Forecariah Group because of structural contrasts. To the east of the Ouankifondi Group is a sequence of volcano-sedimentary rocks known as the Bania Group. It is composed of andesites, diabases, spilites and diorites and exhibits pillow lavas at Mt. Binia. The Bania Group has sometimes been correlated with the Ouankifondi Group, while other authors consider it to be equivalent to the Kolente Group, which ranges from Neoproterozoic to early Paleozoic. Of Neoproterozoic age is also the Walidiala Group in northern Guinea, which commences with a basal tillite. Microfossils recovered from dolomites immediately overlying this tillite place the upper part of the Walidiala Group and the Mali Group into the Cambrian. Hence the Kolente Group, exposed in southern Guinea and also characterized by a basal tillite, probably straddles the Neoproterozoic-Cambrian boundary. The Kolente Group is generally composed of greenish clastics and sands near the base of the sequence, the latter becoming finer grained towards the top. It overlies unconformably the metamorphic complex of the Bania and Ouankifondi Groups. Red sandstones and conglomerates of the Taban Group outcrop in several small basins in Guinea immediately south of the Bove Basin. These strata lie unconformably on metamorphic rocks of the Forecariah and Ouankifondi Groups. The Taban Group is considered to be of fluviatile origin and is interpreted to be post-orogenic molasse, which may represent the southernmost extent of the post-orogenic molasse of the Youkounkoun Group of Guinea north of the Bove Basin, which covers the greatest part of western Guinea. The rock sequences of the Bove Basin have been subdivided into three groups: The Pita Group is the lowest and subdivided into the Kindia Formation at the base and the following Mount Gangan Formation. The Kindia Formation is made mostly up of white, conglomeratic sandstones, probably representing an alluvial plain. The Mount Gangan Formation consists of sandstones with isolated, angular quartz pebbles and argillites with isolated quartz clasts looking like a diamictite. No fossils have been found in the Pita Group, but it appears to be more ancient than the following Telimele Group, which has been dated as early Silurian (Llandovery), due to the occurrence of graptolites. The lower part of the Telimele Group is composed mainly of argillites and siltstones, including also levels of green and pyritic sandstones. 15 fossiliferous layers with graptolites and microfossils have been identified. The upper part of the Telimele Group begins with a sequence of sandstones, containing sometimes brachiopods. In the higher part of this succession black and grey shales are rich in various marine fossils, indicating a late Silurian (Ludlow) to early Devonian (Gedinnian) age. The following Bafata Group is subdivided into three formations: The lower formation is composed of sandstones, intercalated by argillaceous and silty levels, containing brachiopods and sometimes trace fossils. The middle formation begins with a thick yellow sandstone level with brachiopods of Eifelian age. It is followed by pink siltstones including brachiopods of Givetian age. The upper formation is composed of argillites and siltstones, also containing brachiopods, which indicate a Frasnian and Famennian age. The environment of the Bafata Group was apparently shallow marine.

Along the coast occurs a narrow strip of marine and alluvial clastic sediments of Cenozoic age.

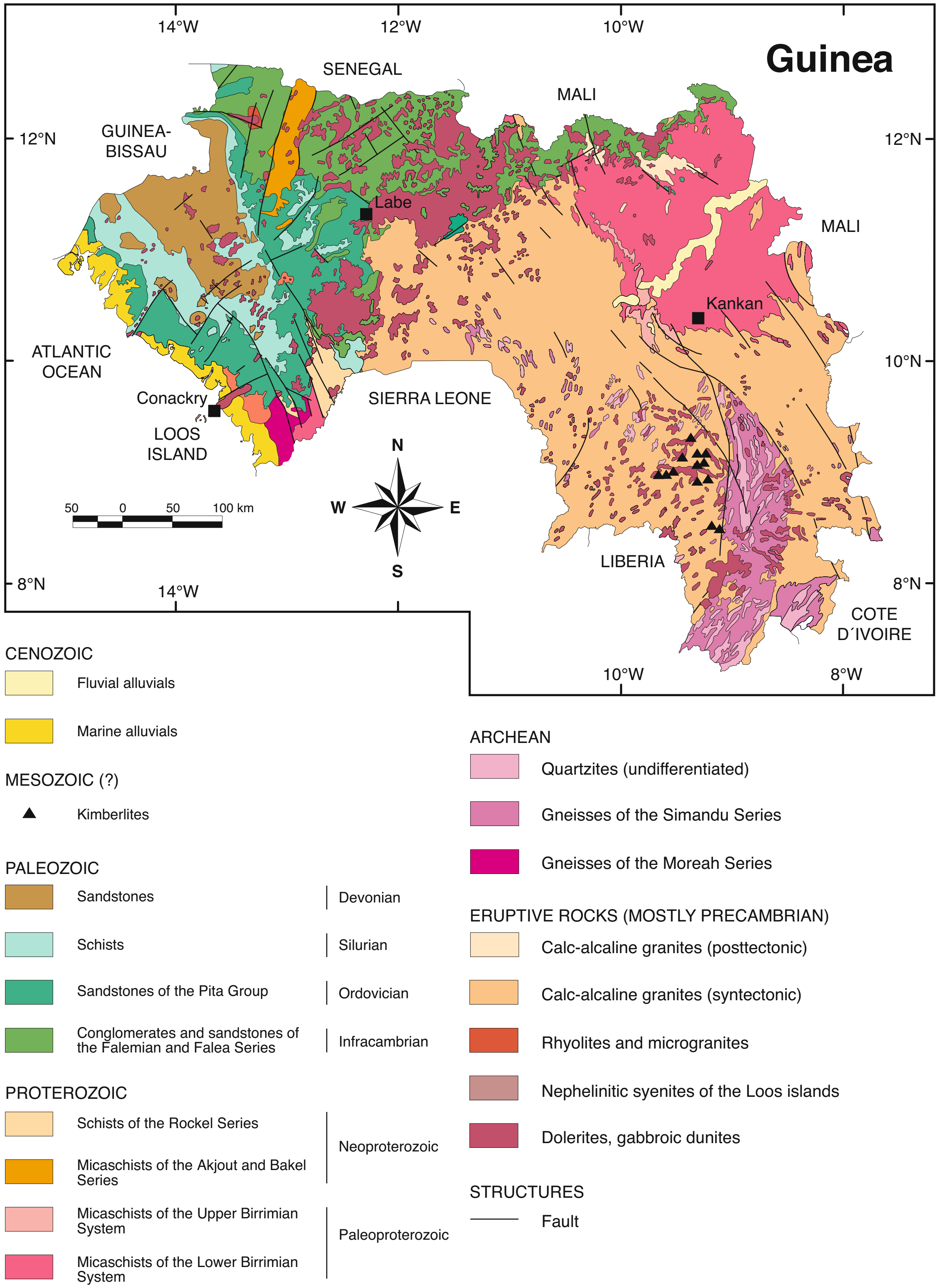

Fig. 94 Geological overview of Guinea (modified after Anonymous, 1998)

Fig. 95 Screening of diamond-bearing gravel by artisanal miners in the Kerouane region.

Fig. 97 Open pit bauxite mine in the Fria area, coastal Guinea.

4 Tectonics

Archean and Pan-African structures are clearly recognizable in Guinea in rocks affected by the Rokelide Orogeny and are similar to those in Sierra Leone.

5 Economic Geology

Guinea is a country rich in various mineral commodities, but largely under-exploited. Among its mining resources bauxite constitutes the major source of foreign exchange revenues, accounting for almost 40% of the bauxite world trade with average annual exports of approximately 14 million tonnes. All bauxite deposits occur in the western and central parts of the country and were formed through the alteration of dolerites, crystalline schists and nepheline syenites from Neoproterozoic and Paleozoic during the peneplanation and laterization of this region. The average thickness of the ore varies from 3 to 9m. Access to the deposits is easy and mining is carried out in open pits (Fig. 97).

Fig. 96 Drag-line set-up of diamond bearing gravels in Banankaro in the Kerouane region.

Diamonds of gemstone quality occur in southern Guinea. They originate from Mesozoic kimberlite dykes and pipes, which are controlled by deep-seated fracture systems. Diamonds can be found in Guinea also in alluvial and eluvial deposits. Artisanal diamond mining is mostly done in relict heavy mineral concentrations in near-to-surface fractures in Ordovician quartzites in the Kindia area of western Guinea (Fig. 95 and 96).

Gold is found primarily in shear-zone hosted Paleoproterozoic greenstone belts. But most economic are those deposits, which were formed through enrichment during laterization. Artisanal mining of alluvial gold is locally widespread.

Major iron ore deposits originating from Banded Iron Formations (BIF) of Archean rocks occur for instance at Mt. Nimba in the east of the country. Other mineral products include a nickel deposit in the Kakoulima-Kaloun range, about 50km away from Conakry. Uranium deposits occur in the north of the country along the border to Mali. Ilmenite, rutile, zircon, tourmaline, etc. are associated with sands from shorelines and large watercourse beds, such as the Niger, the Nandian, the Bofon River, etc. Economical deposits are known in Cape Varga, Boffa and Benty, but not yet exploited.

Hydrocarbon exploration in Guinea began already 1968, and the existence of oil resources in the Guinean offshore has since then been confirmed, but no production unit is yet in operation.

6 Geohazards

Mining operations are the main geoenvironmental hazard, especially causing pollution in groundwaters and aquifers.

6 Geosites

An inventory has not yet been made.

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Guinea Bissau

1 General

Area: 36,125 km²
Population: 1,286,000 (July 2000 estimate)

2 Summary of Geology

Geologically, Guinea Bissau can be divided into three tectono-stratigraphic units. In the extreme northeast occur Neoproterozoic rocks, the rest of the eastern part comprises Neoproterozoic to Paleozoic strata, and the west contains Cenozoic to Recent sediments.

3 Stratigraphy

The oldest rocks of Guinea Bissau are those of the Neoproterozoic (680Ma) Koulountou Group in the extreme northeast of the country, representing schistose lavas of the southern Calc-Alkaline Complex of the Mauritanides Orogen. The Koulountou rocks are attributed to the orogenic volcanism that is related to the evolution of an active continental margin.

The rocks of the Youkounkoun Group are generally unmetamorphosed but slightly folded, originating from sediments of a post-orogenic molasse. Radiometric age data revealed about 580 Ma. Rocks of the Mali and Batapa Groups are probably age equivalent to the Youkounkoun Group or slightly younger. The Mali rocks represent monotonous siltstones with radiolarians, while those of the Batapa Group are the westward equivalent of the Mali Group. The sediments of the Bove Basin cover the greatest part of eastern central Guinea Bissau. The basin is a gentle synclinal feature filled with Ordovician to Devonian strata. The following three units can be subdivided: The Pita Group is 250-600m thick and consists of conglomeratic sandstones, probably representing deposition in an alluvial plain. No fossils occur in the Pita Group, but an Ordovician age has been assumed. The Pita Group is more ancient than the following Telimele Group, which is ranging from Llandovery, as indicated by graptolites, to Upper Devonian (Famennian). Various fossils have been found in the Telimele Group, which has a thickness 150-330m. The third unit is represented by the Bafata Group, which is also of Devonian age and has a thickness ranging from 150-430m. It was probably deposited in a marine shelf environment.

In the western part of Guinea Bissau, these Paleozoic rocks are unconformably overlain by Cenozoic and younger sedimentary deposits, which are mainly of marine origin. Mafic dykes and sills cut all of the above mentioned complexes

Geomorphological evolution was intense during the Quaternary, marked by the formation of large glacis and some terrace levels, while the older plateaux are characteriyed by extensive duricrusts, generally up to 8m thick, sometimes forming table lands. Some transgressive/regressive marine episodes known from other areas in northwest Africa are also indicated in Guinea Bissau, for instance the Tafaratian, Aioujian, Inchirian and Nouakchottian episodes.

4 Tectonics

The Bove Basin features a large-scale, shallow open fold, the Bove-Bafata Syncline, striking NE-SW, and is cut by brittle faults.

5 Economic Geology

Guinea Bissau has traditionally not been considered to be well-endowed with mineral resources, but exploration has continued to prospect for potential deposits. Bauxite associated with lateritic regolith overlaying Paleozoic sediments has been reported, but not as yet been exploited. Some isolated, low-grade gold anomalies occur in the northeast of the country. Associated with the Paleozoic sedimentary rocks are soil anomalies of lead, zinc, copper and molybdenum, but no follow-up exploration has yet been conducted. A larger resource of phosphates occurs in the Eocene carbonate sediments of the Farim region. Locally, small-scale quarries produce road and brick building materials.

6 Geohazards

An inventory has not yet been made.

7 Geosites

An inventory has not yet been made.

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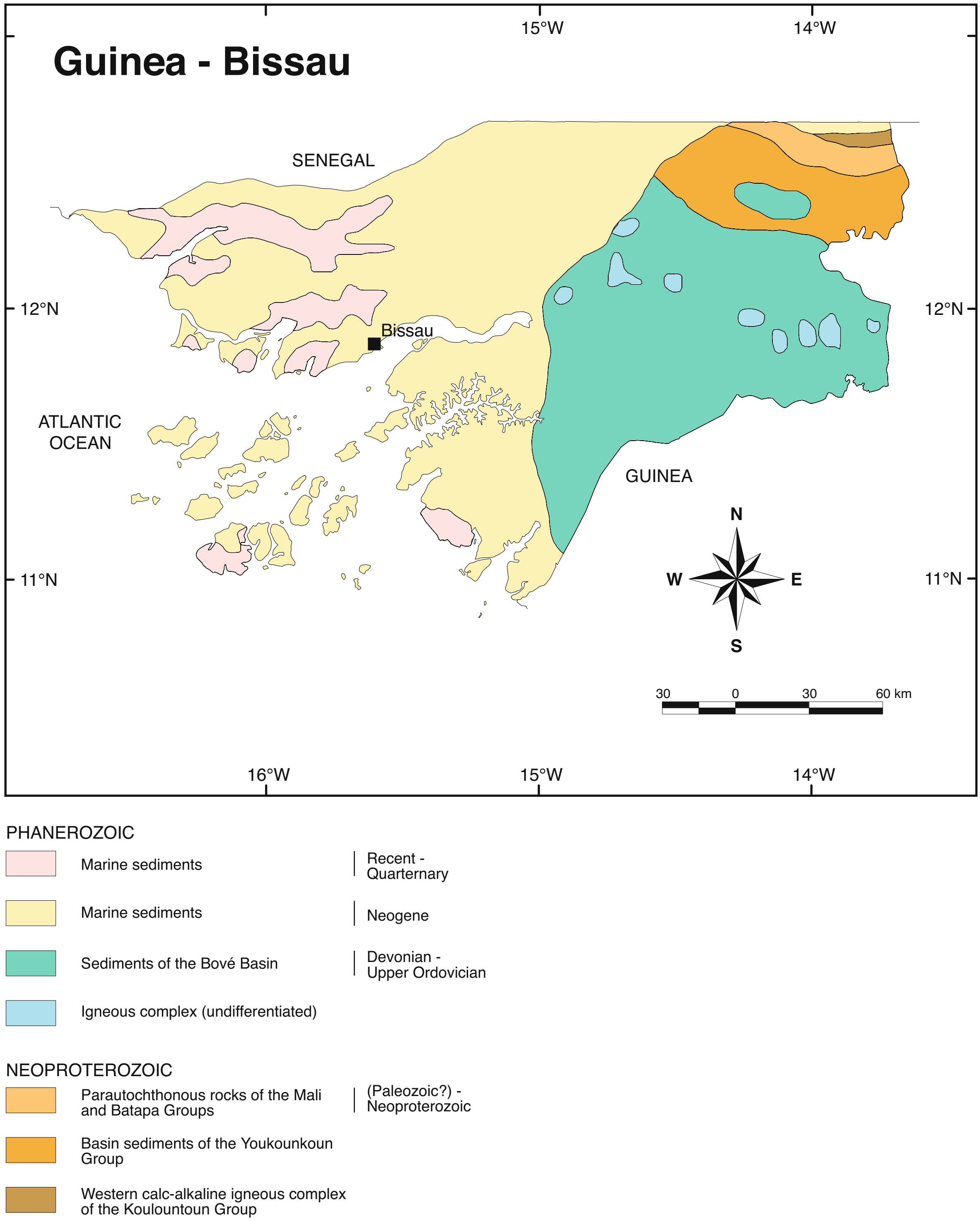

Fig. 98 Geological overview of Guinea-Bissau (modified after Teixeira, 1968)

Ivory Coast - Cote d'Ivoire

1 General

Area: 322,463 km²
Population: 15,981,000 (July 2000 estimate)

2 Summary of Geology

Almost all of Ivory Coast is underlain by rocks of Precambrian age (Archean and Paleoproterozoic), belonging to the West African Craton. Only along the southern and southeastern coastal strip occur oil- and gas-bearing, mostly Cenozoic sediments.

4 Stratigraphy and Tectonics

The Precambrian rocks of Ivory Coast can be subdivided into the Archean Kenema-Man domain in the extreme west of the country around Man, and the Paleoproterozoic Baoule-Mossi domain in central and eastern Ivory Coast. Both are separated by the N-S trending Sassandra mylonitic zone. The Kenema-Man domain consists chiefly of Archean granulitic and migmatitic gneisses with subordinate granitoids and relic supracrustal belts, which are metamorphosed to granulite facies and predominantly composed of banded ironstone formations. The Archean rocks were affected by two major, but poorly constrained tectono-thermal events, the earlier Leonian orogeny (ca. 3,500-2,900Ma) and the subsequent Liberian orogeny (ca. 2,900-2,500Ma). Similarly as in Ghana, the Paleoproterozoic terranes of the Baoule-Mossi domain in eastern Ivory Coast consist mostly of NE-SW trending, subparallel volcanic belts and intervening sedimentary basins. These volcanic belts contain chiefly low-metamorphic-grade tholeiitic flow rocks, minor felsic volcaniclastics, some chemical sediments and syn-volcanic granitoid intrusions, which have yielded ages between 2,190-2,150Ma. The sedimentary basins consist of isoclinally folded, mostly dacitic volcaniclastics, greywackes and argillites. In central Ivory Coast, continuity, spacing and parallelism of the volcanic belts are less clearly developed, and there are terrains in between them consisting largely of gneisses and granitoids. The volcanic belts in this central sector have yielded an age of about 2,100Ma, thus indicating two generations of volcanic belts being present in the Baoule-Mossi domain of Ivory Coast. Sandstones, arkoses and minor quartz-pebble conglomerates belonging to the Tarkwaian Group are found as relatively small, isolated occurrences spatially associated with some volcanic belts, the largest one cropping out in the northeast of the country near Bondoukou. The Eburnean tectono-thermal eventfolded and metamorphosed the supracrustals and syn-volcanic granitoids at around 2,100Ma and is responsible for the formation of high-strain zones close to volcanic belt/sedimentary basin boundaries as well as major, several 100km-long, N-S trending shear zones of regional importance. The basins and locally some belts were intruded by extensive, late-kinematic S-Type granitoid plutons, which vary from tonalite to peraluminous granite.

Mostly Neogene to Recent clastic sediments exist along and offshore part of the country's Atlantic coast, which is generally made up of sandy beaches and lagoons. This sedimentary basin hosts Ivory Coast's modest known oil and natural gas reserves.

4 Economic Geology

Although a relatively large number of mineral occurrences has been identified in Ivory Coast, the production of mineral commodities played only a minor role in the economy of the country.

Gold deposits are economically the most important mineral resources in Ivory Coast. Three types of gold mineralization are known: a) steeply dipping quartz veins with native gold in shear zones at volcanic belt/sedimentary basin boundaries; b) disseminated sulphide bodies, spatially though not necessarily genetically in association with the shear zones and quartz veins, with auriferous sulphides as major host of gold; c) alluvial gold concentrations in Recent and sub-Recent river gravels. Modified paleoplacer gold mineralization in interbedded conglomerates and quartz-sericite schists of the Tarkwaian Group has also been reported, with grades up to 3g/t. An example for types a and b includes the Aniuri Mine in the extreme southeast of the country, which is located in the Afema shear zone, which is a southwesterly continuation of the Bibiani shear zone in Ghana. Alluvial deposits in river gravels are mined at Toulepleu and Babadougou.

Diamond production is mainly undertaken in the alluvial fields at Tortiya in the north-central part of the country south of Korhoga, and at Seguela. Kimberlite dykes are known at Seguela, Kanangone and Tortiya, although none of these kimberlites so far discovered has yielded diamonds.

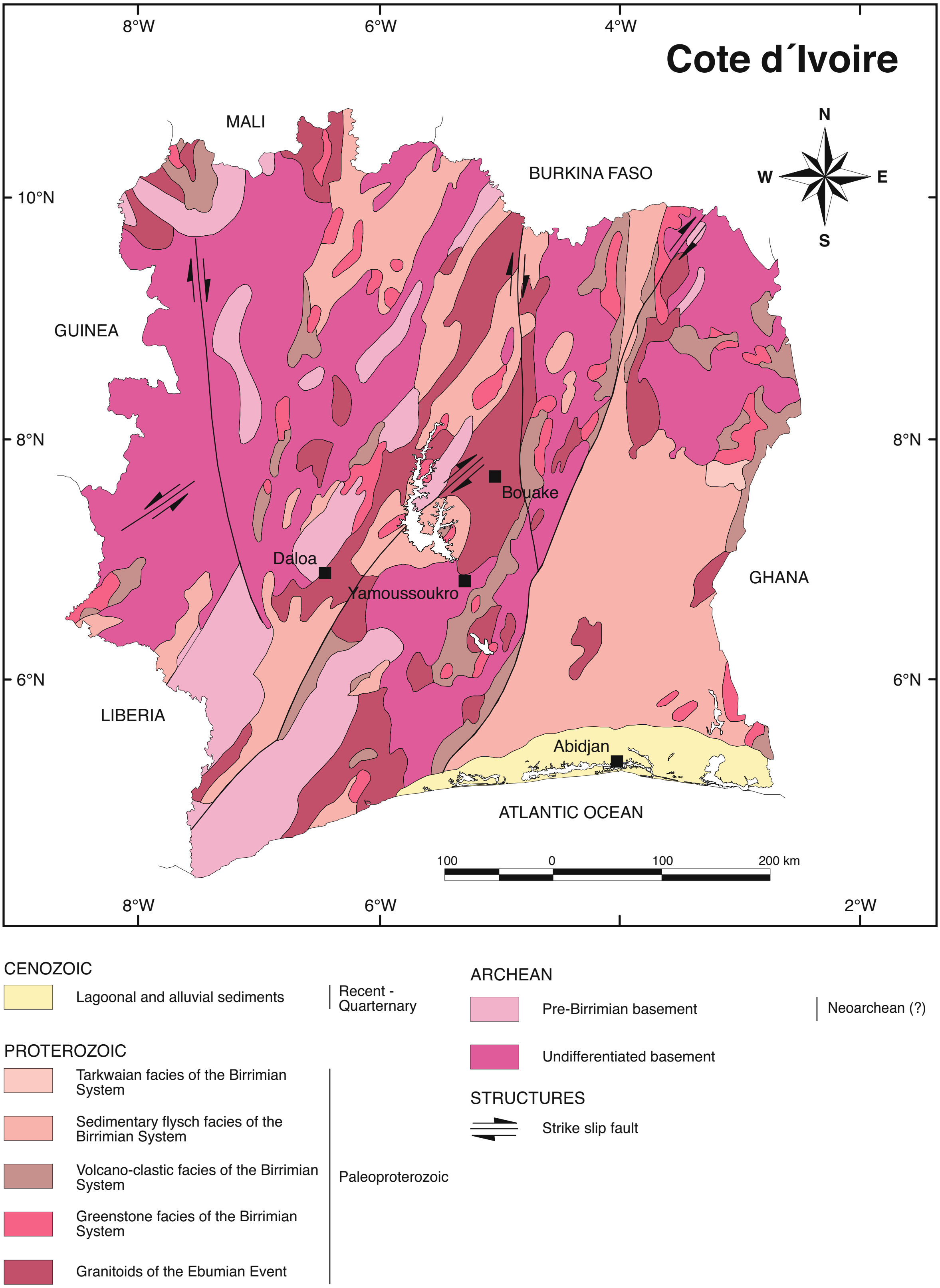

Fig. 99 Geological overview of Cote d´Ivoire (modified after Rocci, 1991)

The two most common types of iron formations found in Ivory Coast are the Minette Oolitic and the Lake Superior types. The Monogaga deposit (Minette Oolitic type) near Sassandra is Miocene/ Pliocene in age and contains 150Mt at 40% Fe. Lake Superior type magnetite deposits occur at Mt. Gao, Segaye, Tortro, Tia and Klahoyo. Lateritic nickel over amphibolitic gneisses has been discovered at Biankouma, close to the Guinea border. Some of the nickel occurrences carry appreciable amounts of cobalt. Manganese is found as oxide, carbonate and silicate. At Ziemougoula in the northwest of the country, lenticular bodies have been drilled indicating potential reserves of 1.2Mt at 47%Mn. At Mokta and the Blafa-Gueto hills manganese occurs as residual caps, formed by secondary enrichment of underlying phyllites and gondites. Other mineral occurrences include bauxite, glass sand, titanium and tantalite recovered from beach sands, and minor Ni-Cu deposits associated with platinum group minerals.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory of potential geosites has not yet been made.

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Kenya

1 General

Area: 582,650 km²
Population: 30,340,000 (July 2000 estimate)

2 Summary of Geology

Kenya is underlain by Neoarchean rocks occurring in the west of the country along Lake Victoria, metamorphic rocks of the Neoproterozoic Mozambique Belt mainly in the northern central part of the country, sediments ranging from Late Paleozoic to Recent times along the coast and predominantly younger volcanics associated with the rift formation in the central part of the country.

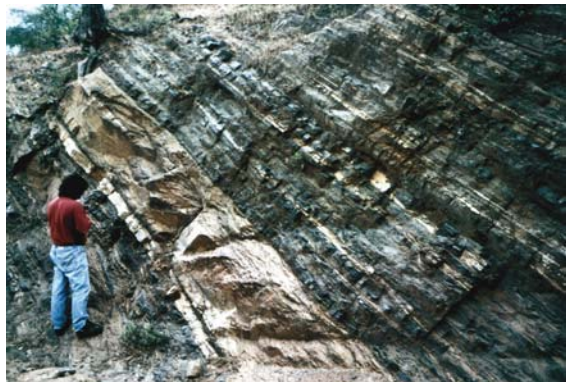

Fig. 100 Argillaceous/arenaceous deposits of the Neoproterozoic Mozambique Belt in the Taita Hills.

3 Stratigraphy and Tectonics

The oldest rocks outcropping in Kenya belong to the Neoarchean Nyanzian System (sometimes known as Nyanza Greenstone Belt) occurring east of Lake Victoria. It is often composed of sedimentary rocks, including slates, greywackes and conglomerates and is geographically subdivided into a southern and a northern terrain. The southern terrain is represented by the Migori segment, which trends in a WNW-ESE direction and is aligned in an almost linear contact of about 75km to the Neoproterozoic Migori granite. This greenstone succession consists of mafic volcanics and BIF at the base, overlain by intermediate to felsic volcanics and sandstones, shales and BIF, interbedded with andesitic tuffs at the top of the succession. Intrusive rocks in the area are of granitic composition. The main occurrence of the northern terrain is to the west of Maseno township, where a sequence of volcanics (basalts, andesites, dacites and rhyolites) is observable. It has been concluded that the Maseno basalts are associated with crustal extension and rifting near a continental plate. Nyanzian rocks also occur east and west of the Nandi escarpment, where they either outcrop as epidiorites or metabasalts, or as low-grade metamorphosed lavas and sediments containing BIF. The following Kavirondian System still belongs to the Neoarchean and is widely distributed in western Kenya. The largest extent is known from an E-W trending basin between the western slopes of the Nandi Hills and Yala Town. The Kavirondian System in wsetern Kenya can be subdivided in ascending order into the following four formations: Shivakala Formation, made up of conglomerates and sometimes intruded by granites; Igukhu Formation, mainly consisting of greywackes; Mroda Formation, consisting of sandstones, greywackes and mudstones; Mudaa Formation, made up of laminated or blocky mudstones.

Paleoproterozoic rocks are not exposed in Kenya and the occurrence of Mesoproterozoic rocks in the country is doubtful. Tabular Neoproterozoic is represented by the Kisii Group in western Kenya forming a succession of flat-lying rocks resting unconformably on Nyanzian and Kavirondian formations. The rocks of the Kisii Group comprise in ascending order non-porphyritic and porphyritic basalts, ferruginous siltstones, cherts, quartzites, sometimes conglomerates, rhyolites, tuffs, fekspathic sandstones, conglomerates, andesites, dacites, porphyritic and non-porphyritic felsites. The Neoproterozoic Mozambique Belt is well exposed in northern central Kenya and has been subdivided into various lithostratigraphic units (Fig. 100). Ophiolites are known from the Samburu-Marsabit and the Baragoi areas in northern central Kenya, and from Moyale close to the border with Ethiopia.

Continental sediments of the Karoo Supergroup outcrop along coastal southeastern Kenya in the Mombasa Basin and at the western rim of the Mandera Basin in northeastern Kenya. In the Mombasa Basin the Karoo rocks are generally at 5° to 7° dipping to the east. From base to top the following five units can be distinguished: The Taru Formation, the Maji ya Chumvi Formation, the Mariakani Formation, the Matolani Formation and the Mazeras Formation. The Taru Formation is dominantly composed of arkoses and comprises at the base probable tillites including sharp-edged particles set in a fine-grained matrix

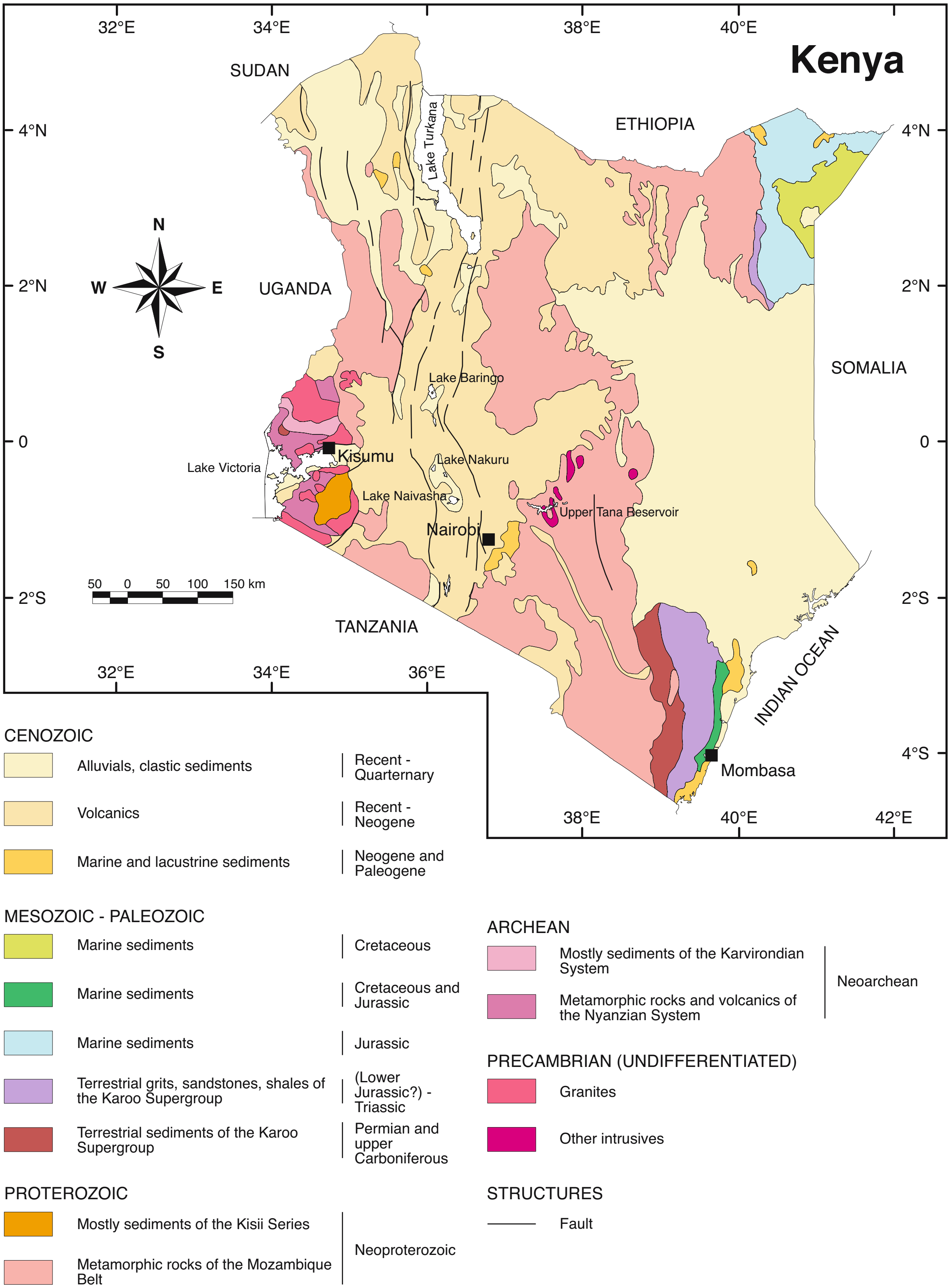

Fig. 101 Geological overview of Kenya (modified after Anonymous, 1987)

and varved siltstones. The assumed glacial origin of these sediments suggests a Late Carboniferous/Early Permian age for the sequence. It is followed by thick wedges of arkoses grading upwards into feldspathic grits and carbonaceous shales with plant debris. The Taru Formation comprises in its upper part a sequence of conglomerates, feldspathic sandstones, calcareous sandstones, flagstones, siliceous limestones and oolithic limestones. Sometimes mudstones are intercalated. The Maji ya Chumvi Formation comprises in ascending order three units: Arkosic sandstones/black shales, blue/black shales and flagstones/sandy shales. A Permo-Triassic age for this formation is indicated by palynomorphs and branchiopods. The Mariakani Formation represents another series of fine-grained sandstones and silty shales lying conformably on the Maji ya Chumvi Formation. It is more sandy and often more massive than its predecessors. It is subdivided into three sandstone members indicating a fluvial low sinuosity/braided channel depositional environment. The Matolani Formation outcrops only in the central part of the Mombasa Basin and is rich feldspathic sandstones. Karoo sedimentation terminated with the deposition of the Mazeras Formation, which has been subdivided into three distinct members: The lower unit contains banded arkosic yellow sandstones, the middle unit consists of coarse arkosic sandstones, sometimes conglomerates, and the upper unit comprises coarse sandstones with pebbly horizons. In northeastern Kenya small isolated exposures of Karoo sediments occur at the western rim of the Mandera Basin. These strata are known as the Mansa Guda Formation and consist mainly of sandstones, sometimes interbedded by grits and conglomerates.

After a long period of peneplanation the transgression of the Jurassic epicontinental sea took place since Liassic times. Wheres in the Mombasa Basin the end-Karoo times are marked by faulting and a sudden change from continental to marine facies conditions, in the Mandera Basin in northeast Kenya the underlying Precambrian rocks of the Mozambique Belt had been worn down to a surface of an undulating relief. The Jurassic in the Mandera Basin has been subdivided in ascending order into the following formations: Didimtu Formation (Toarcian), Bur Mayo Formation (Bathonian - Callovian), Murri Formation (Bajocian - Bathonian), Rukesa Formation (Callovian), Asaharbito Formation (Callovian), Muddo Erri Formation (Oxfordian), Rahmu Formation (Oxfordian), Seir Formation (Oxfordian), Golberobe Formation (Oxfordian?), Hereri Formation (Kimmeridgian), Dakacha Formation (Kimmeridgian - Tithonian?) and Mandera Formation (Tithonian). Most of these formations are richly fossiliferous yielding exclusively marine invertebrates. In the Mombasa Basin the following Jurassic formations are recorded: Kambe Formation (Bajocian - Bathonian), Kibiongoni Formation (Bathonian? - Callovian) and Mtomkuu Formation (Upper Oxfordian - Kimmerdgian). Not all of these formations are rich in fossils, some are apparently deep sea sediments. An isolated occurrence of Jurassic limestones associated with sandstones containing marine fossils of Oxfordian age has been recorded from the Matasade Hills in central Kenya. The Cretaceous sea spread in Kenya along similar lines as the Jurassic sea, but never reached the same extension. In the Mandera Basin as well as in the Mombasa Basin only deposits of the Lower Cretaceous have been recorded. In the Mandera Basin the Lower Cretaceous is represented by the Danissa Formation (Wealden) and the Marehan Formation (Lower Cretaceous), both of which are not rich in fossils. In the Mombasa Basin the Freretown Formation has yielded ammonites indicating a Neocomian to Aptian age. Of possibly Tertiary age are unfossiliferous claystones, which unconformably overlie Jurassic limestones in the Mandera Basin. The Lamu embayment is an extension of the Mombasa Basin and covered by strata of Paleogene and Neogene age. Paleocene, Eocene and Oligocene deposits outcrop near the present-day coast, but are not rich in fossils. Strata of Neogene age are represented in the Lamu embayment by the Middle Miocene Kipevu Beds and the Upper Pliocene Margarini Beds, both of which are largely unfossiliferous.

The East African Rift System is represented in Kenya by the Gregory Rift (also known as the Kenya Rift), which is a graben bounded by fault zones about 50-80km apart. The altitude of the rift floor reaches a maximum at around 2000m in the Naivasha area, and a minimum at around 600m at Lake Magadi, whereas Lake Turkana to the north is located at an altitude of about 300m. The Kenya Rift has major fault scarps, for instance the Elgeyo and Nguruman escarpments reaching 1500m and the Aberdares over 2000m above the rift floor. In the beginning of the Cenozoic most of East Africa was a lowland area with the coast further west than today. The first stage of rifting probably started in Late Cretaceous times, with uplifting in central Kenya and corresponding subsidence in the Turkana Basin. Volcanic activity began with extensive basalt eruptions in the Turkana Basin during the Oligocene. Subsequently during Late Oligocene to Early Miocene times the central area of Kenya experienced uplifting to form the Kenya Dome. On the crest of this dome some downwarp occurred to form the proto-rift, which was accompanied by nephelinite, basanite and phonolite magmatism. Major faulting occurred in the central to northern part of the rift in Middle Miocene times. The faulting continued to propagate the rift southwards, mainly during Pliocene times. By around 1.9Ma the inner rift had formed making a distinct graben. Continued uplift on the rift shoulders through the Quaternary, coupled with intense faulting on the rift floor, produced the nested grabens witnessed today.

Volcanic rocks cover a large proportion of Kenya, many of these rocks being closely related to the Gregory Rift, but significant parts lying away from it. The volcanism has apparently shifted eastwards with time in Kenya. Oligocene eruptions took place mainly west of the present rift. Miocene eruptions were more widespread within and on the flanks of the proto-rift. Pliocene activity tends to be confined within the rift, while Quaternary activity occurred within the rift and in areas well to the east. Volcanism of the pre-rift stage consists predominantly of small basaltic shields in the Turkana - Baringo regions, and of scattered nephelinite-carbonatite central volcanism on the Kenya-Uganda border and in the Kavirondo Rift. Mt Kenya started to develop towards the end of the Pliocene. It consists mainly of basalts, rhomb porphyries, phonolites, kenytes and trachytes. The plug of the volcano is composed of nepheline syenite and phonolite in the form of a ring structure. Activity started in the Aberdares area in Late Miocene times, and it may have been active till the Pleistocene.

4 Economic Geology

Kenya's mineral production is not very significant for the economy of the country (about 1.3% of the GDP). Mining is based primarily on the extraction of industrial minerals and therefore confined to minerals such as trona (soda ash), fluorspar and limestone, which account for about 70% of the total value of Kenya's mineral output.

The development of gold resources in Kenya is a priority of the Government's policies. Prospects have indicated that there is a sufficient amount of commercially viable deposits to enable gold production by openpit methods. Current gold production is limited to small-scale artisanal operations. Prospection for copper, lead and zinc in the Kerio Valley in northeast Kenya has advanced.

Trona is a hydrated basic sodium carbonate, which is converted into soda ash or anhydrous sodium carbonate, being currently the most important mineral product of the country. Vast quantities of the mineral occur in Lake Magadi on the floor of the rift valley close to Tanzania, where the lake is covered by a thick crust of almost pure white crystalline trona. It is dug by a dredge of shallow draught designed to cut at least 6m below the trona surface. The production was in the 1990s at a level of about 100,000mt/a.

Mining operations for other industrial minerals are largely confined to fluorspar and limestone (for cement). Fluorspar is found at several localities within the rift valley in the Elgeyo-Marakwet and Baringo regions, where it occurs as fault fillings in both

Fig. 102 The trona-covered Lake Magadi with factory buildings of the Magadi Soda Company.

Fig. 103 Machinery to be used for the production of ilmenite, rutile and zircon from beach sands at Kwale.

Fig. 104 A geothermal energy producing field at Olkaria near Lake Naivasha.

Precambrian metasediments and Tertiary volcanic rocks. Most of the cement is produced from Meso- and Cenozoic coral reef limestones, which occur along the coast. Other carbonate resources include carbonatites, calcrete and travertine. About 25,000t of lime are annually produced from the Koru carbonatite in western Kenya. Calcrete resources in the Athi River quarry, about 15km southeast of Nairobi, are exploited as a raw material for the Athi River Cement Plant. The combined rate of Kenya‘s cement production exceeds 1.3 million tons per year, a large portion of which is exported to neigbouring countries. A wide range of other industrial minerals is produced on a small scale. These include baryte, diatomite, feldspar, clay, gypsum, marble, salt, dimension stone, vermiculite and wollastonite. Silica sand is mined at Msambweni

Fig. 105 Aerial view of North Island in Lake Turkana, showing the two youngest lava flows breaching the central crater wall (from Key & Watkins, 1988).

Fig. 106 The two main peaks of Mt Kenya, Bation and Nelion.

and Roka on Kenya‘s southern and northern coasts, and shipped for bottle glass manufacture to Nairobi. The production of ilmenite, rutile and zircon from beach sands near Kwale will commence in near future (Fig. 103).

Fig. 107 Eastern shore of Lake Turkana.

Kenya is not a petroleum producer, but exploration in the various sedimentary basins along the coast and in the rift valley is still ongoing. Geothermal energy from hot springs in the Lake Naivasha region contributes already to about 5% of Kenyas electricity production (Fig. 104).

5 Geohazards

In a workshop on "Geoenvironmental Hazards and Disasters in Africa", which was held in July 2002 in Nairobi, various potential and real risks related to the geosciences were presented, analyzed and discussed (Schlüter & Mogere, 2002). The following topics were on the agenda of the workshop: progressive beach erosion, environmental impact of mining, landslides, flood prediction and management, radioactive soil radiation, geoenvironmental hazards related to the use of geothermal energy and geo-medical impacts.

6 Geosites

In a preliminary account of potential geosites in Kenya the following locations have been considered: The volcanoes of the Ngong Escarpment, the prehistoric site of Olorgesaillie (already a National Monument under protection of the Kenya National Museums) (Fig. 108), the Lake Magadi Basin, the Lake Naivasha Basin, the volcano Longonot, the Olkaria volcanic field, the crater of volcano Menengai, the ophiolitic complex of Siambu and the fossil site of Lothagam near Lake Turkana (Schlüter et al., 2001).

Fig. 108 Excavations of Pleistocene stone tools at Olorgesaillie, north of Lake Magadi.

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Lesotho

1 General

Area: 30,355 km²
Population: 2,180,000 (estimate 2001)

2 Summary of Geology

The Kingdom of Lesotho is almost exclusively underlain by rocks of the Karoo Supergroup, comprising sediments, which cover a quarter of the surface area in the northwest and southwest, and volcanics, which dominate in the central and eastern part of the country.

3 Stratigraphy

The lower parts of the Karoo Supergroup, i. e. rocks of the Dwyka and Ecca Groups, are not exposed in Lesotho. Upper Beaufort strata in the west and northwest are the oldest rocks outcropping in Lesotho and although there is no direct evidence of the nature of the pre-Karoo basement, data from drilling, xenoliths from diamond pipes and extrapolation of the geology in neighbouring South Africa establish that crystalline metamorphic basement rocks underlie the Karoo succession. The Burgersdorp Formation being the topmost unit of the Beaufort Group is the oldest Karoo represented in Lesotho. It is similar in appearance and composition to rocks of the Middle Beaufort, which comprises a sequence of variegated mudstones alternating with yellow sandstones. Additionally, the Burgersdorp Formation contains red and maroon sandstones with interspacings of grey-white sandstones and streaks of thin coal seams.

The widely distributed Stormberg Group is composed of a thick sequence of continental clastic rocks, generally subdivided into the Molteno, Elliot and Clarens Formations. The lowermost strata include coarse sandstones and light-coloured shales known as the Molteno Formation with a thickness ranging from 15-300m, which is a shallow lacustrine deposit of Upper Triassic age, sometimes containing a rich assemblage of fossil plants and insects (Fig. 110 and 111). The Molteno Formation is conformably overlain by the Elliot Formation (70-250m thick), which is made up of sandstones, red mudstones and siltstones and sometimes contains silicified wood and dinosaur remains. The Elliot Formation is in turn overlain by the Clarens Formation (15-250m thick), which comprises massive sandstones and siltstones, often cross-bedded and fine-grained with thin bands of cherts.

Capping the sedimentary succession of the Stormberg Group is a series of almost flat-lying amygdale-rich lava flows constituting the Lesotho Formation of the Drakensberg Group, which is of Lower Jurassic age. These lavas form the mountainous part of Lesotho, reaching sometimes a thickness of up to 1600m. The bulk of the lavas is basaltic and they are composed of tholeiites associated with andesites. The widespread nature of this thick volcanic pile, the succession of horizontal flows in rapid sequence and the tholeiitic composition of these rocks are distinctive properties of a plateau basalt. Intrusives are ubiquitous with over 70 volcanic vents and diatremes and more than 1000 dykes and sills are recorded. The dykes and sills are of the same age and composition as the lava flows. A possible emplacement of kimberlites during the Cretaceous constitutes the last phase of the volcanic activity.

Pluvial periods, which alternated with three successive glacial episodes during the Pleistocene, gave rise to intense erosion of the upland areas with cobble bed deposition intercalated with sands and clays in the lowland valleys. These formations sometimes reach a thickness of up to 20m. The erosion of these strata has given rise to the development of characteristic narrow steep-sided ravines, which in Lesotho are referred to as "dongas".

4 Tectonics

Lesotho occupies the central part of the much larger Karoo Basin of southern Africa. Its overall structural pattern is therefore a syncline. Within this framework, three episodes of deformation pre-Drakensberg, Drakensberg and post-Drakensberg are recognised, each influencing the Karoo sedimentation, basalt thickness, geomorphology and hydrology. A major NE-SW trending fault known as Hellspoort with a vertical displacement of 300m, south of Mafeteng, and a few minor faults of much lesser magnitude represent the main structural feature.

5 Economic Geology

The economic mineral potential of Lesotho is due to the restriction of Upper Karoo deposits limited to the following commodities: diamonds,

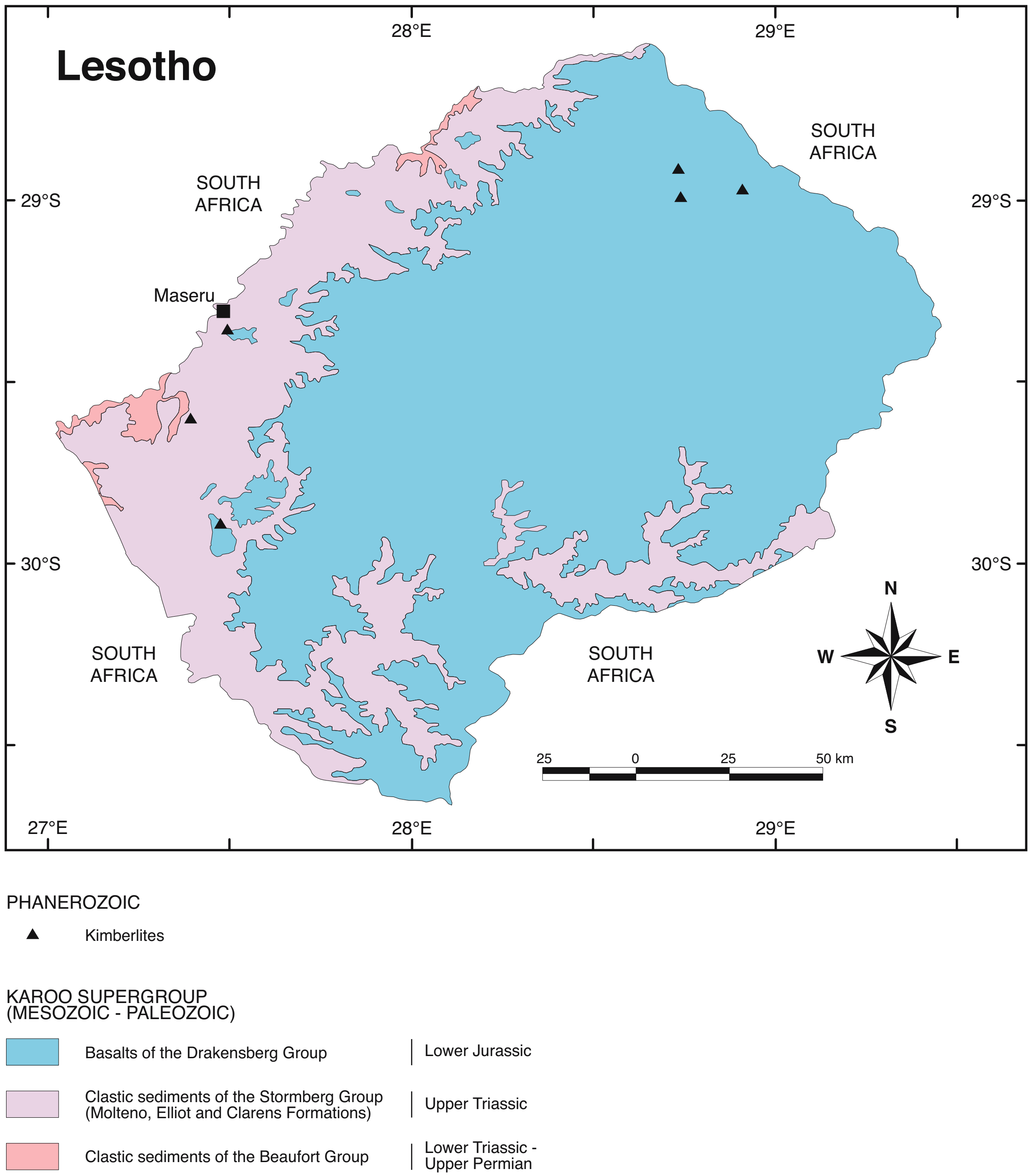

Fig. 109 Geological overview of Lesotho (modified after Ginsburg, 1962)

Fig. 110 A foliage of the widespread fossil plant genus *Dicroidium* from the Molteno Formation, Middle Triassic.

uranium, semiprecious stones, possibly mercury, coal and industrial minerals. Diamonds are found in the kimberlites and in alluvial gravels. Over 400 kimberlite bodies have been recorded, of which 343 occur as dykes and the rest as pipes (39) and blows (23). Whereas kimberlites are widespread distributed throughout the country, northern Lesotho is probably the most concentrated area of kimberlite intrusion in the world, with an average intrusion of one per

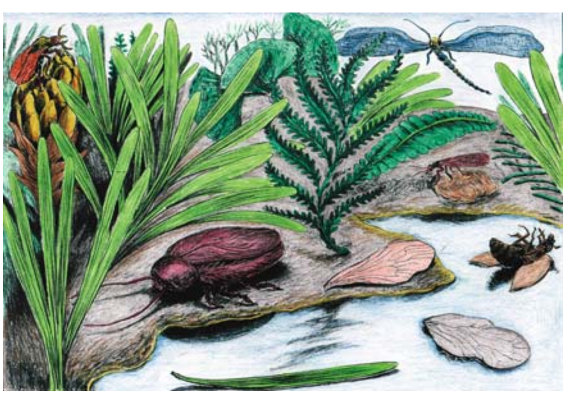

Fig. 111 A reconstruction of the Middle Triassic lacustrine biocenosis of the Molteno Formation, Lesotho and South Africa.

$10km^2$. Despite this abundance none of the kimberlites is exploited on a large scale, but further exploration is underway. Also the potential of alluvial gravels in the lowland of the southwestern region remains still to be assessed. Currently three diamond mines are in operation. The Karoo rocks throughout the southern African region are host to low-grade, low-tonnage deposits of uranium, therefore representing only a limited potential for further exploration in Lesotho. Semiprecious stones of Lesotho are agate, amethyst, olivine, zircon and chrome diopside, which are currently exploited on a small scale. Isolated minor occurrences of cinnabar have been recorded within the lower part of the Drakensberg lava flows. Coal of significant volume and quality is largely a phenomenon of the Lower Karoo, which is not exposed in Lesotho. However, the probability of coal-bed-methane cannot be discounted nor should one overlook the possibility of high rank coal of limited volume within the Upper Karoo. Industrial minerals that deserve to be mentioned are clays in the Quaternary strata and dimension stones originating from the sandstones of the Molteno, Elliot and Clarens Formations and fine-grained basalts of the Drakensberg Group.

6 Geohazards

Landslides are the major geoenvironmental hazards in Lesotho.

7 Geosites

An inventory of potential geosites of Lesotho has not yet been made, but the various outcrops of the fossiliferous Molteno and Elliot Formations need intensified protection. The Drakensberg Mountains should be considered because of their scenic beauty.

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Liberia

1 General

Area: 111,369 km²
Population: 3,164,000 (July 2000 estimate)

2 Summary of Geology

Liberia forms part of the West African Craton and more specifically of the segment known as the Leo or Man terrane. The rocks forming this crystalline shield consist of an older series of granulitic and migmatitic gneisses and amphibolites with subordinate granitoids. Remnants of slightly younger supracrustal rocks of sedimentary and volcanic origin are aligned predominantly in a SW-NE direction. Phanerozoic sediments are only exposed along a narrow coastal strip.

3 Stratigraphy

Approximately 90% of Liberia is underlain by Archean and Paleoproterozoic granitic rocks. They form part of the Leo or Man Shield of the West African Craton. The basement rocks can be divided into three major units on the basis of their radiometric age. The Archean rocks were effected by the earlier Leonian (3,500-2,900Ma) and the younger Liberian (2,900-2,500Ma) Orogenies. SW-NE trending greenstone belts of Birrimian age (2,100Ma) have been reported from the southern central part of the country. The third unit comprises the Pan-African age province, which was metamorphosed and intruded about 550Ma ago. The boundary between the Archean and Birrimian provinces is not well defined, but the Archean and Pan-African provinces are separated by a series of NWW-SEE trending faults comprising the Todi Shear Zone. Gneisses of the Archean and part of the Pan-African age provinces are metamorphosed to amphibolite grade. Granulite facies rock, however, are restricted to the Pan-African age province, but are probably derived from Archean rocks.

Two small outliers of clastic sedimentary rocks, the Gibi Mountain Formation, form heavily forested hills 32km northeast of the Todi Shear Zone. They lie disconformably on Archean gneisses and are overlain by klippen of Precambrian itabirite-bearing quartzites. The Gibi Mountain Formation is probably Neoproterozoic to early Cambrium in age, based on lithologic similarities to basal Rokel River Group units in Sierra Leone. It consists of a basal conglomerate overlain by arkosic siltstones and sandstones, which, in turn, are overlain by shales. A glacial origin has been suggested for the conglomerates and siltstones of the Gibi Mountain Formation, therefore corresponding with Neoproterozoic glacigenic deposits elsewhere in West Africa.

Isolated diabas or gabbro dykes (400-180Ma) are intrusive to the Precambrian rocks. Unmetamorphosed laminated sandstones, arkoses, siltstones and conglomerates of possibly Cretaceous age occur in narrow sections (<5km wide) along the coast

4 Tectonics

The 400km long shear zone separating the Kasila Group from Kenema Assemblage rocks in Sierra Leone continues into Liberia as the Todi Shear Zone and extends an additional 300km to the southeast until it makes a sharp bend to the continuing offshore. It separates amphibolites and granulites of the Pan-African age province from the Archean granite-greenstone terrane.

5 Economic Geology

Liberia‘s iron ore reserves at grades of 30-67% Fe are probably the largest in Africa. Two main types of mineralisation occur: High grade ores (<60% Fe) consisting mainly of hematite and low grade ores (30-40% Fe) composed mainly of magnetite. A third variety is of medium grade (40-60% Fe), which is usually made up of a mixture of hematite and magnetite. Liberia‘s iron ore deposits are hosted by Precambrian itabirites (BIF). High and medium grade ores are the result of laterization and the action of meteoric waters, which have leached silica with

Fig. 112 The Bomi Hills iron ore mine northwest of Monrovia (1964).

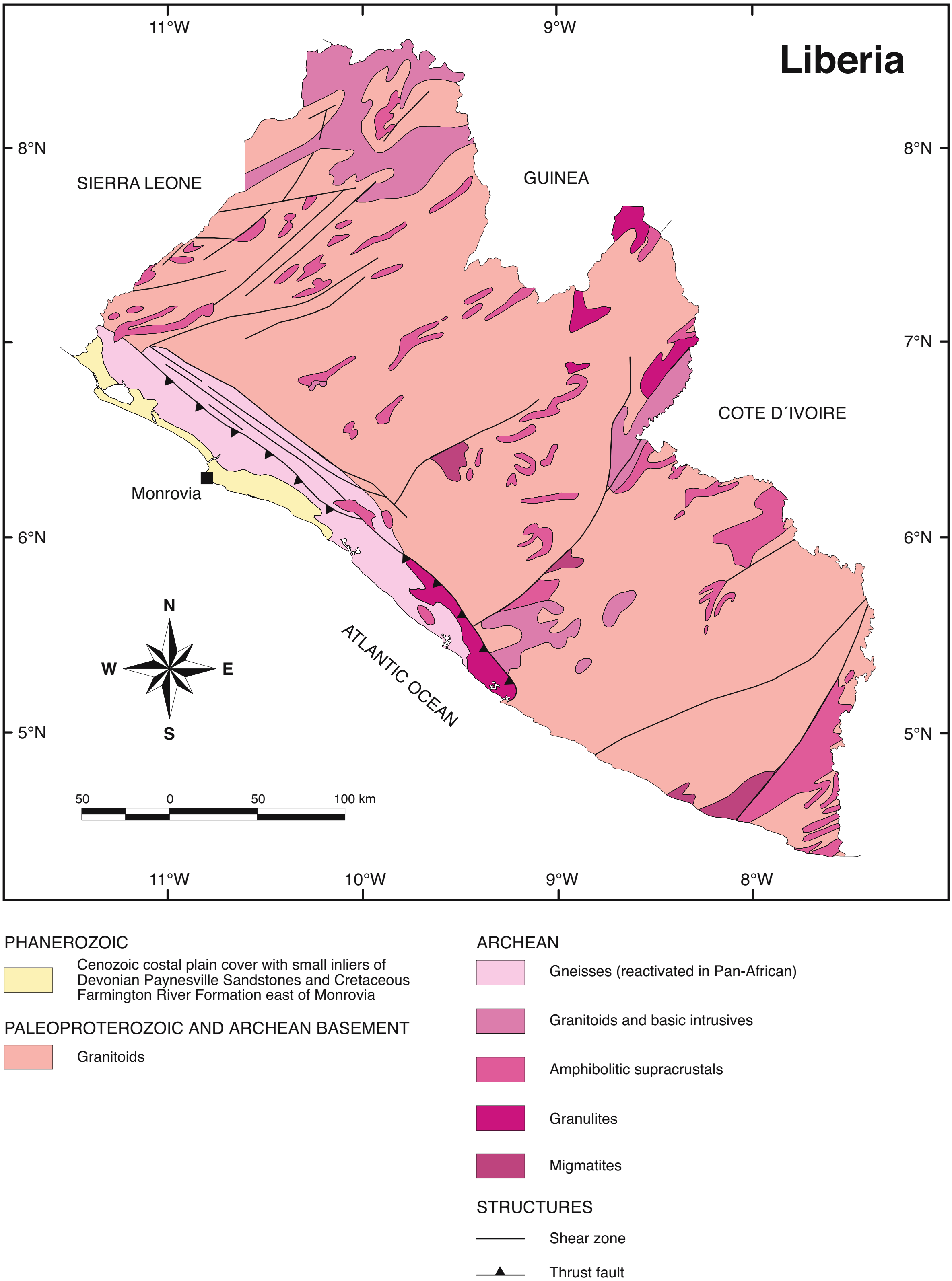

Fig. 113 Geological overview of Liberia (modified after Tysdal & Thorman, 1983)

consequent enrichment of iron. The site with the highest reserves, the Mt. Nimba area, has, however, largely been exploited (Fig. 112).

Much of West Africa's diamond potential is associated with the Archean Man Shield, which covers parts of Liberia, Guinea, Sierra Leone and Ivory Coast. Liberia's diamond potential appears underdeveloped, particularly with regards to kimberlites, although those few, which were assessed in the past, have not proven economic. Numerous alluvial diggings are known from river and marsh gravels, mostly close to the border with Sierra Leone. There may also be a potential for marine offshore placer deposits. A number of primary (lode) gold occurrences are known in Liberia's banded iron formation (BIF) and in Birrimian rocks in the south of the country. Numerous alluvial diggings are known throughout the country, particularly in the west. The widespread laterization in Liberia suggests a good potential for lateritic nickel and cobalt deposits. Other possible commodities include baryte, kyenite and bauxite. Silica sands and ceramic clays have locally been mined.

6 Geohazards

Artisanal mining for gold, which persisted during the civil war, has often caused surface water and aquifer contamination due to the application of mercury.

7 Geosites

An inventory has not yet been made.

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Libya

1 General

Area: 1,759,540 km^2
Population: 5,980,000 (2001 estimate)

2 Summary of Geology

Libya belongs entirely to the Saharan domain forming the northern part of the African Shield. Apart from a few Precambrian deposits the country is mostly covered by Paleozoic, Mesozoic and Cenozoic sediments and Neogene volcanics.

3 Stratigraphy

Precambrian outcrops are rare in Libya, but Precambrian strata have been identified at various places by drilling, consisting of metamorphosed and folded deposits with schists, gneisses, some quartzites and granites.

The Precambrian is overlain in an angular unconformity by the coarse Hassaouna sandstones of probably Cambrian age. There is a local intercalation of the Murizidie purplish-blue intermediary series. Sedimentation continued throughout the Paleozoic, but epirogenic movements occurred from the beginning of the Ordovician. The Silurian, on the other hand, was a period of calm but ending with widespread emersion. The Lower Devonian (Gedinnian) appears to be absent from the basin. The Devonian commences with the Tadrari coarse sandstones of Siegenian age and corresponds to a disturbed period with local subsidences, which went on until the Lower Carboniferous. At Jebel Oweinat, along the eastern limit of the Kufra Basin, the Paleozoic ends with a volcanic series, which was later folded and traversed by "ring-dyke" type extrusions, probably of Early Paleozoic age. Following these movements in the Jeffara plain, further sedimentation occurred in the Upper Carboniferous and went on during the Permian, including active subsidence. This subsidence continued during Triassic and occasionally in Jurassic. In the Murzuk and Kufra Basin, Mesozoic continental sedimentation persisted - after a break during Upper Paleozoic times - till the Lower Cretaceous. At the end of the Lower Cretaceous the Libyan tilt began. Existing basins became stable, while, on the other hand, sinking occurred in the eastern part of the country, which became subsidized. The transgression, which commenced during the Aptian-Albian, spread over the Sirte during the Cenomanian, the eastern Fezzan during the Maastrichtian and reached the Tibesti region in Lower Eocene. The subsidence is irregular, according to different blocks of varying mobility. This mobility persisted during the Miocene and Pliocene. The Oligocene is characterized by the formation of fault troughs in conjunction with the strains stretching the African block. The present margins of the Gulf of Sirte correspond to Pliocene flexures, followed by Quaternary flexures in the same direction. The Ionian Sea depression seems to be very recent to the east of the stable Pelagian block.

Fig. 114 Silurian claystones in the Kufra Basin.

The stratigraphic history of the northern Cyrenaica, which does not belong to the intracratonic basins, is of a special kind. From a palaeogeographic view it is linked to the unstable central Tunisian platforms. Uplifting of this zone took place during the Eocene. It became intensely folded during the Middle Miocene as a result of Hellenic foldings. Some faults still show seismic activity. Northern Jeffara also subsided during the Tertiary. In current marine bathymetry, the Gabes trench marks the negative axis of the basin. Important volcanic activity occurred on the ancient horsts at the end of the Tertiary until Recent times, particularly at Jebel Oweinat and along the Tibesti-Garian axis.

Situated to the north of the Saharan horst, Libya has thus an element of transition. Although its geological evolution is linked to the massifs and Paleozoic basins of the central Sahara, it has, none the less, been extensively invaded by the Tertiary seas of the eastern Mediterranean.

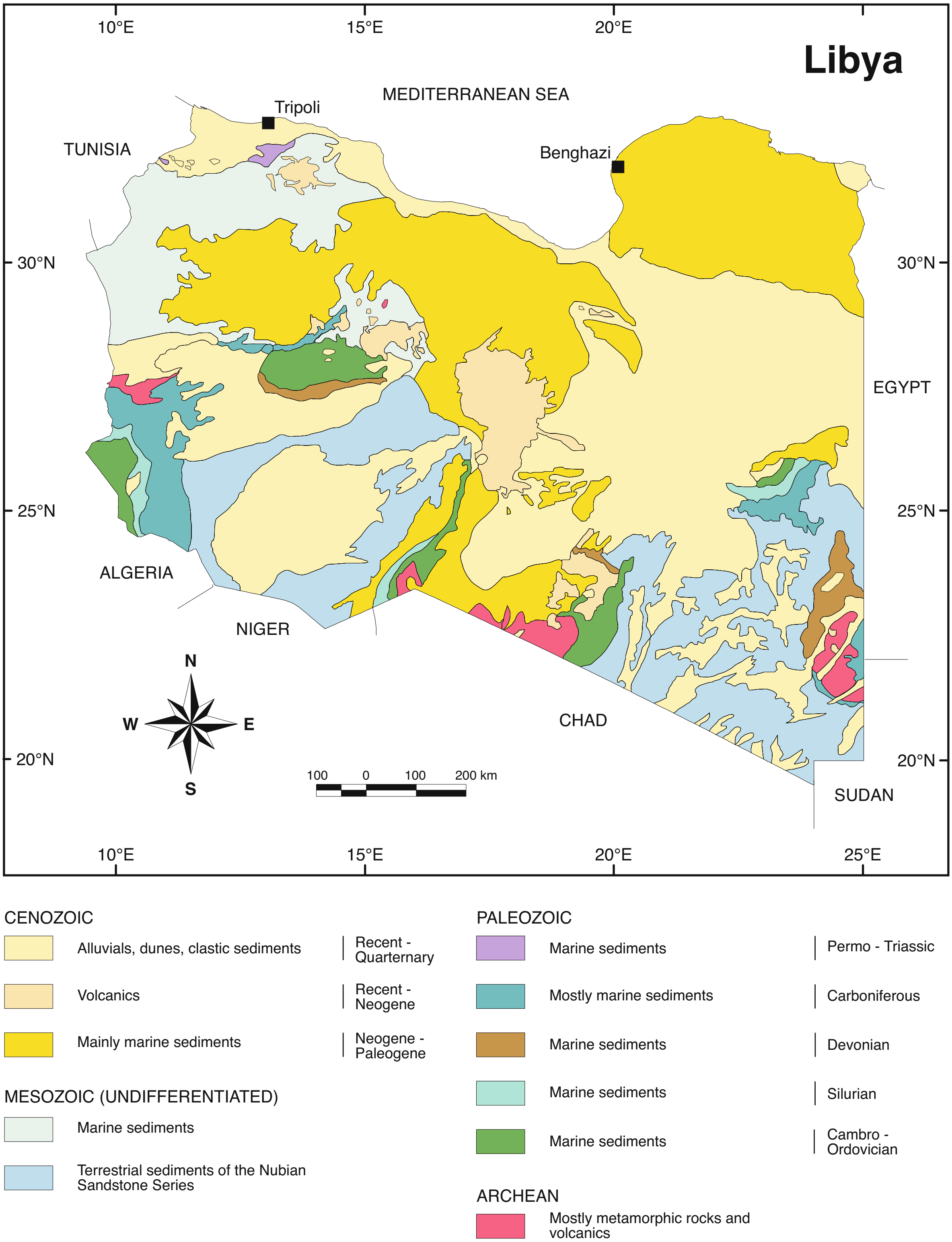

Fig. 115 Geological overview of Libya (modified after Conant & Gondarzi, 1970)

Fig. 116 A granitic inselberg at Murzuk

Fig. 118 A hamada plateau with basalts in Jabal as Sawda, southeast of the Bir al Washka oasis

4 Tectonics

The main phase of Hercynian folding in Libya occurred during the Namurian, generally indicated by a N-S fault pattern. The Cenozoic tectonic trends are reflected just as much in fractures as in the form of the basins. Its Mediterranean connections are clearly defined: The Jeffara-Malta axis prolongs that of the Tibesti-Garian axis, while Alpine foldings in Greece affected the northern Cyrenaica.

5 Economic Geology

The petroleum sector is still the most important component of Libya's mineral industry and will remain so for the foreseeable future, since the country possesses the largest hydrocarbon reserves in Africa. Other commodities include gypsum, magnetite, phosphate rock, potash sodium chloride and sulphur, for which reserves have, however, not been officially reported.

Fig. 117 Eroded Paleozoic sandstones of Jabal Acacus

6 Geohazards

No statement on geoenvironmental hazards has been published, although environmental pollution caused by hydrocarbon exploitation has to be taken into consideration.

7 Geosites

An inventory of potential geosites has not yet been made, but there exist many especially due to their scenic beauty in the Sahara desert (Fig. 114 - 120).

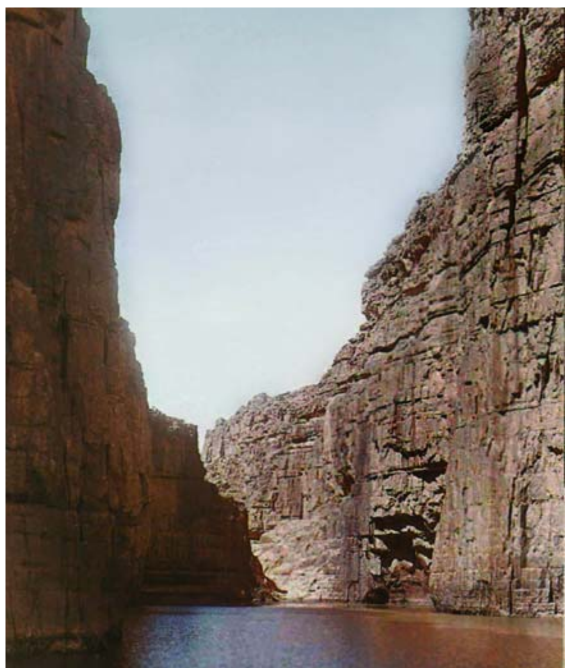

Fig. 119 A guelta (lake) in the Wadi Iharnaren

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Fig. 120 An elephant engraving at Messak, dating from the Bubalus period, about 10Ka.

Madagascar

1 General

Area: 587,041 km²
Population: 16,350,000 (2001 estimate)

2 Summary of Geology

The eastern two thirds of Madagascar are underlain by Precambrian rocks, sporadically intruded by Cretaceous through Neogene basalts and rhyolites, whereas the western third is composed of two large basins of mid-Paleozoic to Recent sedimentary rocks.

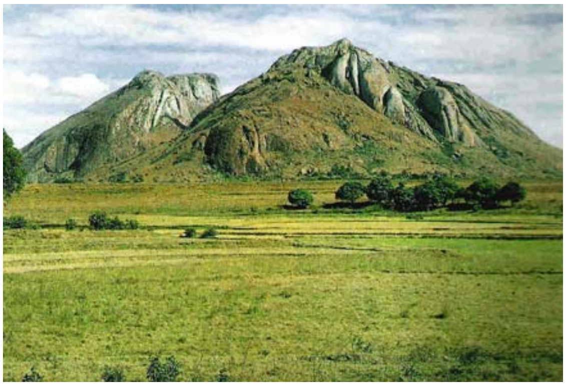

Fig. 121 Granitic inselbergs near Ambalavao

3 Stratigraphy

Archean rocks occur throughout Madagascar, from Ile St. Marie in the northeast of the island to the Ranotsara shear zone in the south. The Antongilian granitoids, the Ambodiriana migmatites, the Masora Group, all located in the east, as well as the Ankazabe Group in the west, the Angavo Group in the centre, and the Behara Group in the south of Madagascar are probably older than 3,000Ma. Assemblages formed during Mesoarchean and Neoarchean times (3,000-2,500Ma) are represented in Madagascar by the following groups: Manapotsy, Ranomena, Antriamena, Marvatanana, Andriba, Ambarolampy, Tolongoina, Beforama, Alaotra, Androna, Vondroza, Ampasary, Soakibany, Vavatenina, Sahantaha and Antenina, which are also summarized as Shamvaian Supergroup. Large assemblages of rocks in the northern part of the island, originally described as "schist verte, quarzite avec magnetite and micaschiste", can be considered as typical greenstone belts, which are either of Archean or Paleoproterozoic age. Belonging to the Paleoproterozoic time interval are the following groups: Isahara, Fort Dauphin, Ranotsara, Antsakomiary, Ste Luce, Tranomaro, Sahambano and Tsitondroina. The Fort Dauphin leptynites, granulites and their gneissic intercalations are superimposed on the Archean Ranomena Group. The neighbouring Tranomaro Group contains calc-magnesium paragneisses, bands of granites and charnockites. A large, well-preserved, mostly Mesoproterozoic sequence of continental shelf sediments (quartzite, marble, schist), referred to as the "Quartzo-Schisto-Calcaire-Series", occurs in central Madagascar. A shallow continental shelf environment is indicated by flat lamination, wave and current ripples, dune cross bedding in quarzites, domal and pseudocolumnar stromatolites in carbonates and high K and Al chemistry in pelites. There are extensive areas of granitoids and/or migmatites, many of which trend approximately N-S, and which are of Neoproterozoic (mostly 900-400Ma) age. At least two major events in the Early and Late Neoproterozoic seem to be represented. Some granitoids, especially those of Late Neoproterozoic age, appear to have been emplaced as concordant sheets or sills up to 500m thick, referred to as the "stratoid" granites of Madagascar.

Depositional sequences equivalent to the Karoo Supergroup of continental Africa are found along the entire western and northwestern coast of Madagascar. Although the deposits form a continuous belt, they are generally subdivided into the Morondava Basin along the western coast and the Diego Basin on the northwestern coast of the island. The succession is subdivided into three lithostratigraphic units, which in ascending order are the Sakoa Group, the Sakamena

Fig. 122 Mesozoic sandstones of the Isalo Mountains in the Isalo National Park

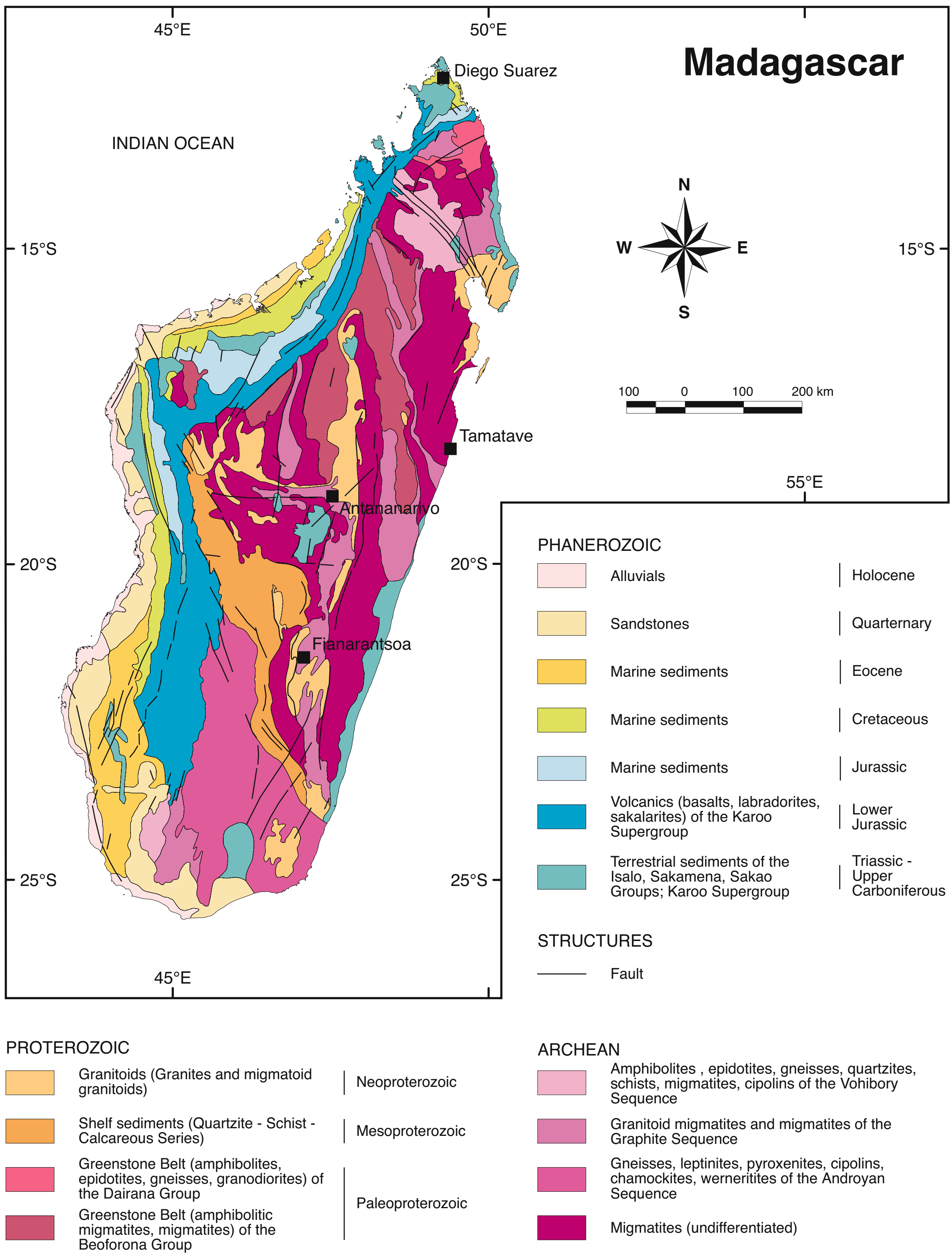

Fig. 123 Geological overview of Madagascar (modified after Besaire, 1964, and Ashwal, 1997)

Fig. 124 Typical lavaka erosion gullies cutting into a denuded hillside on the Hauts Plateaux north of Antsirabe

Fig. 125 The "Tsingy" Massif of Ankarana exhibiting impressive karstification processes

Group and the Isalo Group. The Sakoa and Sakamena Groups are time equivalents of the Karoo Supergroup on the continent and were deposited in individual graben structures. The overlying Jurassic Isalo Group drapes across the Karoo-equivalent sequence and represents the post-Karoo pericratonic basin facies (Fig. 122). The Late Paleozoic sequence commences with glacigene deposits, which are overlain by a coal bearing succession. The succeeding strata rest in some places disconformably on the latter or overstep onto basement. The following Isalo Group is of marine origin and contains various brachiopods and nautiloids.

4 Tectonics

One of the most striking features of Malagasy geology is a prominent NW-SE trending, sinistral shear belt, the Bongolova-Ranotsara lineament, which possibly separates two different crustal terranes, a northern and a southern one. Older structures, such as the N-S trending Ampanihy ductile shear zone of southwestern Madagascar were produced by intense flattening events associated with granulite metamorphism, isoclinal folding, flattened sheaths, steep to vertical foliations and sheath-like geometry of massif-type anorthosite bodies.

Comparable tectonic developments to those known from Karoo basins in continental East Africa also took place in Madagascar, where the Early Permian glacigene and coal-bearing graben fills of the Sakoa Group are overstepped by the Permo-Triassic Sakamena Group. The structure of the Permo-Triassic basins of Madagascar appears therefore almost to be a mirror image of that described from the coastal Karoo basins of eastern Africa.

5 Economic Geology

Chromite and graphite are still the two dominant mineral commodities produced in Madagascar. Generally, the mineral resources of the island remain under-exploited mostly due to lack of significant foreign investment. Ilmenite beach sands near Toalagnaro (formerly Fort Dauphin) yield exploitable quantities of TiO_2, but an environmental impact study concluded that the mining operation would destroy 75% of the coastal forest zone in the mining area. Other potential deposits include bastnaesite, bauxite and iron ore. Hydrocarbons have been found in the form of natural gas, tar sands, heavy oil and coal, but are not economic.

6 Geohazards

An inventory has not yet been made, but deforestation has caused many environmental problems, for instance gully erosion (Fig. 124 and 125).

7 Geosites

A formal inventory has not yet been made, but Madagascar offers many potential sites of geoscientific interest (Fig. 121 - 122, 126).

Fig. 126 The skull of a prosauropod, possibly the oldest dinosaur, from the Middle Triassic of Madagascar

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Madeira (Portugal)

1 General

Area: 810 km^2 (Madeira alone 728km^2)
Population 253,000 (1995)

2 Summary of Geology

The Madeira Archipelago is essentially a product of Neogene times and made up of alternating deposits of pyroclastics, lavas, intrusives, extrusives, marine and terrestrial sediments.

3 Stratigraphy and Tectonics

During Lower Cretaceous times intense sedimentation took place on marginal oceanic plains and basins lying off to the east of Madeira. Fissuring and fracturing of these deposits caused by engendering stresses allowed the ascension of magma and its pouring forth as submarine effusions. By the end of the Paleogene, volcanics had built up to beyond the sea level to create the initial Madeira archipelago. By Early Miocene (possibly already in late Oligocene times) Madeira was well established as a volcanic edifice. Coral relief testifies to uplift. In deeper offshore environments, Globigerina limestones of Vindobonian age were formed. Subsequent to the development of these biofacies, uplift of Madeira occurred to varying elevations, with limestones now found as high as 400m. Contemporaneous with the formation of biogenic deposits there occurred diabasic, trachytic and doleritic intrusions, representing the Vindobanian Volcanic Complex. In post-Vindobanian times effusions continued rather erratically. During this period also biodetritic limestones, lavas and pyroclastics were formed. Quiet emissions were alternating with more violent episodes and reefs developed along coastal areas. Fossil plants and lignites are found in the Paul da Serra Beds, which are overlain by basalts. The piling-up of all these deposits during Miocene and possibly into early Pliocene times caused additional stress on the crust, resulting into down-buckling of the volcanic edifices. In post-Miocene times, trachytic lavas and tuffs some 600m thick and plateau basalts some 400m thick developed. The pre-basalt surface was one of considerable relief, the lignites suggesting poorly drained depressions, whilst coarse clastics (breccias, agglomerates, conglomerates) suggest scree or torrential deposition resulting from powerful erosion down steep slopes. Laterization is a common feature of the pre-basalt surface. In Quaternary times marine incursions invaded the existing low and flat coastal areas, and in depressions freshwater lakes formed, which gradually dried out and furnished lacustrine deposits for aeolian reworking. The marine incursions left on the coast biodetrital sands. Contemporaneous with these incursions is the last volcanism prolonging into sub-Recent times. The presence today of Quaternary marine terraces as high as 100m result from a combination of both uplift and eustatic adjustments of the sea associated with the Ice Ages.

4 Economic Geology

There is no mining industry in the archipelago, apart from local use of building materials. Fossil fuels and hydroelectric development are also unknown.

5 Geohazards

An inventory has not yet been made.

6 Geosites

Madeira as a tourist destination offers various geosites mainly because of their scenic beauty.

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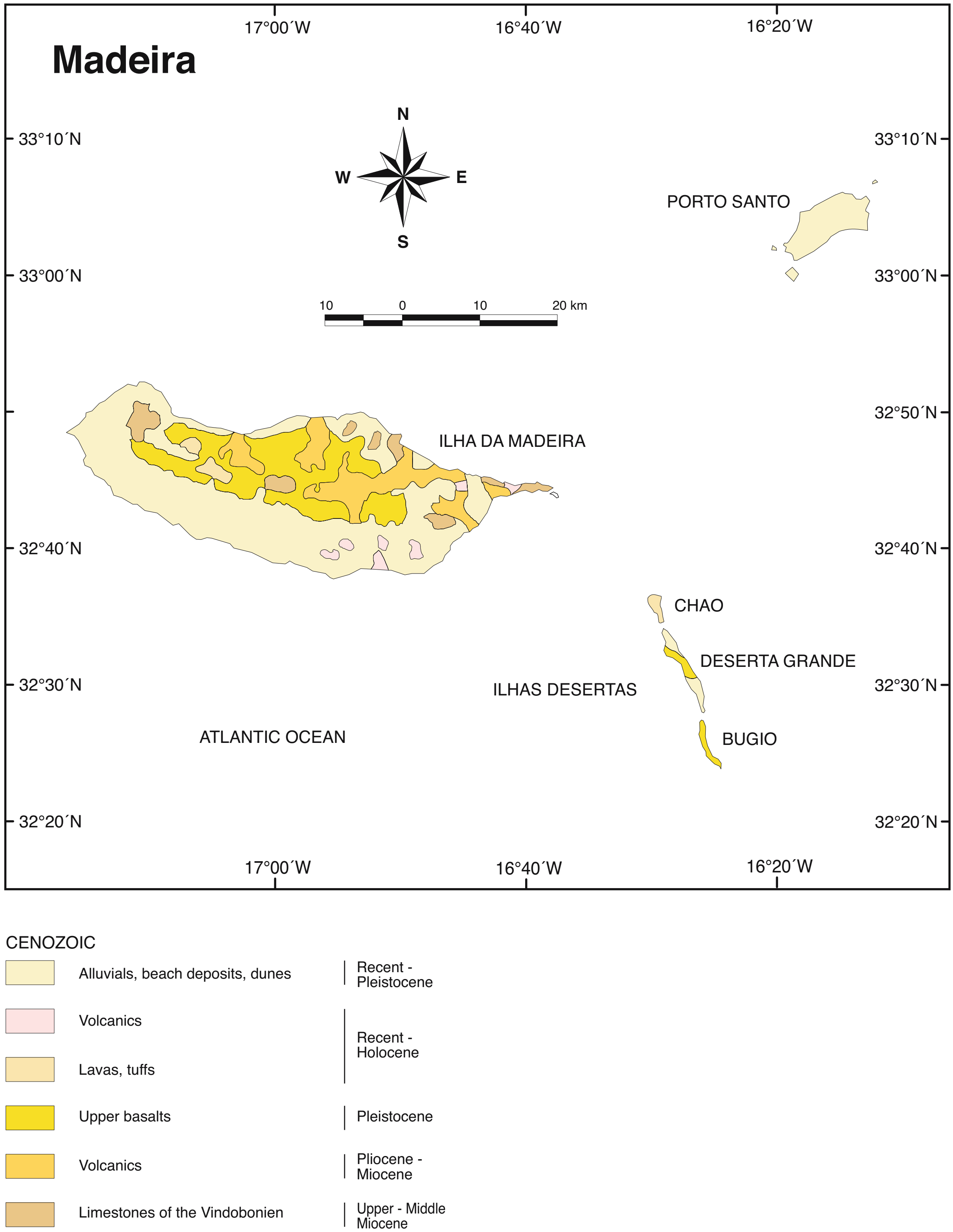

Fig. 127 Geological overview of Madeira (modified after Mitchell-Thomé, 1976)

Malawi

1 General

Area: 118,484 km^2
Population: 10,386,000 (July 2000 estimate)

2 Summary of Geology

Much of Malawi is made up of igneous and metamorphic rocks of the Basement Complex of Precambrian age. Parts of the country are covered by Karoo strata and by Cretaceous igneous and sedimentary rocks. Alluvium occurs along Lake Malawi

3 Stratigraphy

The Basement Complex of Malawi is bounded by the Zambezi Valley in the south, Lake Malawi in the east and the Luangwa Valley in Zambia in the northeast. The oldest rocks of the Basement Complex are probably metamorphic rocks in the southern part of the country, which are possibly derived from marine geosynclinal sediments with some igneous rocks. This assumption is based partly on the occurrence of intercalated marbles, which may have originally been marine limestones and partly on the fact that the chemical composition of the metamorphic rocks approximates to that of some modern marine sediments with igneous material. About 1,800Ma ago the Rusizi-Ubendian orogeny deformed and metamorphosed the original rocks in the north of the country along a zone of diastrophism running in NW-SE direction from the Democratic Republic of Congo, Rwanda and Burundi through southern Tanzania and northern Zambia into northern Malawi. This zone may have extended at that time south through Malawi and Mozambique into the Limpopo Orogenic Belt of Zimbabwe and northern South Africa. However, most evidence in the south has been destroyed by succeeding orogenesis. The Irumide Orogeny occurred between 1,600 and 900Ma ago and caused deformation, intrusion and metamorphism in a belt extending east to east-northeast through Zambia, northern Malawi and Tanzania. The Nyika granite was intruded at this time in a small area in the north of the country. The mudstones, sandstones and conglomerates of the Mafingi Group, which also occur in the north, were deposited on a shallow marine shelf following the intrusion of the Nyika granite. The Dzalanyama granite, which occurs around the junction of the borders between Malawi, Zambia and Mozambique, may be contemporaneous with the Nyika granite, due to similarity of lithology and mode of occurrence of the two granites. The Dzalanyama granite intruded the sandstones and partly calcareous mudstones of the Mchinji Group, which were deposited in a marine shallow-water shelf environment. The earlier part of the Neoproterozoic Mozambique Orogeny is termed Katangan episode, and the later part is the Damaran episode. During the Mozambique Orogeny most of the Basement Complex became regionally metamorphosed and migmatized to a greater or lesser extent. In southern Malawi, where plastic deformation and high-grade metamorphism were common, large areas of biotite and hornblende gneisses, charnockitic granulites and gneisses were produced. Isoclinal folding in some areas was accompanied by the formation of metasomatic perthite gneisses and granulites. Some infracrustal ring complexes were also intruded at this time. The Mchinji sedimentary rocks underwent some slight metamorphism, which altered them to low-grade metamorphic rocks. The final event in the Mozambique Orogeny in the south of the country was the emplacement of granites, syenites and associated minor intrusions, which probably occurred during early Paleozoic times. In the north of Malawi were phyllonites within older gneisses produced during the Mozambique Orogeny, indicating that much of the deformation was of brittle type. Syenites and nepheline syenites were intruded in a few places at this time. In addition, the Mafingi sedimentary rocks, like the Mchinji, underwent some slight metamorphic alteration to low grade metamorphic rocks.

Terrestrial sedimentation and subsequent volcanism of the Karoo Supergroup probably began during Permian and ended in Early Jurassic. The sedimentary rocks of the Karoo Supergroup consist of interbedded mudstones, sandstones, marls and some coal seams. Volcanicity of the Stormberg Group during Early Jurassic resulted in dolerite intrusions and basalt flows in the south of Malawi.

During Late Jurassic and Early Cretaceous, alkaline magmatism resulted in the intrusion of carbonatites, granulites, feldspar and feldspathoidal syenites of the Chilwa Alkaline Province in the southern part of the country. Most of the intrusions took the form of ring complexes, which now form prominent topographic features such as the Zomba and Mulanje Mountains. The intrusions were associated in a complex fashion with rifting, which probably allowed some terrestrial

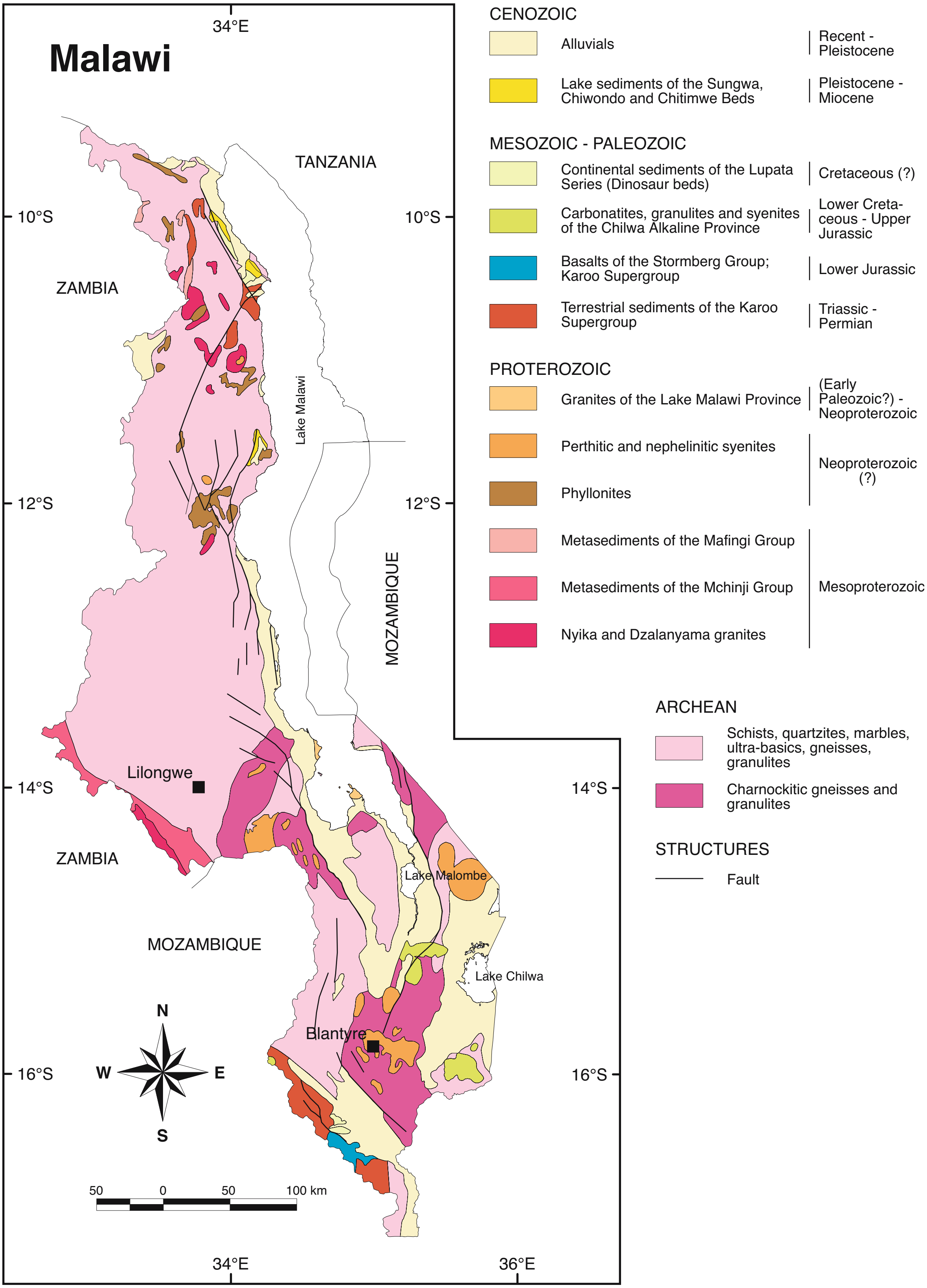

Fig. 128 Geological overview of Malawi (modified after Bloomfield, 1966)

Fig. 129 The Chambe Peak of Mt Mulanje in central Malawi.

Fig. 130 The eastern shore of Lake Malawi.

sedimentation into NW-SE trending fault troughs. This resulted in the fossiliferous Dinosaur Beds in the north of Malawi and possibly in the calcareous pebbly sandstones in the south.

Possible down-warping or fault-trough sedimentation in the Tertiary and Quaternary resulted in the deposition of varied sediments of the Sungwa, Chiwondo and Chitimwe Beds of the northern lakeshore area, representing probably the earliest sedimentation of Lake Malawi. At this time the lake surface may have been sometimes about 300m above its present level and was possibly confined to an area in the north, which was about one quarter the size of the present lake. Continued down-faulting and possible tilting allowed the lake to advance to the south and lowered it to an elevation of about 200m above its present level. A continuation of this trend caused the lake to extend as far as the present Cape Maclear Peninsula and dropped the water surface to about 120m above the present lake level. The Dwangwa gravels, which occur in various places around the shores of Lake Malawi, may then have been produced as a beach deposit. At some time during the Pleistocene, the Songwe Volcanoes in the extreme north of the country erupted.

4 Tectonics

The Karoo rocks were probably deposited in a series of tectonically controlled basins. Subsequently these rocks were down-faulted into a series of N-S and NW-SE trending normal fault troughs in northern and southwestern Malawi. The first indications of faulting occur during the later part of Karoo deposition and could possibly be the first fractures associated with rift-faulting. The Rift Valley in Malawi is but a small part of a much larger feature, which extends in a discontinuous fashion through Africa from the Zambezi River to the Red Sea. In Mozambique and Malawi the southern Rift is a single linear zone of lakes and valleys created by downfaulting of large sections of the earth‘s crust during the late Mesozoic and Cenozoic.

5 Economic Geology

Exploration for exploitable minerals in Malawi has recently shown a wide range of undeveloped mineral deposits. Some of the carbonatite complexes contain rare earth elements, e. g. the Kangankunde Carbonatite about 60km south-southeast of Ncheua, and the Songwe Carbonatite about 60km north-northeast of Mlanje. These deposits may also contain apatite, baryte, strontianite and pyrochlore. Uranium occurs near Thambani about 75km west of Blantyre. Pyrite and pyrrhotite near Lilongwe could be mined. Vermiculite deposits of commercial value have been found near Mpatamanga about 60km west of Blantyre. Although coal deposits had been known for many years in the northern part of the country, they were not mined until recently because it was determined to be more economical to import coal from Mozambique. Malawi now operates two coal mines in the Livingstonia Coalfield in the northern part of the country. Other commodities include a bauxite deposit on the Mlanje syenographic massif, 25km northeast of Mlanje. China clay, corundum, dimension stone, graphite and silicon sand have also been investigated but not yet exploited. Exploration for chromite, copper, gold, gypsum, nickel, petroleum, rutile and salt has been conducted in recent years.

6 Geohazards

An inventory has not yet been made.

Fig. 131 Bird Island in Lake Malawi.

7 Geosites

A formal inventory of potential geosites has not yet been made, but the mid-Cretaceous Dinosaur Beds near Mwakasyunguti in the north of the country may be considered as well as hominid-bearing sites in central Malawi. However, the country offers also many places of geoscientific interest with scenic beauty (Fig. 129 131).

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Mali

1 General

Area: 1,241,232 or 1,240,192 km²
Population: 11,830,000 (estimate 2001)

2 Summary of Geology

Mali is underlain by two cratonic nuclei, extensions of the West African Craton and the Tuareg Shield, which were welded together during the Neoproterozoic Pan-African orogeny. The West African Craton outcrops in the west along the Senegalese border, in southern Mali as part of the Leo Shield and in the far north. The Tuareg Shield outcrops in the east in the Adrar des Iforas mountains. Sediments of the intracratonic Taoudeni Basin underly most of Mali. Parts of eastern Mali are covered by Cretaceous and Tertiary sediments.

3 Stratigraphy and Tectonics

Northern Mali is part of the Reguibat Shield, a northern extension of the West African Craton. It is bounded to the north by the Tindouf Basin, to the south by the Taoudeni intracratonic basin and to the west by the West African polyorogenic mobile belt, i. e. the Mauritanides. The Reguibat Shield is composed of Archean rocks in the west and centre, whereas Paleoproterozoic rocks predominate in the east. The Archean basement of the Reguibat Shield, known as the Amsaga Group in the west and the Ghallaman Group in the east, has been divided into a migmatitic and a metamorphic unit comprising at the base typical granulites. The metamorphic unit consists from bottom to top of charnockitic pyroxene-amphibolites, granulites, pyroxene-amphibolites, sillimanite-gneisses, granulites, biotite gneisses, amphibolites, marbles and ferruginous quartzites. These assemblages are intruded by metagabbros, anorthosites and serpentines and are cut by small massifs of biotite granite and by beryl-tourmaline pegmatites. The Amsaga assemblage is about 10km thick. In the central part of the Reguibal Shield the Archean includes abundant leptynites, biotite and muscovite gneisses, amphibolites, marbles and quatzites. In the eastern Reguibat Shield Archean rocks are represented by leptynites, amphibolites, garnet gneisses and migmatites. The metamorphic grade varies from low pressure granulite facies to amphibolite facies and decreases towards the east. Syntectonic granites are abundant in the eastern zone and include mica granites, porphyritic biotite granites, granodiorites and diorites. The gneisses have yielded ages indicating a major tectono-thermal event at around 2,700Ma, whereas the granites are dated at about 2,400Ma. Eburnean reactivation produced biotite ages falling in the range of 2,000-1,500Ma.

Polycyclic Archean to Paleoproterozoic high-grade assemblages are also preserved in the Adrar des Iforas granulites of the southwestern Tuareg Shield and were last affected by the Eburnean Orogeny. In the central part of the Adrar des Iforas region an extensive Neoproterozoic volcano-clastic sequence belongs to the Tafeliant Group, which rests unconformably on pre-Pan-African or older basement and comprises unstratified tillites with large local blocks, littoral calcareous sandstones and a unit of black pelites with clasts of marine tillites. The succession passes upward into volcanic greywackes with abundant andesitic material partially mixed with semipelitic siltstones, and with arkoses derived from the sialic basement. The Tafeliant Group was apparently deposited in a shallow marginal basinbounded by N-S trending faults. It may correlate westward with the Tessalit-Tilemsi volcanic greywackes, which contain deep trough sedimentary features including a marine diamictite. The Oumassene Group, an andesite-basalt complex, located at about 100km to the north, may also correlate with the Tafeliant Group. In the northwestern part of the Adrar des Iforas region the Tessalit-Tilemsi volcanic and volcano-clastic series is of island-arc affinity. It is characterized by metamorphic and structural features, which are different from the rest of the Tuareg Shield.

The extensive Taoudeni Basin covers a large part of the West African Craton between the Reguibal Shield in the north and the Leo Shield in the south, and the encircling Pan-African Belts to the west and east. It contains tabular sequences of Neoproterozoic to Carboniferous age. Thus, during this long period shallow seas periodically flooded the Taoudeni Basin and persisted long after the Pan-African tectono-thermal events had ended. It underlies most of Mali, but extends also into Algeria, Burkina Faso and continues into Guinea, Guinea-Bissau and Senegal. Structurally the Taoudeni Basin is a simple shallow interior sag basin with very low dips. It lies unconformably upon the Eburnean basement. Stratigraphically, it has been subdivided into several main sedimentary sequences separated by discontinuity surfaces. The Taoudeni

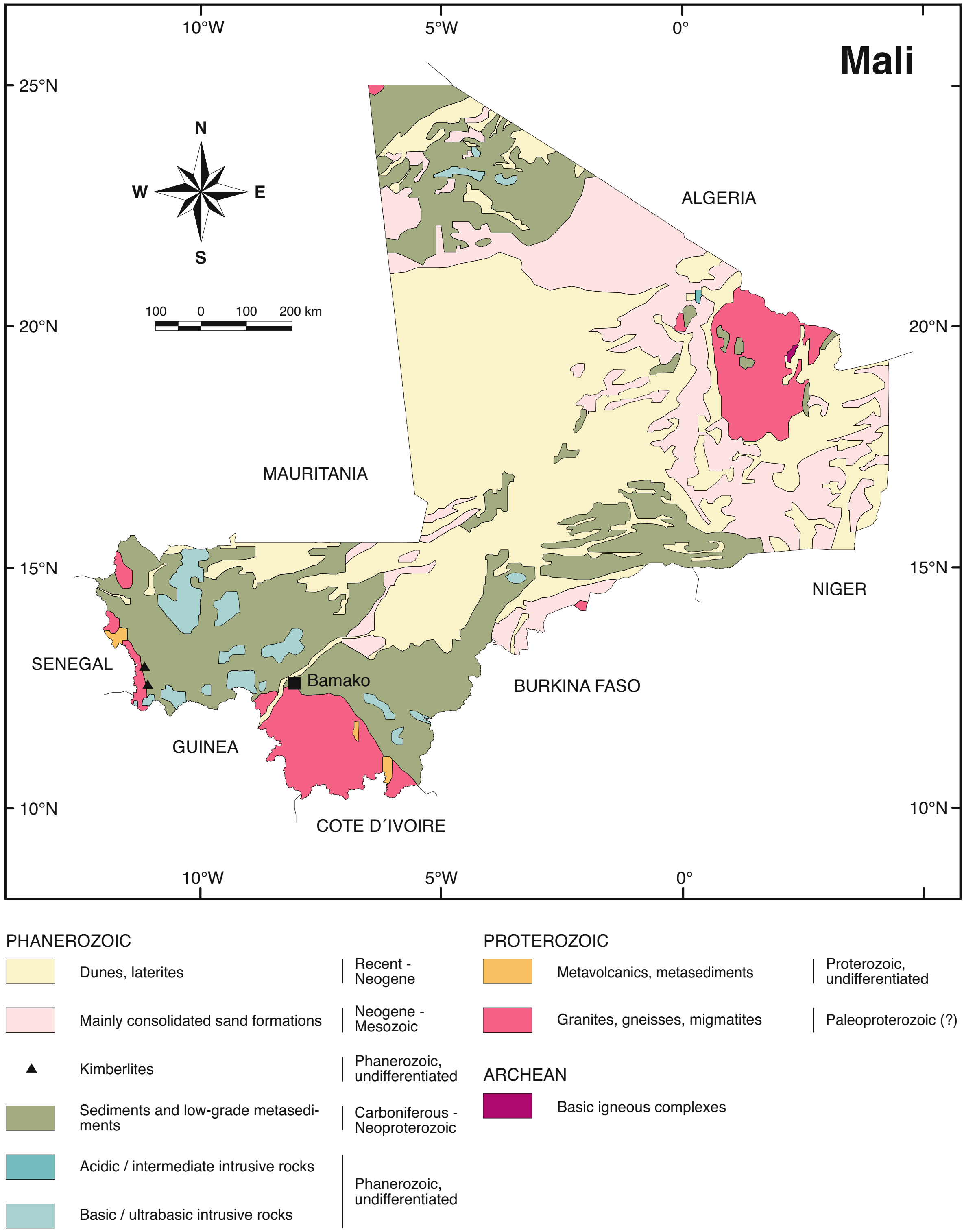

Fig. 132 Geological overview of Mali (modified after various sources)

Fig. 133 A village of the Dogon people at Tirelli in central Mali, where huts and cave homes are carved into the towering face of the escarpment

Fig. 134 Some huts in the escarpment at Tirelli in central Mali

Basin contains the most extensive outcrops of Lower Paleozoic strata in West Africa. The succession comprises the following supergroups: Supergroup 1 (Middle Neoproterozoic): sandstones and stromatolitic carbonates; Supergroup 2 (Late Neoproterozoic to Cambro-Ordovician): basal tillites, baryte-bearing dolomites, marine cherts and shaly siltstones and Skolithos-bearing sandstones with inarticulate brachiopods; Supergroup 3 (Late Ordovician to Devonian): tillites, graptolite-bearing shales and fine sandstones, reefal limestones. Specifically in Mali Carboniferous clastics and carbonates are exposed, which rest unconformably on Devonian shales. Fossiliferous marine Lower Carboniferous clastics with conodonts and brachiopods are overlain by evaporitic carbonates. Cretaceous and Tertiary clastic sediments underlie large parts of northern and eastern Mali.

4 Economic Geology

Gold is the only mineral commodity produced that is currently of significance to the economy of Mali. The country has a wide variety of other mineral deposits, but few have been developed because of a lack of infrastructure and local demand. Gold accounted for more than 95% of the estimated total value of mineral commodities produced in Mali and about 20% of the country‘s total export of goods. The greenstone belts at Kéniéba, Bougouni and Sikasso host gold deposits, commonly within shear zones and quartz veins. Artisanal mining of gold is also reported in this area, but no data exist.

Mali has a potential for diamonds in the Kéniéba area, close to the Senegalese border at the contact between Birrimian and Neoproterozoic sediments. 21 kimberlitic pipes have been recorded, but outcrop is poor, with the exception of mountainous areas. Iron ore reserves are estimated at more than 300Mt in the west of the country. Bauxite reserves in the southwest are estimated at over a billion tonnes. Phosphate reserves in the northeast are estimated at 10Mt. Limestone and marble resources are spread over several areas. Rock-salt, lithium, gypsum, lead, zinc, lignite and bituminous shales are also present on Malian territory.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made, but the huts and caves of the Dogon people at Tirelli in central Mali exhibit both cultural and geoscientific aspects of heritage to be preserved (Fig. 133 and 134).

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Mauritania

1 General

Area: 1,030,700 km²
Population: 2,668,000 (July 2000 estimate)

2 Summary of Geology

Geologically, Mauritania can be subdivided into four major domains: The Archean Reguibat Shield in the north of the country, which strikes into Western Sahara and Algeria; the Neoproterozoic N-S striking Mauritanide Belt, folded and thrust during the Variscan orogeny; the Taoudeni Basin with predominantly continental sediments of Neoproterozoic to Phanerozoic age, covering most of central and southern Mauritania; and parts of the Senegal Basin in the southwest of the country with marine sediments of Jurassic to Recent age. Sand dunes cover about 50% of Mauritania's surface, which forms a vast peneplain studded with inselbergs over the folded belts.

3 Stratigraphy and Tectonics

The West African Craton crops out along an ENE-WSW axis, in the Reguibat Shield or uplift. Its western half consists mainly of metamorphic rocks in granulite or hornblende facies, Neoarchean in age. The sequence of these rocks is known as Saouda Series and consists of various types of gneiss (with hypersthene, sillimanite-garnet, leptynitic-garnet), pyroxene amphibolites, magnetite quartzites and amphibolites and marbles, interpreted as a series of sedimentary to volcanoclastic rocks, isoclinally folded, striking N-S and verging west. The Saouda Series was intruded by basalts, gabbros and anorthosites and by conformable serpentinites. Rocks of the Saouda Series appear to be restites within a complex of magmatic and anatectic granites known as "Rag el Abiod complex". The crystalline basement exposed within the Kayes and Kenieba inliers is generally polydeformed, variably metamorphosed (low grade) volcanoclastic sedimentary rocks were intruded by syn-tectonic or post-tectonic granites. The granites have yielded ages of about 2,050Ma, which correspond to the Eburnean Event. Pebbles of microgranites and microsyenites in folded conglomerates of a metasedimentary unit could be remnants of an older (Archean?) basement. Isoclinal-type folds with cleavage parallel to the bedding are NE-SW striking and SE vergent.

Fig. 135 Paleozoic tableland west of Adrar in the Mauritanides along Chinguetti to Atar

The Mauritanide Orogen is part of the West African fold belts including the Bassarides, Rokelides and Mauritanides. Largely allochthonous, the Mauritanides rest in abnormal contact on the crystalline terrains of the Reguibat Shield and the platform cover of the Taoudeni Basin. From south to north, the Mauritanides show a series of changes that provide valuable information on its history. The southern and central Mauritanides are characterized by a readily observable continuity: from east to west, the parautochthon and the infrastructural allochthons are present in all areas. The poorly extended suprastructural allochthons or related formations appear in different structural setting along the segment, nappes of the northern type are unknown. The northern Mauritanides display an obvious change: the parautochthon tends to disappear northward; the infrastructural allochthons are poorly exposed, scattered and very incomplete; the supracrustal allochthons and the nappes are largely extended; on the northern front, the latter rest directly on foreland.

The vast Taoudeni Basin is centred on the West African Craton, serving as Neoproterozoic to Early Paleozoic foreland to the encircling Pan-African mobile belts to the west and to the east. Apart from Mauritania it underlies large areas of Mali, southern Algeria, Burkina Faso and continues into Guinea, Guinea-Bissau and Senegal, where it is known as the Bove Basin. Structurally, the Taoudeni Basin is a simple shallow interior sag basin with very low dips of one degree or less. It is flanked and overthrust to the west by the Mauritanides along a narrow tectonized margin with folds and fractures, which resulted from Hercynian deformation. Stratigraphically, the Taoudeni

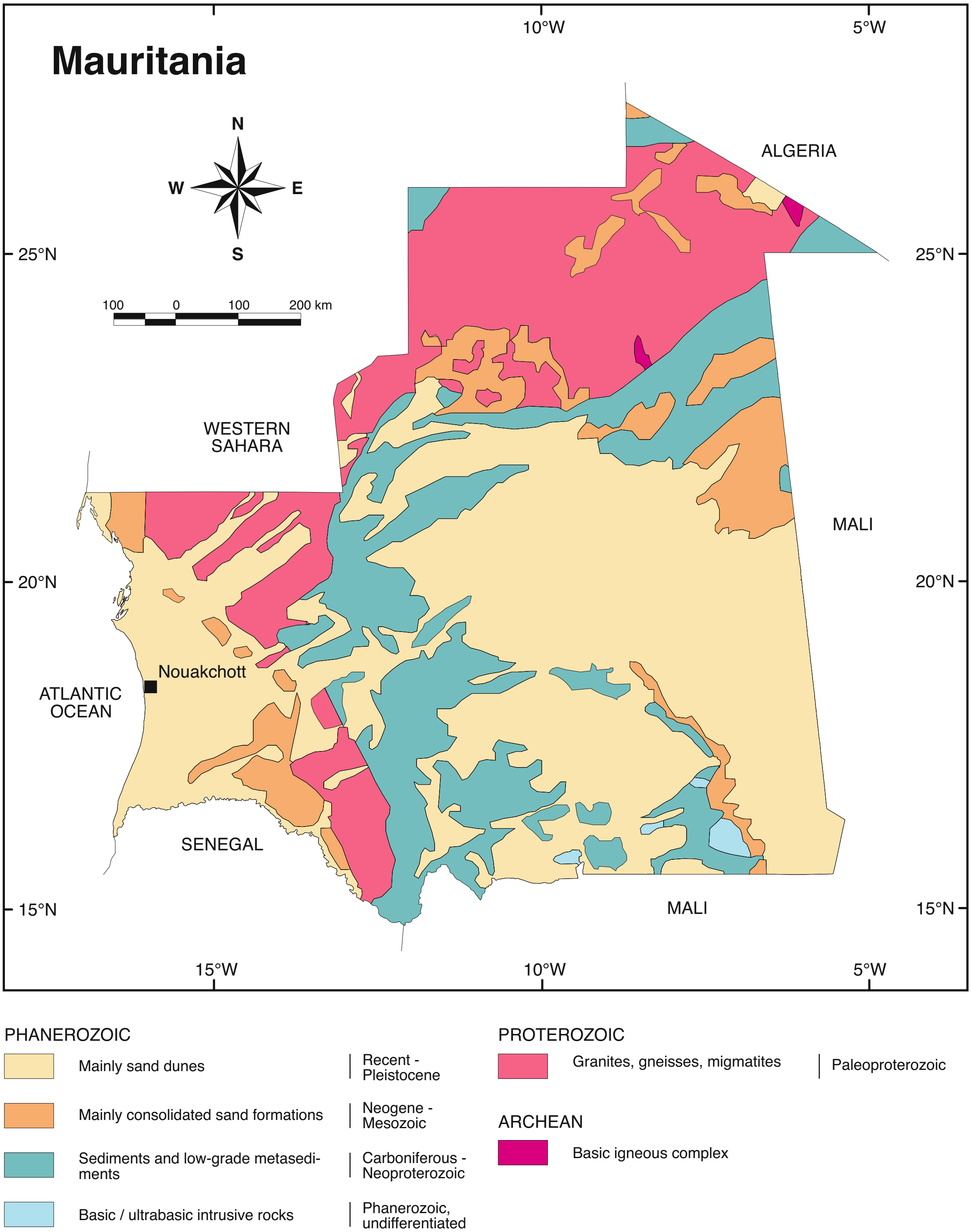

Fig. 136 Geological overview of Mauritania (modified after Anonymous, 1968)

Basin consists of fine-grained clastics and carbonates, 2,000-3,000m thick. The succession comprises the following three supergroups in ascending order: Supergroup 1, made up of Middle Neoproterozoic sandstones and stromatolitic carbonates; Supergroup 2, made up of Neoproterozoic basal tillites, baryte-beraing dolomites, marine cherts and sandstones, and Cambro-Ordovician Skolithos-bearing sandstones with inarticulate brachiopods; Supergroup 3, made up of Late Ordovician tillites, graptolitic Silurian shales and fine sandstones, and Devonian shales with reefal limestones.

Mauritania comprises a wide part of the Senegal Basin, which is the largest onshore embayment in northwest Africa. Stratigraphically, its onshore succession starts with Late Jurassic marine dolomitic sandstones. Offshore, Early Cretaceous detrital sediments overlie Early Jurassic evaporites, while more calcareous lithofacies developed on a western carbonate platform. In the overlying Late Cretaceous to Tertiary sequence continental beds in the east interfinger westward with marine terrigenous deposits. A pronounced regression occurred at the end of the Maastrichtian before a widespread Early Tertiary transgression.

Fig 137 Loading of the train at the iron ore mine of Guelb near Zouerat.

4 Economic Geology

The iron ore production is still the dominant mineral production in Mauritania. In the 1970s the reserves of iron ore were estimated at about 200Mt, grading of 64% Fe as hematite lenses and developed over Proterozoic banded iron formations (BIF) at F'Dérik-Segazou, Rouessa and Tazadit hills, all close to the border with the Western Sahara. Since the mid-1980s the so-called Guelb projects at El Rhein, 25km northeast of Zouerate, where reserves of itabirites grading in average of 37% Fe and in the order of 300Mt, are also exploited (Fig. 137). However, the production there has remained well below nominal capacity (less than 2Mt/y) largely due to problems with the beneficiation plant, including rapid wear of the mills and build-up of dust. Another Guelb project at Oum Arwagen, 12km east of El Rhein, with a grade of about 64% Fe and identified reserves of 80Mt, came into production in the early 1990s.

The Akjoujt copper deposit is located about 250km northeast of Nouakchott at the northern tip of the Mauritanides Orogenic Belt. It consists of a 1,000m long and up to 250m wide lens-shaped copper-bearing carbonate body occurring on top of two hills, the west and east Moghrein Guelbs. The carbonate unit is part of a volcano-sedimentary pile of Neoproterozoic age, which was thrust from a western internal portion of the Mauritanides into a synformal nappe structure, which was overturned during Paleozoic times. The ore bearing carbonate unit is believed to be of sedimentary origin and the copper mineralization to be essentially syngenetic in a volcanogenic environment. About 40m below the original surface of the deposit, the supergene mineralization consists of cuprite, tenorite, malachite and azurite. The sulphide mineralization consists of pyrrhotite, chalcopyrite, cubanite and arsenopyrite, with an average grade of 2.25% Cu and 1.17g/t Au. Apparently the only current mining operations are those of reprocessing about 2.5Mt of tailings with an average gold content of 2.5g/t from previous mining in the 1970s. Recently an evaluation of occurrences in southern Mauritania was presented by Salpeteur et al. (2004).

The production of gypsum was derived from the N'Drahamcha quarry, 50km northeast of Nouakchott. Most of the output was processed into plaster, additional amounts were used in the production of concrete blocks.

The phosphate resources identified at Bofal and Loubboira in southern Mauritania were estimated at 120-150Mmt of phosphate rock averaging 20% P_2O_5.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made, but Mauritania's desert offers many places of scenic beauty (Fig. 135, 138 - 139).

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Fig. 138 Paleozoic formations of the Mauritanides along Chinguetti to Atar

Fig. 139 An ancient lake in sandstones of the Mauritanides along Chinguetti to Atar

Mauritius

1 General

Area: 2,040 km² (including Rodriguez)
Population: 1,179,000 (July 2000 estimate)

2 Summary of Geology

Except for the beaches and coral reefs, the main island of Mauritius is entirely of volcanic origin. The island of Rodriguez (560km to the east of Mauritius) is also volcanic in origin and consists of basaltic rocks.

3 Stratigraphy and Tectonics

Three major periods of volcanic activity formed the island. The first period, called the Emergence and Older or Ancient Series, lasted from 10 to about 5Ma. The Ancient Series can be further subdivided into two distinct parts: the Breccia Series from 10 to 7.8Ma and the Old Series from 7.6 to 5Ma. The second major period called the Early Volcanic Series or Intermediate Series lasted from 3.5 to 1.7Ma. The third period is termed the Younger Series or the Recent Series and lasted from 0.7Ma to 20,000 years ago. The lithology of the island is basically basalt, but the three main phases have given rise to different types of rock. The Older Series consists mainly of olivine basalts and agglomerates with intrusive trachyte and trachyandesitic plugs. The Younger Series comprises mainly olivine-bearing flood basalts. (Simpson, 1950; McDougall and Chamalaun, 1969).

The island of Rodriguez is of volcanic origin, its highest peak reaching an altitude of 450m. The lavas are basaltic with olivines. A radiometric dating has yielded an age of 1.54Ma. The southwestern plain is composed of coral reef debris, reaching up to 62m in altitude. In caves the skeletons of an extinct bird, called "solitaire" have been discovered (*Pezophaps solitaria*).

4 Economic Geology

The mineral industry of Mauritius is a negligible factor in its economy. Historically, mineral output consisted of the local production and use of basalt construction stone, coral sand, lime from coral and solar-evaporated sea salt. Polymetallic nodules occur on the ocean floor at a depth of about 4,000m, extending from 400 to 800km north of Port Louis, northeast of Tromelin Island. However, currently it appears unlikely that these resources will be developed in the foreseeable future. The oil company Texaco has explored offshore areas at shallower depth for oil in the 1970s.

5 Geohazards

Environmental concerns regarding the mining of coral sand and its impact on coastal lagoons have been raised. As sand is a very slowly renewable resource, its extraction from sand quarries along the coast has been banned since 1991. However, sand mining in the lagoon is still allowed at certain places, but it is thought that the extraction of large quantities will have an impact on the littoral drift of sediments and so hinders the replenishment of beaches.

6 Geosites

An inventory of potential geosites has not yet been made. As a tourist destination, Mauritius offers various locations of scenic beauty. Palaeontologically, Mauritius was home for the flightless Dodo, which is extinct since the early 17th century. Its remnants are exhibited in the National Museum of Mauritius.

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Fig. 140 The extinct Dodo (*Raphus cucullatus*), being the national symbol of Mauritius. Hand-coloured etching by George Edwards from his book "Gleanings of Natural History" (1758-1764)

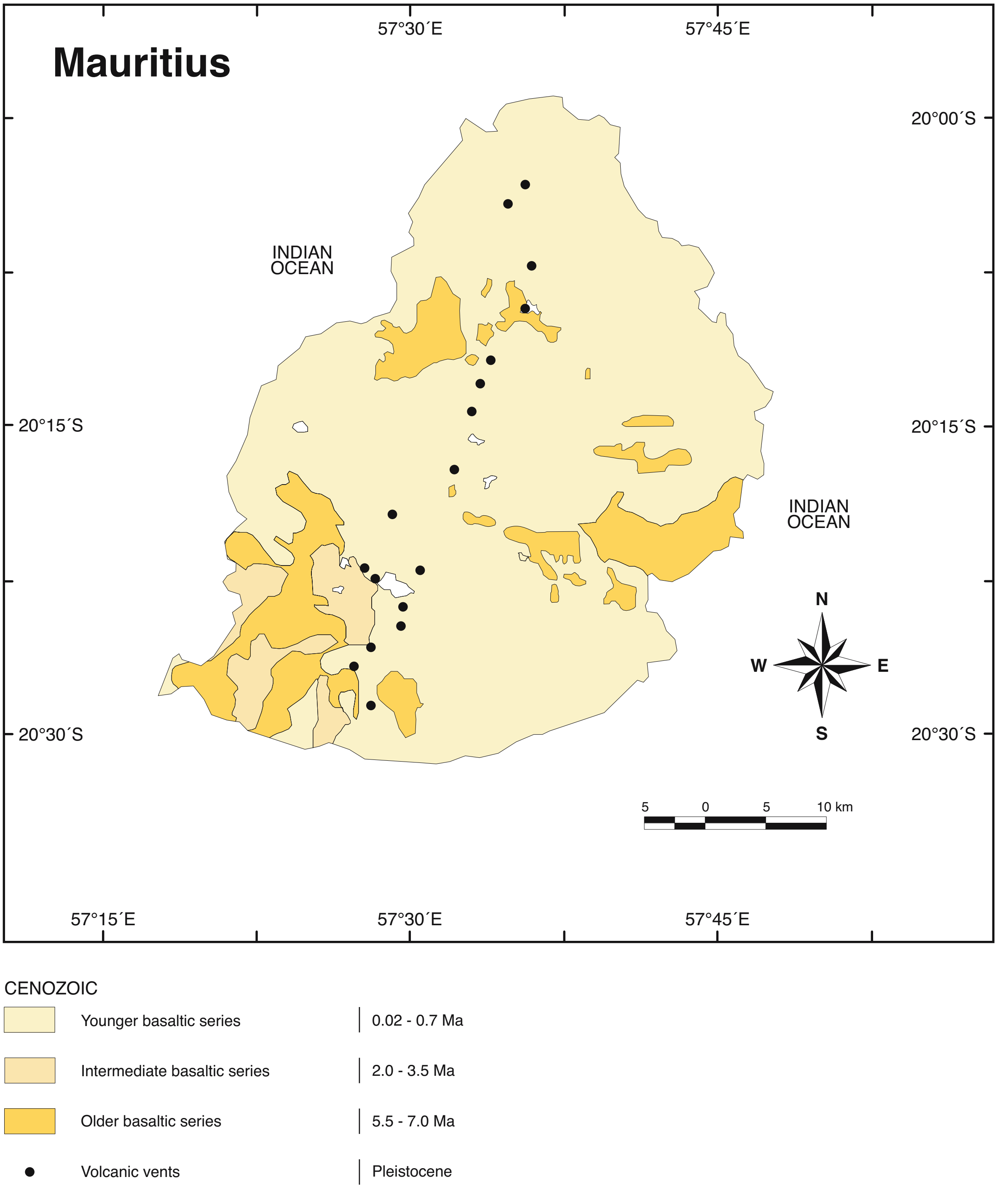

Fig. 141 Geological overview of Mauritius (modified after Simpson, 1950)

Morocco

1 General

Area: 458,730 km²
Population: 28,010,000 (2001 estimate)

2 Summary of Geology

Morocco's geology has generally been subdivided into four structural domains or provinces. These are from south to north the Anti-Atlas Domain, the Meseta Domain, the Atlas Belt Domain and the Rif Domain. Whereas the Rif domain (or Mediterranean Morocco) is part of the vast Alpine system of Europe and North Africa, the other domains (or African Morocco) are essentially of West African affinities. Apart from these structural units, along the Atlantic coast basins filled with mostly Mesozoic and Cenozoic tabular sediments are recognizable.

3 Stratigraphy and Tectonics

The Anti-Atlas Domain is only very slightly affected by Alpine movements and was formed by wide-spanned up-doming of marginal parts of the West African Craton. Precambrian rocks form the core of major domes in the axial zone of the range. Normally, this basement is covered by poorly deformed sediments of Neoproterozoic to Lower Paleozoic age. In the Tafilalt region in southeastern Morocco the Anti-Atlas Domain dips to the E beneath undeformed Cretaceous sediments of the Sahara platform. However, all the older assemblages of Morocco only crop out within inliers mainly situated in the Anti-Atlas Domain. The oldest rocks may be the augen gneisses of Jbel Ouiharem and the gneisses of Oued Assemlil. The Zenaga Series is a unit of augen gneisses, metadolerites and metamorphic rocks, which are highly affected by sub-horizontal composite foliation. Their metamorphism is attributed to an ancient orogeny, because anatectic granitoids were apparently emplaced in Paleoproterozoic times. Similar ages are also recorded from granites at Azguemerzi and Tazenakht in the central Anti-Atlas and farther west in the anticlinal inlier of the Lower Draa. The Quartzite Series north of Kerdous is a detrital unit with siltstones, pelitic sandstones, conglomerates and especially thick quartzitic layers, which yielded Neoproterozoic ages. Limestones, often stromatolitic, are intercalated. Basic intrusions of dolerites and tholeiitic gabbros were emplaced into the quartzites as sills and laccoliths that are more or less concordant with the sedimentary bedding. In the Bou-Azzer inlier, the Quartzite Series is replaced by an ophiolitic complex. Similar conditions occur at Jbel Siroua, whereas at Jbel Saghro sandy-pelitic terrigenous formations correspond to an environment at the base of the continental margin with clastic supply coming from the north. Ranging from late Neoproterozoic to Infracambrian is the Ouarzazate Series, which has been considered as molasse of the Panafrican orogenesis. Above the Ouarzazate Series follows the Adoudounian Series, which represents the base of the Cambrian. It consists at the base of conglomerates, followed by carbonates, marls, sandstones and finally again carbonates. For instance, the Amouslek Formation with shales and limestones, contains a rich fauna of trilobites and archaeocyathids, indicating a Lower Cambrian age of a shallow marine environment. The Middle Cambrian is represented by the Goulimine Quartzitic Series containing various trilobites. The Upper Cambrian is often not exposed. To the south the Cambrian is overlain by Ordovician strata, which have a widespread outcrop and are mostly made up of sandstones, micaceous clays and occasionally limestones. Typical fossils are graptolites and trilobites. The presence of a Saharan glaciation during the Upper Ordovician is indicated by tillites at Djebel Serraf. Silurian strata are recorded from the Iriqui section in the central Anti-Atlas, represented by platy sandstones, shales and dark mudstones,

Fig. 142 Paleozoic succession near Erfoud in the Tafilalt region

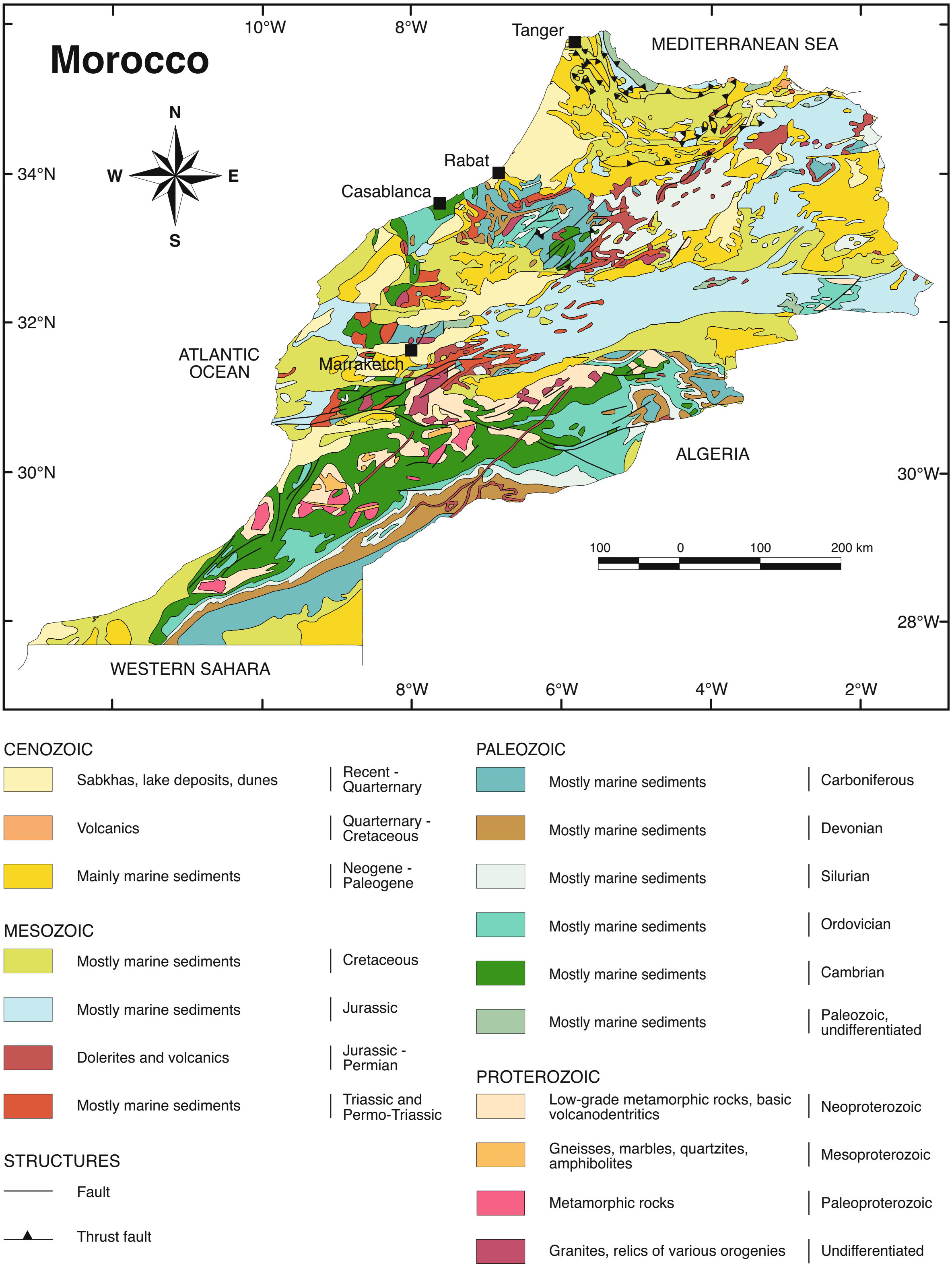

Fig. 143 Geological overview of Morocco (modified after Fabre et al, 1978)

sometimes containing carbonate nodules. Graptolites, a few lamellibranchs and nautiloids are found. In the eastern Anti-Atlas in the Tafilalt predominate black shales. Two types of facies can be subdivided within the Devonian of the Anti-Atlas: In the western Anti-Atlas, sandy mudstones of the Gedinnian-Siegenian, containing limestone beds, overlay conformably the Upper Silurian. The fauna is composed of brachiopods, trilobites, conodonts and tentaculites. In the eastern Anti-Atlas, in the Tafilalt, basaltic rocks are erupted at Hammar Laghdad. The Middle Devonian and Frasnian is represented in the western Anti-Atlas mostly be black limestones, whereas to the east the Upper Tafilalt Limestones are rich in goniatites and tentaculites. The Famennian of the western Anti-Atlas exhibits a clayey facies at the base, followed by detrital beds and finally a calcareous horizon. In the eastern Anti-Atlas, platforms are uplifted in the western Maader and Tafilalt, containing a condensed limestone with cephalopods. In the central and western Anti-Atlas, the Carboniferous is represented in a series of cuestas, which dominate the plains of Draa and constitute the northern side of the Tindouf Basin. The Anti-Atlas can be regarded as a domain that remained largely free of shortening during the Hercynian orogeny. Metamorphism is extremely weak, often non-existent, and there are no Hercynian granites.

As in Spain, where this term has its origin, the Meseta is a domain where the Paleozoic terrains remained stable after having been affected by the Hercynian orogeny. They were then covered by thin tabular successions of Mesozoic and Cenozoic sediments. Extensive exposure of Precambrian rocks in this terrain is nowhere, but within the cores of the Mesetan anticlines crop a few Neoproterozoic strata out, for instance at El Jadida, Rehamna and in the eastern part of the Central Massif. Generally, the Meseta Domain is separated into two parts by the NE-SW trending Middle-Atlas fold belt (or Middle Atlasic axis). The Western Meseta has well-developed massifs and a reduced cover, whereas the Eastern Meseta extends on both sides of the Algerian-Moroccan border and is characterized by Paleozoic massifs of small size. From Neoproterozoic to Middle Devonian times the Anti-Atlas and western Morocco belonged to the same depositional setting. This phase is characterized by a post-Panafrican molasse deposition of redbeds and by post-collisional volcanism. Later, southern and middle Morocco constituted one vast epicontinental shelf during the early Paleozoic with terrigenous sediments coming from the Sahara. A carbonate shelf was installed in this region during Early to Middle Devonian. In Late Devonian times the western part of Morocco and the Anti-Atlas platform disintegrated into fault-bounded basins. These basins progressively deformed and closed during the Middle to Late Carboniferous, the main phase of Hercynian movements in northern Africa.

Fig. 144 Jurassic fossiliferous limestones in the Meseta in western Morocco.

Between the largely allochthonous Rif Domain in the north, the Western Meseta Domain in the northwest and the Anti-Atlas Domain in the south, the Atlas Domain extends from Agadir in the west to eastern Tunisia in the east. The Moroccan part of the Atlas Domain is composed of four main units: From west to east, there are the Western High Atlas, the Paleozoic High Atlas, the Precambrian High Atlas, and the Central and Eastern High Atlas. In its tectonic and stratigraphic evolution the Western High Atlas was more related to the development of the Atlantic margin of northwest Africa than to the rest of the High Atlas. From the Atlantic coast it extends eastwards for about 70km to the Argana Basin, where the Triassic is up to 5km thick and comprises essentially a detrital and locally conglomeratic facies with evaporitic sequences appearing in the west. Mesozoic strata in the Western High Atlas thicken to the west and contain Jurassic (Fig. 144) and Cretaceous calcareous marly (Fig. 145) and locally evaporitic facies, whereas continental strata are predominant in the east. The Western High Atlas was only affected by differential subsidence. The Paleozoic High Atlas is a horst of Paleozoic terranes intruded by Carboniferous granites and thinly covered by Mesozoic strata, whereas the Precambrian High Atlas is a horst of slightly deformed Infra-Cambrian and Precambrian rocks with very thin Mesozoic cover. The Central and Eastern High Atlas, also known as the Calcareous High Atlas because of thick Mesozoic carbonates, extends as a deep rift trough all the way

Fig. 145 Cretaceous badlands in northwestern Morocco.

to the Algerian border. Its stratigraphic and structural evolution can be divided into the following major phases: Continental rifting in the Late Triassic created the Atlas rift, in which broad alluvial fans prograded towards the centre of the grabens and deposited fluvial sandstones, conglomerates and mudstones. These mudstones are intercalated with evaporitic horizons of dolomite, gypsum and halite, and with tholeiitic dolerites at the top of the Triassic sequence. The supply of terrigenous clastic materials continued into the Jurassic. From Early to Middle Jurassic epicontinental limestones and reefs were established on fault blocks, which were shoal areas, whereas gravity-generated limestones and olistostromes accumulated in adjacent deeps. Early to Middle Cretaceous subsidence in the Atlas rift and global sea-level rise caused maximum transgression, which extended over adjacent platform areas. During the regression that followed fluvial and deltaic fans prograded into the Atlas gulf from east and west. Subsidence ended after the Turonian and from later Cretaceous the Atlas began to rise. Border faults developed into thrust faults along which slices of Mesozoic strata were thrust onto the adjoining platforms. The trough fill, now uplifted, was eroded into new alluvial fan systems, which filled marginal foredeeps.

The Rif Domain is part of a folded chain extending over the entire length of the Maghreb, known as the Rifo-Tellian Domain (Piqué, 2001), which forms part of the Alpine chain and especially resembles the Betic cordillera of southeastern Spain. Sediments in the Rif Domain initially accumulated from Triassic times on at a more easterly location of present-day Tunisia. This sequence was apparently transported to its present position by progressive WSW movement of this microcontinent, where it collided with the African plate in Oligocene-Miocene times and produced the complicated Rif overthrust.

From Essaouira to Tarfaya, the Moroccan Atlantic margin shows a rather constant morphology with tabular strata and a continental shelf, which is very gently sloping. Seismic sections indicate as earliest sedimentary formations Carnian sandstones, mudstones and conglomerates lying discordant on the basement. On land, the Doukkala sub-basin is capped at outcrop by Quaternary terrains overlying Mio-Pliocene marls and carbonates. In the west, these deposits cover a marine succession beginning with middle Cretaceous sediments that are unconformable onto the folded Paleozoic terrains and the Triassic-Liassic.

4 Economic Geology

The mineral industry of Morocco is still a major source of revenue despite various economic impacts generated by political uncertainties such as the Middle East conflict and the pending Western Sahara problem. Morocco is the world's leading exporter of phosphate rock, but since the early 1990s the export has declined.

The metal production of Morocco, particularly lead, silver and zinc, has experienced some resurgence since the early 1990s, due in part to the coming on-line of the Douar Hajar polymetallic mine located approximately 30km south of Marrakech, which produces lead, zinc, copper, silver and sulfur. El Heimer is located 20km southeast of Oujda in northeastern Morocco and is the site of the only operating lead smelter in North Africa, with a capacity of about 100,000mt/a of Pb-Zn and associated metals (copper, antimony and silver).

Phosphate rock is mined in several regions of Morocco. The most actively mined area is Khouribga, which represents the single largest producing phosphate mine in the world. The two open pit mining operations at Khouribga account for approximately 50% of all phosphate rock mined in Morocco. The reserves of phosphate rock are estimated to be approximately 20 billion tons.

Salt is recovered from a mine approximately 10km east of Mohammedia. It is the largest salt mine in Morocco and has a production capacity of 1Mm/a. Probable salt reserves are estimated at 600Mm/t. The deposit is of Triassic age, probably transgressively deposited in a shallow sea, where blocked seawater could not return to the ocean. Tectonic activity later folded the salt and recrystallized it to a 98.9%-pure form. The salt deposit reaches a thickness of 80m in some places in the mine.

Fig 146 The road through the High Atlas Mountains near Tizi n Tchika at an altitude of about 2500m.

Fig 147 Local selling of amethyst crystals found in the High Atlas Mountains.

5 Geohazards

A complete inventory has never been compiled, but many fatal earthquakes (e. g. Agadir 1960) and pollution caused by various mining activities are recorded.

6 Geosites

An inventory of potential geosites has not yet been compiled, but there are many exceptional sites, which are significant because of their scenic beauty (High Atlas) (Fig. 146) and/or their palaeontological content (Amouslek with its trilobites, Tafilalt region with ammonites, etc.) (Fig. 142 and 147).

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Fig 148 A lake in the Jurassic limestones in the Meseta, western Morocco.

Mozambique

1 General

Area: 801,590 km²
Population: 19,105,000 (July 2000 estimate)

2 Summary of Geology

Mozambique's geology is highly diversified and represented by rocks of Archean, Paleo-, Meso- and Neoproterozoic, Karoo, Meso- and Cenozoic age.

3 Stratigraphy and Tectonics

The Irumide Belt outcropping along the border with Zimbabwe consists of Archean and Paleoproterozoic rocks, which are forming an extension of the greenstone belts and granite-gneisses of the Zimbabwe Craton. This schist belt is made up of rocks of the Umkondo, Gairezi and Manica Groups representing the oldest rocks of Mozambique. The Irumide orogenic event is dated at about 1,350 Ma.

The Mozambique Belt is divided into the Mozambique, Niassa and Central Zambezi tectonic provinces. The Mozambique Province is the biggest of those and outcrops over most of the northern part of the country. It is divided into two regions, the northwestern region along the eastern shore of Lake Nyasa, represented by granulites and charnockites, and the northeastern region, consisting of quartzitic marbles, schists, gneisses, migmatites, granitic and charnockitic complexes. The Mozambique Province is represented by the Mecuburi and Muaguibe Groups and the Nampula, Chiure and Lurio Supergroups.

The rocks of the Niassa Province occur in the west of the country along the northern side of the Zambezi River and are limited to the south by the grabens of of Chire and Zambezi (these grabens originated along Precambrian trends and are filled with Phanerozoic sediments). The rocks of this province continue north through Malawi and outcrop on the eastern side of Lake Nyasa, where they are known as Meponda Group. The rocks are generally composed of quartzites, micaschists and marbles intruded by magmatic gneisses, syenites, dolerites, gabbros and anorthosites. The province is represented by rocks of the Meponda, Zambue, Luia, Tete, Angonia and Fingoe Groups and the Pre-Fingoe granites.

The Central Zambezi Province runs between the eastern edge of the Irumide Belt and the mid-Zambezi graben. The rocks are composed of schists, quartzites, migmatites and gneisses. The province is represented by rocks of the Rushinga, Nhamatanda and Madzuire Groups and the Barue Complex.

The Pan African metamorphic event (600-450Ma) is an intensive thermo-tectonic event with emplacement of granites and pegmatites that overprint the whole sequence of the Precambrian. Associated sedimentation of peri-glacial and glacial origin occurs in the extreme NW of the country (Katangula Group). These sediments correspond with the Katanga Supergroup of the Democratic Republic of Congo and Zambia.

The Phanerozoic Karoo Supergroup (Permo-Carboniferous to Lower Jurassic) in Mozambique forms three main sedimentary basins, the intracratonic basins of Alto Zambezi, Rio Lunho and Rio Lugenda. These are filled with continental deposits and in the Alto Zambezi Basin at the top with volcanics. A general similarity in the lithological succession between the different basins seems apparent. Some fluvio-glacial sediments - if present - are overlain by coal-bearing strata, sometimes covered by reddish mudstones containing septaria and reptile levels, which are absent in the Lugendo Basin in northeastern Mozambique and in the Democratic Republic of Congo. At the top there are sometimes thick molasse-like cyclical fluvial sequences, whereas in the south in the Alto Zambezi Basin volcanic rocks of basaltic and rhyolitic composition cover the whole succession.

Post-Karoo sediments of Jurassic, Cretaceous, Tertiary and Quaternary age occur in the coastal basins of Rovuma, Mozambique, Save/Limpopo and Baixa Zambezi. Sedimentation generally changes from continental to marine environment going from west to east. Marine sediments consist of calcarenites, sandstones and conglomerates.

4 Economic Geology

Sales of domestically produced mineral commodities are still a relatively minor factor in Mozambique's agriculture-dominated economy, although many metallic and non-metallic mineral occurrences have been identified in the country.

The Archean to Paleoproterozoic Manica Belt as the continuation of the Zimbabwe Mutare-Manica Gold Belt is a greenstone belt, which hosts the country's gold, copper, asbestos, lead, iron ore and nickel resources. Lode and placer gold deposits have been mined from this region. Small high-grade

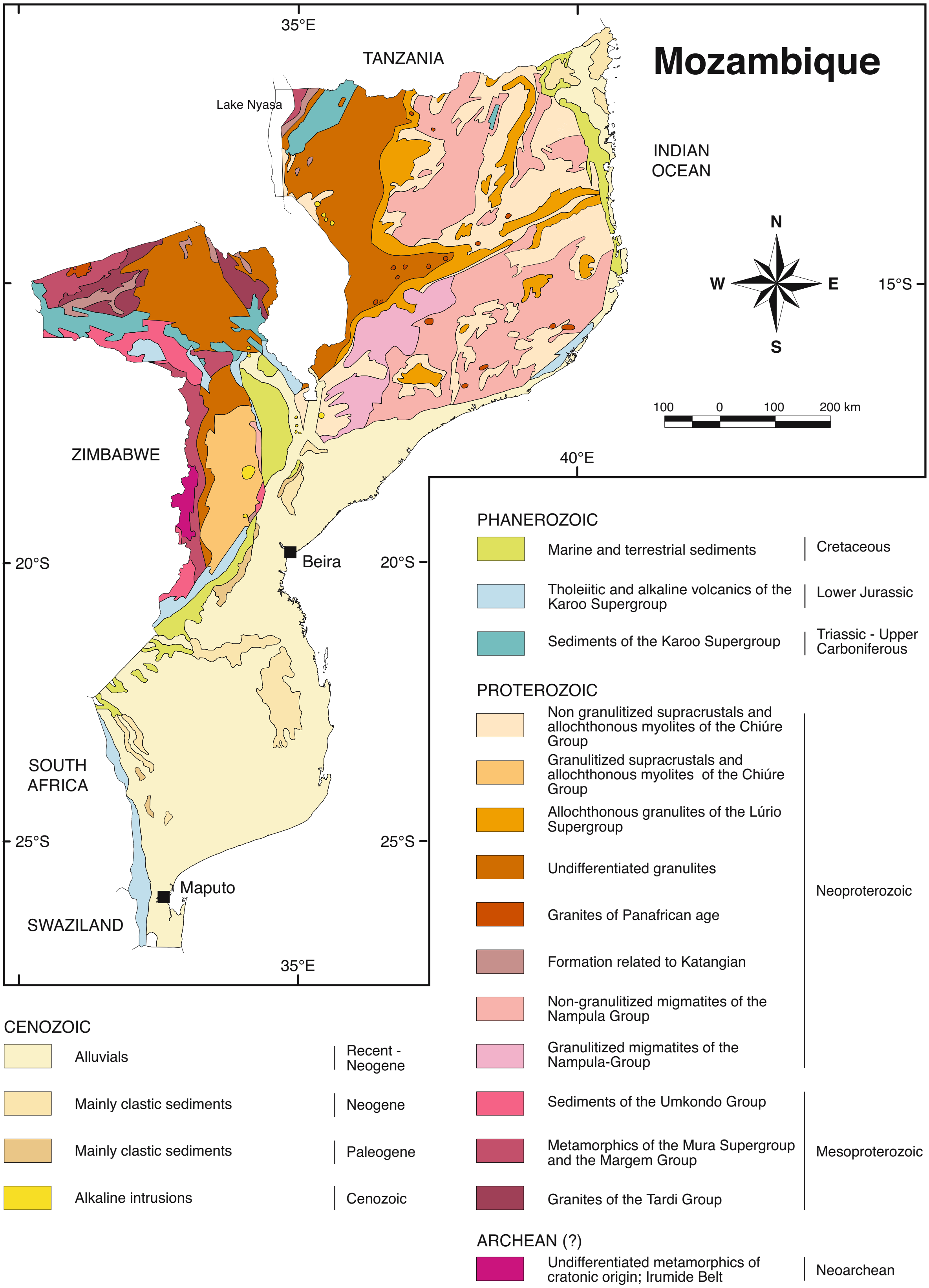

Fig. 149 Geological overview of Mozambique (modified after Pinna et al., 1987)

bauxite deposits also occur within this area. The metasediments of the Gairezi and Umkondo Groups along the frontier with Zimbabwe host deposits of iron, copper and limestone. Asbestos occurs in four areas in Mozambique. Chrysotile asbestos deposits occur in serpentine bodies originating from metamorphosed Archean greenstones of the Zimbabwe Craton, e. g. at Serra Mangota near Manica. Small chrysotile asbestos bodies occur as clusters of reworked old greenstone belts within the Mozambique Belt in the Manica, Sofala and Upper Zambezi Provinces. Anthophyllite asbestos originating from serpentinisation is known from Mavita, south of Manica. Anthophyllite asbestos also occurs in biotitic ultrabasic rocks of the Mulatela-Nampula Province. Graphite deposits occur in seven of the ten provinces of the country, i. e. Niassa, Cabo Delgado, Nampula, Zambezia, Tete, Manica and Sofala. All graphite occurrences are found in Proterozoic rock units associated with gneisses and schists, mostly as small silvery flakes and also as narrow veins and small lenses often in the proximity of limestones. The Proterozoic sequences in the Zambezia and Nampula Provinces contain pegmatites with a variety of minor metals as well as precious and semiprecious gemstones, beryl, mica, feldspar and radioactive minerals. Niobium and tantalum are the most important of those currently being mined. Numerous auriferous quartz veins and alluvial gold areas are also found in this region. The economic potential of the pegmatites is enhanced by their association with the beryl group of minerals (aquamarine, morganite), mica, feldspar and quartz. In northeastern Mozambique, near Alto Ligonha, pegmatites host significant tantalum resources in association with subordinate columbium, antimony and bismuth as well as lithium minerals, industrial and gem quality quartz and beryl.

Coal occurs in some lower sequences of the Karoo Supergroup. These deposits are among the biggest and most important mineral resources of Mozambique. Provisional estimates range from about 120-380 million tons of reserves for the Rio Lunho Basin only.

Some sedimentary sequences in the Rovuma Basin in the north and the Mozambique Basin in the south show a potential for hydrocarbons, e. g. the Cretaceous Grudja Formation, where some gas fields are to be explored. Fluorite, blue and yellow in colour with resources of about 1.1 million tons occurs in Mesozoic fractures in association with the rift evolution and in carbonatitic bodies, e. g. at Monte Muambe east of Moatize in the Tete Province. Bauxite is known to occur in a few localities, especially in high altitude areas and by alteration of alkaline rocks. The only deposit currently in production is Serra de Moriangane in the Manica Province. Other areas with bauxite occurrences are Monte Salambidua in the Tete Province and Monte Mauze in the Zambezia Province. The Eocene Cheringoma and the Miocene Jofane Formations include large reserves of limestones, halite and gypsum. Heavy mineral sands include ilmenite, rutile, monazite and zircon. Extensive deposits occur along the coast in dunes and beach sands especially in the sector between Quelimane and south of Angoche.

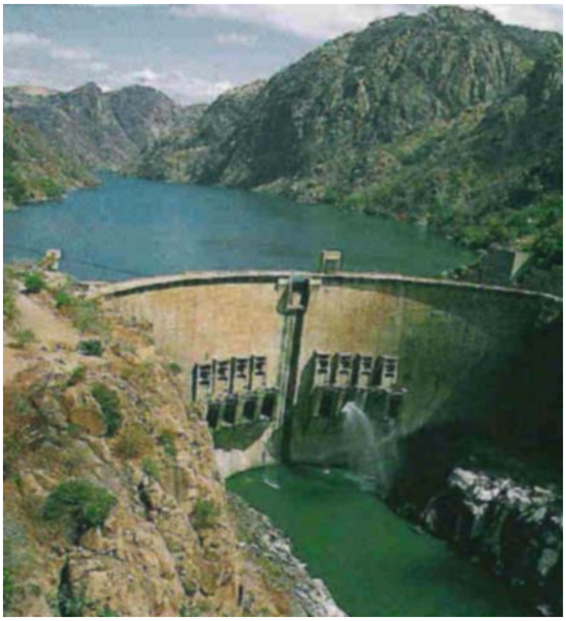

Fig. 150 The wall of the Cahora Bassa dam in central Mozambique.

Fig. 151 The gorge of the Cahoa Bassa dam in central Mozambique

Fig. 152 The national park of Benguera Island with fresh water pools along coastal Mozambique

Fig. 153 Unique in Africa, a museum devoted only to geology - in Maputo.

5 Geohazards

An inventory has not yet been made, but flooding and pollution of aquifers caused by mining has to be considered.

6 Geosites

An inventory of potential sites has not yet been prepared, but there is in Maputo a museum that is devoted only to geology (Fig. 152 and 153).

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Namibia

1 General

Area: 824,292 km²
Population: 1,660,000 (July 1998 estimate)

2 Summary of Geology

Namibia's geology encompasses rocks of Paleo-, Meso- and Neoproterozoic and Paleozoic to Cenozoic age. About 46% of the country's surface are bedrock exposure, while the remainder is covered by the young surficial sediments of the Kalahari and Namib deserts.

3 Stratigraphy and Tectonics

The geology of Namibia is dominated in the north by metasediments of the Neoproterozoic Damara Orogenic Belt (or Namibian System), while in the south large areas are underlain by the unmetamorphosed, relatively undisturbed sediments of the Cambrian Nama Group. Locally, within the Damaran terrain, inliers of older basement occur, for instance in the extreme northwest at the Kunene River the oldest rocks of the country belong to the Paleoproterozoic (about 2,100Ma) Epupa Metamorphic Complex. Only slightly younger are metamorphic rocks of the Huab Complex west of Outjo. Similar ages are also recorded from rocks of the Grootfontain Metamorphic Complex in the northeast of the country. The Rehoboth-Sinclair Complex in Namibia's southwest is of late Paleo- or Mesoproterozoic age. The Epupa and Huab Complexes were attached to the Congo Craton, whilst the Grootfontain and the volcano-sedimentary formations of the Rehoboth-Sinclair Complexes were assembled with the Kalahari Craton. The Namaqua Metamorphic Complex consists of metasediments originally eroded from the Congo and Kalahari Cratons. Granitic/metabasic intrusions also occur. It is of Mesoproterozoic age and covers large areas in the south and southwest of the country. Of Neoproterozoic age are the rocks of the Damara Orogenic Belt, which are widespread in central and northern Namibia. These are high-grade metamorphics, but granitic intrusions are also frequent. The overlying rocks of the Nama Group in central southern Namibia consist of marine sediments indicating a shallow shelf environment, deposited during the Cambrian. The clastic components of the Nama Group were mainly derived from the Damara Orogenic Belt, while the basal pelites and carbonates have eastern source areas.

No deposition is recorded from Cambrian till the beginning of the Karoo episode, which in its initial phase is characterized by glaciogene sediments of the Dwyka Group. This type of rocks is well-distributed in the Kaokoveld of northwest Namibia. It is followed by continental sediments of the Omingonde Formation of the Ecca and Stormberg Groups in central Namibia. The Permo-Triassic Karoo Sequence is intruded by mostly Mesozoic dolerite sills and dyke swarms, which, together with extensive basaltic volcanism and alkaline sub-volcanic intrusions, are related to the breakup of Gondwanaland, and the formation of the South Atlantic Ocean during the Cretaceous. The currently last chapter of Namibia's geological history is represented by the widespread Cenozoic to Recent deposits of the Kalahari Sequence.

4 Economic Geology

Targets for mineral exploration have been identified throughout the stratigraphic column. Metamorphic complexes host a variety of prospective environments such as copper-molybdenum porphyry, volcano-exhalative base metals and gold, volcanogenic copper, sedimentary-exhalative lead-zinc, fluorite, shear-zone gold, and beryllium-niobium-tantalum mineralisation.

Paleo- to Mesoproterozoic rocks locally contain extensive red-bed copper, while calc-alkaline units of the same age have potential for porphyry and hydrothermal copper, as well as vein-type gold mineralisation.

Namibia is one of the major producers of diamonds, 95% of which are of gem quality. The bulk of the country's known diamonds occur along the southern coastline, north of the Orange River mouth. The dia-

Fig. 154 Sieving for diamonds during German colonial times (1912) at Kolmanskop, western Namibia.

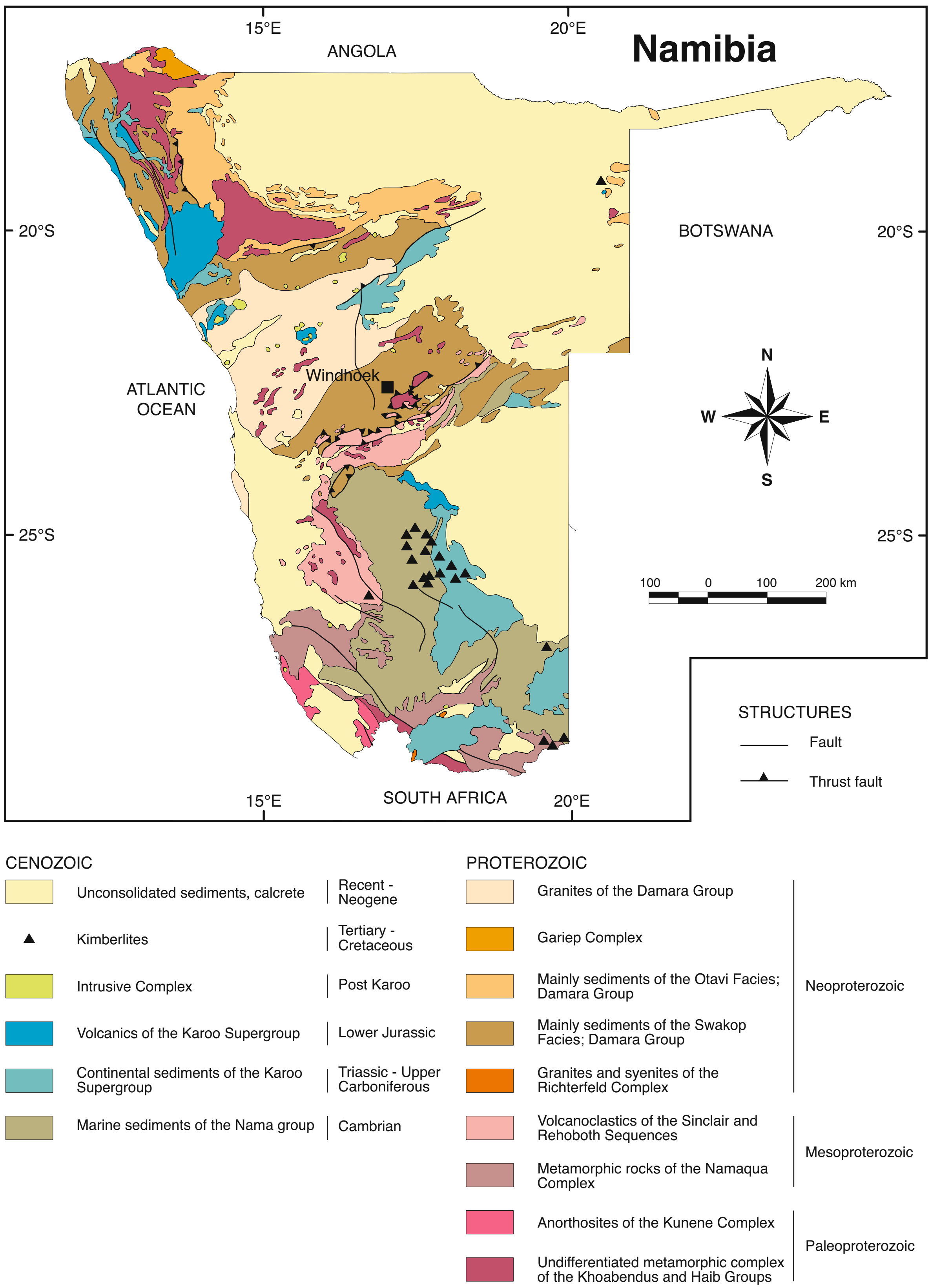

Fig. 155 Geological overview of Namibia (modified after Grünert, 1999/2000)

Fig. 156 An extinct geosite: the “Mukorob” or “Finger of God”, an eroded sandstone fragment that collapsed naturally on 8 December 1988, at Mariental in southern Namibia.

monds originated in the interior of southern Africa and were transported by the Orange River to the Atlantic coast, where they were deposited within beach sediments. Almost the entire coastline is covered by exploration and mining licenses. Offshore mining techniques have been pioneered in Namibia and the country has firmly been established as the world leader in marine diamond mining. Inland, in the vicinity of Gibeon, 60 barren pipes of kimberlite of post-Karoo age have been identified. The northeast of the country also hosts some kimberlites, which are currently being explored for their diamond potential.

The main occurrences of gold are in the Karibib and Rehoboth regions, the Omaruru area and the Kunene region. Silver is present in several deposits mined principally for their copper, lead and zinc contents. It is found in the orebodies of Tsumeb, Kombat and Rosh Pinah mines. Graphitic deposits in the Damara Sequence, calcrete hosted deposits of the Tertiary and sedimentary deposits in sandstones of the Karoo Supergroup, are the three major types of uranium hosting lithologies in Namibia. The deposits at Rössing and Valencia are of granitic origin. Currently, Rössing is the country’s only producer of uranium. Major base metal production in Namibia includes copper, lead and zinc. Large-scale mining of base metals, especially copper, plays an important role in the economy of Namibia. Copper occurs at several locations, but is currently dominated by the Damara deposits: Otavi Mountainland (including the defunct

Fig. 157 Trunks of the petrified forest at Khorixas, northern Namibia, with specimens of the recent plant genus Welwitschia.

Tsumeb Mine) and the Matchless Amphibolite Belt of the Swakop Group. Minor amounts come from Rosh Pinah. A feasibility study of the Skorpion zinc project has confirmed that Skorpion could rank as one of the world’s largest integrated zinc mining and refining operations. Haib at the border to South Africa is a classic porphyry copper-gold-molybdenum deposit featuring oxide and sulphide copper with a predominance of chalcopyrite in the sulphide ores.

Namibia presently imports all its power station requirements. A large low-grade coalfield was found near Aranos, at depths of 250-300m. Large, low-grade anthracite coal deposits are located along the coastline between the Huab River and Toscanini. They are, however, sub-economic. Following the discovery of the offshore Kudu Gas Field, recent exploration also intersected oil-prone source rocks in boreholes.

Industrial mineral production in Namibia includes salt, fluorspar, wollastonite and dimension stone. Salt is recovered on a large scale from coastal solar evaporation pans in the Swakopmund and Walvis Bay areas, and at Cape Cross. The Okorusu Fluorspar Mine produces high quality acid-grade fluorspar. The Okanjande graphite deposit (near Otjiwarongo) is comprised of high quality flake graphite, but the mine has not yet gone into operation. Wollastonite is produced in the Usakos area. Namibia also produces a variety of semi-precious stones through both small and medium scale mining. Tourmaline, aquamarine, heliodore, morganite, rose quartz, smokey quartz, garnet, chrysocolla and dioptas are quarried in various parts of the country. Marble, granite and other dimension stone for export or local processing are produced between Swakopmund and Karibib.

5 Geohazards

An inventory has not yet been made.

Fig. 158 The Hobo iron meteorite in the Otavi Mountains in northern Namibia, discovered in 1920 and being the largest ever found.

Fig. 159 The Fish River Canyon in southern Namibia, worldwide the second deepest after the Grand Canyon in Arizona, USA.

6 Geosites

Namibia's geological exposures contribute to a wide variety of geosites. Some of them have already been protected, but some are unfortunately already spoiled. A formal inventory of all the known sites is currently in preparation (Schneider, in litt.), who has given the following list of 32 sites: Brandberg, Brukkaros, Burnt Mountain, Dieprivier, Dolerite Hills, Etendeka Plateau, Erongo, Etosha Pan, Fishriver Canyon, Gamsberg, Gibeoan Meteorites, Hoba Meteorite, Kalahari Desert, Karas Mountains, Kolmanskop, Kuiseb Canyon, Lake Otjikoto and Lake Guinas, Messum, Mount Etjo, Mukorob, Namib Desert, Naukluft, Omatako Mountains, Organ Pipes, Dinosaur Footprints at Otjihaenamaparero, Petrified Forest at Khorixas, Sesriem Canyon, Sossusvlei and Tsondabvlei, Spitzkuppe, Twyfelfontein, Vingerklip and Waterberg. Some detailed information on their topography and geological significance is also presented in the book of N. Grünert (1999/2000).

A spoiled geological monument is the so-called Mukarob or Finger of God, a weather-resistant remnant of a sandstone pinnacle that was left standing on its own as erosion slowly cut back the surrounding Weissrand Escarpment of the Karoo Supergroup in southern Namibia (Fig. 156). The Mukarob consisted of a large head of sandstone supported by a narrow neck of soft, fragmented mudstone. The head was almost 12m high and weighed about 450t. On 8 December 1988 the Mukarob collapsed, possibly due to a destructive earthquake that had occurred the previous day in Armenia, but which was recorded strongly on the seismograph in Windhoek (Miller et al., 1990).

The petrified forest near Khorixas (Fig. 157) in northwest Namibia is an impressive palaeontological monument, which may serve as an already well-protected geosite (Grünert, 1999/2000). Similarly, the Hoba Meteorite in northern Namibia (Fig. 158), which is the largest known iron meteorite on Earth, is well-protected as a national monument and attracts many visitors at the site and in the museum. The famous copper deposit at Tsumeb in northern Namibia was closed as a mine in 1996, but in addition to commercial sales of blister copper, Tsumeb has to be noted for its mineralogical diversity, having provided innumerable specimens of unique or rare minerals to the world's museums. Tsumeb therefore also deserves to achieve the status of a geosite. Other locations in Namibia that are of geological significance include the following: Traces of Triassic dinosaurs at Otjihaenamaparero (central Namibia); the Fish River Canyon (Fig. 159) in southern Namibia is the second largest canyon of the world and is famous for its scenic beauty.

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Niger

1 General

Area: 1,267,000 km^2
Population: 10,120,000 (2001 estimate)

2 Summary of Geology

Precambrian rocks underlie large parts of Niger, but Cenozoic continental weathering products and sand dunes conceal most of the Precambrian rocks. Paleoproterozoic rocks are exposed west of Niamey, forming a continuation of Birrimian rocks from Burkina Faso. Other Precambrian rocks occur in the Aïr Massif in the north of the country. Neoproterozoic rocks crop out south of Niamey along the border with Benin and Burkina Faso, in a continuation of the Volta Basin. Paleozoic sediments occupy parts of northeastern Niger and the Agadez Basin west of the Aïr Massif. Cretaceous marine and epicontinental sediments of the Iullemiden Basin occur in central Niger. Volcanic activity, with associated lava, tuff and ash deposition is recorded from some places intermittently since Devonian times.

3 Stratigraphy and Tectonics

Eastern Burkina Faso and the adjacent parts of Niger and northern Ghana constitute a region, in which pre-Birrimian basement is common. The rock types include a variety of gneisses and migmatites formed under conditions of the amphibolite metamorphic facies, locally possibly reaching the granulite facies. In the Liptako region of western Niger a group of mesozonal amphibolites, chlorite schists, meta-andesites, garnet-gneisses, meta-arkoses and micaceous quartzites are younger than the mole-forming granite-gneiss complex, but older than virtually unmetamorphosed greywackes, shales, mudstones, tuffs, quartzites and conglomerates comprising the Amarasindé and Bellekoiré beds. Granites intrude these mesozonal assemblages, which have been assigned to the Upper Birrimian Supergroup. Neoproterozoic rocks occur close to the border with Burkina Faso, in a continuation of the Volta Basin, which is a synclinal basin with the oldest deposits exposed around its margin.

The Aïr Massif in the southeast of the Hoggar Mountains includes three geological units: Precambrian basement, circular Paleozoic subvolcanic ring structures and Cenozoic volcanism. The Precambrian basement can be subdivided into two main formations: a heterogeneous metamorphic sequence and several granitic intrusions. About half the exposed area of the basement is formed by metamorphic rocks, which are symmetrically disposed along a N-S axis with prograde metamorphism from the outside towards the centre. One may distinguish the Edoukel mesozonal micaschists, the Azanguerene gneissic formation and the Tafourfouzete leptynitic formation, which occupy the catazonal axial zone of the Aïr massif. To the southeast, the Aouzeueur formation is represented by epizonal rocks. This formation may also be interpreted as an ophiolite. The rest of the basement is composed of granitic rocks, subdivided into ante-, syn- and post-kinematic intrusives, of which the Renatt and Dabaga types are the most important. All types of the granites have yielded Pan-African ages.

Anorogenic ring-complexes comprise about 30 massifs within the Niger-Nigerian “Younger Granite Province”, which is a striking alignment, about 1500km long, and dated from the Cambrian in the north to the Jurassic in the south. The ring-structures in the Air are most probably entirely Paleozoic in age and are characterized by a great variety of structures and rock types. The largest ring-dyke in the world (Meugueur-Meugueur, 65km in diameter) and one of the smallest intrusions (Taguei, 0.8km in diameter) occur in the province. Most have a circular form, but others have a elliptical or semicircular form. From a petrographic viewpoint three types may be distinguished: The Taghouaji-type is composed of plutonic alkaline rocks with or without peraluminous granites. The Goudai-type is composed dominantly of acid volcanic rocks. The Ofoud-type comprises a great petrographic variety from gabbros to granites, and is characterized by the presence of anorthosites.

Although being a basin largely filled with Mesozoic and Cenozoic sediments, the northern part of the Iullemeden Basin at Tamesna belongs to a lower Paleozoic basin that centred in the present Hoggar Mountains, prior to the post-Hercynian uplift of the Hoggar Mountains. Generally Paleozoic strata in the Tamesna sub-basin thicken towards the Hoggar Mountains and thin southwards where they disappear. Cambro-Ordovician strata are up to 500m thick in eastern Tamesna, where they comprise basal conglomerates, sandstones with Cruziana and Skolithos, which are unconformably overlain by glacial deposits. These are followed by Early Silurian graptolitic shales, Devonian sandstones and shales and Late Devonian to Early Carboniferous

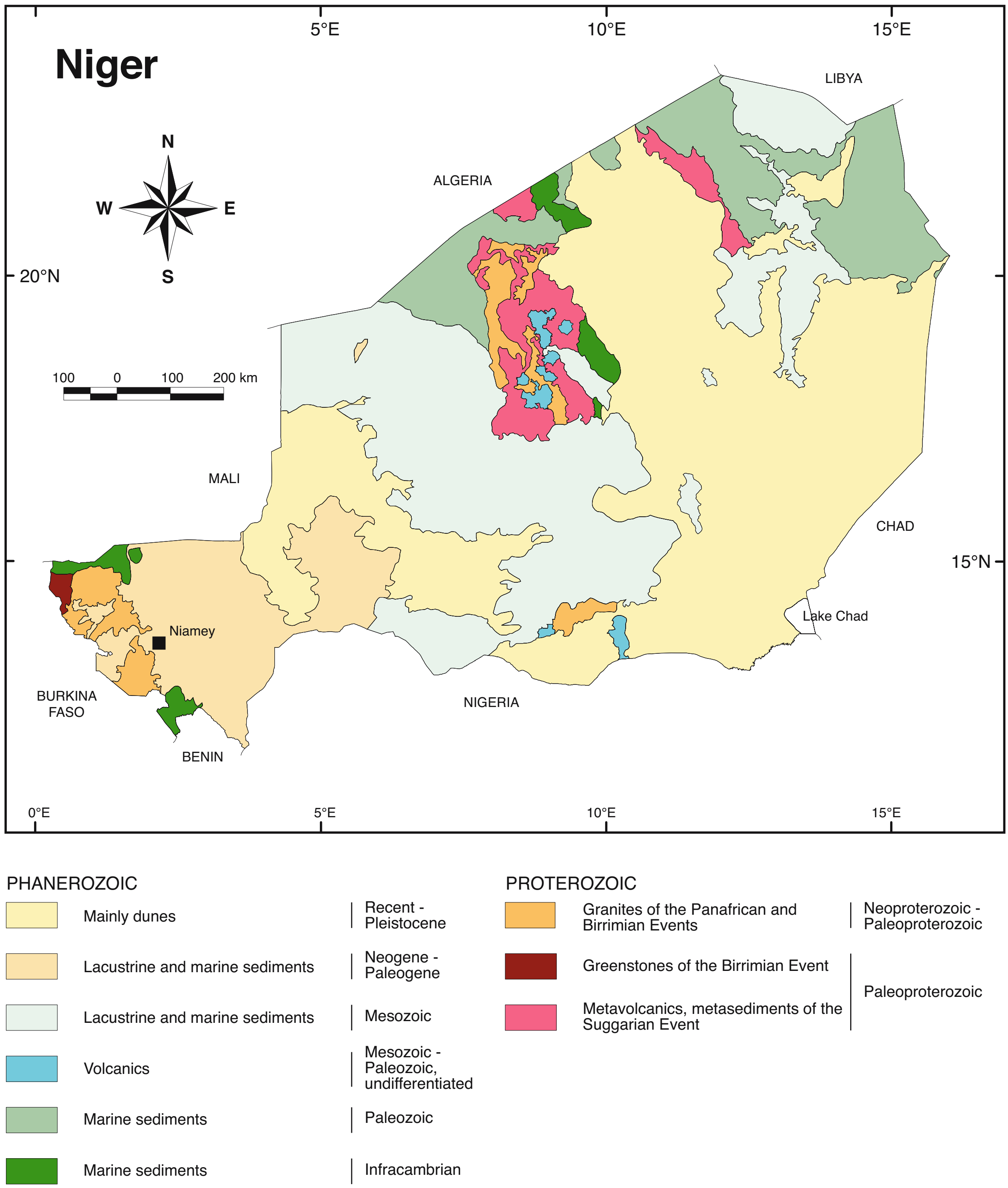

Fig. 160 Geological overview of Niger (modified after Razack, 2002)

deltaic sandstones. A transgressive Tournaisian coal-bearing paralic sequence is unconformably overlain by Visean shales and limestones, containing corals and conodonts. Mesozoic marine sedimentation in the Iullemeden Basin began with the Cenomanian transgression, sometimes overlying non-marine Lower Cretaceous strata. Till the end of the Paleocene marine sediments are widespread, but from Eocene continental deposits predominate, also known as "Continental Terminal".

4 Economic Geology

The mining industry of Niger is still dominated by uranium production, which is the country's principal export, but it is a poor contributor to the GDP. Other productive mineral commodities include coal and gold, whereas the tin and phosphate production have already ceased.

Uranium concentrate is produced mainly from two concessions, one near Arlit and the other at Akouta, 250 and 240km northwest of Agadez, respectively. The production is on a decline since 1986 stemming from low world demand for uranium and subsequent decline prices. Uranium reserves in the Arlit-Akouta region are estimated to be approximately 200,000 tonnes. Substantial but undeveloped resources are also reported to exist in other parts of the country, reaching an estimate of altogether 350,000 tonnes. These include deposits at Imouraren, Abkorum-Azelik, Afasto Ouest, Afasto Est, Tassa N'Taghalgué and Teguida N'Tessoun. Grades range from 0.22-0.45% U_3O_8.

There are indications of gold mineralisation in several parts of Niger, especially in the Liptako, Aïr and South Maradi regions. The Liptako area is at the northeastern tip of the major West African gold belt running from the Atlantic coast in Ghana to the Niger River. It continues to the east of the river, but is increasingly covered by younger sediments. The Birrimian greenstones in Liptako occur in the following areas: The Gorouel belt in the northwest and the Tera-Gassa belt in the southeast of the Liptaka region. Other occurrences include the Niamey and Makalondi belts. Gold is found in quartz veins in association with sub-vertical shear zones. Deep weathering during Quaternary wet periods has led to laterisation that freed the gold from its enclosing sulphides.

Silver mineralisation has been identified in the Liptako, Damagaram-Mounio and Air regions. At Liptako, silver occurs in quartz veins, commonly with grades of 1-3g/t, although some veins carry up to 43g/t. These veins, which often contain gold and sulphides (pyrite, arsenopyrite, chalcopyrite, sphalerite, covellite, etc.) occur at the contact between the greenstones and the granitic intrusions.

The only indication of platinum in Niger has come from the Makalondi District in the south of Liptako. It is associated with chromite lenses in gabbros, anorthosites and chloritoschists. Grades vary from 0.1-9g/t. Ophiolites associated with the Abuzegueur overthrust in the Aïr region have a good potential for platinum mineralisation as well as cobalt, chromite and nickel. A number of geochemical nickel anomalies have been found in Liptako. The most important is the Fantio deposit, derived from the wEAthering of ultrabasic rocks. Reserves are estimated at about 200,000t grading at 0.8% of nickel. Makalondi, also in Liptako, has the most significant chromium resources, grading at 5.1-17.4% of chromium, but the amount of mineralisation is probably small. Iron ore occurs at a number of stratigraphic levels from the Precambrian to the Tertiary. The Cenozoic deposits are the most important, found in the Ader-Doutchi and Termit-Agadem regions, and especially in Liptako. The grade of iron varies from 34.7-55.4%.

Tin from the Aïr Massif was commercially produced between 1984 and 1991. Today only artisanal mining operations occur. Three types of tin deposits are known in the Aïr Massif: pegmatite-hosted veins, stockwerks in greisenised granites and secondary deposits (alluvial, eluvial and colluvial), only the latter have been worked.

Molybdenum has been produced as a by-product from the uranium mining. Over 150 copper occurrences have been recorded throughout the country. In Liptako, copper generally occurs in vein-type deposits of chalcopyrite, often associated with malachite and elements such as lithium, molybdenum or silver. Copper mineralisation in the Proche-Ténéré District is found in veins that also contain zinc and lead. Sedimentary copper occurrences are known in the region around Agadez, where a lower Cretaceous sequence hosts cuprite, chrysocolla and native copper.

The most important coal deposit is located at Anou-Araren, where coal was formed in a small basin. Coal reserves are estimated to be about 10Mt. The coal is high in ash and has a low calorific value, but is suitable for on-site thermal power generation, the electricity being supplied to the uranium mines. In the Iullemmeden Basin are numerous lignite-bearing strata known. Recently hydrocarbon exploration resulted in the discovery of petroleum resources of about 300m barrels in the Iullemeden Basin. Two

Fig. 161 Cretaceous sauropod bone of Jobaria tiguidensis, recently discovered by Paul Sereno in the Niger desert.

areas with phosphate occurrences have been identified: The Tapoa deposit, 135km southeast of Niamey, is hosted by Volta Group sediments of Neoproterozoic to Cambrian age and contains proven resources of 207m at a grade of 23% P_2O_5. The Tahoua deposit, 375km northeast of Niamey, consists of nodular apatite, hosted in Paleocene to Eocene sediments. Reserves are about 7.4m at a grade of about 30% P_2O_5. The saline rich waters in the region of Tidekelt contain about 25 million tonnes of brines, yielding a salt content of about 70% NaCl and 30% Na_2SO_4.

5 Geohazards

Uranium mining has caused serious pollution in the limited aquifer reserves in this desert region. Additionally, the regular seasonal sandstorms distributed emitted radon gas from the heap of the uranium mines over large areas of the country.

6 Geosites

An inventory of potential geosites has not yet been made, but there are non-governmental activities to establish a museum of natural history in Niamey, where newly discovered Cretaceous dinosaur bones shall be exhibited (Fig. 161 and 162).

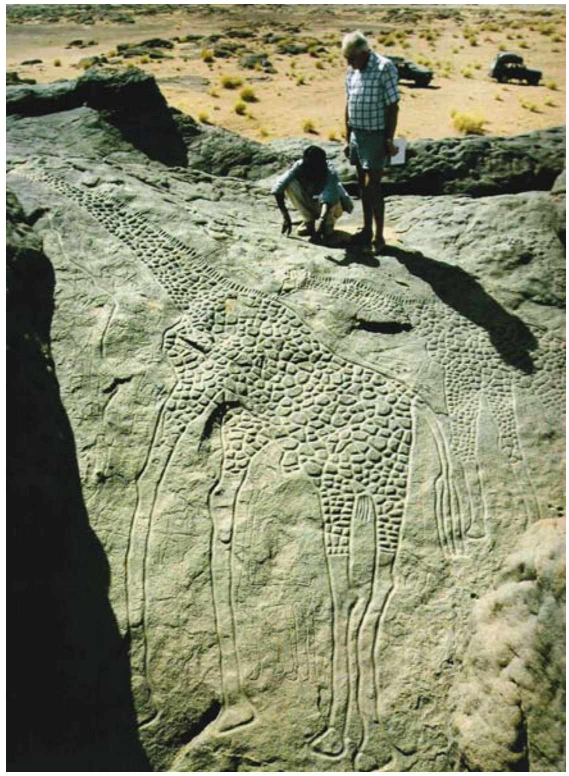

Fig. 162 Engraving of two huge giraffes into a sloping slab, probably between 8-6 Ka old, from central Niger. The site was in 2000 listed by UNESCO as one of the worlds most endangered monuments.

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Nigeria

1 General

Area: 923,768 km²
Population: 123,338,000 (July 2000 estimate)

2 Summary of Geology

Geologically Nigeria is underlain by rocks belonging to the following units: Mostly gneisses and schists of possibly Archean to Paleoproterozoic age occur widespread in the north, west and east of the country, sometimes intercalated by the so-called Older Granites and various metasediments of Proterozoic (to Paleozoic?) age. The Younger Granites of the Jos Plateau are of Jurassic age. Mesozoic and Cenozoic sediments of marine and continental types are found in the Sokoto (or Iullemmeden) Basin, the Chad Basin, the Benue and Niger Valley and the Niger Delta.

3 Stratigraphy and Tectonics

The basement rocks of the so-called Nigerian Province include the Beninian gneisses in the internal zone of the Pan-African Benin-Nigeria Orogen, and the vast expanse of reactivated high-grade, probably Archean gneisses and Paleoproterozoic supracrustals. The Nigerian Province is the southernmost continuation of the central Hoggar reactivated basement. Thrust and shear zones within the Nigerian Province allow the subdivision of this region into various units: The Migmatite-Gneiss Complex consists of predominantly Archean polycyclic grey gneisses of granodioritic to tonalitic composition. This reactivated basement occupies nearly half of the surface area of Nigeria. Often occur schists and migmatites, in which minerals such as garnet, sillimanite, kyanite and staurolite suggest a high-amphibolite facies metamorphism. Granulite-facies rocks are confined to charnockite bodies, which are generally associated with granites of probably igneous origin. In the Ibadan area of southwestern Nigeria the predominant rock types are banded gneisses, schists and quartzites, representing metamorphosed shales and greywackes with interbedded sandstones, whereas the intercalated amphibolite layers are probably metamorphosed tholeiitic basalts. The geological history of the Ibadan Migmatite-Gneiss Complex began with the deposition of shales, greywackes and sandstones with interbedded basalts. An early phase of folding and high-amphibolite facies metamorphism was succeeded by the emplacement of aplite schists in the banded gneisses at about 2,750Ma, during the Liberian Orogeny, and by the emplacement of microgranodioritic dykes. A second phase of intense folding followed at about 2,200Ma during the Eburnean Orogeny. The last tectono-thermal event recorded in the Ibadan (and Ife area) was the Neoproterozoic Pan-African Orogeny. The Ibadan banded gneisses had apparently a polycyclic history, which in spite of the current paucity of reliable isotopic age determinations, is also true for most of the Nigerian basement. Supracrustal relicts in the Nigerian basement are sometimes intercalated with the reworked Archean gneisses. These so-called Older Metasediments are best known in the Ibadan-Ife region and are represented by schists and metaquartzites within the banded gneisses. The Ibadan metaquartzites of possibly Paleoproterozoic age are overlain by pelitic schists, which were intruded by Mg-rich mafic sills. The Younger Metasediments are Neoproterozoic pelites (represented by phyllites, muscovite-schists and biotite-schists) with quartzites forming prominent strike ridges in several belts. Some belts contain ferruginous and banded quartzites, spessartite-bearing quartzites, conglomeratic horizons, marbles and calc-silicates. Igneous rocks, generally minor constituents in these belts, include amphibolites (originally lavas or minor intrusions), serpentinites and other ultramafics, which were probably intruded along deep fractures during the deformation of the supracrustal belts. There are also small occurrences of acid meta-volcanics of dacite to rhyolitic composition. The Younger Metasediments are mostly found in northwestern Nigeria, but occur also in the southwestern part of the country. They are common in synclinorial schist belts, where the low-grade rocks are characterized by tight to isoclinal folding and steeply dipping foliation with gradational, faulted or sheared boundaries with the surrounding migmatite-gneiss complexes. The schist belts of northwestern Nigeria are interpreted as typical volcano-sedimentary assemblages with tensional and compressional-related rocks, displaying the influence of paleo-rift systems. The characteristic structural trend in the schist belts is N-S or NNE-SSW, sometimes also E-W. It is, however, assumed that a single Pan-African tectono-thermal event affected both the Archean-Paleoproterozoic rocks and their supracrustal cover. One of the implications of the Pan-African tectonic model of eastward subduction and

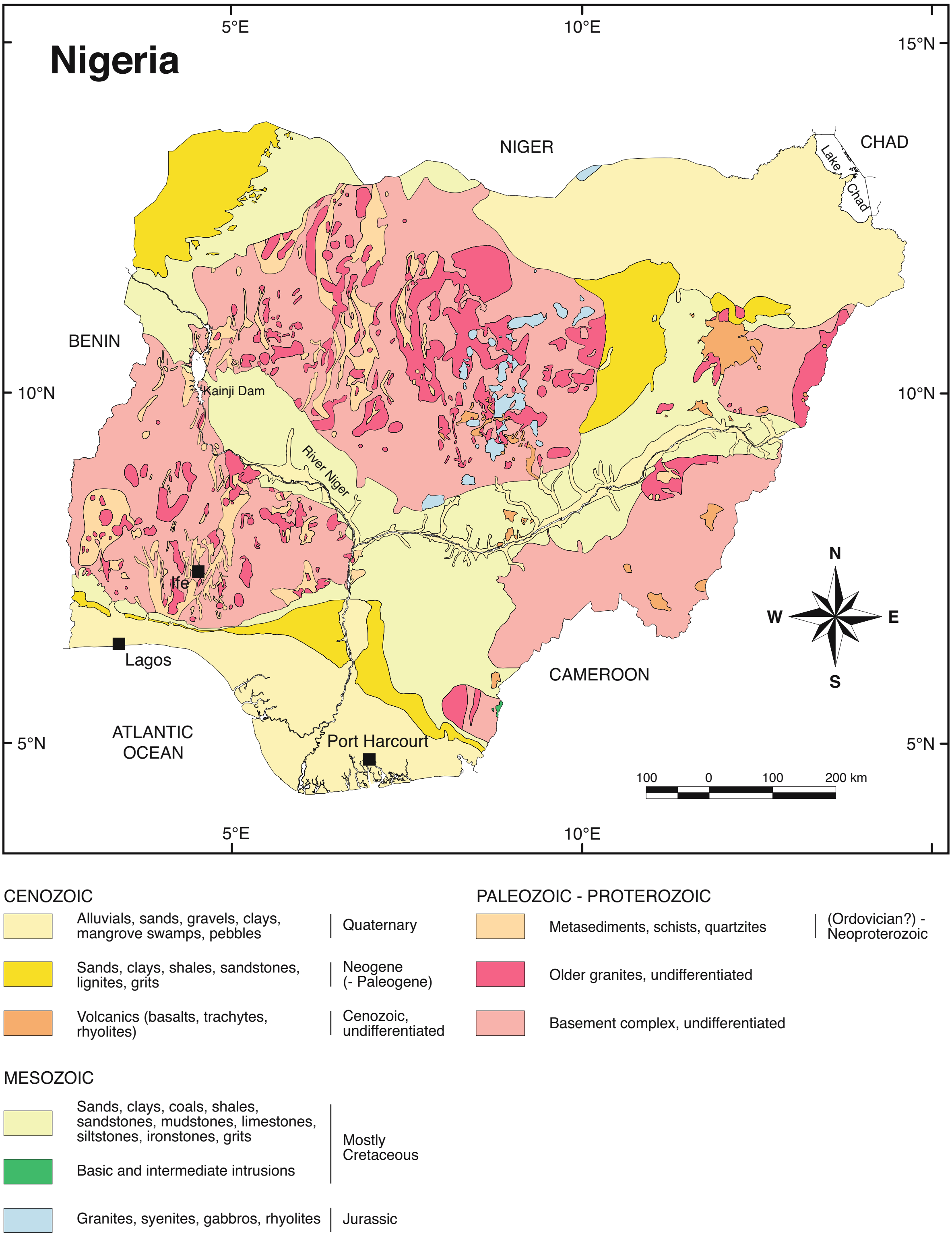

Fig. 162 Geological overview of Nigeria (modified after Okezie, 1974)

continent-continent collision in the southern part of the Trans-Saharan mobile belt is that it generated abundant granitoids in the Nigerian Province. Syn-tectonic to late-tectonic granites, diorites and syenites were intruded into both the migmatite-gneiss complexes and the overlying supracrustals. These Pan-African intrusives (700 - 500Ma) are termed in Nigeria the Older Granites, to distinguish them from the Younger Granites of Jurassic age. In northwestern Nigeria occur volcano-detrital materials including dacites and shonshonites, which were dated as Cambrian and interpreted as Pan-African molasse grabens. The Older Granites range in seize from small subcircular cross-cutting stocks to large granodioritic batholiths. Some of the batholiths have adamellitic composition and coarsely porphyritic textures. Charnockites also occur among the Older Granites. Pan-African late-to-post-tectonic basalt and dolerite dykes have also been found in the Nigerian basement.

Ring complexes of Jurassic age, the so-called Younger Granites, intrude the Neoproterozoic to early Paleozoic basement rocks of the Jos Plateau in central-northern Nigeria in a N-S trending zone, which continues to the Aïr region in Niger. This zone is parallel to the main Pan-African trends in the basement, indicating control by earlier structures. The Younger Granites represent a petrologically distinctive series of alkali feldspar granites, associated with rhyolites and minor gabbros and syenites. Characterized in sub-volcanic intrusive complexes as ring dykes and related annular and cylindrical intrusions they are richly mineralised with tin and niobium.

The southern Nigeria sedimentary basin is partially divided into western and eastern portions by the Okitipupa Ridge. In the western part of this basin sedimentation did not begin until the end of the Cretaceous, whereas the earliest transgression in the east was during the Albian. These sediments in southeastern Nigeria consist of rather poorly bedded sandy shales with sandstone and sandy limestone lenses. Palaeontologically, ammonites, radiolarians, echinoids, bivalves and gastropods have been recorded. The beds are sometimes associated with a lead-zinc mineralization. Deposits of Cenomanian to Lower Turonian age near Calabar with a thickness of about 600m have been assigned to the Odukpani Formation and consist of arkoses, sandstones, limestones and shales. Other related deposits belong to the Eze-Aku Formation, which comprises grey to black shales and siltstones, sometimes changing into sandstones or sandy shales. Ammonites, bivalves, gastropods, echinoids, fish teeth, etc. indicate a Turonian age. The Coniacian sediments have been assigned to the Awgu Formation, which consits of bluish-grey shales with occasional intercalations of fine-grained sandstones and thin marly limestones. The beds are rich in ammonites, molluscs and fish teeth. The Santonian is regressive. Campanian sediments in southeast Nigeria are part of the Nkporo Formation, which consists of dark shales and mudstones with occasional thin beds of sandy shales and sandstones. The major part of the Nkporo Formation probably belongs to the Maastrichtian, which is made up of dark grey, often friable shales, sometimes intercalated by limestones and sandstones. Lateral equivalents of the Nkporo Formation are the Owelli Sandstone, the Enugu Shale and the Asata Shale, which are all of shallow water origin. The Mamu Formation is a coal measure sequence, sometimes containing marine intercalations with ammonites. The following Nsukka Formation is very similar to the Mamu Formation and consists of an alternating succession of sandstones and dark shales with thin coal seems at various horizons, probably also of Maastrichtian age. The first major marine transgression in southwestern Nigeria occurred during the Maastrichtian, when sediments constituting the Abeokuta Formation were deposited, which contains marine molluscs and has yielded a microfauna towards the top. During the Paleocene in the western part of the basin, the Ewekoro and Akinbo Formations were deposited, whereas contemporaneously in its eastern part the Ino Formation lies on the Nsukka Formation, forming mostly thick clayey shales. The last cycle of sedimentation began in the Eocene and continues till present times. It is during this period that the modern delta of the Niger River was formed.

The Benue Valley is characterized by a linear shape and its sedimentary formations are continuous with the Nigerian coastal basin. The Iullemmeden Basin in northwestern Nigeria is locally known as the "Sokoto Basin" and defines the sedimentary basin, which extends from Mali and the western boundary of Niger through northern Benin and northwestern Nigeria into eastern Niger. The sediments found in Nigeria accumulated since the late Jurassic. The "Continental intercalaire" of late Jurassic to early Cretaceous are made up of grits and clays and are overlain by the Maastrichtian Rima Group of a mostly brackish environment. The subsequent Sokoto Group of Paleocene age is marine. Since the Eocene continental sediments are predominant.

About one tenth of the Chad Basin, the largest area of inland drainage in Africa, is situated in the northern part of Nigeria. The oldest sediments recorded are the Albian Bima Sandstones, which are lying unconformably on the Precambrian basement. During the Turonian the Gongila Formation, a mixed limestone/shale sequence, was deposited. These beds are overlain by marine shales of the Fika Formation, dated as Senonian. Towards the end of the Cretaceous during Maastrichtian an estuarine-deltaic environment prevailed and the Gombe Sandstones were deposited with intercalations of siltstones, shales and ironstones. Subsequently, the Cretaceous layers were folded into a series of anticlines and synclines that were later partly eroded, creating an erosional unconformity at the base of the Tertiary deposits. During the Paleocene, continental strata of the Kerri Kerri Formation were deposited. Since the Pliocene lacustrine deposits of the Chad Formation are unconformably overlying the Kerri Kerri Formation.

Fig. 164 Tin mining at the Big Paddock Mine on the Jos Plateau in central Nigeria, in the mid -1950s.

Fig. 165 Part of a tin mine on the Jos Plateau in central Nigeria, in the mid -1950s.

4 Economic Geology

Nigeria is Africa's largest crude oil producer and one of the 10 largest in the world. The hydrocarbon sector remains the mainstay of the economy, accounting for more than 80% of the total Government revenues and more than 95% of the country's total export earnings. However, the country has apart from its oil reserves considerable mineral wealth and potential for diversified development of the mineral industry.

Nigeria is estimated to have oil reserves of approximately 20 billion barrels. Known natural gas reserves are about 2.6 trillion m³. Almost 70% of the oil and gas reserves are onshore, and all are in the delta of the Niger River. Nigeria's oil reserves have high gas-to-oil ratios, and most of the gas discoveries occurred during oil exploration.

Gold is found almost throughout the western and northwestern part of the Nigerian basement, and was successfully mined already before World War II in several parts of the country, but due to low gold prices as well as a non-conducive legal environment all mines were closed. Over the last years some of these restrictions were abandoned and potential investors have shown interest to evaluate and re-explore the Nigerian gold deposits.

Large tin deposits occur within the Younger Granites of the Jos Plateau, where they have been mined since pre-colonial times (Fig. 164 and 165). Some of the finest pre-colonial artifacts of the so-called Ife culture (11-15 A. D.) (Fig. 168) have been produced from tin of the Jos Plateau. However, tin production is currently very low, due to various reasons, e. g. expansive extraction of the cassiterite ore, fall of world tin prices and frequent flooding of the mines. Additionally, tin mining on the Jos Plateau has also caused pollution of the aquifers in this region, which is a watershed for large parts of Nigeria (Onyekakeyah, 1991). The strategic minerals tantalite and columbite are associated with the tin ore occurrences of the Jos Plateau and may become world class deposits once they are properly explored. Many lead/zinc occurrences are known in the Plateau, Benue, Taraba and Anambra States of Nigeria. Some of these deposits are currently mined on small scale or artisanal basis. Almost all occurrences have a high content of arsenic, antimony and cadmium. Barite veins are often associated with the lead/zinc deposits and found in the Plateau State and many of the eastern States. Large reserves of iron ore are known from the Agbaja Plateau and at Itakpe Hill in the Kwara State. Furthermore, there are large deposits of industrial minerals such as kaolin, gypsum, feldspar, etc.

Fig. 166 Granitic inselberg north of the Jos Plateau along the Kano to Masduguri road.

Fig. 167 Granitic inselberg north of the Jos Plateau and west of Azare.

Coal production in Nigeria started already in 1915, and a wide market existed until 1960, when oil and gas began to replace coal as a source of fuel. It has since then steadily declined, but is locally still in operation, for instance for smaller brick kilns and ceramic works. There is a lignite belt across the southern portion of the country, but reserves of the lignite deposits are not accurately known.

5 Geohazards

The production of crude oil and natural gas in the Niger Delta has contributed to the pollution of the surface and the aquifers of large parts in this region. Heavy metal contamination in urban drainage systems was recently evaluated by Tijani and Onodera (2004). The decade-long tin mining on the Jos Plateau has changed much of the original socio-economic infrastructure in this region. An inventory of other potential geohazards has not yet been made.

6 Geosites

An inventory of potential geosites has not yet been made, but many places are of geoscientific interest, for instance on the Jos Plateau (Fig. 166 - 168).

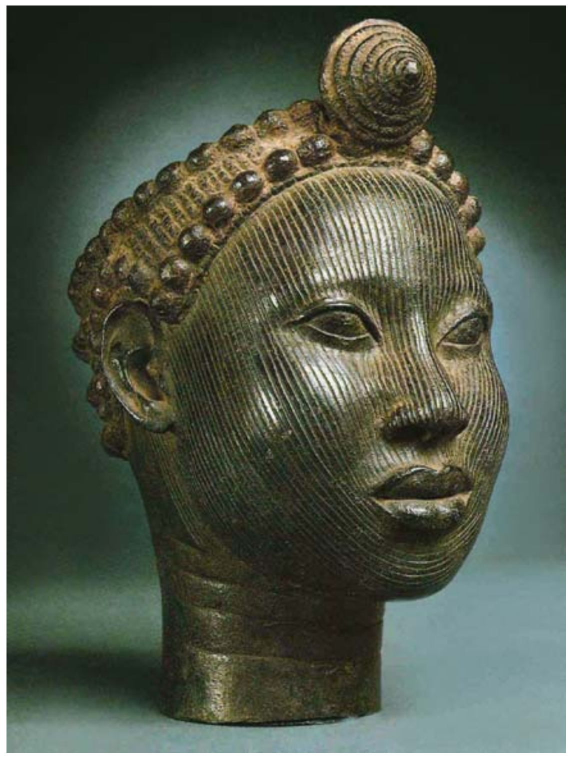

Fig. 168 The famous head of an (female?) Oni from the 12-15 century A. D. of the Wunmonije Compound, Jos Plateau, composed of locally produced bronze.

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Reunion (France)

1 General

Area: 2,512 km²
Population: 611,000 (1995)

2 Summary of Geology

The Indian Ocean island of Reunion is generally formed by two volcanoes, the Piton de la Fournaise (2,650m) and the Piton des Neiges (3,069m) (Fig. 169).

3 Stratigraphy and Tectonics

The Piton des Neiges mainly consists of very basic lavas. The main crater has almost disappeared due to intense erosion, but several smaller parasitic craters are still preserved. Apart from the dominant basalts, there exist also trachytes, phonolites and andesites. Also a few intrusions of alkaline syenites forming dykes and sills have been described. The Piton de la Fournaise, situated in the south of the island, is still active. Two semi-circular recent craters surround old calderas. The lavas are generally labradoritic basalts, almost without olivines. Very rarely occur oceanites. The eruptions are a mixture of the Hawaian-Strombolitic type, sometimes with very liquid lava flows.

Only very few sedimentary deposits are known from Reunion, for instance from the foot of the Piton des Neiges, the fragment of a larger calcareous block, which had been submerged and later been brought up together with the basaltic magma.

4 Economic Geology

No economic valuable deposits are known from Reunion, but building materials are locally mined.

Fig 169 Aerial view of Reunion

Fig 170 Eruption at the Piton de la Fournaise, a Hot Spot volcano intermittently being active

5 Geohazards

The volcanic eruptions of the Piton de la Fournaise are a potential geoenvironmental hazard, but have yet only caused a limited loss of property and human fatalities.

6 Geosites

Due to their scenic beauty the two volcanoes Piton de la Fournaise and Piton des Neiges may be considered as potential geosites (Fig. 170).

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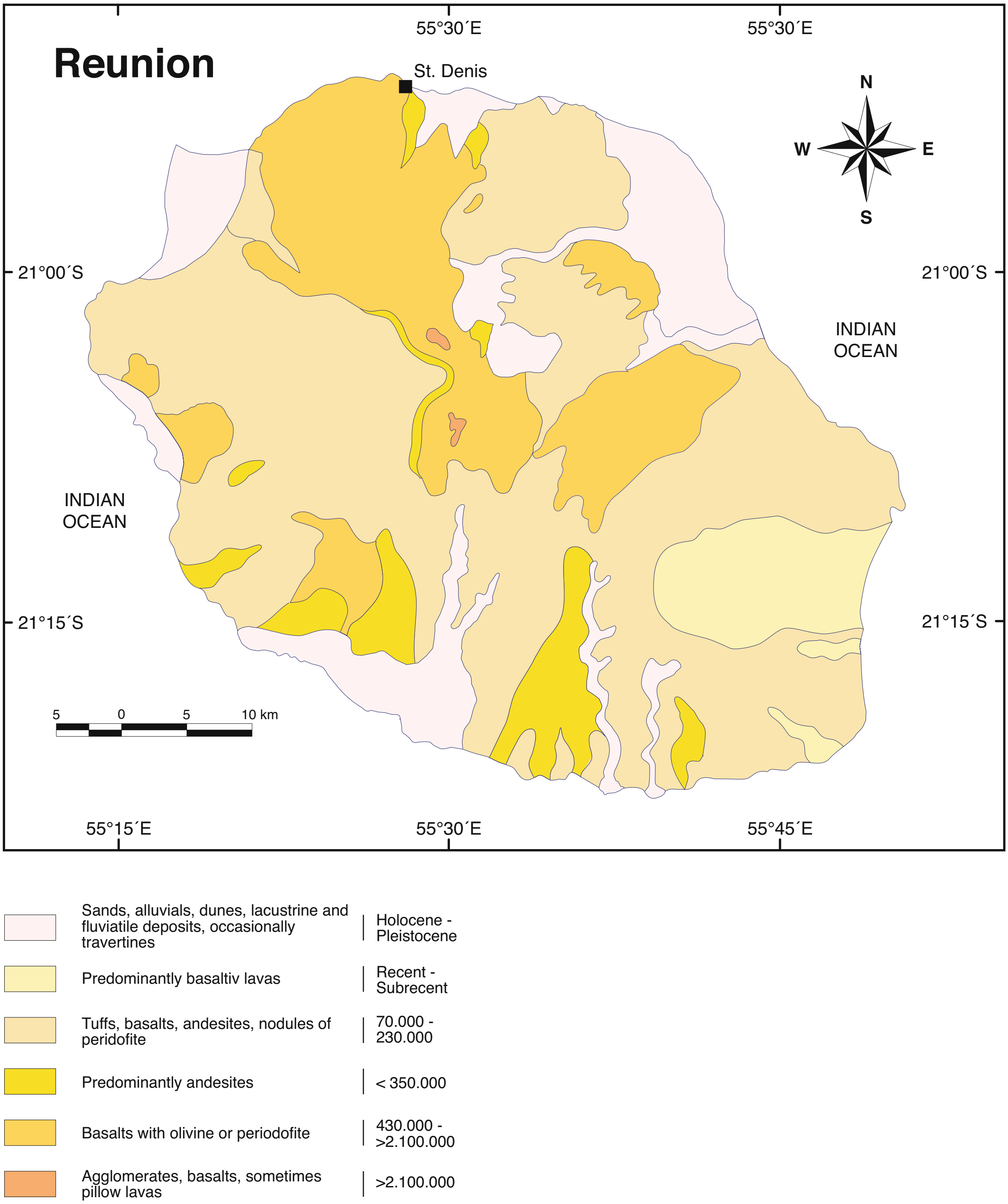

Fig. 171 Geological overview of Reunion (modified after Billard, 2004)

Rwanda

1 General

Area: 26,338 km²
Population: 7,229,000 (July 2000 estimate)

2 Summary of Geology

The Geology of Rwanda generally is made up of sandstones alternating with shales, which are all assigned to the Mesoproterozoic Burundian Supergroup, sometimes intercalated by granitic intrusions. In the east of the country predominate older granites and gneisses. Neogene volcanics are found in the northwestern and southwestern parts of Rwanda. Young alluvials and lake sediments occur along the rivers and lakes.

3 Stratigraphy and Tectonics

In various localities of Rwanda, for instance to the south and southwest of Butare and in the Congo-Nile watershed to the southwest of Rwengeri, pre-Burundian migmatites and gneisses accompanied by crystalline whitish quartzites occur. Some of these rocks in the Butare area have been retrometamorphosed (initial stages of sericitization) and slightly cataclased by a later deformation. Generally, the stratigraphic sequences established in Rwanda can more or less be identified with those, which appear in neighbouring Burundi. However, in Rwanda it was not yet possible to observe the contact with the underlying Archean basement. The sedimentary succession of the Burundian Supergroup can be subdivided into the following units: The Lower Series ("La Série Inférieure"), the Byumba Series, and the Miyove Series; each of these can be subdivided into formations of quartzites (Fig. 172) and various undifferentiated rocks. The base of the Lower Series is the most developed formation, characterized by black sericitic shales. The metamorphic rocks in the east of the country probably represent metamorphosed Burundian formations. All these sedimentary sequences indicate a former shallow marine, high-energetic environment, as often shown by the oblique stratification, the conglomerates and the symmetric ripplemarks within the layers. At least four types of granitic rocks are known within the Kibaran Belt. Of these, the two first are synorogenic and the two last postorogenic. The culmination of the Kibaran orogeny occurred from about 1,370 to 1,310Ma; the first of these ages dates early granites in Rwanda. Postorogenic granites are also known from Rwanda and have been dated at about 1,136Ma.

Cenozoic to Recent volcanic rocks occur in the northwest and west of the country. Some of these volcanoes are highly alkaline and are extensions from the Virunga volcanic area of southwestern Uganda and eastern Democratic Republic of Congo.

Tertiary and Quaternary clastic sediments fill parts of the Western Rift in the western part of the country.

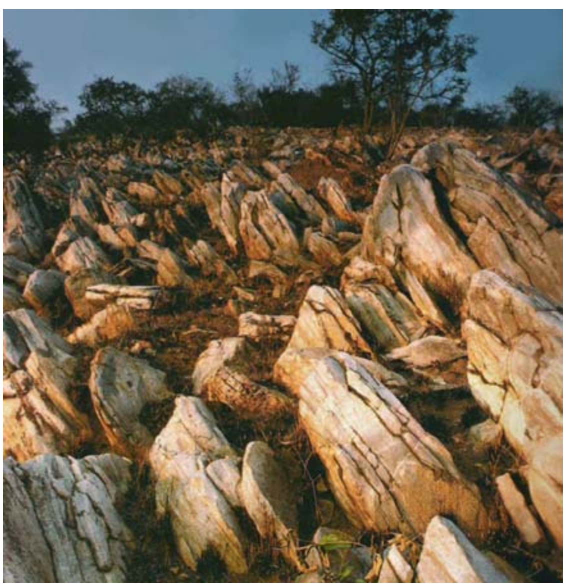

Fig. 172 Mesoproterozoic quarzitic sediments of the Kibaran Belt in the Akagera region

4 Economic Geology

Since the early 1990s the mineral exploitation of Rwanda witnessed an increased production by cooperatives and artisans. This included ores and concentrates of gold, tin, tungsten and columbium-tantalum (coltan) from a few of the many recorded deposits of a large quantity of minerals. Production of natural methane gas from Lake Kivu as well as limestone and cement was also maintained. Minor production of gem stones was reported as well, and undoubtedly, some construction materials were produced.

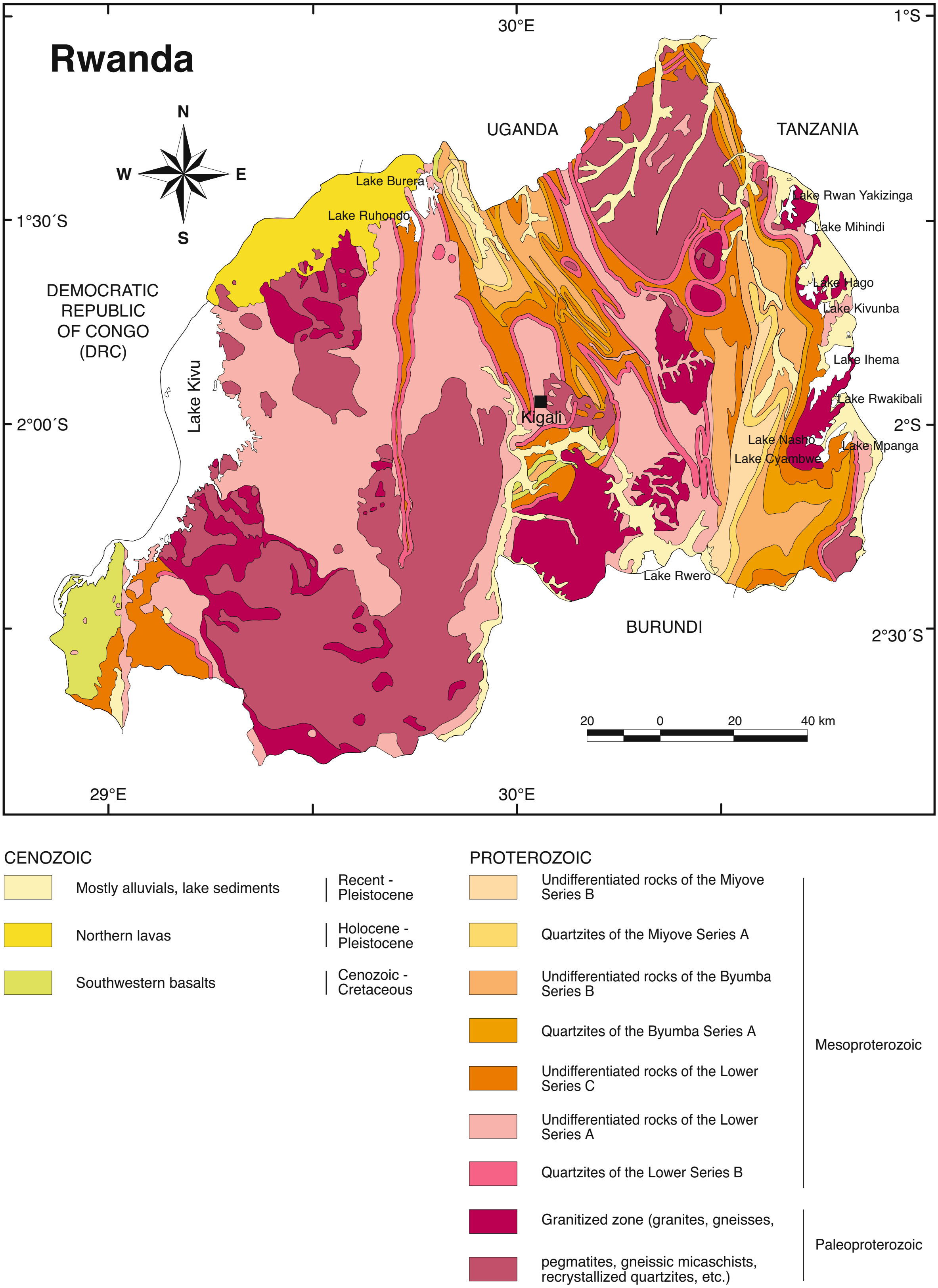

Fig. 196 Geological overview of Rwanda (modified after Baudin et al., 1984, and Theunissen et al., 1991)

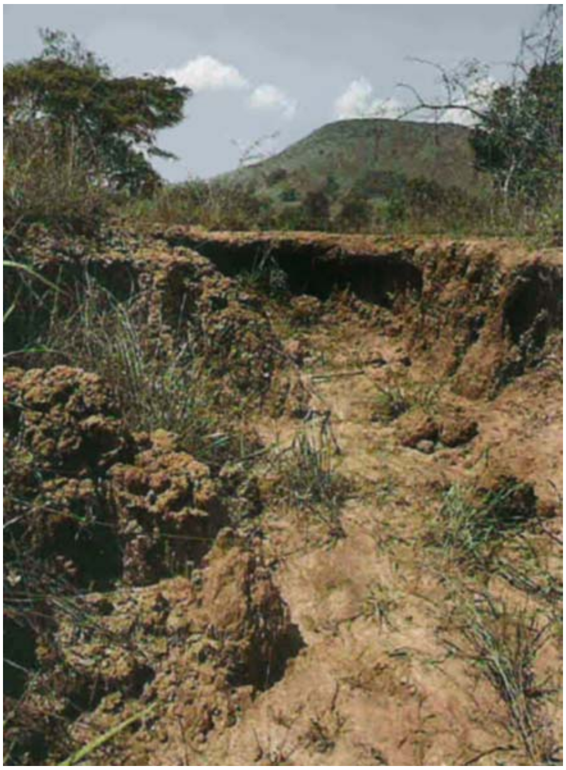

Fig. 174 Accelerated erosion in the Akagera region

5 Geohazards

A systematic inventory has not yet been made, but toxic gas emissions on the ground surface of some valleys of the Virunga volcanoes, locally known as "Muzukas", have been noted (Krafft, 1990). The densely populated country is also affected by problems of erosion, for instance the formation of gullies (Fig. 174), and environmental destruction caused by intensive terracing of the available land (Fig. 175).

Fig. 175 Intensive terracing near Kigali

Fig. 176 The Bisoke crater lake in western Rwanda

6 Geosites

An inventory has not yet been made, but the Virunga volcanoes offer many sites of exceptional scenic beauty. (Krafft, 1990) (Fig. 176 - 178).

Fig. 177 The Kagera River, the source of River Nile, in southeastern Rwanda

Fig. 178 The Rusuma Falls in the Ruhengeri area

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São Tomé et Príncipe

1 General

Area: 1001 km²
Population: 165,034 (July 2000 estimate)

2 Summary of Geology

São Tomé et Príncipe is a dual island nation, geologically being part of the Cameroon Line, which is an alignment of oceanic and continental volcanic massifs and of anorogenic plutonic complexes trending from Pagalú Island (Equatorial Guinea) in the south to Lake Chad in the north.

3 Stratigraphy and Tectonics

São Tomé is a complex strato-volcano about 5000m high. It rises from the abyssal plain to an elevation of 2024m above sea level. The island is made essentially of basaltic lavas; phonolitic plugs and necks are abundant in the southern part of the island. The basaltic lavas rest upon Cretaceous quartzose sandstones with metamorphic minerals, which crop out at the centre of the island. Palagonitic tuffs and pillow-lavas characterize submarine eruptions and are overlain by younger subaerial lavas. Trachy-phonolitic plugs cut the basaltic material, but the centre of the island has not yet been described. The oldest dated rocks are trachytes (15.7Ma). Other lavas gave ages between 13.2Ma and Recent. The mineralogy of the basaltic lavas is characteristic for an alkaline lava series and comprises phenocrysts of olivine, augite and magnetite in a microlitic groundmass of labradorite-bytownite, augite, ferric oxides and accessory titanite. Hornblende phenocrysts have been found in some lavas. The phonolitic lavas contain haüne or sodalite phenocrysts; barkevicite has been seen in some trachytes. From basalts to phonolites and trachytes a continuum exists with no Daly gap. The basaltic lavas are all nepheline normative. The lava series is the result of differentiation of material from mantle source by fractional crystallization of olivine, augite, plagioclase, hornblende, magnetite and apatite.

Príncipe rests upon the oceanic floor at a depth of about 3000m and culminates at 948m above sea level on Pico do Príncipe. Basaltic rocks predominate in the north, while phonolites and tephrites are common in the south. The lavas rest upon palagonitic breccias, which contain blocks of tholeiitic basalt and represent a submarine phase in the evolution of the island. The basaltic lavas have been subdivided into an older lava series (basanites, hawaiites) intruded by numerous dykes of basaltic lavas, and a younger lava series (basanites, nephelinites). The lavas of both series have been overlain by tristanites, phonolites and trachyphonolitic lavas in the centre and in the south of the island. Dated lava samples gave K-Ar radiometric ages around 30.4Ma (tholeites from the palagonitic breccia) and 4.9Ma (trachy-phonolitic suite). The basaltic lavas of the older lava series contain phenocrysts of olivine and titanaugite plus phenocrysts and microphenocrysts of plagioclase and titano-magnetite; the groundmass contains microlites of the same minerals except olivine. In addition, alkali feldspar, nepheline and apatite occur in the groundmass of the younger lava series. The phonolitic lavas are porphyritic with a microlitic groundmass. The dominant phenocrysts are nepheline, sanidine, aegirine-augite and barkevicite, titanite and magnetite with possible sodalite and plagioclase. The basaltic lavas (MgO>6wt%) are nepheline normative; their Y:Nb ratios are less than 1. Sr87:Sr86 ratios of the older lava series are in the range 0.7030-0.7037Ka.

4 Economic Geology

Sao Tomé and Príncipe has no significant mineral industry, with the exception of some small clay and stone open pit operations, utilized for local construction needs. Sporadic interest has been generated concerning possible offshore hydrocarbon-bearing strata. Deepwater exploration may start in 2008.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made, but the volcanoes are of scenic beauty.

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São Tomé & Príncipe

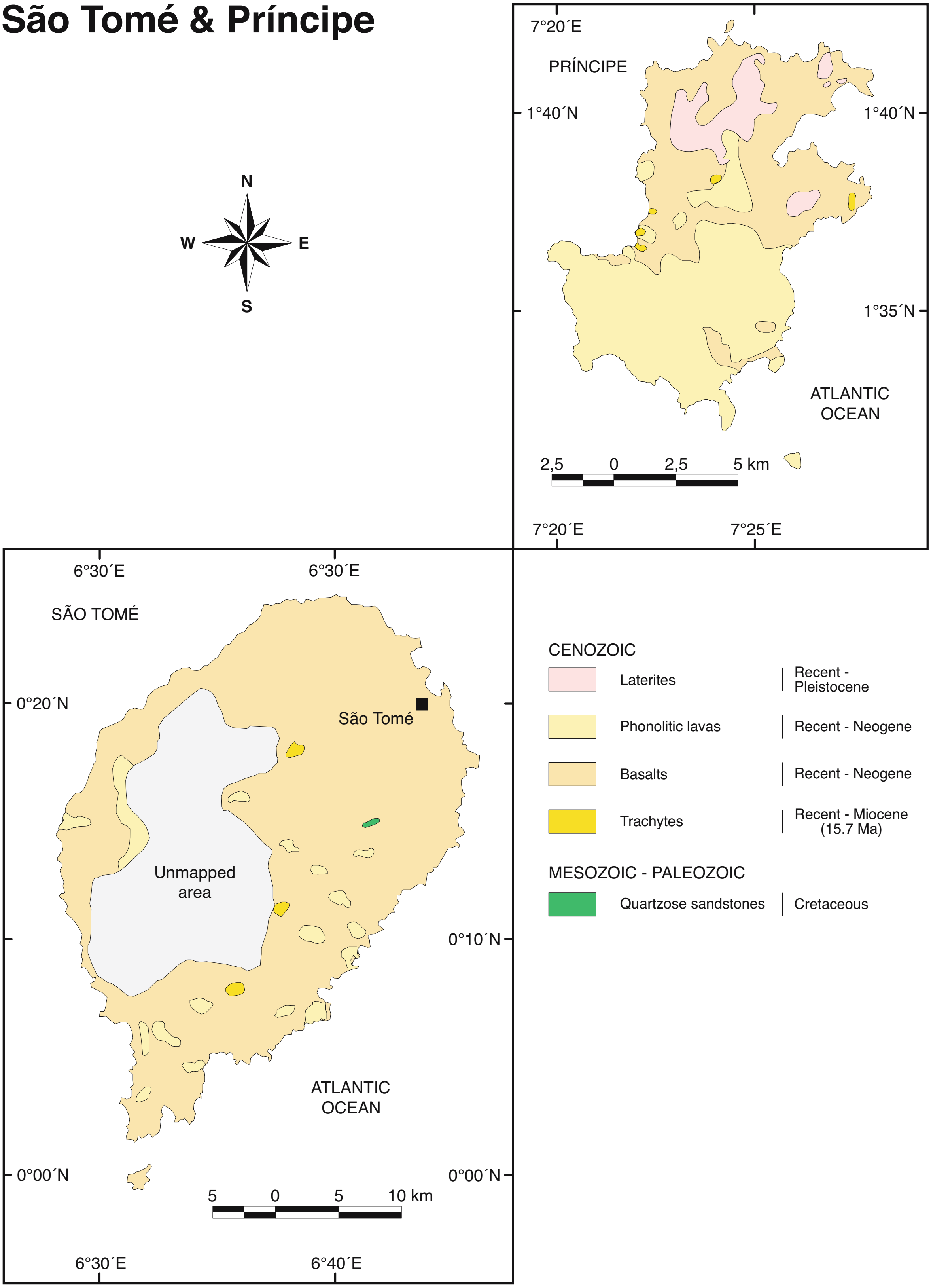

Fig. 179 Geological overview of São Tomé & Príncipe (modified after Caldeira et al., 2004)

Senegal

1 General

Area: 196,722 km²
Population: 9,987,000 (July 2000 estimate)

2 Summary of Geology

Senegal is dominated by two geological units: the Precambrian basement in the southeast of the country, including some sediments of Cambrian age, and a large sedimentary basin of Mesozoic to Recent age.

3 Stratigraphy and Tectonics

The Bassaride Orogen of eastern Senegal of Pan-african age constitutes a segment of a continuous orogenic terrane, which borders the western edge of the West African Craton. Two tectonic branches can be distinguished within the Bassaride Orogen of Senegal: The eastern one, called the Bassaris branch, has a NNE-SSW trend, while the western one, called the Koulountou branch, has a NE-SW trend. These two trenches are separated by the triangular Youkounkoun Basin. The Bassaris branch is separated from the West African Craton, represented by the Koudougou inlier, by the Paleozoic Youkounkoun, Mali and Batapa Groups. In the Kedougou inlier, Birrimian volcano-sedimentary rocks have been metamorphosed and intruded by granitic plutons during the Paleoproterozoic (2,000-1,800Ma) Eburnean Orogeny. Within these Birrimian formations three different series with a SW-NE trend can be distinguished: The Mako Series with metabasic rocks, metaandesitic breccias and greywackes; the Diale Series with metabasites, red jaspers, conglomerates, marbles, schists and micaschists; and the Dalema Series with schists, greywackes and conglomerates. The northern part of the Neoproterozoic Madina-Kouta Basin outcrops along the southern boundary of the Kedougou inlier in the extreme southeast of the country.

The Komba Basin is limited on its western side by the Kedougou inlier and the Madina-Kouta Basin, and on its eastern side by the Bassaris branch. Most of its sediments are almost horizontal and all rock infillings are probably belonging to the Lower Cambrian Mali Group. The Faleme Basin is the northern extension of the Komba Basin and represented by tillites, cherts and limestones.

The Senegal sedimentary basin, also known as the Senegal-Mauritania Basin, is the westernmost and largest marginal basin of West Africa: 340,000km², 1,400km from north to south, and 500km in its maximum width at the latitude of Dakar, for its onshore part. Because of the Oligocene to Recent sandy cover, the knowledge concerning the stratigraphy of the basin is mainly based upon data from oil and water exploration drillings. The overall structure of the basin is that of an "Atlantic type" passive margin halfbasin with a sedimentary infilling, which becomes thicker seaward, and consists of superposed prograding elementary wedges, a very weak, commonly westward, dip of the layers, with a more or less progressive slope of the substratum in the same direction, and an apparent transgressive character of the deposits westward and eastward, which is linked with oceanic spreading and subsidence. The pre-Mesozoic basement, which slopes gently westward in the onshore part of the basin, is downthrown to the west along a north-south fault between 15° W and 16° W meridians. It lies at a supposed average depth of 6,000m underneath Dakar and at more than 8,000m under the continental shelf of Casamance. This model becomes more complex southward because of the presence of ten salt diapirs, which pierce the sedimentary cover of the continental shelf of Casamance. Their upward motion started in early Cretaceous and still continues. Northward the basin is disturbed by several horsts and grabens, delineated by roughly north-south trending faults. This block-faulting and uplift tectonics occurred from the late Cretaceous to the late Miocene. Two main discontinuities affect the sedimentary cover. The older of Senonian age is visible offshore the Casamance and Dakar area, the younger, dated as Oligocene, is found all over the basin, and is characterized by an erosion gap. The sedimentary sequence begins with evaporites, such as halite, gypsum and anhydrite of Triassic to Liassic age. Their deposition apparently coincided with a phase of tholeiitic magma activity. The Jurassic (Callovian to Portlandian) consists of a 2,000m-thick sequence of carbonates. This stage continued with a higher occurrence of detrital elements up to the late Aptian (Fig. 181). From late Aptian to the Lutetian, a more extensive clastic sedimentation occurred in the basin. It is represented by fine argillaceous and organic matter-bearing deposits from Albian to Turonian, and by chemical to biochemical deposits since the Paleocene. The alkali syenite dome of Leona near Saint Louis was emplaced before the deposition of the "aquiferous sands of Senegal" during the Maastrichtian. After this

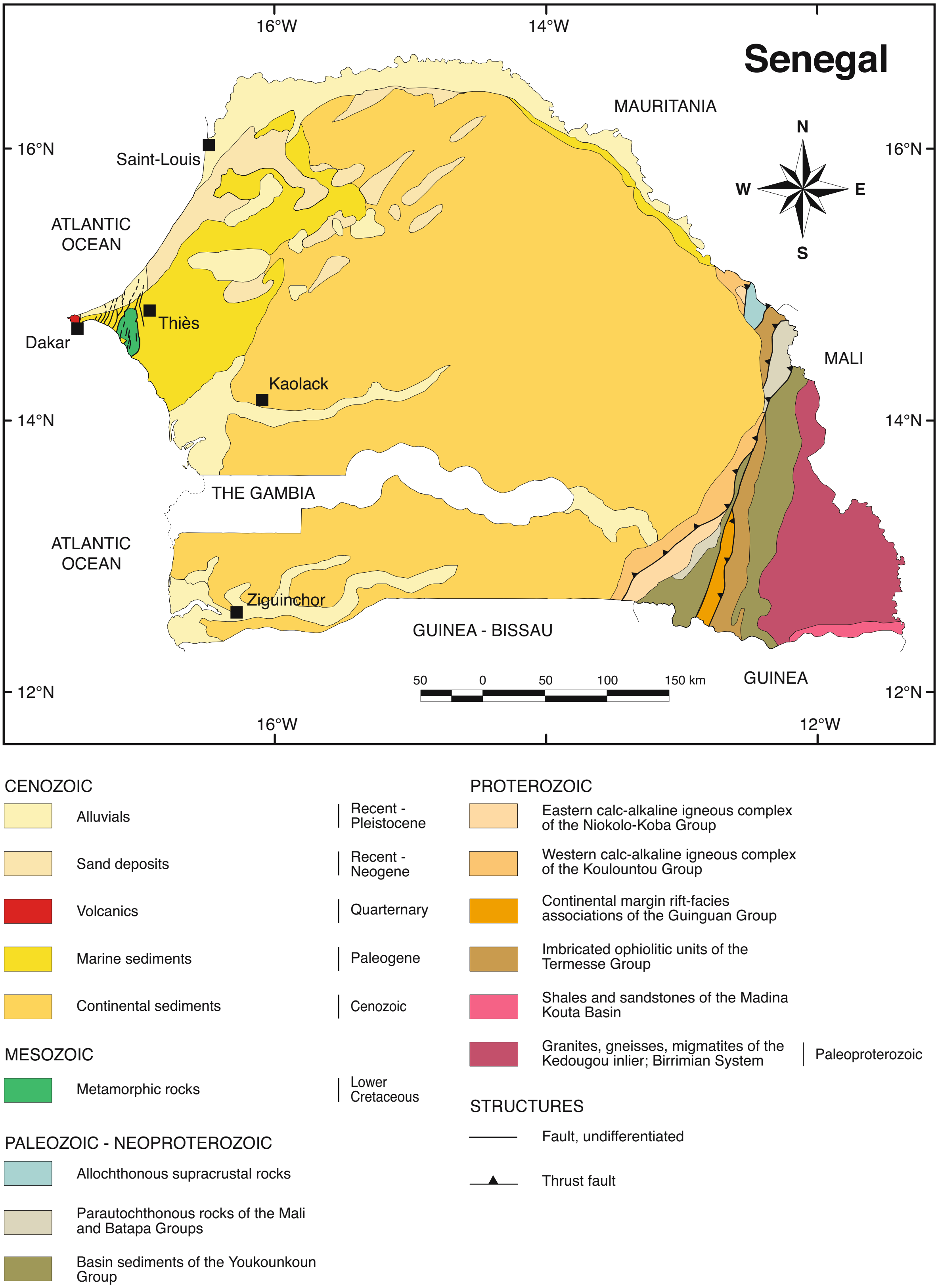

Fig. 180 Geological overview of Senegal (modified after Bellion & Guiraud, 1984, and Villeneuve et al., 1991)

Fig. 181 The oldest cement factory in Africa at Bargny near Dakar, where Cretaceous limestone is quarried (1964)

Fig. 182 Neogene clayey deposits with numerous large shells of Mollusca near Dakar

phase, which represents the major tectonic episode in the basin's history, and the general withdrawal of the sea, which only locally remained in the Casamance Gulf, the Senegal Basin experienced an essentially continental evolution, from the late Eocene to the Present. Such evolution is characterized by an intense ferralitic weathering and by volcanic events, which occurred in the Cap-Vert area, with two climaxes in the Miocene and Quaternary. The Miocene volcanism is represented by numerous small and scattered occurrences of alkaline and strongly undersaturated lavas. The Quaternary volcanism, which is confined to the head of the Cap-Vert peninsula, consists of a main complex volcanic edifice, the Mamelles volcano, of minor adjacent vents and of several sets of flows and tuffs, which are interbedded among generally azoic aquiferous sands (Fig. 183).

4 Economic Geology

The Paleoproterozoic formations of Senegal are comparable to those found in other parts of West Africa and have therefore a good potential for gold and a variety of other mineralisations. The gold potential of the Birrimian greenschist belts of southeastern Senegal is exploited by numerous artisanal mine workings in this region. The Faleme iron deposit, evaluated at more than 800 million tons of ore, is one of the largest in the Paleoproterozoic formations of West Africa. It is composed of magnetite and iron hydroxide grading between 55-60% Fe. The reserves of the Faleme deposit are located in three main sites (Koudekourou, Karakaene and Kouroudiaka) in carbonate rocks affected by a later intrusion of Paleoproterozoic calc-alkaline rocks. Diamonds have been found as placers in the beds of the Gambia and Faleme Rivers. Exploration of titaniferous sand deposits began in the late 1980s.Chemical sediment formation and the dynamics that were characteristic of the sedimentary basin of Senegal have been favourable to the precipitation of phosphates since the beginning of the Tertiary. The most important phospotic deposits have been formed during the middle Eocene. Phosphate accumulations are associated to a carbonate sedimentation near the high areas, along a NW-SE trend in the Thies and Taiba domains. At the end of the middle Eocene, the advent of a continental regime following a transgression has resulted in a continental alteration, which has transformed the lime phosphate into aluminium phosphate through an enrichment process. Senegal is generally endowed with large reserves of lime and aluminium phosphates of high market quality.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

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Fig. 183 Quaternary basalts at Cap Vert Peninsula near Dakar

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Seychelles

1 General

Area: 455 km^2
Population: 79,330 (July 2000 estimate)

2 Summary of Geology

The archipelago of the Seychelles lies in the western part of the Indian Ocean and comprises 41 granitic and 74 coralline islands, being part of a former micro-continent.

3 Stratigraphy and Tectonics

The basement of the Seychelles microcontinent comprises a suite of granites emplaced during the Neoproterozoic extension within the Gondwana Supercontinent. Granite is the bedrock of the main island Mahe and of the nearby islands of Praslin, La Digue, and Fregate. Mahe has three varieties of Neoproterozoic granites (about 755Ma), ranging from "grey granite" over much of the island to "pink granite" in the southwest, "porphyric granite" in the northwest and gneissose granodiorite in the far north. Pink granite is also exposed on Praslin, La Digue, Fregate and the adjacent smaller islands.

The first Gondwanan rift phase to affect Seychelles took place in the Late Paleozoic forming a series of elongated failed rift grabens. The second phase of rifting, during Triassic to Middle Jurassic, resulted in the deposition of at least 2,000m, and possibly as much as 6,000m, of clastic sediments along the western margin of the Seychelles microcontinent. Following the subsequent split of Gondwana, the Seychelles lay on the passive northwestern margin of eastern Gondwana upon which more than 1,000m of fine marine clastics were deposited as the Somali oceanic basin developed into the Early Cretaceous.

At about 120Ma the fragmentation of East Gondwana began. Initially Antarctica-Australia left Madagascar-Seychelles-India, then at about 100Ma (mid-Cretaceous) Seychelles-India began rifting from Madagascar, eventually separating at about 85Ma to form the intervening Mascarene oceanic basin. During the subsequent northward drift of Seychelles-India, the emergence of the Deccan hotspot at about 65Ma initiated the Carlsberg Spreading Ridge of the Arabian oceanic basin and completed the isolation of the elongate Seychelles sliver. Silhouette and North islands are early Tertiary (about 63Ma) alkaline plutonic-volcanic complexes. No sediments have been drilled in optimal locations in Seychelles, although thin sequences of Late Cretaceous coarse calcareous rift clastics and ensuing limestone and shale drift deposits were encountered in the wells on the western shelf of the plateau. Maastrichtian and/or Paleocene volcanics were observed in all four wells on the Seychelles Plateau, but their full tectonic significance has not yet been established.

Limited well samples indicate that source rocks accumulated in various depositional settings during each of the identifiable rift and drift tectonic phases that were responsible for the isolation of the Seychelles microcontinent. Best documented from this dataset are a variety of depositional environments that developed within and marginal to the paralic Tethyan gulf during the Triassic to Middle Jurassic and its descendant Middle Jurassic to mid-Cretaceous ocean basin, the Somali Basin. In addition, the very limited data available from the Late Cretaceous sequence suggest that source rocks possibly developed during both the Cenomanian-Santonian rift and the Campanian-Maastrichtian drift of the Seychelles from Madagascar.

The Seychelles microcontinent covers an area of approximately 300,000km^2 within the western Indian Ocean. Until Late Cretaceous this microcontinent was sandwiched between northern Madagascar and the western coast of India. The Mesozoic geology of the Seychelles evolved through three phases of rift/drift tectonics that included multiple periods of uplift, erosion and associated volcanism. The burial and thermal histories of the resultant sedimentary packages are therefore quite complex, and a thorough understanding of the relationship between time generation and time structuring is critical for a proper assessment of the prospectivity of hydrocarbons.

4 Economic Geology

Mineral production in Seychelles traditionally consisted mostly of unspecified quantities of construction materials, e. g. clay, coral, stone and sand. Output of guano, an organic fertilizer composed of bird droppings, ceased in the mid-1980s, but occasional small production was unofficially reported.

5 Geohazards

An inventory has not yet been made.

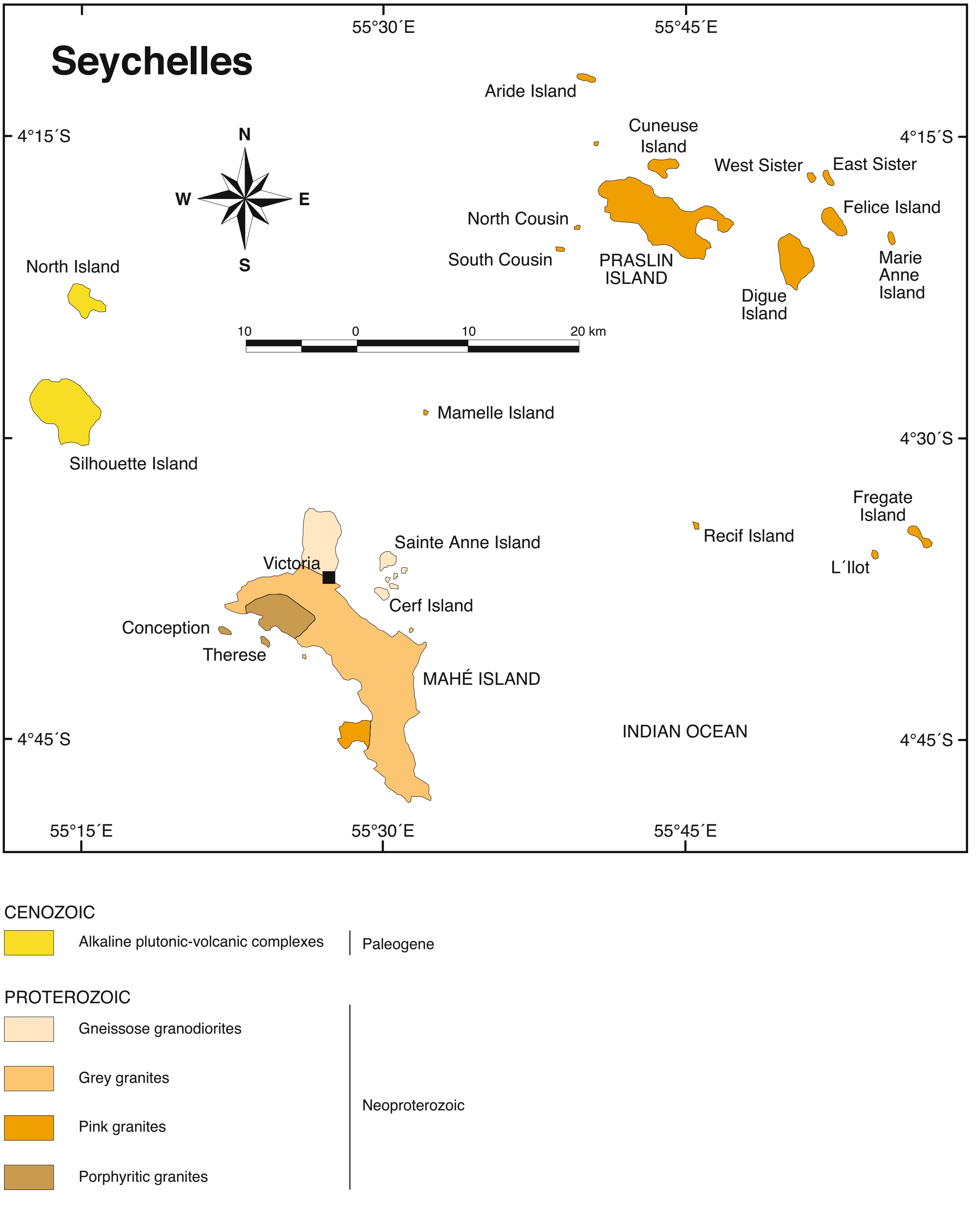

Fig. 184 Geological overview of the larger islands of the Seychelles (modified after Baker, 1963)

Fig. 185 Eroded grey granite along the coast of Mahe Island.

Fig. 186 Eroded pink granite from the southeast of Mahe Island.

6 Geosites

An inventory has not yet been made, but most of the islands are of special geoscientific interest because of representing a so-called micro-continent (Fig. 185 and 186).

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Sierra Leone

1 General

Area: 71,740 km²
Population: 5,233,000 (July 2000 estimate)

2 Summary of Geology

Sierra Leone is divisible into two major tectono-stratigraphic units. The eastern one is part of the stable Precambrian West African Craton and consists of high-grade metamorphic rocks and granitic gneisses. The western unit contains the elements of an orogenic belt named the Rokelides that was deformed during the Pan-African tectonothermal event, about 550Ma ago. A 20-40km wide coastal strip is made up of Pleistocene to Recent sediments.

3 Stratigraphy

Archean rocks are well developed in the eastern half and partly the west of Sierra Leone, constituting the Kenema-Man domain, which is also outcropping in neighbouring Guinea and Liberia and in southwestern Ivory Coast. The Kenema-Man domain is characterized by relic zones of supracrustal rocks occurring as greenstone belts, mainly forming synclinal structures amid granitic gneisses and autochthonous and parautochthonous granitoids. In western Sierra Leone the greenstone belts are large, up to 130km long with thick successions (up to 6,500m), and metamorphosed to amphibolite grade. Banded ironstone (BIF) is a minor lithological character. In southeastern Sierra Leone the schist relics are smaller (up to 40km long) with thinner stratigraphic successions, in which banded iron formations are dominant. The metamorphic grade is variable, both within belts and between belts, from greenschist to granulite facies. The type area of the Kenema assemblage in central Sierra Leone comprises granites and acid gneisses, granulite facies rocks, and greenstone belts of schistose sediments and volcanics. In the northeast of the country two separate suites of a greenstone belt have been distinguished in the Kenema assemblage. The older suite is represented by the Loko Group of the Kamokwie area and is composed of amphibolites with subordinate serpentinites, quartzites and banded ironstones. It was deformed and metamorphosed during the Leonean tectonothermal event dated at about 2,960Ma. The younger suite, termed the Kambui Supergroup, consists of a lower volcanic formation, which includes massive pillow lavas of basic (amphibolitic) and ultrabasic (serpentinite) composition, overlain by tuffs, psammites, pelites and banded ironstones. These rocks were deformed and metamorphosed during the Liberian tectonothermal event dated at about 2,750Ma. Deformation during the Leonian event was along E-W axes and during the Liberian event along N-S axes.

The term "Rokelide Orogen" was proposed for the orogenic belt in Sierra Leone that was deformed during the Pan-African tectonothermal event, about 550Ma ago. It extends some 600km from western Guinea along coastal Sierra Leone into Liberia. The Kasila Group represents a linear belt, no more than 30km wide, of high-grade supracrustal rocks of Archean age, which were reworked during the Pan-African Orogeny. It consists mostly of acid gneisses in the granulite facies, charnockites, garnet-hornblende gneiss and garnet-plagioclase gneiss, and, in places, hornblendite and pyroxenite. To the east of the Kasila Group, low-grade supracrustal rocks of the recumbently folded Marampa Group overlie granitic terranes and are probably in fault contact with Rokel River strata. The Marampa Group contains ironstone, mafic to felsic volcanic rocks and derived volcanogenic sediments that are similar to greenstone belt lithologies seen to the east within the Kenema Assemblage. The rocks of the Marampa Group were originally formed about 2,100Ma ago, their Pan-African deformation was dated at about 560Ma. The Rokel River Group comprises the easternmost domain in the Rokelide orogenic belt in Sierra Leone. It occupies a belt some 30km wide and 225km long and is subdivided into 10 different units (Culver et al., 1991), which are named as follows: Tibai Member, Taban Member, Dodo Member, Teye Formation, Mabole Formation 1, Taia Formation 1, Kasewe Hills Formation, Taia Formation 2 and Mabole Formation 2. Generally these units are comprised of marls, quartzites, sandstones and volcanic rocks. There are no direct geochronological data available for the Rokel River group, but its basal glacigenic deposits can be correlated with similar strata in Senegal and Mauritania, which are generally accepted to be Neoproterozoic in age.

The peninsula of Freetown is made up of Mesozoic basic intrusives.

The Bullom Group comprises a 20-40km wide strip of Cenozoic sediments along coastal Sierra Leone.

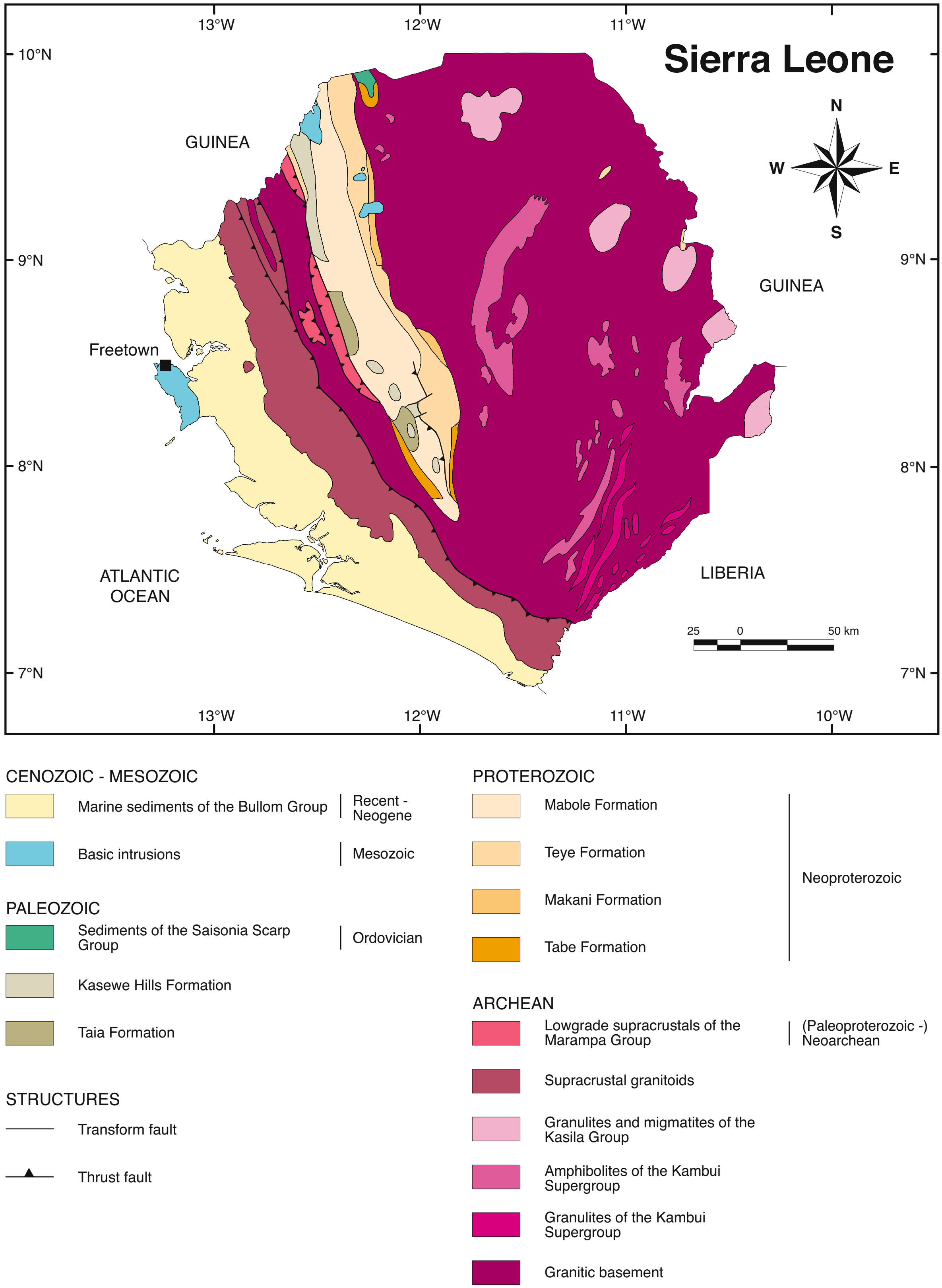

Fig. 187 Geological overview of Sierra Leone (modified after Anonymous, 1960)

4 Tectonics

Sierra Leone is structurally divisible into two units, which correspond almost exactly with the two morphological units. The main strike of foliation in the eastern unit is NE-SW, extending far into the African continent and being the main component of the West African Craton. The western structural unit corresponds with the coastal plain, trending NNW-SSE and being oblique to the grain of the central highlands.

5 Economic Geology

Before the civil war broke out in the mid-1990s, the production and export of various mineral commodities, particularly rutile and ilmenite, bauxite, diamonds and gold (Fig. 188) sustained Sierra Leone‘s economy. Political turmoil caused an almost total decline of all mineral exports, except illegal trading of diamonds for the provision of arms.

Fig 188 Open cast gold mine at Baomahun near the Kangari Hills Forest Reserve

6 Geohazards

An inventory has not yet been made.

7 Geosites

An inventory has not yet been made.

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Socotra (Yemen)

1 General

Area 3,650 km^2
Population: ?

2 Summary of Geology

Socotra is the largest and most easterly of a group of islands, which includes Abd-Al-Kuri, Semha (Fig. 190) and Darsa. It lies some 250km ENE of Cape Gaurdafui at the northeastern tip of Somalia, and some 380km SSE of Ra‘s Fartaq, the nearest point on the south Arabian coast. It is made up mainly of Precambrian rocks and Cretaceous to Tertiary sediments.

Fig. 189 View of coastal Socotra.

3 Stratigraphy and Tectonics

Precambrian basement rocks crop out in three main uplift areas. Elsewhere they are overlain by a veneer of Cretaceous and Tertiary plateau limestones. The oldest basement rocks are amphibolite facies metasediments and metaigneous rocks, which have been intruded by syn-kinematic granites and late-kinematic gabbros. Younger weakly metamorphosed tuffs and mudstones also occur. Post-kinematic igneous activity gave rise to a sequence of volcanic rocks, hornblende/biotite and peralkaline granites, gabbros and minor intrusions, which make up the bulk of the Haggier Mountains. After a long period of basement formation, sediments were deposited, which consist of Lower and middle Cretaceous limestones, with some basal sandstones, followed without apparent break by cliff-forming shelf limestones of Paleocene to Eocene age. Oligo-Miocene calcareous deposits are only preserved in structural depressions. Vertical movements were predominantly responsible for the structure, which is simple in the east but dissected by WNW-ESE block faulting in the west. Correlation with southern Arabia and Somalia suggests that the metamorphic basement is Precambrian and the post-kinematic igneous rocks are early Paleozoic. The sedimentary formations broadly correlate with those of southern Arabia and the Oligo-Miocene deposits in particular are most closely related of Dhufar.

Fig. 190 The peak of Semha Island.

4 Economic Geology

Off- and on-shore drilling for hydrocarbons over the last decades was apparently not yet successful. Other significant mineral resources are unknown, but building materials are mined locally.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

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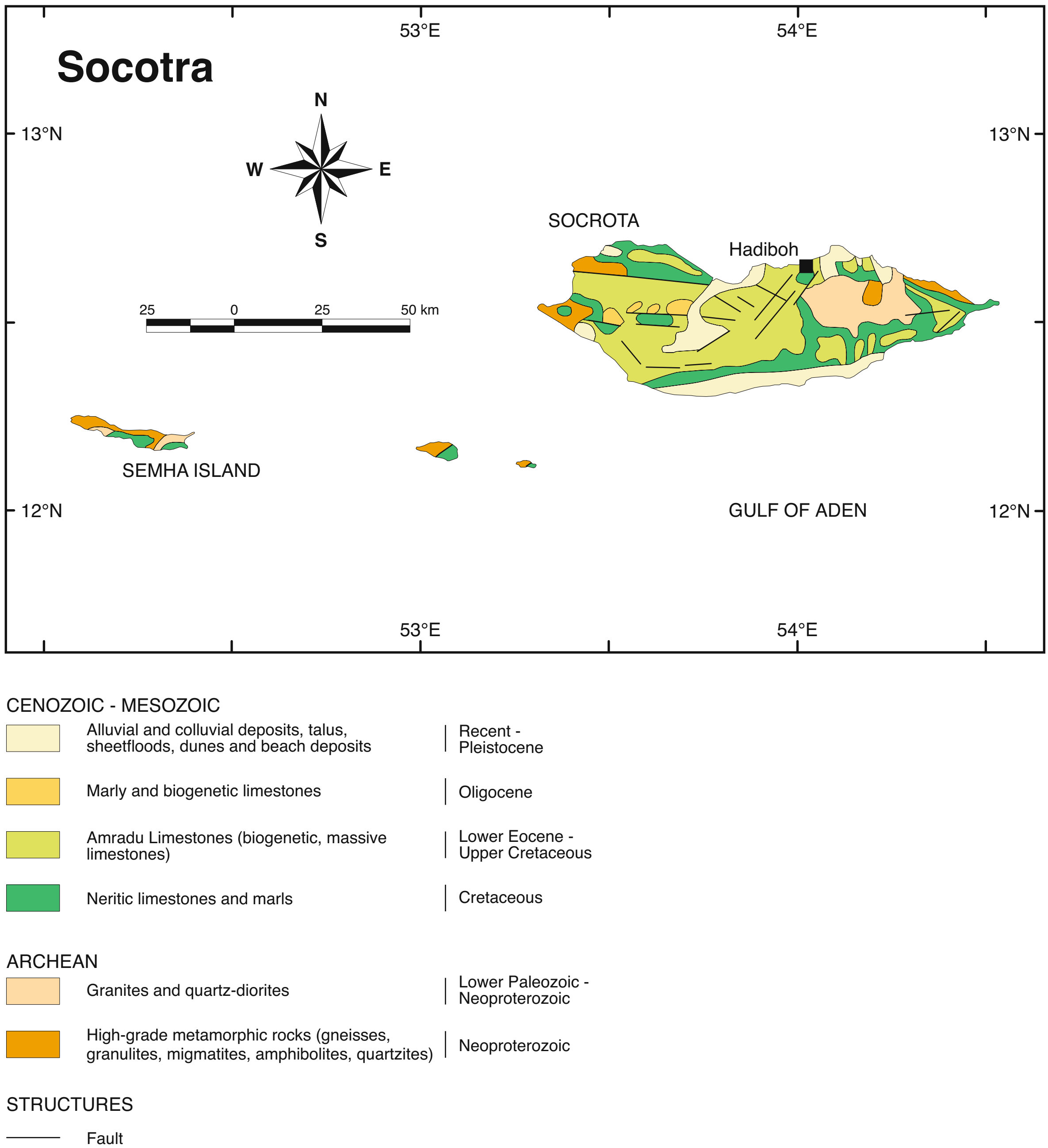

Fig. 191 Geological overview of Socotra (modified after Merla et al., 1973)

Somalia

1 General

Area: 637,657 km²
Population: 10,650,000 (2001 estimate)

2 Summary of Geology

Conventionally, Somalia is geologically subdivided into two regions, namely the one in the northern part of the country, which comprises mostly crystalline basement rocks and minor parts of a sedimentary succession, and the one in its southern part, which consists of two Phanerozoic basins, sandwiching an elliptical area also of crystalline basement rocks.

3 Stratigraphy

The northern Somali crystalline basement consists of seven major rock complexes, five of which are mainly metasedimentary sequences with some meta-igneous intercalations, while two are plutonic complexes. The metasedimentary complexes are named as follows: 1. Qabri Bahar complex; 2. Mora complex; 3. Abdulkadir complex; 4. Mait complex; 5. Inda Ad complex. The first two units make up the medium- to high-grade, polymetamorphic basement of northern Somalia. The Abdulkadir and Mait complexes are composed of greenschist-facies, volcano-sedimentary sequences and are exposed in the western and central part of the northern Somali crystalline basement, respectively. The Inda Ad complex is a low- to very low-grade, essentially metasedimentary sequence, located in the eastern part of the northern Somali crystalline basement. The igneous plutonic complexes comprise the following two units: 1. The Gabbro-Syenite belt and 2. The Younger Granites. Layered gabbros occur systematically associated with (rarely nepheline-bearing) syenites, however, probably not belonging to an ophiolite suite, but apparently reflecting intracrustal magmatic activity, perhaps related to an underplating event and probably developed under extensional conditions. Two different groups of granitoids are included within the Younger Granites: 1. Foliated granites: Their foliation is well developed in the outer part of the granitoid bodies, but may be weak or lacking in the inner parts; 2. Unfoliated granitoids representing, with their aplitic and pegmatitic dykes, the youngest plutonic rocks in the northern Somali crystalline basement.

The northern Somali crystalline basement records a complex history of deformational, igneous and metamorphic activity, which may be subdivided into four major events. Major Event I (Paleo- to Mesoproterozoic) is only recorded by relics of granulite-facies metamorphism and basic and granitoid protoliths, from which rocks of the Qabri Bahar complex were derived. It may represent the vestiges of a pre-Pan-African continental crust. Major Event II (older than about 700Ma) includes amphibolite-facies metamorphism, anatexis and associated deformation. The emplacement of post-tectonic granitoids was also referred to this event, but it could also be referred to Major Event III. Major Event III (about 700-640Ma) includes crustal thinning, extension and aborted lithospheric rupture, deposition of a Neoproterozoic sequence with basic volcanic activity in the Abdulkadir and Mait complexes, and related emplacement of the Gabbro-Syenite suite through the thinned crust, followed by regional heating and metamorphism. Major Event IV (about 600-500Ma) includes emplacement of granites, deposition of the Inda Ad sequence, a further thermal pulse with regional heating accompanied by deformational activity and finally emplacement of granites. The northern Somali crystalline basement represents apparently not a juvenile Pan-African terrain but a composite basement. Its eastern part consists of juvenile terranes (the Inda Ad and Mait complexes), whereas the western part consists of pre-Pan-African crust, which was affected by igneous and metamorphic processes at about 840Ma, about 800-760Ma and about 720Ma, respectively. The Pan-African sequence of events was controlled by dynamic and thermal processes related to crustal thinning and took place at the same time in which, farther north in the Arabian-Nubian Shield, subduction-related magmatism led to the formation of intraoceanic island arcs and marginal basins.

The sedimentary succession of northern Somalia can be subdivided into two main depositional sequences: 1. A Jurassic to Early Eocene sequence and 2. A Middle Eocene to Neogene sequence. The first one is related to events along the East Africa-Arabia continental margin, resulting from the dismembering of Gondwana. Deposition began in Early Jurassic, when the Tethys flooded this continental area from the northeast. After a Cretaceous upwarping, testified by the continental Yesomma Sandstones in the northwestern part of the country, the sequence ended with an Early to Middle Eocene regional transgression. The Middle Eocene to Neogene sediments were

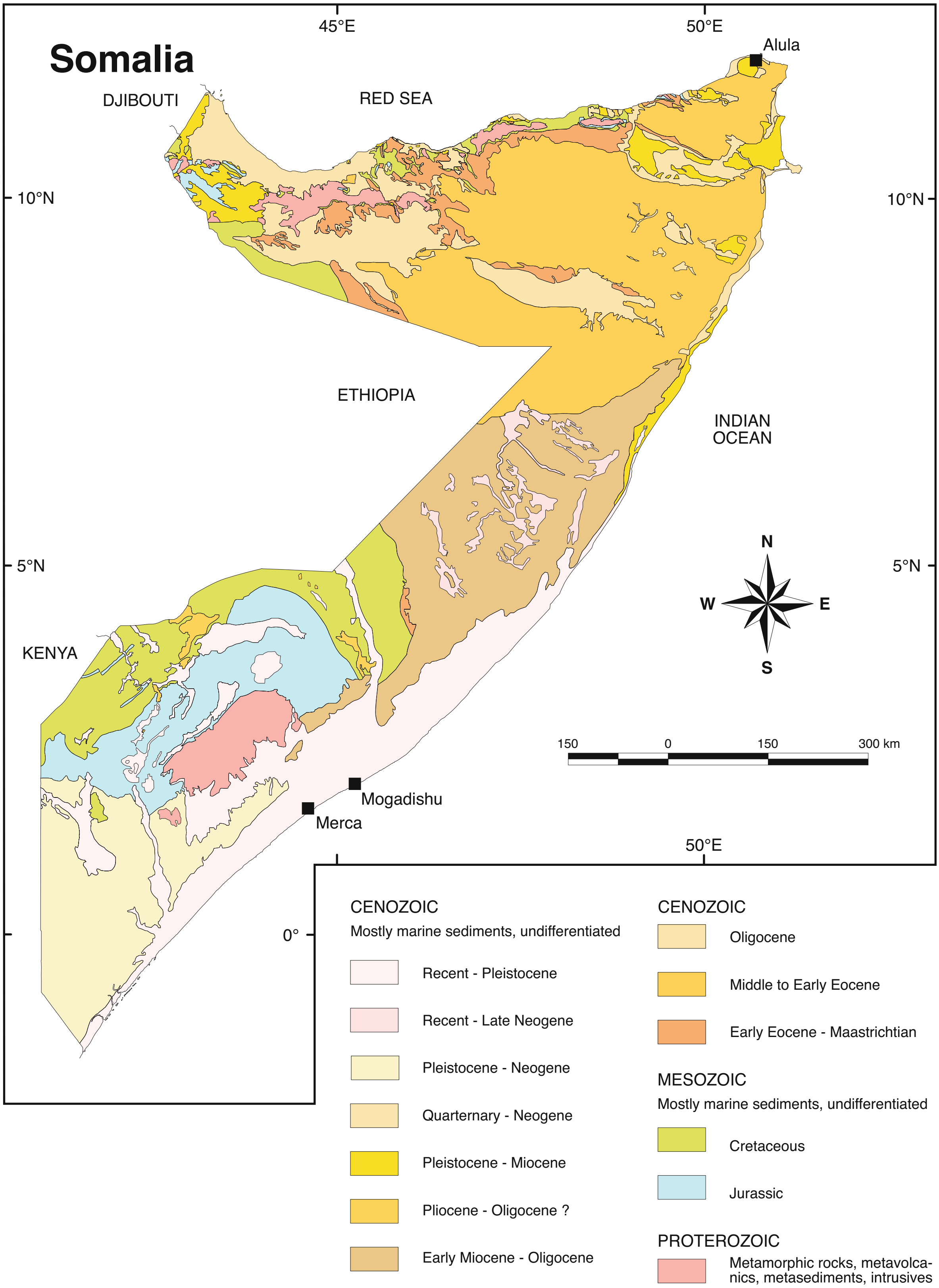

Fig. 192 Geological overview of Somalia (modified after Merla et al., 1973)

deposited during the development of the northern Somalia continental margin and the opening of the Gulf of Aden. Continental or brackish marine deposits occur in more or less confined basins bordering the rising Somali Plateau (Fig. 193). The outcropping sequences are limited to the coastal region and are only preserved in places, but offshore Middle to Late Tertiary sediments reach a thickness sometimes >2km and are related to rapidly faulted basins.

Two main sedimentary basins can be recognized in southern Somalia: The NE-SW trending Mesozoic-Tertiary Somali Coastal Basin in the northeast and the NNE-SSW trending Luuq-Mandera Basin in the southwest. These two basins, where the top of the underlying basement is as deep as 5000m or more below sea level, are separated by the so-called "Bur Region", a wide elliptical area, where the basement rises to the surface.

The crystalline basement of the Bur Region covers an area of about 30,000km^2, but outcrops only locally in isolated and relatively small hills. Most of this region is covered by a thin (1-30m) veneer of recent residual sediments. The Bur crystalline basement is made up of two units: The Olontole Complex and the Dinsor Complex. The Olontole Complex consists of migmatites, gneisses, granulitic amphibolites and quartzites, all of them cross-cut by injected granitoid bodies. The Dinsor Complex partly consists of metapelitic and metapsammitic high-grade sequences and migmatites, and partly of quartzites, iron-rich quartzites and marbles. Injected granitoid bodies also cross-cut this series. Rb-Sr whole rock isochrons indicate a lower Paleozoic age for the younger granites. The youngest rock-producing process in the Bur Region therefore belongs to the Pan-African.

The NE-SW trending Coastal Basin consists of a more than 7000m thick succession of Jurassic to Recent calcareous, marly and terrigenous units, sometimes intercalated by Cretaceous and Lower Tertiary volcanic episodes (Fig. 194). The succession is known exclusively by means of geophysical prospections and drillings for oil exploration, which, however, have not reached the basement. The environmental and structural development of this basin is strictly related to the birth of the Indian Ocean and the relative motions of India, Madagascar and East Africa.

The NNE-SSW trending Luuq-Mandera Basin consists of a Late Triassic to Early Cretaceous succession, whereby the Late Triassic to Early Jurassic clastic, evaporitic and carbonate materials have only been found by drilling for oil exploration. Early to Middle Jurassic carbonate and shaly sediments are associated with a marine transgression, which started during the Liassic in the Arabian-Madagascar arm of the Tethys. Open sea environments are indicated by the deposition of marls with ammonites during early Toarcian. Middle to Late Jurassic strata, possibly extending up to Early Cretaceous, consist of shaly, carbonate and clastic sediments. Pelagic faunas with ammonites and belemnites of Callovian to Early/Middle Oxfordian age indicate an open but quite shallow epicontinental sea environment.

Fig. 193 Red and green siltstones in playa mud-flat deposits, Daban Basin, northern Somalia.

4 Tectonics

Rifting of the Arabia-Somali Plate began in Oligocene and the uplift of the plateau margin was substantially achieved at the end of Oligocene and the beginning of Miocene, with the exception of later, minor fault renewals. In the Gulf of Aden contemporarily intense stretching and magmatic intrusions occurred, giving rise to the formation of a belt, which is characterized by a 100km long quiet magnetic zone. Sea-floor spreading started during Late Miocene. It is likely that the Gulf of Aden developed in the eastern termination of a belt of crustal weakness, which runs longitudinally from the Gulf of Guinea to the Indian Ocean. The Arabian and Nubian plate motion was oblique to this weakness zone and produced en échelon ESE-WNW fractures, followed by subsiding basins and active clastic sedimentation.

5 Economic Geology

Somalia's mineral output is an insignificant part of its economy. The mining sector remains marginal and

Fig. 194 Mesozoic limestones in coastal southern Somalia.

Fig. 195 Mesozoic limestones being prepared as building materials in coastal southern Somalia.

largely undeveloped. Gypsum, limestone, sepiolite and sea salt were probably the only minerals produced in recent years of political turmoil. Locally some stone, sand and gravel for construction may have also been mined (Fig. 195). However, a variety of other potentially economic mineral deposits are known to exist in many parts of the country. Also oil exploration, which in the 1980s was still the most active sector in the mineral industry, has largely ceased following the civil war.

6 Geohazards

An inventory has not yet been made.

7 Geosites

An inventory has not yet been made, but the civil-war torn country offers many places of scenic beauty, especially along the coast and in the interior desert region.

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South Africa

1 General

Area: 1,219,912 km^2
Population: 44,300,000 (2001 estimate)

2 Summary of Geology

South Africa's diverse rock formations span almost the entire range of the geological time scale and include some of the world's best-preserved and most typical examples. Large parts of the country are underlain by Precambrian rocks, including the Barberton and Murchison Belts, the Limpopo mobile belt and the Witwatersrand Supergroup, all of which are of Archean age. For the Transvaal Supergroup, the Bushveld Complex, the Vredefort Dome (an ancient meteorite impact structure) and the Waterberg (Mokolian) Supergroup a Paleoproterozoic age has been assigned. The Namaqualand Metamorphic Province is of Mesoproterozoic age. The lower Paleozoic is characterized by sediments and granites that were folded into the Cape Fold Belt. Approximately two-thirds of South Africa's surface is covered by rocks of the Paleozoic to Mesozoic Karoo Supergroup, comprising mainly continental clastic sediments and volcanics. Several alkaline complexes, carbonatites and kimberlites, have intruded the Precambrian and Karoo strata. Cenozoic terrestrial and fresh water sediments, mainly sands of the Kalahari Group, cover large parts of northwestern South Africa along the borders with Botswana and Namibia.

3 Stratigraphy and Tectonics

The oldest rock formations of South Africa are of Archean age and constitute the Kaapval Craton, an ancient nucleus of continental crust that has remained relatively undisturbed for about 3,500-2,500Ma. These basement rocks consist mainly of large masses of granite, which have intruded into the older greenstone belts of volcanic and sedimentary composition. This ancient granite-greenstone terrane extends from northern Natal and Swaziland to the Soutpansberg, and underlies most of the country known as the Lowveld. Similar rock formations extend west through Pietersburg and also comprise most of the Limpopo valley, north of the Soutpansberg. Oval or circular domes of the granite-greenstone basement occur elsewhere as isolated exposures, surrounded by younger rocks. Examples include the Makoppa Dome along the Botswana border, the Johannesburg Dome between Pretoria and Johannesburg and the Vredefort Dome southwest of Johannesburg. The Barberton Mountain Land epitomizes the granite-greenstone terrane of South Africa, giving rise to a rugged mountain range that extends from the Mozambique border at Komatiport in the east to the Mpumalanga Drakensberg escarpment near Kaapschehoop in the west. Close to the northern flank of the Barberton Greenstone Belt, a younger granite body (about 2,600Ma old) has been eroded by the Crocodile River. Some 250km north of the Barberton Greenstone Belt lies the Murchison Greenstone Belt, which is well mineralized with antimony, gold, base metals, mercury, emeralds, vanadium and titanium. The Pietersburg Greenstone Belt in the northwest of the Murchison Greenstone Belt has yielded the first discovery of gold in the former Transvaal Republic. Rocks of the Limpopo Belt, which runs parallel to the borders of Zimbabwe and Botswana, also form part of the Archean basement and are gneissic and migmatitic in nature. After formation of the basement, sedimentary basins with associated volcanic rocks developed. The Witwatersrand Basin contains a sequence of quartzites, conglomerates and shales, which are about 3,000Ma old. These deposits have been largely covered by younger sediments and generally outcrop only when they have been exhumed by uplift and erosion. The gold in the sedimentary rocks of the Witwatersrand Basin occurs as minute grains in narrow pebble bands of conglomerate layers called 'reefs'. Rocks that are similar in nature and age to the Witwatersrand beds outcrop fairly extensively in the Pongola area of northern KwaZulu-Natal, but do not contain significant gold mineralisation. The Witwatersrand sediments, as well as much of the country between Kimberley and Mafikeng, were subsequently covered by huge volumes of lava flows of the Ventersdorp Supergroup, formed about 2,700Ma ago, which sometimes also contain economic gold concentrations.

During Neoarchean and Paleoproterozoic times (2,600-2,250Ma) large parts of the Kapvaal Craton were inundated by an inland see, and the Ventersdorp lavas and other older formations were covered by a widespread sequence of sediments of the Transvaal Supergroup. These rocks were deposited in a huge sedimentary basin lying roughly between Mafikeng in the west, Nelspruit in the east, Pietersburg in the north, and Vredefort in the south. A similar basin, the Griqualand West Basin, lies between Vryburg and Prieska in the North West and Northern Cape provinces. The Paleoproterozoic Bushveld Complex represents the world's largest layered intrusion and

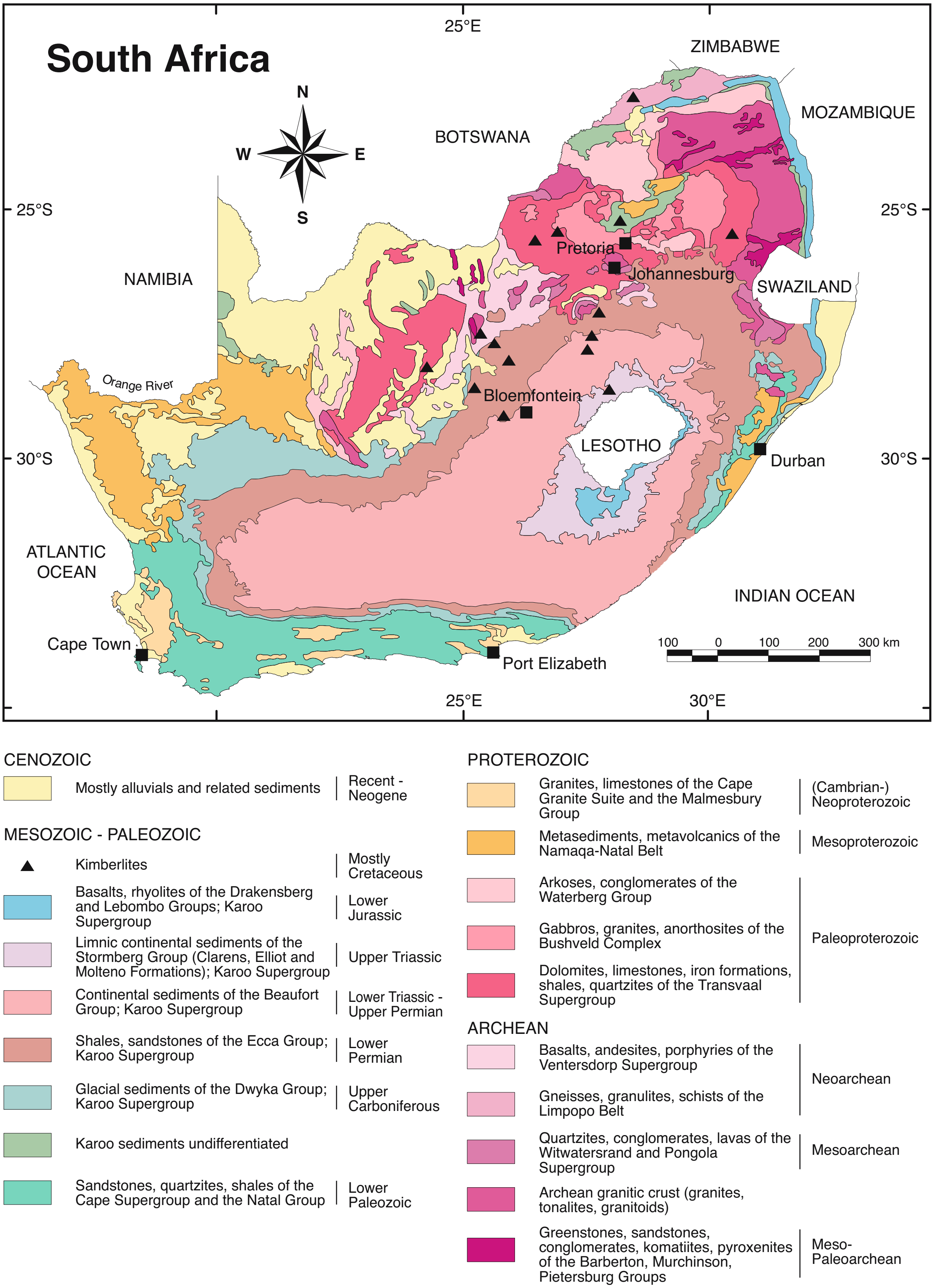

Fig. 196 Geological overview of South Africa (modified after Macrae, 1999, and Viljoen & Reimold, 1999)

occupies the area between the Pilanesberg Volcano in the west, Lydenburg in the east, Pretoria in the south, and Potgietersrus in the north. Associated with the complex are a number of smaller adjacent bodies, as well as sills that have intruded into rocks of the Transvaal Supergroup. As the Bushveld magma cooled slowly, minerals of different composition and crystallisation temperatures formed and had time to settle through the liquid magma or float to the top. This gave rise to the remarkably continuous layers of differing mineral composition of the Bushveld Complex. For instance it contains discrete layers of the platinum group elements, copper, nickel, chromium, vanadium and titanium. Some 35 million years after the emplacement of the giant Bushveld Complex, at about 2,020Ma, the central part of the Kapvaal Craton was slammed by a huge meteorite. This site, which is now marked as the Vredefort Dome, is characterised by an uplifted core of basement rocks, which are surrounded by overturned sedimentary rocks. About 1,800Ma ago parts of the Bushveld Complex, the Transvaal Supergroup and the basement rocks were covered with sediments of the Waterberg Group, comprising mainly quartzites, arkoses and conglomerates. The largest portion of Waterberg rocks lies in the western part of the Northern Province. Little geological activity succeeded in the northern and eastern parts of South Africa till the formation of the large Karoo Basin. Minor volcanic activity is marked by the intrusion of the Pilanesberg alkaline volcanic complex and the Premier Kimberlite Pipe east of Pretoria during Mesoproterozoic times. In contrast, the southern and western parts of South Africa are characterised by crustal instability and geological activity persisted throughout the Precambrian. The Namaqualand Metamorphic Province in the west of the country forms part of the Namaqua-Natal Belt, which is adjacent to the much older Kapvaal Craton. The Bushmanland Craton was formed by an orogenesis about 1,750Ma ago, and the sedimentary and volcanic rocks of the Bushmanland Group were deposited between 1,600 and 1,400Ma ago. The sedimentary rocks, which have been metamorphosed into a variety of gneisses, schists and quartzites, host a cluster of lead, zinc and copper deposits located some 60km west of the town of Pofadder. In the eastern part of Namaqualand, volcanic rocks were intruded along a zone of rift faults close to the interface between the Kapvaal Craton and the Namaqualand terrane. These now metamorphosed rocks also host a number of base metal deposits.

From Phanerozoic times onwards, geological activity shifted to the southern and southwestern coastal areas of South Africa. A chain of basins formed into which were deposited a variety of sedimentary rocks, including the Malmesbury Group, about 600Ma ago. These sediments were subsequently intruded by the Cape Granites, which contain tin and tungsten. A series of shales, sandstones and conglomerates was deposited on the partially eroded Cape Granites, about 500Ma ago, which extend from the vicinity of Vanrhynsdorp on the West Coast to beyond Port Elizabeth in the east and give rise to the spectacular mountain ranges that make up the Cape Fold Belt. In the southwestern Cape, the Table Mountain Group overlies the Cape Granites. The contact between the granite and the sedimentary rocks can be seen in a number of places around the Cape Peninsula. Rocks correlated with the Cape Supergroup also occur in Natal, where they overlie the rolling hills of older granite in the form of flat, tabular strata, mainly composed of quartzite.

About two-thirds of South Africa are covered by sedimentary and volcanic rocks of the Karoo Supergroup, spanning the time period from about 300 to 140Ma ago. The succession is best developed in the main Karoo Basin, which extends from Touwsrivier in the Western Cape to Witbank in Mpumalanga over a distance of almost 1500km. The sediments of the Karoo Supergroup record a changing geological environment and the migration of Gondwana from polar to tropical latitudes over a period of more than 150 million years. Sedimentation commenced with extensive deposits of glacial debris, known as the Dwyka Tillite, which can be seen in many localities from Namibia in the west to the Klein Karoo in the southwest, KwaZulu-Natal in the southeast, and the area between Vredefort, Vereeniging and Middelburg in the north-central parts of the country. The Dwyka Group, bearing testimony to the presence of former huge ice sheets, was deposited when South Africa was migrating over the South Pole. After the ice sheets waned and disappeared, the shales and sandstones of the Ecca Group were deposited in a vast, shallow, landlocked sea. During Ecca times, the northeastern part of the Karoo Basin - in southern Mpumalanga and northwestern KwaZulu-Natal - was covered in many places with impenetrable forest or swamp. As this vegetation died and became submerged in the swamps, chemical processes converted the vegetable matter into coal. The Ecca Group coal measures constitute more than a third of all coal reserves found in the Southern Hemisphere and provide the main source of energy in South Africa. The succeeding Beaufort Group sediments were deposited mainly on extensive river flood plains in a warmer and drier climate. The Beaufort rocks are famous for their amphibian and reptile fossils, whereas the upper Triassic Molteno Formation contains a rich plant and insect lagerstaette, preserved in shallow lake sediments. The Karoo succession was terminated by the eruption of vast volumes of basaltic lava of the

Drakensberg and Lebombo Groups, which heralded and accompanied the break-up of Gondwana. Large areas of South Africa were covered by these flood basalts, which have now been mostly removed by erosion. The numerous individual lava flows may reach a thickness of 1400m and can be clearly seen in the KwaZulu-Natal Drakensberg Escarpment and also in the Lebombo Mountains, along the border to Mozambique.

Pipe-like intrusive bodies, which in most cases represent the root zones of ancient volcanoes of various ages, abound in South Africa. The most important are several kimberlite pipes and fissures, which were intruded during mid- to late-Cretaceous, following the break-up of Gondwana. Kimberlite is the main host for diamonds, but weathers easily, and the pipes are generally poorly exposed. The best known kimberlite, now mined out and manifested as a spectacular pit, is the "Big Hole" at Kimberley.

Geologically younger deposits, ranging in age from Cretaceous to Recent times, abound also in South Africa. These include the Kalahari Group sediments, coastal, shallow marine and lagoonal sediments, as well as present and ancient river terraces.

4 Economic Geology

For more than 100 years, minerals have been the base of South Africa's economy. The country is the world's leading producer of precious metals (gold and platinum-group metals) and important steel making metals, chromium and vanadium, and ranks among the top producers of diamonds, iron ore, manganese, coal, titanium, and zirconium. Sales of minerals and mineral products contribute for about 16% of the gross domestic product. Only small reserves of petroleum and natural gas exist, but offshore exploration for these commodities is continuing.

South Africa is still the leading producer of gold, with an output about twice as much as the next largest producer, the USA, though the production is in decline. Gold was first mined on a large scale from the Pilgrims Rest-Sable gold deposits in eastern Transvaal in 1872. Quartz-pyrite reefs, cross-cutting veins, sausage-like swellings in stratiform quartz veins and gold impregnations were the primary types of mineralization. Stratified gold veins are hosted by the Malami Dolomite, the upper Wolkberg Group, the Black Reef Quartzite and the basal 1,700m of the Pretoria Group. Mineralizing fluids concentrated the auriferous ores by migrating through conformable passageways created by intrastratal tectonic movements, which also produced slickensided surfaces around the reefs, offset dykes, as well as non-penetrative cleavage in the shaly rocks. These banded reefs extend up to 10km along strike. Mineralogically, the reefs consist of early-phase quartz, carbonates and pyrite with some scheelite, arsenopyrite, pyrrhotite, sphalerite and galena. Gold and chalcopyrite represent a later mineralization. In addition to gold, byproducts such as silver, copper, arsenic, bismuth and pyrite are mined (Fig. 197).

Fig. 197 Aerial view of Harmony Mine, where gold production began in 1954 down to a depth of 3,300m

South Africa continues to be the world's largest primary producer of platinum group metals (PGM) and has almost 90% of world reserves. Production of PGM originates almost exclusively from mines in the Bushveld Complex, north of Pretoria.

Titanium and zirconium are produced from beach sands north of Richard's Bay, which contain ilmenite, rutile and zircon. Titaniferous magnetite also is recovered at the Phalaborwa carbonatite as a byproduct of copper and phosphate rock production. Titaniferous slag is produced with magnetite ores from the Mapochs Mine. Palabora Mining Co. Ltd. produces 70% of the world's baddeleyite (zirconium sulphate) used in specialised applications in the refractory, ceramics, tanning industries, and in kidney dialysis machines.

The production of chromite is from more than 20 mines exploiting the Bushveld Ultramafic Complex. South Africa has about 68% of the world's chromium reserves.

The Palabora Mine is by far the largest copper producer of the country. It also produces baddeleyite, nickel sulphate, uranium oxide, phosphate concentrates and vermiculite, as well as modest amounts of precious metals contained in refinery tankhouse slimes. Since 2002 open pit operations have ceased, but mining continued on underground. The production of antimony in South Africa is the fourth largest in the world.

Uranium production is largely a byproduct of three Witwatersrand gold mines. Additionally, approximately 100,000kg of uranium oxide has been produced by the Palabora copper mine.

Vanadium is produced from titaniferous magnetite

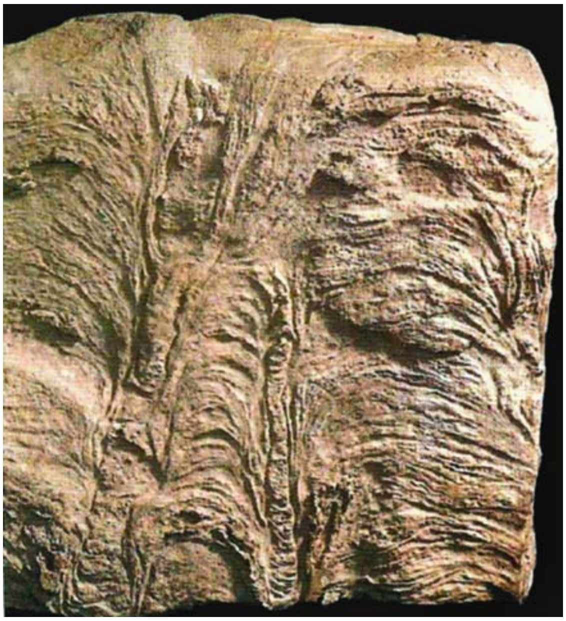

Fig. 198 Columnar stromatolite from the Barberton Supergroup, Mpumalanga Province, one of the oldest known organisms

Fig. 199 Cape Point, the rocky promontory of the Cape of Good Hope, mostly made of granite

mined from the Bushveld Complex. South Africa has about 45% of the world‘s reserves of vanadium.

Lead, zinc, vanadium and fluorite mineralization in the Malami Dolomite near Zeerust in the western Bushveld is perhaps the oldest known Mississippi Valley-type mineral province in the world. The production of lead and zinc has ceased, but fluorite still represents one of the largest deposits in the world.

The first diamonds in South Africa were found in alluvial gravels along the Vaal and Orange Rivers in what is now the Northern Cape Province, in the late 1860s. The only economically significant primary source of diamonds is currently kimberlite, an unusual ultrabasic igneous rock that occurs as small volcanic pipes, dykes and sills. Most of the country‘s kimberlites are Jurassic to Cretaceous in age. Diamonds have been found in all of South Africa‘s provinces, apart from KwaZulu-Natal. South Africa ranks fifth in world diamond production by volume, but third in terms of value.

The Transvaal Supergroup is also a rich source of asbestos, aluminous minerals and limestone. Chrysotile asbestos occurs around the Transvaal Basin, where Bushveld-age sills have intruded into and thermally altered the Malami Dolomite. A variety of aluminous minerals including andalusite, staurolite and kyanite occur in the thermal aureole of the Bushveld Complex with the aluminous shales of the Pretoria Group.

South Africa has a highly-developed domestic and export oriented phosphate industry. There are several types of phosphate rocks in the country, the main source being of igneous origin, which is currently mined at Phalaborwa, as well as sedimentary and biogenic resources. The latter two types are however not mined at present. Large resources of phosphate-rich sediments are located offshore along the Atlantic Ocean coast.

South Africa is the fifth largest coal-producing country in the world and the third largest coal exporter. After gold, coal is South Africa’s second largest export. The main coal-producing area is the Witbank Basin, which accounts for more than 40% of the country’s output. About 65% of the coal is produced from underground mining operations, with the reminder coming from open pit mines.

Except for a minor amount of gas condensate, South Africa has not yet produced crude petroleum. The Southern Oil Exploration Co. (Soekor), the state owned petroleum exploration company, controls all offshore oil and gas prospects.

5 Geohazards

A comprehensive inventory has not yet been compiled, but various effects of aquifer and surface pollution due to mining activities are known.

6 Geosites

For about 20 years the Conservation and Environment Committee of the Geological Society of South Africa

Fig. 200 Skull of Thrinaxodon liorhinus from the Karoo (Permian) of South Africa

has worked towards the protection of important geological sites. A new National Heritage Legislation was formulated in 1998, with the aim to stipulate the registration of national heritage, including geological sites and rare geological materials. As a result a book entitled “An Introduction to South Africa’s Geological and Mining Heritage” was published (Viljoen & Reimold, 1999), in which comprehensively all potential geosites of the country are listed, photographed and described. These include more than 100 named sites, making this book a standard reference for all future work on geoconservation in South Africa (Fig. 198 - 203).

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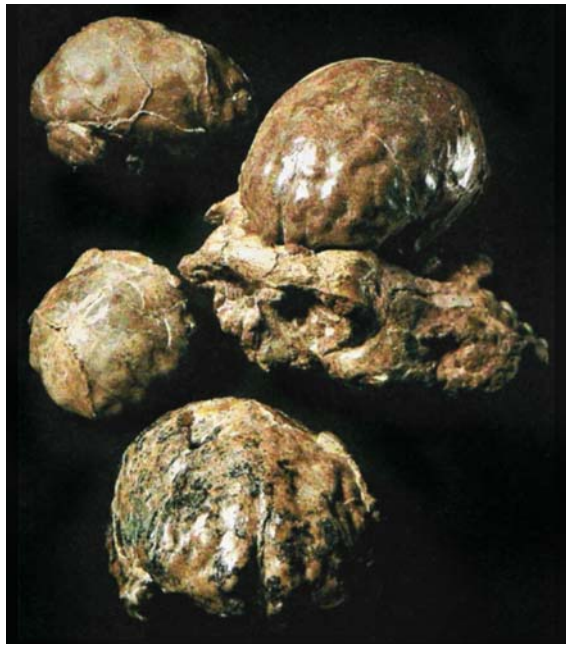

Fig. 202 Fossilized brain casts of hominids from cave deposits at Swartkrans near Pretoria

Fig. 201 Excavation of a Pleistocene cave deposit at Swaartkrans, where early hominids were found

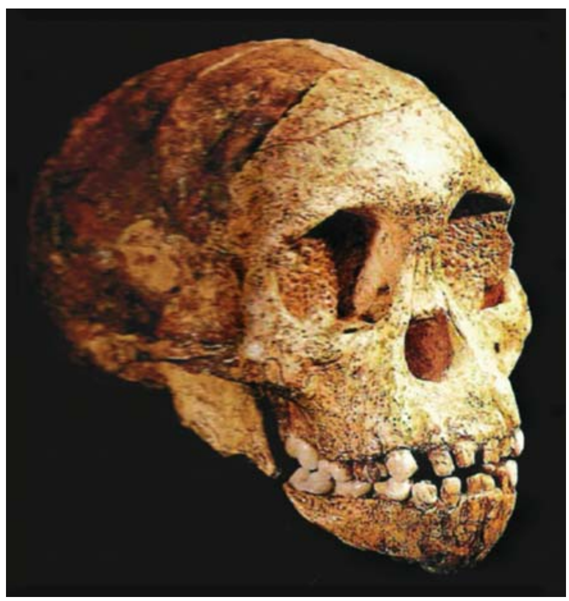

Fig. 203 The famous skull of the Taung Child, discovered by Raymond Dart in 1924

Sudan

1 General

Area: 2,505,813 km²
Population: 35,080,000 (July 2000 estimate)

2 Summary of Geology

Sudan is largely underlain by Precambrian rocks, particularly in the southwest, centre and northeast, which were almost exclusively reactivated during the Neoproterozoic Pan-African tectono-thermal event. Large parts in the north of the country are covered by continental clastic sequences of the predominantly Mesozoic Nubian cycle (previously Nubian Sandstone), and in the south by Tertiary to Quaternary unconsolidated superficial sediments. Some Tertiary and younger basalts occur in the border zone with Ethiopia.

3 Stratigraphy and Tectonics

Some rifted fragments of the East Saharan Craton occur as high-grade metasedimentary exotic terranes among the Sudanese Red Sea Hills and near Haya, southwest of Port Sudan. These terranes are also termed the "older shelf sequences" and contain mostly quartzites associated with marbles probably representing a passive continental margin about 900-800Ma ago.

Otherwise the basement complex of Sudan includes reworked Precambrian inliers reactivated during Pan-African tectono-thermal activities, namely the Nuba Mountains, the Darfur block and the Bayuda and Nubian deserts. In the latter area high-grade granitoid gneisses with minor inliers of high-grade metasediments were migmatized and intruded by voluminous granitoids late in Pan-African times. Small inliers of amphibolite-facies gneisses and metasediments occur also within the lower-grade volcanogenic ophiolite assemblages of the Red Sea Hills of the country. Generally it has been assumed that the metasedimentary belts scattered between the East Saharan Craton and the Red Sea fold and thrust belt represent a zone of early rifting that developed along the eastern margin of the East Saharan Craton during the initiation of a Neoproterozoic ocean. The Jebel Rahib Belt in central northwestern Sudan contains complexly deformed ultrabasic and basic igneous rocks and a thick sequence of arenaceous and subordinate carbonaceous metasediments, which have been interpreted as a Red Sea-Type Pan-African rift basin. An age of 570Ma from post-orogenic granitoids, which were not affected by the penetrative NNE-SSW strike-slip shearing in this belt, sets the minimum age for its deformation and low-grade metamorphism. An ophiolite assemblage with ultramafic rocks, pyroxenites, podiform chromites, massive and layered gabbros, dykes, pillow-lavas and chert deposits furnish the evidence of newly formed oceanic crust in the Jebel Rahib rift. These ophiolitic rocks imply the suggestion that juvenile Pan-African rocks were generated in the Nubian Shield outside the Red Sea fold and thrust belt. In its depositional setting and structural style the North Kordofan Belt in central Sudan is similar to the Jebel Rahib Belt, except that ophiolites have not been found. Among intrusive granitoids a tourmaline-bearing granite has been dated at about 590Ma. Late Pan-African shear zones, which are sealed by mica-bearing pegmatites, have yielded ages of about 560Ma. The low-grade metasedimentary Darfour Belt in central western Sudan, structurally overlying basement gneisses in the southeastern Darfour block, may also be equivalent to the North Kordofan and Jebel Rahib metasediments. Intrusive granitoids have yielded ages of about 570-590Ma in the Darfour Belt. In the eastern Nuba Mountains in central Sudan a NE-SW to NNE-SSW striking belt of low-grade volcano-sedimentary rocks is exposed, which contains fragments of highly dismembered ophiolites and basic to acidic plutons. These arc ophiolitic assemblages were metamorphosed at about 700Ma, with post-tectonic magmatism ceasing at around 550Ma. The Pan-African juvenile terrane of the eastern Nuba Mountains represents either a klippe thrust over a considerable distance from the east, or more likely a minor ocean basin behind a large, probably rifted-off continental fragment. Pan-African rocks occur also as two different tectono-stratigraphic units in the Bayuda Desert in northern central Sudan. First, on the eastern part along the River Nile, is a narrow strip of low-grade metasediments, metavolcanics and granitoids, which range compositionally from early tonalites through granodiorites to large peralkaline granites. Granitoids were emplaced twice, at about 898Ma and at about 678Ma. Anorogenic within-plate magmatism followed and yielded an age of about 549Ma. An extensive metasedimentary sequence of marbles and intercalated metaquartzites is exposed between River Nile and the Red Sea Hills west of

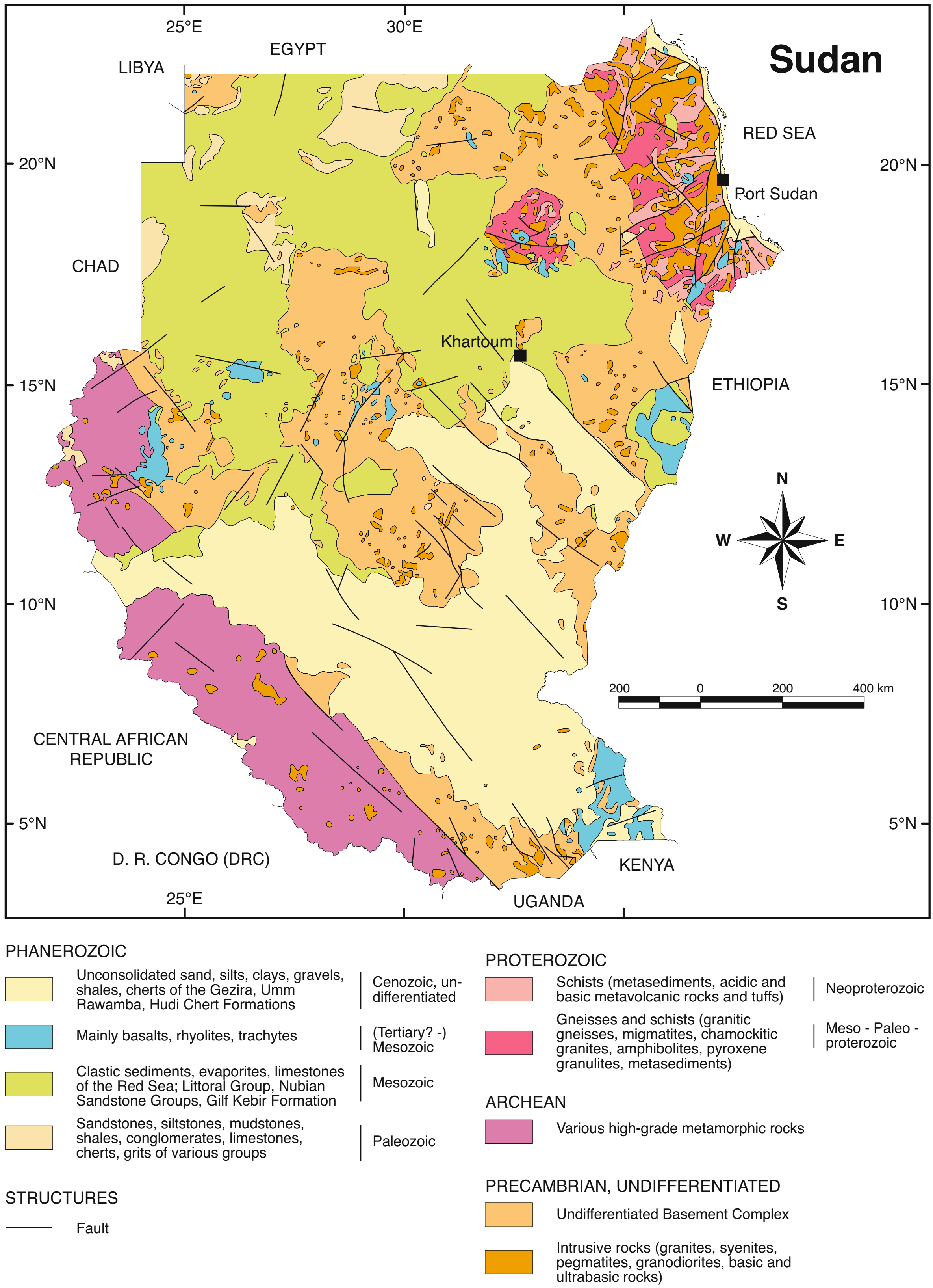

Fig. 204 Geological overview of Sudan (modified after Anonymous, 1981)

Fig 205 Inauguration of a newly discovered oil well in central Sudan

Fig 206 The crater lake of Jebel Marra in northern Sudan

Gabgada, which may represent an autochthonous continental margin deposit.

A long period of pediplanation ensued after the formation of the basement complex structures, and as a result unmetamorphosed Paleozoic and Early Mesozoic rocks are unknown or uncommon in Sudan. Early Cambrian rocks occur at Sabaloka, which yielded an age of about 530Ma.

The overall structural picture, which emerges for the Red Sea depression is that it is not fault bounded. Apparently developed during Carboniferous times a zone of subsidence in the Gulf of Suez, and probably during Mesozoic times this had extended to the central zone, the Red Sea depression having developed largely between two marginal monoclinal flexures situated near the present Sudanese and Arabian shores. The swell continued to rise reaching a culmination in Late Eocene times. The climax of rift-system faulting took place in Oligocene and Early Miocene times. Subsidence accompanied by faulting continued on the down-side of the Sudan monocline zone resulting in the accumulation of more than 4,300m of sediments in the near-shore part of the Suakin Archipelago. The sediments probably filled the trough from shore to shore. In Miocene times lagoonal conditions apparently prevailed throughout the Red Sea and evaporites were laid down. Intense faulting took place in Pliocene and Early Pleistocene times culminating in the formation of the central trough and the intrusion of ultrabasic and basic dykes derived from the upper mantle. By this time the Red Sea depression had attained much of its present shape. In Pliocene times the connection with the Mediterranean Sea was closed, but the connection with the Indian Ocean via the Bab el Mandeb opened. During Late Pleistocene times the area was apparently reasonably stable and undeformed marine benches were cut into Monastirian elevated reefs.

4 Economic Geology

Sudan's mineral commodities remain still largely unexploited because of political instability. Oil and gas, gold, chromium and manganese ores, and several industrial minerals have most attraction. Many of the solid minerals are found in the eastern highlands, where transport distance to Port Sudan on the Red Sea is not a major obstacle. There is natural gas offshore near the port. Oil has been discovered in the southern central part of the country (Fig. 205).

Mineral production is mainly chromite, gold, gypsum, limestone, cement, petroleum refinery products and salt. However, the main mineral exports consisting of chromite, gold and salt provide currently only for about 1% of export revenues.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made, but the Sudanese desert offers many places of scenic beauty (Fig. 206 - 208).

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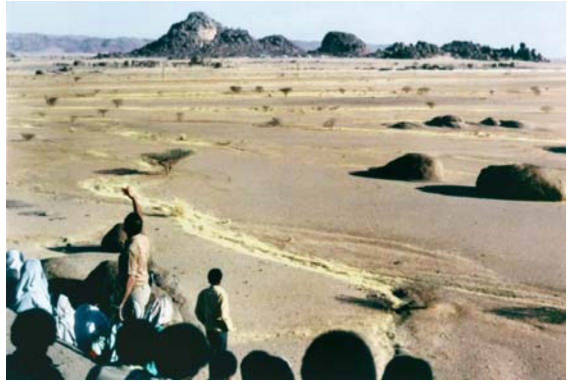

Fig 207 Granitic inselbergs east of the sixth Nile Cataract

Fig 208 Yardangs, wind-eroded lake deposits in the now arid north of Sudan

Swaziland

1 General

Area: 17,364 km²
Population: 1,083,000 (July 2000 estimate)

2 Summary of Geology

The country's geology is dominated in the western part by rocks of Precambrian (mostly Archean) age, whereas in the east these are overlapped by sedimentary and volcanic rocks of Karoo age.

3 Stratigraphy

Swaziland lies on the eastern edge of the Kaapval Craton. In the Archean terrain, the oldest rock unit is probably the Ngwane Gneiss, which comprises layered, grey tonalitic gneisses (Fig. 212) with subordinate thin amphibolites, possibly representing part of a proto-continental sequence. It has consistently high metamorphic grade, has suffered the greatest number of deformations, its amphibolites are geochemically distinct from those of other formations, and it is cut by mafic dykes, some of which, because they are absent in the Onverwacht Group, are deemed to predate that next-oldest rock unit. Rocks of the tripartite Swaziland Supergroup crop out within the Barberton Greenstone Belt in the northwest of the country. The irregular wedge-shaped synclinorial tract is typical of such Archean greenstone belts. The base of the Onverwacht Group is not seen but the sequence comprises a greenstone assemblage of mafic and ultramafic lavas, associated serpentinites, and minor sedimentary and acid volcanic rocks. The succeeding Fig-Tree Group yields flysch-type sedimentary rocks associated with ironstones. The Moodies Group lies unconformably on the Fig-Tree and Onverwacht outcrops, both of which together with an igneous/metamorphic terrain supplied the bulk of detritus to the conglomerates of this youngest part of the sequence. Rocks of the Dwalile Metamorphic Suite in southwest Swaziland are lithologically similar to those of the Onverwacht Group with which they are equated. The Mahamba Gneiss in southern Swaziland represents high-grade semi-pelitic garnetiferous gneisses. Subsequent to the development of the greenstone belt the Ngwane Gneiss was intruded by hornblende tonalites, the Tsawela and Mhlatuzane Gneisses, and by the sheet-like Mponono Anorthosite Suite. The post-greenstone intrusive phase continued with the emplacement of the composite Usutu Intrusive Suite after the climax of deformation had passed. The Lochiel Granite is a major batholith, which was intruded in a number of pulses to form a sheet-like carapace or hood over the subjacent gneisses. Lavas and sediments of the Pongola Supergroup were laid down in the mid-Archean, within a cratonic basin, which lay across the eroded top of the Lochiel batholith. The Insuzi lavas, which form the lower half of the supergroup, have continental affinities, and after warping were overlain disconformably by sediments and lavas of the Mozaan Group. Some of the Shiselweni Amphibolites, which crop out in southern Swaziland, are believed to be lavas as they contain flattened, amygdale-like quartzose blebs. The deposition of the Mozaan sediments was followed by the basic intrusion of the Usushwana Complex, which resembles the Great Dyke of Zimbabwe. The Mliba Granodiorite is geochemically akin to the older granodiorite plutons, but its stratigraphic age is unclear, because it is cut by leucocratic dykelets, which may belong to the Lochiel Granite. Subsequently an increase in the geothermal gradient remobilised the basement, which together with its Pongola cover rose diapirically to form a series of mantled gneiss domes, of which the Nhlangano Gneiss is the central core. The Mkhondo Valley Metamorphic Suite and adjacent outcrops were deformed into a series of dome-and-basin interference folds. The Kwetta and Mtombe Granites are rapakivi granites and belong to a formerly continuous post-deformation intrusion. The Hlatikulu Granite resembles in its structural and tectonic setting the Lochiel Granite. The Mswati Granites are sharply transgressive anorogenic plutons, being probably all of similar age. Only a few post-Archean events can be definitely assigned to the Proterozoic, although much of the Archean outcrop is cut by innumerable faults and shear zones of varying age, trend and displacement.

The main Karoo outcrop in Swaziland is confined to and draped over the eastern edge of the Kapvaal Craton, but a number of important outcrops are also in the southwest. The patchy development of the Dwyka Group of glacigenic sediments reflects deposition within an area of considerable relief. The widespread Lower Ecca claystones were deposited in a shallow marginal-marine basin, but were overlain during middle and upper Ecca by a prograding fluvio-deltaic sequence, in which the presence of Gondwana-type coals indicates an amelioration of the climate.

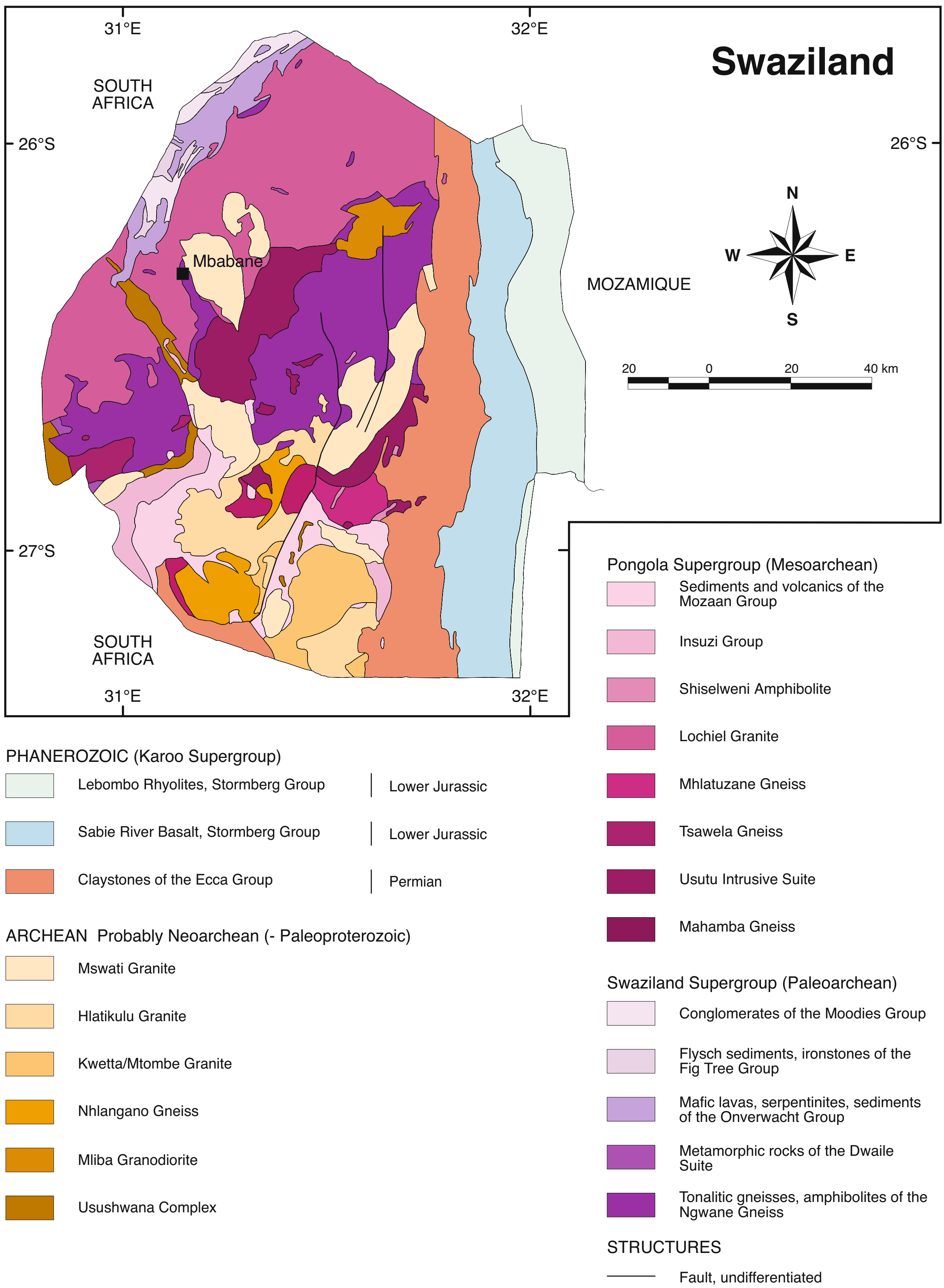

Fig. 209 Geological overview of Swaziland (modified after Wilson, 1982)

Fig. 210 Former iron ore mine of Ngwenya near Mbabane, with deposits of Archean age.

Fig. 211 Karst erosion features near Manzini.

Subsequently continental sedimentation commenced with braided stream deposits, sometimes intercalated by aeolian sediments. A relatively thin (40m) sequence of the Beaufort Group comprising a series of sandstones and shales is overlain by a thick unit of Stormberg Group red rocks. The oldest Stormberg is the Molteno Formation, while the youngest is the Cave Sandstone Formation. The latter is overlain by a thick succession of basaltic lavas, which cover the greater portion of the Lowveld. Detrital diamonds occur within the Nkondolo sediments, which had derived from the Dokolwayo kimberlite pipe. The presence of tuffs at the top of the Nkondolo succession suggests that there was no major break before the succeeding olivine-poor tholeiitic Sable River Basalts flooded much of the lanscape. The disconformity separating the main sequences of basic volcanic rocks from the acidic Lebombo Rhyolites may represent the main phase of folding along the Lebombo Monocline. Some granophyric dykes within the Archean outcrop together with some gabbroic sills and basic dykes are probably of Karoo and even younger age.

4 Tectonics

Tight northeast-aligned overfolds and associated high-angle thrust faulting have telescoped the Swaziland Supergroup in the northwest. Late stage cross folding along NW-SE trending axes have resulted in the buckling and warping of the pre-existing folds. Repetition and duplication of succession demonstrate the region's structural complexity.

5 Economic Geology

Historically, Swaziland has been a significant regional producer of asbestos, iron ore and gold. However, the level of exploitation has declined considerably. Diamonds were located in the Ehlane area near the Dokolwayo kimberlite pipe, from where alluvial diamonds have spread southward in several stretches east of the Karoo trough. Gold production began as early as 1882, but has steadily declined with almost no current production. Among 25 mines, the Piggs Peak mine, Forbes Mine Reef, Daisy, Avalanche, Devil's Reef, She, Waterfall, Kabolondo and Wylesdale were the main producers. Iron ore is currently not mined, but Swaziland has three to four deposits that may prove worthy of consideration. The Ngwenya iron ore mine in the west was the country's biggest mining operation in the 1970s, but is still closed (Fig. 210). Swaziland has large reserves of coal, which are low-volatile bituminous coals or anthracite. Mpaka and Moaka Collieries are currently closed, whereas the anthracite mine at Maloma commenced with production in 1993. Swaziland has an excellent potential for ceramic minerals, i. e. kaolin, talc, silica and a variety of clays. Very good quality cross-fibre chrysotile asbestos occurs in seams within a serpentinite sequence at Bulembu in the northwest. It is Swaziland's most important mineral commodity and is won from one of the world's largest asbestos mines. Two commercial quarries for stone aggregate, Kwalini and Mbabane Concrete Centre, are operating.

Fig. 212 Tonalitic gneisses of Archean age in a river bed near Manzini.

Fig. 213 Ripple marks in sediments of the Archean Fig Tree Series in northeastern Swaziland.

6 Geohazards

Few earth tremors have been recorded in Swaziland, but the country is of low seismicity. A comprehensive inventory of potential geohazards has not yet been made (Fig. 211).

7 Geosites

No formal inventory of geosites has yet been made, but the Lions Cavern, possibly one of the oldest mines in the world, where mining of specularite ore, presumably for pigment, was carried out as early as 4,100BC, should be nominated as well as parts of the Fig-Tree and Moodies Groups, which yielded some of the oldest known organisms (Fig. 213).

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Tanzania

1 General

Area: 945,087 km^2
Population: 35,306,000 (July 2000 estimate)

2 Summary of Geology

Tanzania is cradled on an Archean craton. Progressively younger crystalline rocks rim this granitic nucleus, with sediments and volcanics of Paleozoic to Recent age occupying the rifted grabens, coastal plains and inland basins. Rocks belonging to the Archean, Proterozoic, Paleozoic, Mesozoic and Cenozoic are all well represented.

3 Stratigraphy

The oldest rocks of the country form part of the Tanzania Craton, rigid since the Precambrian and clearly defined to the east and west. Ingrained in this shield are vestiges of at least two Archean orogenic belts, the Dodoman of central Tanzania and the Nyanzian-Kavirondian of northern Tanzania. These vestiges take the form of small, often irregular enclaves, lenses and other relics of sedimentary and volcanic rocks within a setting of migmatites and mobilized granites. The Dodoman extends some 480km along an E-W trend and broadens westwards. It is mainly composed of banded and ferruginous quartzites, sericitic schists, aplites, pegmatites and ironstones, all highly-altered, frequently coarsely-crystalline rocks of extreme composition that have resisted the change to granite. The Nyanzian occurs in irregularly separated areas south and east of Lake Victoria. It is characterized by acid and basic volcanics (rhyolites, trachytes and tuffs with basalts and dolerites) together with banded ironstone. Closely associated geographically with the Nyanzian, but separated from it by an unconformity and intense crustal deformation, are rocks of the younger Kavirondian System. Typical Kavirondian rocks are grits, mudstones, conglomerates and volcanics, probably derived as molasse from the Nyanzian. Along the southwestern edge of the Tanzania Craton lies a zone of complex, high-grade, strongly folded metamorphic rocks and intrusive granites. This zone, which trends NE-SW parallel to Lakes Tanganyika and Rukwa, is known as the Ubendian Belt, but is structurally younger than the craton. The rocks are mostly pelitic and volcanic in origin, and hornblende, biotite, garnet and kyanite are common in the gneisses. This belt is probably of Paleoproterozoic age, though it may be polycyclic. The Mesoproterozoic is represented by the Karagwe-Ankolean. Its rocks, occurring principally over northwestern Tanzania, are largely argillaceous, mildly metamorphosed to phyllites, argillites and low-grade sericitic schists, while arenaceous formations have been changed to quartzites. Comparatively simple folds are characteristic, deformation and metamorphism increasing with depth and proximity to granite intrusions. A varied assortment of rock types, classified as the Bukoban, succeeds the Karagwe-Ankolean in western Tanzania. Conglomerates, thick-bedded sandstones, red shales, quartzites, dolomitic sandstones and extensive flows of basalt stretch from the Ugandan border as far as the northern end of the Rukwa Rift. Predominantly terrestrial and volcanic, the series is characteristically slightly-folded, virtually unmetamorphosed and considerably faulted. The Mozambique Belt abuts against and truncates the eastern margin of the Tanzania Craton and is partly overlain to the east by Karoo, Mesozoic and younger sediments. It is a zone of great structural and metamorphic complexity, polycyclic in origin and of Neoproterozoic age. The dominant rocks are highly metamorphosed, consisting typically of hornblende, biotite, pyroxene gneisses, charnokites with crystalline limestones and sparing occurrences of graphitic schists and quartzites.

Following the Mozambique orogenic episode there was apparently a long erosional interval before the deposition of rocks of the Karoo Supergroup (Upper Carboniferous - Lower Jurassic). These represent terrestrial sediments, consisting of sandstones, conglomerates, tillites, shales, red and grey mudstones, coal measures and occasional limestones and were principally laid down in downfaulted or downwarped areas and have been preserved, though easily eroded, because they occupy structural basins. Often the Karoo formations contain plant and animal remains. Marine rocks - chiefly marls, limestones, sandstone and shales of Jurassic, Cretaceous (Fig. 220), Tertiary and Quaternary age - make up a belt of limited though variable width parallel to the present coast. The sequence is disconformable and indicates long instability of the continental margin. Contemporaneously with this marine deposition a variety of terrestrial deposits accumulated inland, mainly in rift troughs. Volcanic activity commencing in late Cretaceous times with carbonatitic centres,

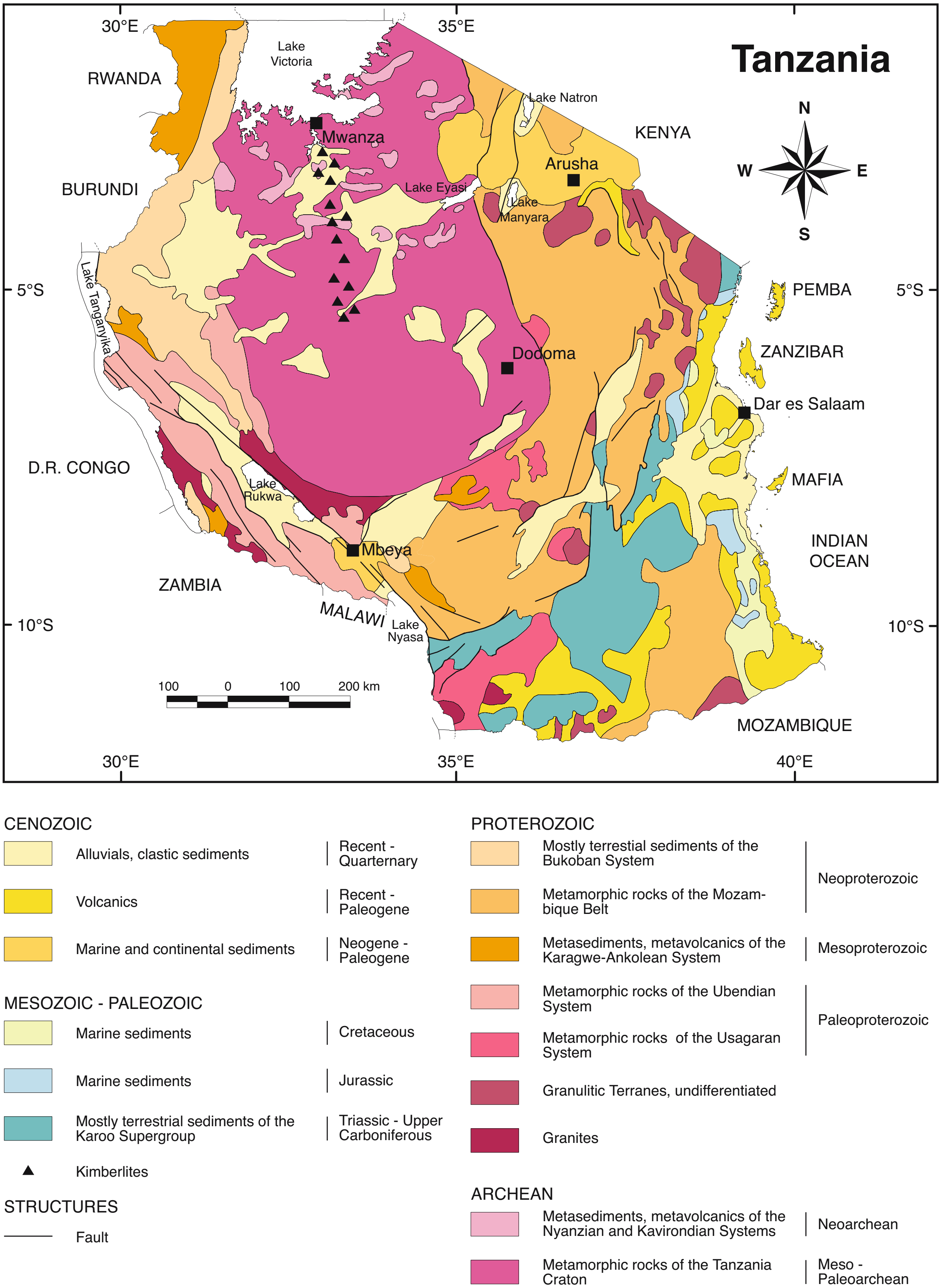

Fig. 214 Geological overview of Tanzania (modified after Muhongo, 1989, and Pinna et al., 2004)

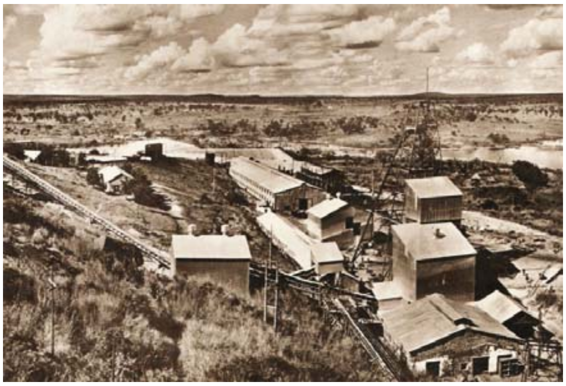

Fig. 215 The gold mine of Mpanda in western Tanzania in 1949

caused the local and regional accumulation of typically alkaline volcanics in the Neogene, particularly north of Lake Nyasa in Rungwe, from Hanang to Kilimanjaro and north to Lake Natron. Typical of these rocks are olivine and alkali basalts, phonolites, trachytes, nephelinites and pyroclastics.

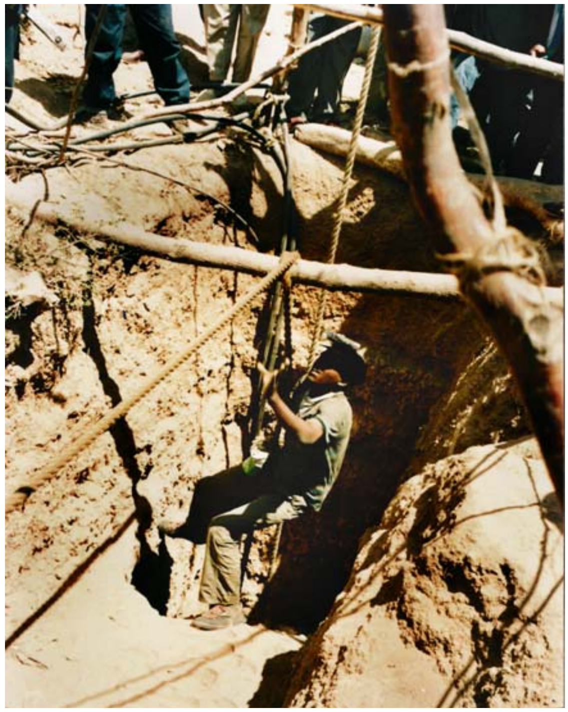

Fig. 216 Artisanal mining operations for tanzanite at Lelatema near Arusha

4 Tectonics

The East African Rift System, the main element of the structural geology of Tanzania, consists of a series of en-echelon grabens or rift valleys, often including associated volcanism. In Tanzania rifting is concentrated along two arms, the Western Rift occupied by Lake Nyasa and Lake Tanganyika and the Eastern (or Gregory) Rift, passing through Lake Natron to Lake Nyasa. There are also subsidiary rift grabens at Lake Rukwa, along the coast in the Selous Basin in the southeast, and elsewhere. The rifting created the lakes and interrupted the drainage system. Lake Victoria is generally interpreted as being formed by gentle down-warping between the Eastern and Western Rifts.

5 Economic Geology

Tanzania is generally rich in minerals, but these have never been fully explored nor exploited. Gold and diamonds have always been the mainstay of the country's mineral production. Over 300 kimberlites are known in Tanzania, of which about 20% are diamondiferous. Most of those occur within 200km of the northern town of Shinyanga. Although alluvial diamonds have been recorded, large deposits of transported diamonds have not been found. Gold constitutes the second most important mineral product of Tanzania. Over 90% of the about 70t of gold produced to date has come from Archean rocks in the vicinity of Lake Victoria, the rest from Proterozoic rocks in the Lupa and Mpanda (Fig. 215) districts. The principal gold deposits are those generally referred to as Archean greenstone lodes plus their weathering products, including the areas of Musoma-Mara, Geita, Rwamagaza, Nzega and Iramba Sekenke. These greenstone belts are characterized by flat to steep dipping quartz lodes carrying pyrite,

Fig. 217 The open-cast phosphate mine of Minjingu in northern Tanzania

gold and minor base metal sulphides, with carbonate or sericitic alteration of wall rocks. The association of lodes with BIF units and shearing is common. Geologically both the Archean and the Proterozoic rocks are very prospective for copper, lead and zinc. However, only limited output of copper and lead has been achieved. The numerous basic and ultabasic rocks of the northwestern region together with the metasediments of the Karagwe-Ankolean System offer an excellent potential for nickel, chromium and the platinum group minerals. Numerous iron ore bodies have been identified in several settings. Titaniferous magnetite and haematite bodies in close proximity to coal occurrences and the railroad offer a good potential for development. Tin and tungsten have been produced from both lode and alluvial deposits in the Karangwa District. A variety of coloured gemstones including tanzanite, the famous blue zoisite, are produced (Fig. 216). Tanzanite is mined from weathered rock, sometimes in association with graphitic bands, which are also of commercial value. Other gemstones include ruby, rhodolite, sapphire, emerald, amethyst, chrysoprase, peridot and tourmaline. More than 20 carbonatites associated with Mesozoic-Cenozoic volcanics have been identified in the southwest of the country, which could prove to be a useful source of rare earths, niobium and phosphates.

Tanzania is the country in East Africa with significant coal resources, similar in age and quality to the Gondwana coals of southern Africa. The country's currently only productive coal mine at Kiwira near Lake Nyasa has an average output of 35,000t/y, all of which is processed and consumed locally. Good resources of high purity limestone and dolomite occur in the white marble deposit of the Morogoro region. A variety of clays - bentonite, kaolin, fullers earth - in sizeable deposits have been identified and are only scantily exploited, of which the Pugu Hill kaolin deposit still remains to be fully exploited. Evaporites and saline deposits of signifcance occur in the rift valley lakes and along the coast, and some of these are currently under exploitation. The production of sedimentary phosphates at Minjingu in the north of the country has ceased in the late 90s (Fig. 217). The graphite resources of Tanzania are substantial and have recently attracted major development investment interest from overseas companies. At Merelani in northern Tanzania two types of graphite have been identified: the kyanite gneiss type, which hosts quality coarse flakes and the altered ore type, which hosts coarse flakes along with tanzanite and tsavorite. In the cement sector, the country's largest cement plant, Tanga Cement, based on Jurassic limestones, had a production capacity of 500,000t/y of cement and held 40% of the market share in Tanzania.

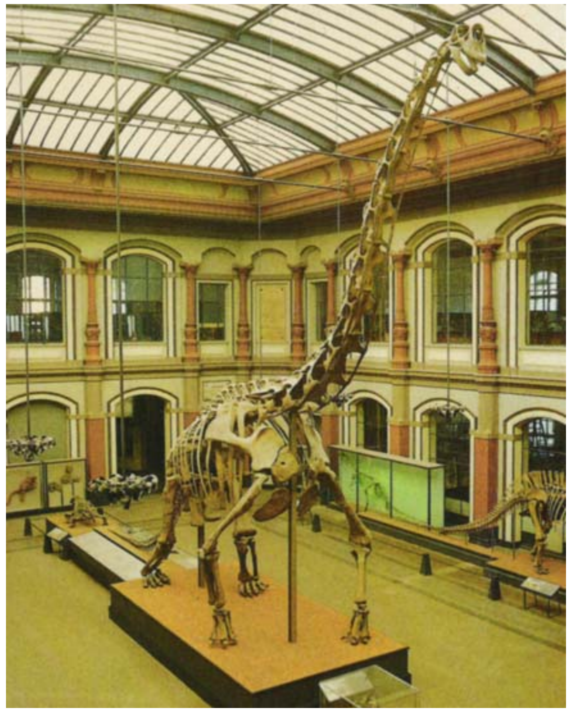

Fig. 219 Skeleton of *Brachiosaurus brancai* from Tendaguru near Lindi, mounted in the Berlin Natural History Museum

Exploration for hydrocarbons on the mainland of Tanzania between Lake Tanganyika and Lake Rukwa was not yet successful. Also offshore concessions have not yielded significant oil deposits. However, large deposits of natural gas were found at Songo Songo, a small island about 300km southeast of Dar es Salaam in the Indian Ocean.

Fig. 218 Mt Kilimanjaro with its two peaks Kibo and Mawenzi seen from Moshi

Fig. 220 Cretaceous clayey deposits at Kilwa, yielding a rich fossil trace fauna that has not yet been described

Fig. 222 The famous Pleistocene hominid-bearing site of Olduvai in northern Tanzania seen from the bottom

6 Geohazards

Various geoenvironmental hazards and catastrophes over the past few years have been recorded in Tanzania: Physical pollution of human settlements as well as soils, waters and river sediments was largely caused by often uncontrolled use of mercury in artisanal gold mining areas.

7 Geosites

The following geosites were proposed and recommended as primary targets for geoconservation measures during a workshop on "Geosites and Geoconservation in East Africa", which was held in Nairobi in February 1999: Tendaguru Hill, Ngorongoro Crater, Oldoinyo Lengai Volcano, Laetoli Fossil Site, Olduvai Gorge, and Mbozi Iron Meteorite. The status of geosites in East Africa was debated during a workshop in September 2004 in Arusha (Fig. 218 - 218, 221 - 225).

Fig. 221 Part of Ngorongoro Crater in northern Tanzania

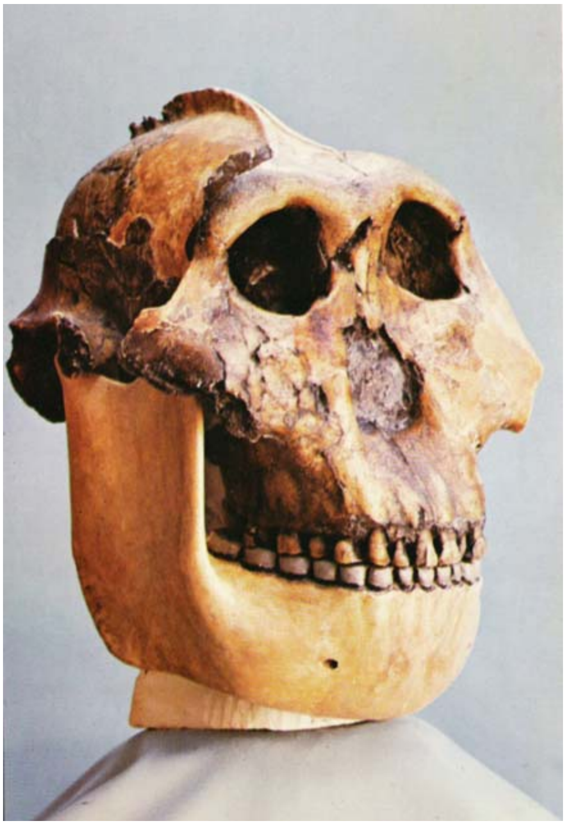

Fig. 223 The skull of *Australopithecus boisei*, excavated by Mary and Louis Leakey in 1959 at Olduvai

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Fig. 225 The site of the Mbozi Iron Meteorite near Mbeya

Fig. 224 Pleistocene stromatolitic nodules from the Paleo-lake Manyara, being used as building material at Mto wa Mbo in northern Tanzania

Togo

1 General

Area: 56,785 km^2
Population: 5,019,000 (July 2000 estimate)

2 Summary of Geology

Most of Togo is underlain by Precambrian rocks. Only in the southern part of the country occur Cretaceous to Tertiary basin sediments, which dip gently towards the sea.

3 Stratigraphy and Tectonics

Part of the eastern margin of the West African Craton is the North-Dapaong zone, consisting of various crystalline formations, and considered to range from Neoarchean to Paleoproterozoic (Birrimian) age. Within this zone widely occur migmatites, gneisses, amphibolites, granodiorites and granites. The sedimentary formations of the Togo portion of the Neoproterozoic Volta Basin lie unconformably on the Birrimian bedrocks and can be divided into two lithological units: an intra-tillite group, which is dominated by sandstones interspersed by pelites and siltites, and which is slightly monoclinal towards the southeast; a supra-tillite group, consisting from bottom to top, of a tillite, carbonates and silexites. It is overlain by the Mango shales, which are interspersed by sandstones. This group is also monoclinal towards the southeast and progressively folded towards the east. A mobile zone corresponds to the Neoproterozoic Panafrican range of the Dahomeyide Orogen. Its external part consists of a sedimentary sequence, dominated by shales of low metamorphic grade, which form the transition zone between the Volta Basin in the west and the Atacora range in the east. The Atacora structural unit includes the Kande schists, which are made up of jasper and sandstone formations, and strongly folded and deformed epimetamorphic formations, made up of micaschists and quartzites. The external part of the mobile zone also includes an anatectic domain at Kpalime-Amlame, which consists of calc-alkaline granitoids, micaschists and gneisses. The internal part of this mobile zone consists a) of a basic-ultrabasic trend at Kabye-Sotouboua-Agou, which is characterized by an association of crustal metamorphic and supracrustal rocks, an abundance of basic to ultrabasic rocks and local eclogites, and b) of a structural unit of the Benin-Togo plain, which is represented by granitoids, migmatites, gneisses, metasedimentary rocks, orthogneisses and ultrabasic rocks.

The coastal sedimentary basin covers about 3,300km^2 in the south of the country and is essentially represented by detrital formations. Complex deposits of rivers, lakes, swamps and mangroves are widespread.

4 Economic Geology

Togo's mineral industry is dominated by the production of phosphate. Phosphate rocks are found in Eocene deposits at Hahotoe-Akoumape and at Dagbati of the coastal basin. There are also considerable Neoproterozoic phosphate deposits, which, however, are hardened and therefore have not yet been exploited. Gold anomalies have been discovered in many locations of Precambrian age, but exploitation has not yet begun. Diamonds have been found in alluvial formations in the rivers crossing the basic-ultrabasic trend and the Atacora structural unit. Zinc-mineralisation has been discovered near Pagala, about 280km north of Lome. In northern Togo are the manganese deposit of Nayega and the iron deposit of Bassar located. Marble deposits are widespread in Togo. The most important are those of Gnaoulou and Pagala, which are both under production. Limestone is locally mined for the production of cement in the coastal basin.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

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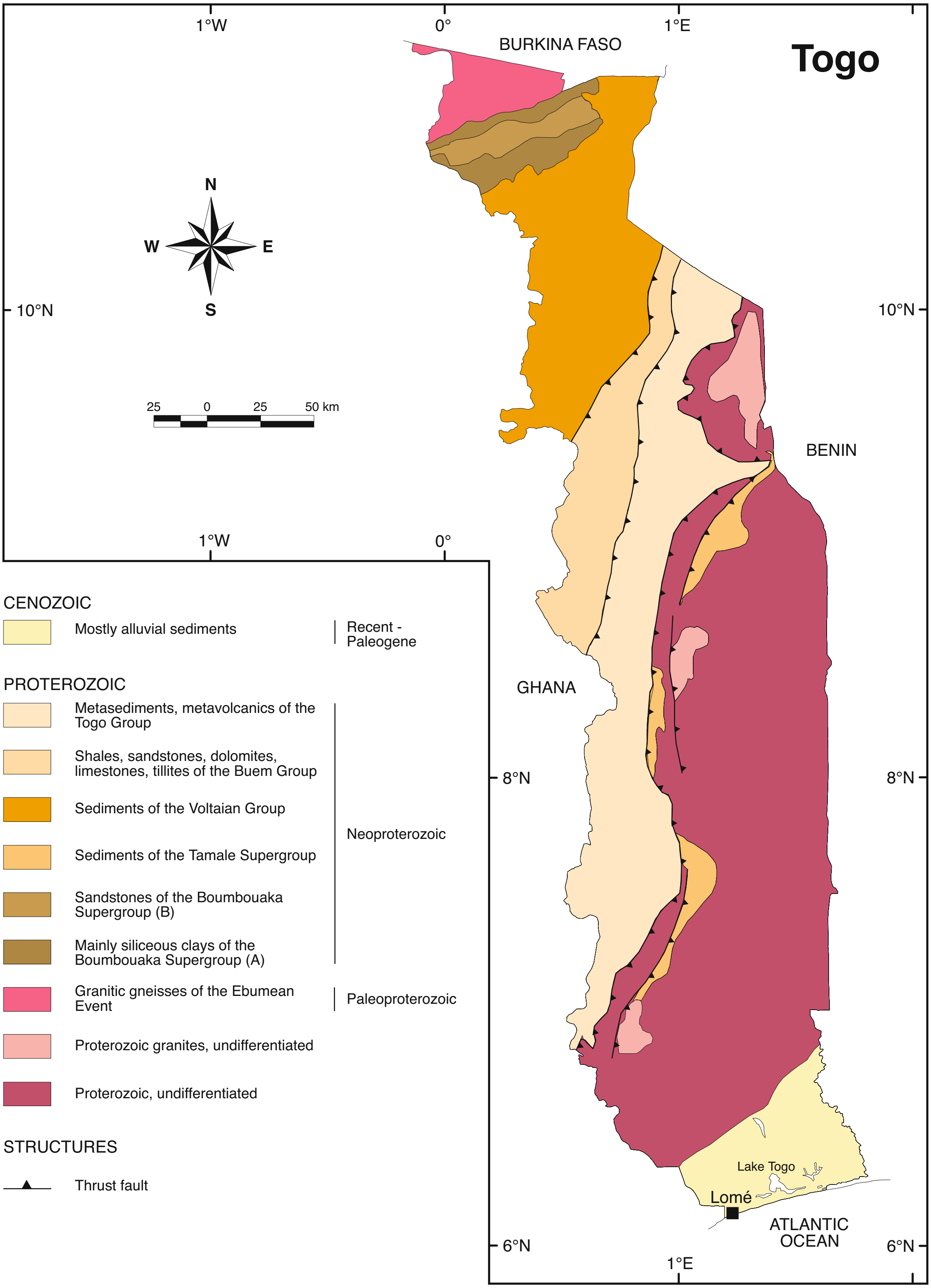

Fig. 226 Geological overview of Togo (modified after Anonymous, 1956, and Affaton, 1987)

Tunisia

1 General

Area: 163,610 km²
Population: 9,500,000 (2001 estimate)

2 Summary of Geology

Most of northern and central Tunisia is underlain by sedimentary rocks ranging from Permian to Recent and belonging to the structural unit of the Atlas Domain. In the south of the country Mesozoic and Cenozoic sediments overlying the Saharan platform are well developed. Northwestern Tunisia is influenced by the structural unit of the Tellian Domain, which is part of the Alpine orogeny.

3 Stratigraphy and Tectonics

Like the Moroccan and Algerian branches, the Tunisian Atlas constitutes a folded domain between the Rifo-Tellian chain in the northwest, which is part of the Alpine chain, and the Saharan platform in the south of the country. In the north, the so-called Tunisian Trough (or "diapir zone") separates the Atlas itself from the Rifo-Tellian chain (in Algeria only known as Tellian chain). The Atlas in the strict sense extends between the diapir zone in the north and the Negrine-Tozeur-Kebili fault in the south.

The oldest strata known at outcrop are of Permian age. In the Djebel Tebaga and beneath the Jeffara in southeastern Tunisia, the Permian is clayey-sandy with limestone bands containing a marine fauna with brachiopods, foraminifers (e.g. large fusulinids), corals, etc. The Triassic is quite well known at outcrop in the south, in oil drillings elsewhere, and also by some lithostratigraphic observations that could be carried out in the diapirs. In the Medenine area, where it overlies marine Permian strata, the following three members represent the Triassic from base to top: The Lower to Middle Triassic is characterized by argillaceous-sandy fluviatile sequences. A carbonate unit containing some detrital partings with palynomorphs indicates a Ladinian age, whereas the Ladinian-Carnian limit is situated within the carbonates. It is overlain by an argillaceous and evaporitic series of Upper Triassic age covered by the transgressive Messaoudi dolomite. Jurassic deposits are known from northern Tunisia at various localities, represented in the Lower and Middle Jurassic by calcareous and marly sediments, in the Upper Jurassic by a deep-sea facies with radiolarites. In the area southwest of Jebel Zaghouan the Jurassic strata are mostly composed of limestones, ranging from Sinemurian to Tithonian. On the north-south axis at Jebel Nara Jurassic deposits are made up of dolomites ranging from Liassic to Lower Tithonian, and of argillites ranging from Lower Tithonian to Upper Cretaceous. In southern Tunisia a northern and a southern domain can be distinguished. In the former one at Jebel Tebaga, a rather thin succession consists of limestones, whereas in the latter one from base to top evaporitic deposits with limestones, sandstones and clays interchange. Within these strata, paleosols and beds rich in plant remains alternate with sandy layers. The Cretaceous is well distributed in Tunisia. The Lower Cretaceous of the Tunisian Trough in the north accommodates several thousands of metres of clays with ammonites and calpionellids, intercalated by calcareous and sandy deposits. In central Tunisia the following units have been observed: The Meloussi Formation contains sands, carbonates and marine sandstones of Berriasian to Valanginian age. The Boudinar Formation is made up of poorly sorted fluviatile sandstones of probable Hauterivian to Barremian age. The Gafsa Group consists of clayey-sandy-carbonate alternations of the Bou Hedma Formation, then the Sidi Aich sands and the Orbata carbonates, of Barremian to Aptian age. In southern Tunisia the Lower Cretaceous is represented, as in many Saharan domains, by the "Continental Intercalation", which has sometimes yielded dinosaur bonebeds (Fig. 229 and 230), and then by a marine carbonate unit of Aptian to Cenomanian age, reflecting the onset of a mid-Cretaceous transgression. The deposits of the Upper Cretaceous and Eocene in central Tunisia have been grouped together into the following formations: The Zebbaq Formation is a carbonate unit with an argillaceous and gypsiferous middle unit of Cenomanian to Turonian age; the Aleg Formation consists of clays and marls with limestone intercalations of Turonian to partly Campanian age; the Abiod Formation consists of massive limestones of Campanian to partly Maastrichtian age; the El Haria Formation consists of clays and marls of Upper Maastrichtian to Thanetian age; the Metlaoui Formation consists of marls, gypsum, dolomite, phosphatic, calcareous, chert and argillaceous beds of Ypresian to Lower Lutetian age; The Souar Formation consists of marine clays and marls, then of sands and gypsum of end-Eocene age. Synsedimentary

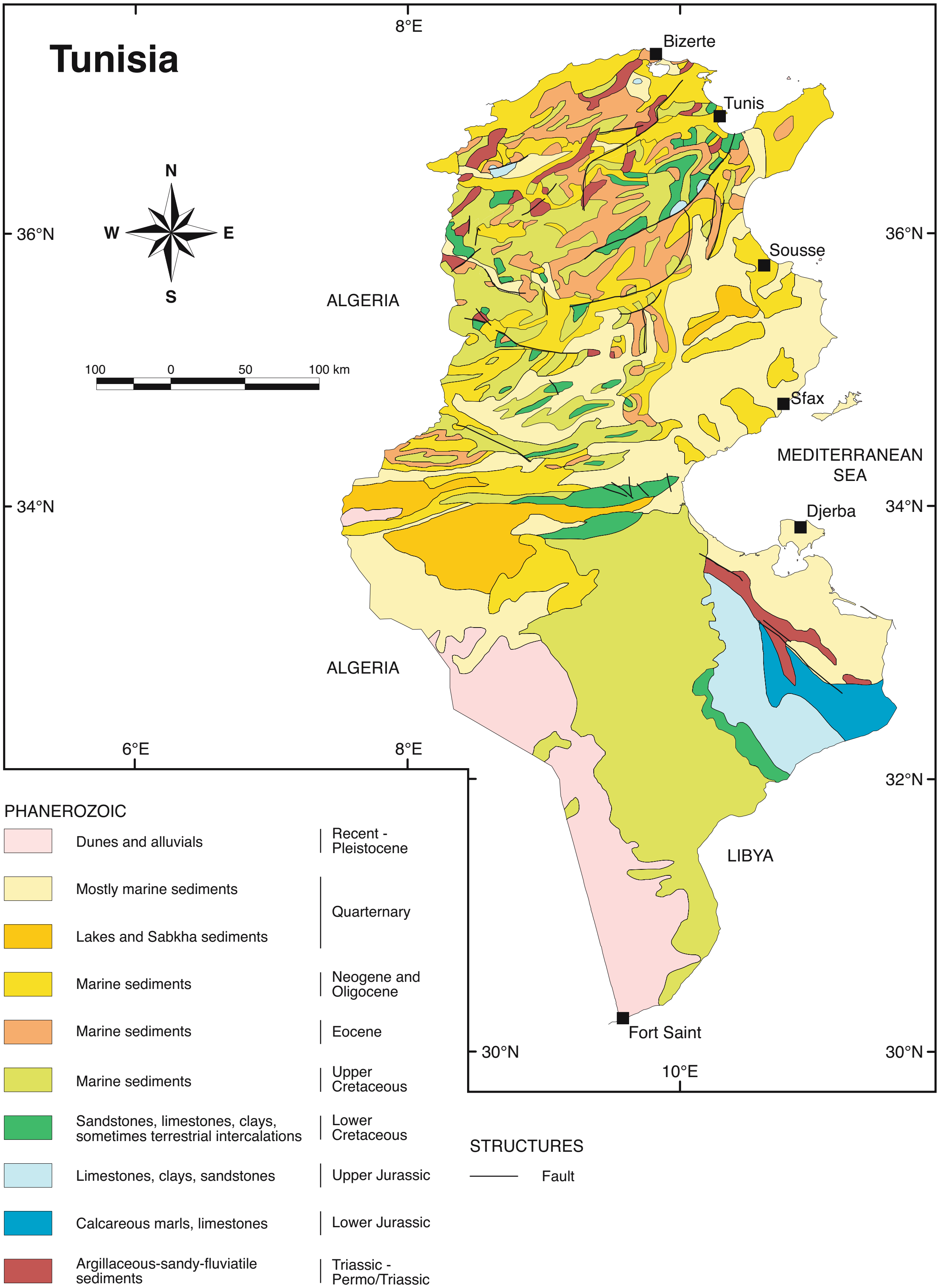

Fig. 227 Geological overview of Tunisia (modified after Fabre, 1978, and Ben Hajali et al., 1985)

tectonics, already active during previous periods, remained well marked during the Late Cretaceous and Eocene. Its effects on paleogeography are combined with the eustatic variations. In the Tunisian Atlas, the sedimentary substratum is segmented into unstable blocks bounded by three regional faults at Gafsa, Kasserine and Kaala-Djerda-Sbiba, underlined by the development of rudist reefs from the Turonian to the Santonian. The Oligocene and Neogene is in Tunisia defined by the Fortuna Formation in the Cap Bon area, where it is composed of sandy limestones and nummulitic marls, overlain by coarse sandstones with ellipsoidal quartz pebbles, and finally, Aquitanian continental beds. The Formation is absent in the southwestern part of the country. In central Tunisia, it corresponds to the more littoral facies of the Cherichira sandstones. The overlying successions comprise the following units: The Messiouta Formation of Aquitanian to Lower Burdigalian age comprises fluviatile or lagoonal sediments. The Grijima Formation of Upper Burdigalian age comprises marine clays, sands and conglomerates. The Ain Grab Group of Langhian age comprises sandy carbonates with bivalves, echinoderms and foraminifers. The Oum Domil Formation of Middle and Upper Miocene comprises sandstones and marls with lignites.

The Quaternary deposits consist of three units, from the oldest to the most recent: quartzose sands rich in lamellibranchs, reaching an elevation of +11m above sea level; sands and marine bioclastic sediments, with an elevation along the coast varying from 2-10m. These are often overlain by aeolian deposits; oolitic sands with *Strombus*, often overlain by aeolian deposits. The elevation of the marine bands varies from 4-13m.

Fig. 228 Marine Pleistocene deposits along coastal northern Tunisia

Fig. 229 The castle of Ksar Krerachfa with exposure of a bone bed-bearing site of Cretaceous age

In northwestern Tunisia the allochthonous unit of the Numidian nappe, which is part of the Tellian domain of the Maghreb in northwestern Africa, crops out. Its final emplacement occurred late during the Alpine orogeny, but it pre-dates the deposition of the "post-nappe Miocene", a new autochthonous unit covering the whole pile of allochthonous units.

4 Economic Geology

The mineral industry does not play a very significant role in the economy of the country. The key mineral commodity is phosphate rock, but the production has decreased over the years.

Tunisia is a marginal producer of lead-zinc worldwide, which is coming from two occurrences at Bougrine and Lahdoum in northwestern Tunisia. Phosphate rock was mined mostly in the southern region in the Gafsa and Sehib areas. Another new open pit phosphate rock mine at Kef Eddour is about 10km northwest of Metlaoui.

Hydrocarbons have been explored in Tunisia, but the proven reserves are steadily declining. The bulk of natural gas comes from the El Borma field. Offshore the tourist island of Djerba is the natural gas field of Ezzaoiua located. The Upper Cretaceous Abiod Formation has yielded in the Gulf of Hammamet offshore the Maamoura oilfield.

Fig. 230 Bone bed bearing sediments of Cretaceous age at Ksar Krerachfa, southern Tunisia

5 Geohazards

An inventory has not yet been made.

6 Geosites

A formal inventory has not yet been made, but Tunisia is a tourist destination and offers many places of geoscientific interests, especially along the coast and in the outskirts of the Sahara desert (Fig. 228).

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Uganda

1 General

Area: 236,040 km²
Population: 23,318,000 (July 2000 estimate)

2 Summary of Geology

More than two thirds of Uganda are underlain by Archean and Proterozoic rocks. Apart from the vast Archean Gneissic-Granulitic Complex in the north there are at least three major Proterozoic belts exposed in the country: the Paleoproterozoic Buganda-Toro System, the Mesoproterozoic Karagwe-Ankolean System and the Neoproterozoic Mozambique Belt. Tabular Neoproterozoic sediments are also widespread. Tertiary to Recent sediments filled parts of the downfaulted Western Rift. Tertiary carbonatites and Cenozoic volcanics are related to rift activities and occur along the eastern and western borders of the country.

3 Stratigraphy

About 60% of rocks outcropping in Uganda - especially in the northern and central regions - are high grade metamorphics, for which the name Gneissic-Granulitic-Complex has been proposed (Schlüter, 1997). The oldest unit embedded into the Gneissic-Granulitic Complex in the West Nile region comprises largely granulite facies grade rocks, for which the name Watian Group is used. The Watian is apparently of Mesoarchean age (2,910Ma). Similarly, some of the rocks of this grade appear to form the earliest unit in the Karamoja District, where they form enclaves in the gneissic sequences. Rock types include acid and intermediate granulites and charnockites, quartz diorites, banded, porphyroblastic and quartz-feldspathic types. Basic granulites are less common and pure calcareous rocks are unknown. Retrogressive metamorphism is extensive. Folding is usually relatively simple. Rocks of the Aruan Group tectonically and stratigraphically succeed the Watian in the West Nile region. The group has a monotonous lithology, uniformity of metamorphic grade, and a structural style typified by tight folding on steep axial planes with generally northerly directed axes. Rock types include biolite gneisses, banded, migmatitic and granite gneisses with lesser quantities of hornblende gneiss, amphibolite, quartzites and very few ultrabasic pods. In Karamoja the Central Karamoja Gneiss Group has very similar lithological, metamorphic and structural characteristics. Rocks belonging to the Mirian Group occur in the eastern West Nile region, where they tectonically post-date the Aruan rocks. They are characterized by a similar lithology to the Aruan rocks, but are isoclinally and intensely folded on recumbent axes trending approximately northeast and overturned to the northwest. The rocks are typically flaggy and of epidote-amphibolite facies grade. Rocks ascribed to the Neoarchean Nyanzian System in Kenya also occur in southeast Uganda. They comprise mainly rhyolites, porphyries, tuffs and basalts. This unit is not appreciably regionally metamorphosed, but is well folded. The Buganda-Toro System (or Ruwenzori Fold Belt) is of Paleoproterozoic age and occupies much of the south-central and western parts of the country. Argillites predominate, but basal or near basal arenites are an important feature. Locally, as in the Jinja area, occur thick amphibolites, which are probably derived from basaltic material. Large tracts of the system are granitized; on the other hand low-grade phyllites also occur, particularly towards Lake Victoria in the southeast. Folding is fairly tight on predominantly ENE axes in the east, but varies in the west. Axial planes are steep and there is a tendency for this folding to decrease in intensity with lowering of metamorphic grade southwards. Included in the Buganda-Toro System are the Igara Schists composed mainly of quartzites, mica schists and gneisses, the Bwamba Pass Series of the Ruwenzori Mountains, which is made up of grits, sandstones, slates and phyllites, and the Kilembe Series of Toro. The rocks of the Mesoproterozoic Karagwe-Ankolean System (or Kibaran Belt) rest unconformably on the Buganda-Toro System in the southwest. Argillites predominate, but arenites and silty rocks are also regularly distributed as thin bands throughout. At the base of the system metacalcareous rocks generally occur. Metamorphism is less highly developed than in the Buganda-Toro System and many parts are entirely unmetamorphosed. Fairly open folding in two main directions, i. e. approximately north-westerly and north-easterly on steep axial planes is typical, but the fold pattern is more complex in the lower parts, where earlier isoclinal structures are encountered. The age of the low-grade metamorphic rocks of the Madi Series in the northwest of Uganda has not yet been established. Tabular Neoproterozoic rocks are known from various sites: The Bunyoro Series occupies a narrow tract of country over 160km in an ENE-WSW direction in central Uganda. The rocks are predominantly argillaceous, but pebbly beds are locally abundant. Near the base of this formation a tillite has been recognized. The Singo and Mityana Series of the Bukoban System occur in the

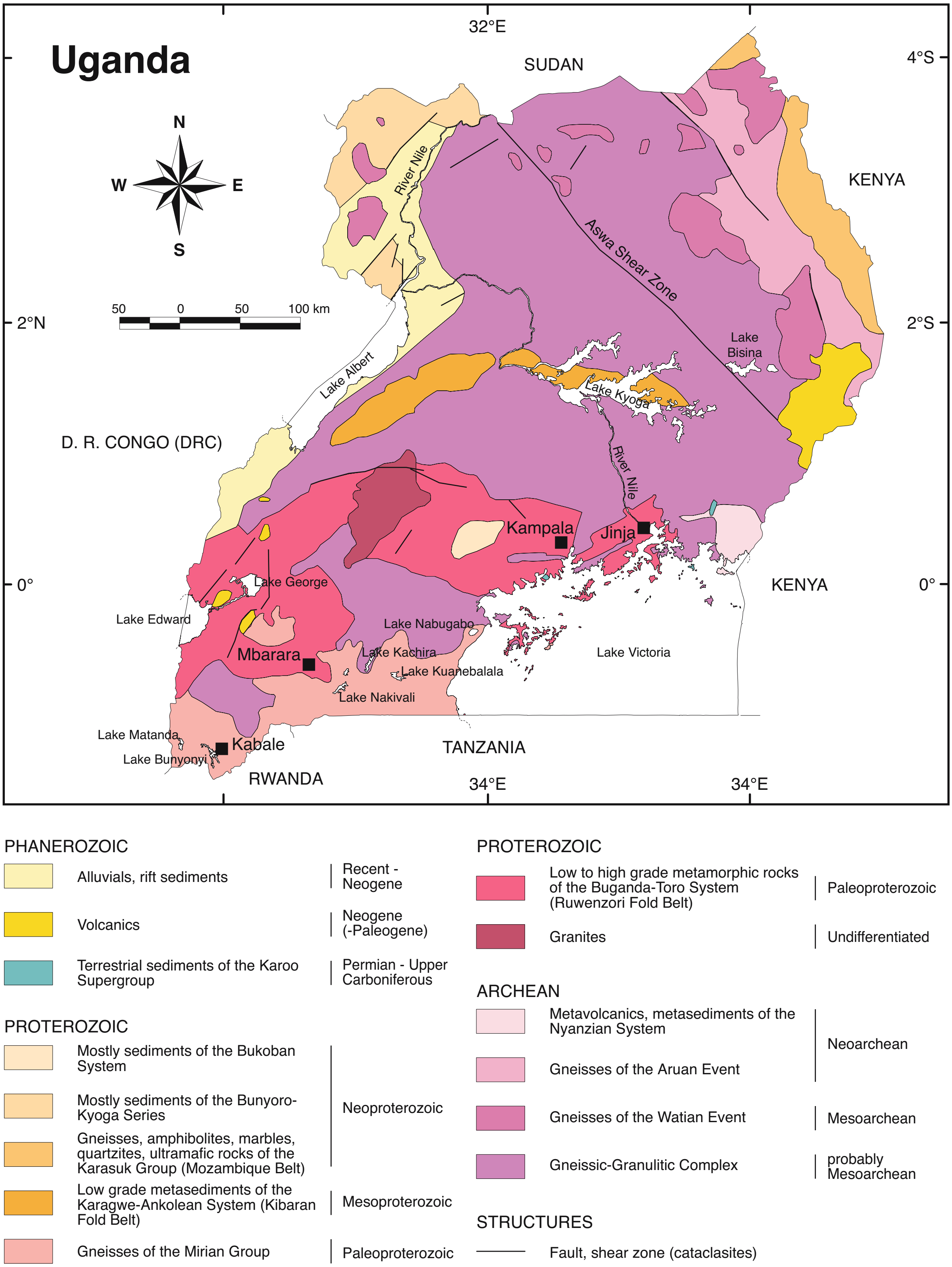

Fig. 231 Geological overview of Uganda (modified after Macdonald, 1966, and Muwanga et al., 2001)

southern and western central part of the country and are both arenaceous and unmetamorphosed, probably representing molasse-type deposits. An assemblage of gneisses, amphibolites, marbles, quartzites and ultramafic rocks occupies a strip of about 200 by 40km along the Uganda/Kenya border in the Karamoja area and is called Karasuk Group. This unit is apparently part of the Neoproterozoic high-grade metamorphic Mozambique Belt. Intrusive rocks of various Precambrian ages occur in many parts of Uganda.

Three small exposures of Karoo-aged strata are also recorded from Uganda. These occur in apparently down-faulted outliers near Bugiri, on Dagusi Island and underlying part of Entebbe, probably indicating an Ecca age.

Miocene volcanics outcrop in several areas of eastern Uganda, close to the Kenyan border and are denoted topographically by prominent mountains of the southern Karamoja region. Carbonatitic ring complexes, possibly formed since Cretaceous times and representing the eroded remnants of volcanoes of a similar geological suite, occur in several eastern locations. Other Cenozoic rocks are either of sedimentary or volcanic origin and are found in the western Rift Valley adjoining Rwanda and the Democratic Republic of Congo. The sediments are often fossiliferous and sometimes exceeding 4,000m in thickness. The volcanics have been ejected from vents, but are now dormant. There are some hot springs in this region.

4 Tectonics

The major structural controls of Uganda include orogenic fold belts and shear zones within the Precambrian rocks, and the processes of formation of the rift valley and later volcanic centres, followed by crustal warping during the Pleistocene that probably resulted in the formation of Lake Victoria. Shear zones occur in the Precambrian rocks in several areas of the country. The Aswa Shear Zone is the most extensive, following a northwesterly trend for over 300km through northern Uganda and into southern Sudan. Other shear zones, probably all of Neoproterozoic age, run through the Karamoja and Acholi regions and the West Nile District. The Rift Valley extends along the western border with the Democratic Republic of Congo and encompasses Lake Albert, Lake George, Lake Edward and the Ruwenzori Mountains horst block. Sediment thicknesses of 1,800 to 4,000m are estimated to lie within the Rift Valley.

Fig. 232 Lacustrine Neogene lake deposits and quarry at Hima, western Uganda.

5 Economic Geology

Extensive portions of Uganda have been exposed to prolonged and intense weathering. These processes have led to some materials being concentrated into ores, most notably gold, tin, pyrochlore (niobium, tantalum and rare earths) and apatite. Mineral occurrences include gold in Busia in the southeast, hosted by an Archean greenstone belt, whilst in the southwest at Buhweju and Kigezi, gold occurs in Paleo- to Mesoproterozoic metasediments. Gold mining has taken place at Busia in both alluvial and quartz vein occurrences. Recent exploration in the Buhweju-Mashonga area indicates that much of the gold being extracted by artisans derives from lateritic gravel lying under on kaolinised bedrock. Other potential gold areas include Mubende and Karamoja. The most prospective region for base metals is in the Kilembe area, where volcano-sedimentary rocks of Paleoproterozoic age outcrop for a distance of over 90km. Other copper ores have been recorded from Bobong and Kaabong in the Karamoja region. Chromite occurs in ultramafic rocks at Nakiloro, also in Karamoja. An ultramafic rock assemblage at Moroto has the potential for nickel, chromium, copper and platinum-group mineralisation. Lead, zinc and gold have been found in the Buganda-Toro System at Kitaka, within the Buhweju gold district. The Muko iron ore deposit occurs in Mesoproterozoic Kibaran rocks, whilst magnetite occurrences in the east, such as at Sukulu, are found in Tertiary carbonatites. Most of the cassiterite, tungsten, columbo-tantalite, beryl and lithium mineralisation is hosted by pegmatites and granites of the Buganda-Toro and Karagwe-Ankolean Systems. Amongst industrial minerals, phosphates are found in the east in Tertiary carbonatites that also host limestone, titanium and rare earths elements. There is also limestone at Hima (Fig. 232) in the southwest, in a secondary deposit derived from calcareous tuffs and hot springs. Other industrial minerals include clay, kaolin, feldspar, diatomite, silica sand and various types of dimension stone.

Fig. 233 A church hit by the Fort Portal earthquake of 5 February 1994 in western Uganda.

Fig. 235 Alexandra Peak seen from Margherita Peak in the Ruwenzori Mountains.

6 Geohazards

Various geoenvironmental hazards have been reported from Uganda: Earthquakes along the Western Rift have been noted (Hampton, 1995), sometimes triggering landslides (Muwanga et al., 2001). Groundwater pollution caused by mining has for instance occurred in the Kilembe area (Muwanga, 1997).

7 Geosites

A preliminary inventory of potential geosites of Uganda was presented by Schlüter et al. (2001) and includes the following six locations: Nyero Rock Shelter and Paintings, Napak Volcano, Bukwa Fossil Site, Nkondo-Kaiso Fossil Site, Kisegi-Nyabusosi Fossil Site and Nyakasura Caves with Speleothems.

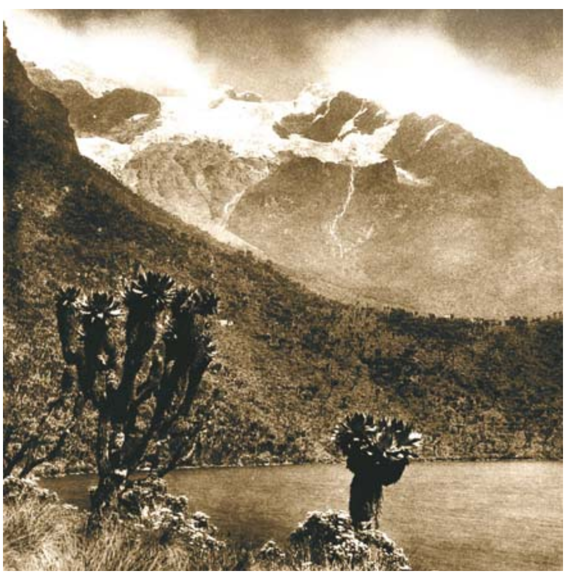

Fig. 234 Mt Stanley and Lake Bujuka photographed by the Luigi Amedeo di Savoia expedition in 1906.

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Fig. 236 The Murchison/Kabalega Falls descending into Lake Albert, western Uganda.

Western Sahara (under Moroccan administration)

1 General

Area: 266,000 km² (or 252,000 km²)
Population: 74,000 (1974), 120,000 (estimate 2000)

2 Summary of Geology

The eastern part of the Western Sahara is underlain by Archean rocks of the Reguibat Shield. An allochthonous unit of the Mauritanid Orogen, known as Ouled Dhlim, outcrops in the southern central part of the territory. The Zemmour Domain is a southern continuation of the Anti-Atlas Domain in Morocco. The western part of the Western Sahara consists of coastal basin sediments. Large NE-SW striking dune accumulations cover the southeastern part of the country.

3 Stratigraphy and Tectonics

The Reguibat Shield is the northern extension of the West Africa Craton. Its core consists mainly of migmatites, which are overlain in the Tiris region in the eastern Western Sahara by imbricated gneiss belts. The Tiris Series is made up of granulite-to-amphibolite facies metamorphites.

The Zemmour Domain is a southern continuation of the Anti-Atlas Domain in Morocco and forms a peripheric part of the West Africa Craton. The following succession has been identified: Stromatolitic carbonates of possible Neoproterozoic age occur at the base. These are overlain by the Oumat el Ham Group of Ordovician age, which consists of sandstones and shales with graptolites. The Garat-el-Hamoueid Group rests on an erosive surface of end-Ordovician glacial origin and is probably of Upper Ashgillian age. It follows transgressive Silurian, represented by clays and shales with graptolites, and then by limestones with corals. The Devonian succession, more than 1000m thick, is complete from Gedinnian to Frasnian and can be correlated with that of the Western Anti-Atlas Domain. It is represented by ferruginous oolitic limestones, sandstones, siltstones and clays. Brachiopods, bryozoans and corals are widespread.

The allochthonous unit of Ouled Dhlim in the southern central Western Sahara, consisting of crystalline nappes of Neoproterozoic age and a narrow Cambro-Ordovician parautochthon along its eastern side, is thrust eastwards upon the West Africa Craton during the Mauritanide orogeny. The western part of this domain underlies the coastal plain.

In the Aaiun-Tarfaya coastal basin clastics, evaporites and basalts extruded in a late tensional rifting phase and are succeeded by Jurassic carbonates, marls and clastic sediments. These are overlain by a Cretaceous-Tertiary clastic sequence, in which Paleocene to Eocene sediments generally lie unconformably upon the Cretaceous deposits.

Late Pleistocene to Holocene deposits are well exposed in pluvial lake beds and as large dune accumulations in the southeastern part of the Western Sahara. The latter are characterized by a SW-NE striking trend.

4 Economic Geology

Western Sahara has been claimed and administered by Morocco since 1976. Debate over the sovereignty of the territory still continues. The only significant mineral production from this region is from the phosphate mine at Bou Craa in the central northern Western Sahara. The production of phosphates was stable over the past several years totaling 1.5mt/a. Exploration for hydrocarbons offshore Tarfaya near the border to Morocco was not yet successful.

5 Geohazards

An inventory has not yet been made.

6 Geosites

An inventory has not yet been made.

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Fig 237 Exfoliated granitic rocks used by members of the Polisario as shelter.

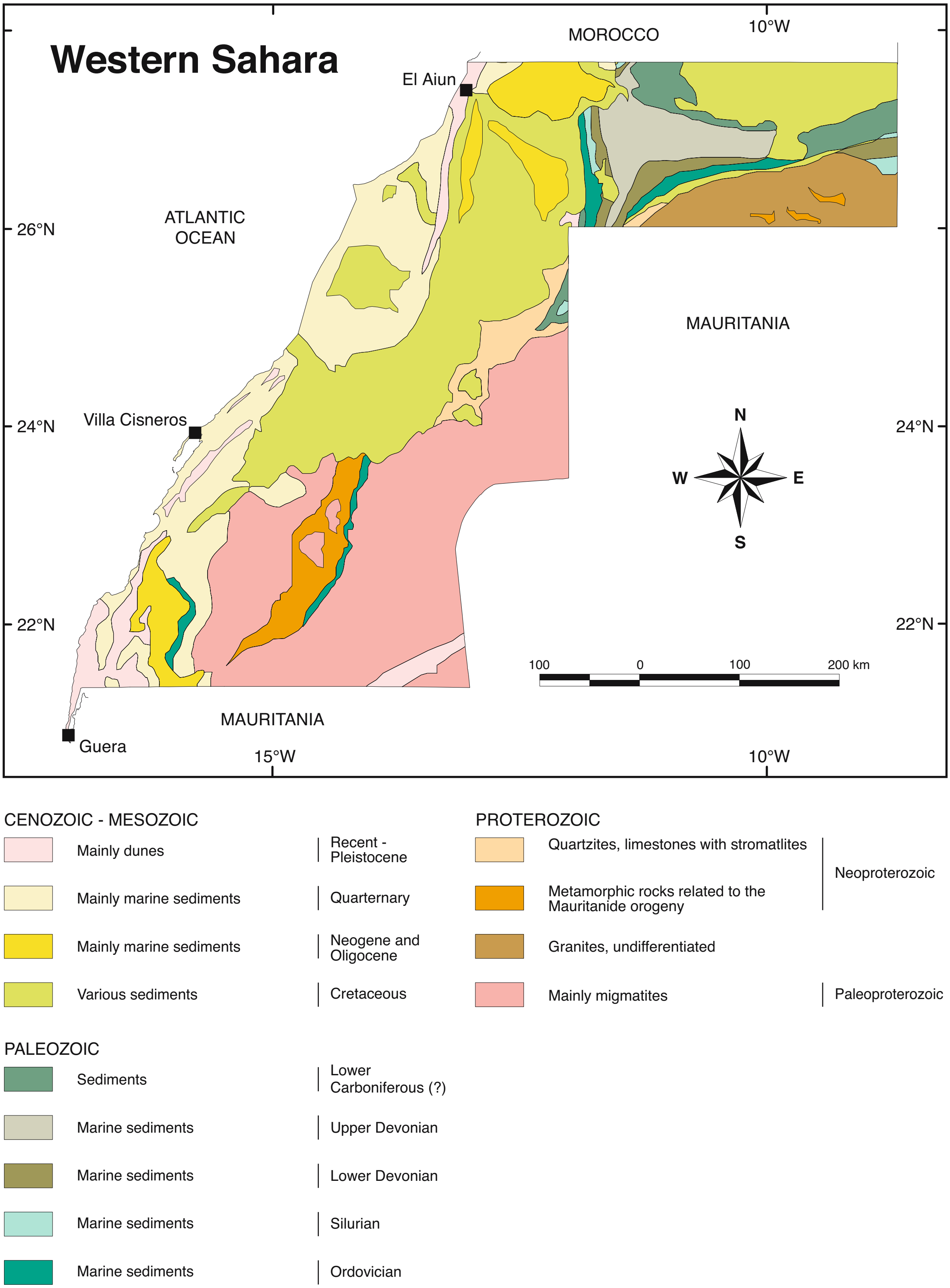

Fig. 238 Geological overview of Western Sahara (modified after Fabre et al., 1978)

Zambia

1 General

Area: 742,618 km²
Population: 9,582,000 (July 2000 estimate)

2 Summary of Geology

The rocks of Zambia are grouped into the Basement Complex, the Muva Supergroup, the Katanga Supergroup and the Karoo Supergroup. Above the Karoo strata are late Mesozoic, Tertiary and Quaternary sediments.

3 Stratigraphy

The oldest rock system of Zambia, the Basement Complex, is most extensively exposed in the east and southeast of the country. The rocks of the Basement Complex, known on the Copperbelt as the Lufubu System, are structurally complex. They have been folded and faulted and have undergone repeated metamorphism, so that their original character has been completely obliterated. The main rock types are: granites, gneisses, schists, migmatites, amphibolites, granulites, charnockites, khondalites, phyllites, limestones and metaquartzites. These rocks are of Paleoproterozoic age. The intrusive and extrusive rocks in the Basement Complex are granites, syenites, dolerites, granodiorites, pegmatites, quartz veins, aplites, pyroclastics, gabbros, rhyolites, ultrabasic rocks, andesites and metavolcanic rocks. The Basement Complex occupies a large part of the Eastern and Northern Provinces, while isolated domelike outcrops occur elsewhere on the plateau, e. g. at Solwezi and Luswishi.

The Muva Supergroup has a much lower grade of metamorphism. It is separated from the Basement Complex by an unconformity, which probably represents a period of about 1Ga. It is mainly exposed in Central, Copperbelt, Southern and Northern Provinces and is composed of conglomerates, grit, quartzites, iron-rich sandstone and red mudstone, gneissose schists and metavolcanic rocks. Intrusive rocks in the Muva Supergroup are granites, granite porphyry, granodiorite, syenites, dolerites, norites, lamprophyres, carbonatites, pegmatites, quartz veins, gabbros, basic volcanic and ultrabasic rocks. A belt of porphyritic rock, largely rhyolitic in character and associated with volcanic breccia, is thought to be equivalent in age to the Muva Supergroup. It extends along the eastern side of the Luapula River from Lake Mweru to Lake Tanganyika.

The Katanga Supergroup is unconformably located above the Muva Supergroup or the Basement Complex, and is composed of conglomerates, shales, argillites, quartzites, arkoses, greywackes, iron formations, dolomites and aeolian sandstones. The Katanga Supergroup rocks are Neoproterozoic to Cambrian in age. Intrusive rocks in the Katanga Supergroup are granites, dolerites, adamelites, lamprophyres, gabbros and ultrabasic rocks. Rocks of the Katanga Supergroup occur extensively in Northern, Luapula, Copperbelt, Northwestern and Central Provinces. On the Copperbelt the Katanga Supergroup has been divided into the Roan, Mwasha and Kundelungu Groups. In the remainder of the country, it has been usual to divide the Katanga Supergroup simply into upper and lower divisions. Part of the Roan Group is highly mineralized, and copper occurs in local synclinal basins in shales, sandstones, dolomites and quartzites on the margins of the broad Kafue anticline. Copper minerals include chalcopyrite, bornite, chalcocite, malachite and azurite. The Mwasha Group consists largely of carbonaceous shales, argillites and interbedded quartzites. The Kundelungu Group rests unconformably on the Mwashia Group and its lithology varies greatly from place to place. It can be divided into a lower part consisting of a conglomerate of glacial origin, dolomites, limestones and carbonaceous shales, and an upper part predominantly of sandstones, quartzites and shales.

The Karoo Supergroup of upper Carboniferous to Jurassic times is best represented in the rift block valleys of the eastern and southern parts of the country, the valleys of the Luangwa, Lukusashi, Lunsemfwa, Rufunsa and mid-Zambezi, although further outcrops occur on the plateau to the west. The lowest part of the sequence is represented by a possible tillite indicating a glacial phase of upper Carbonifrous age. This is followed by sandstones and then by the Gwembe Coal Formation. These coal seams outcrop in the Maamba-Nkandabwe area of the Zambezi Valley, but thin seams occur elsewhere in the mid-Zambezi Valley and also in the Luangwa Valley. Higher in the sequence, the Karoo Supergroup consists mainly of mudstones, grit and sandstones with an upper layer of basaltic lava of Jurassic age. The basalt outcrops around Livingstone and is exposed in the walls of the Batoka Gorge below the

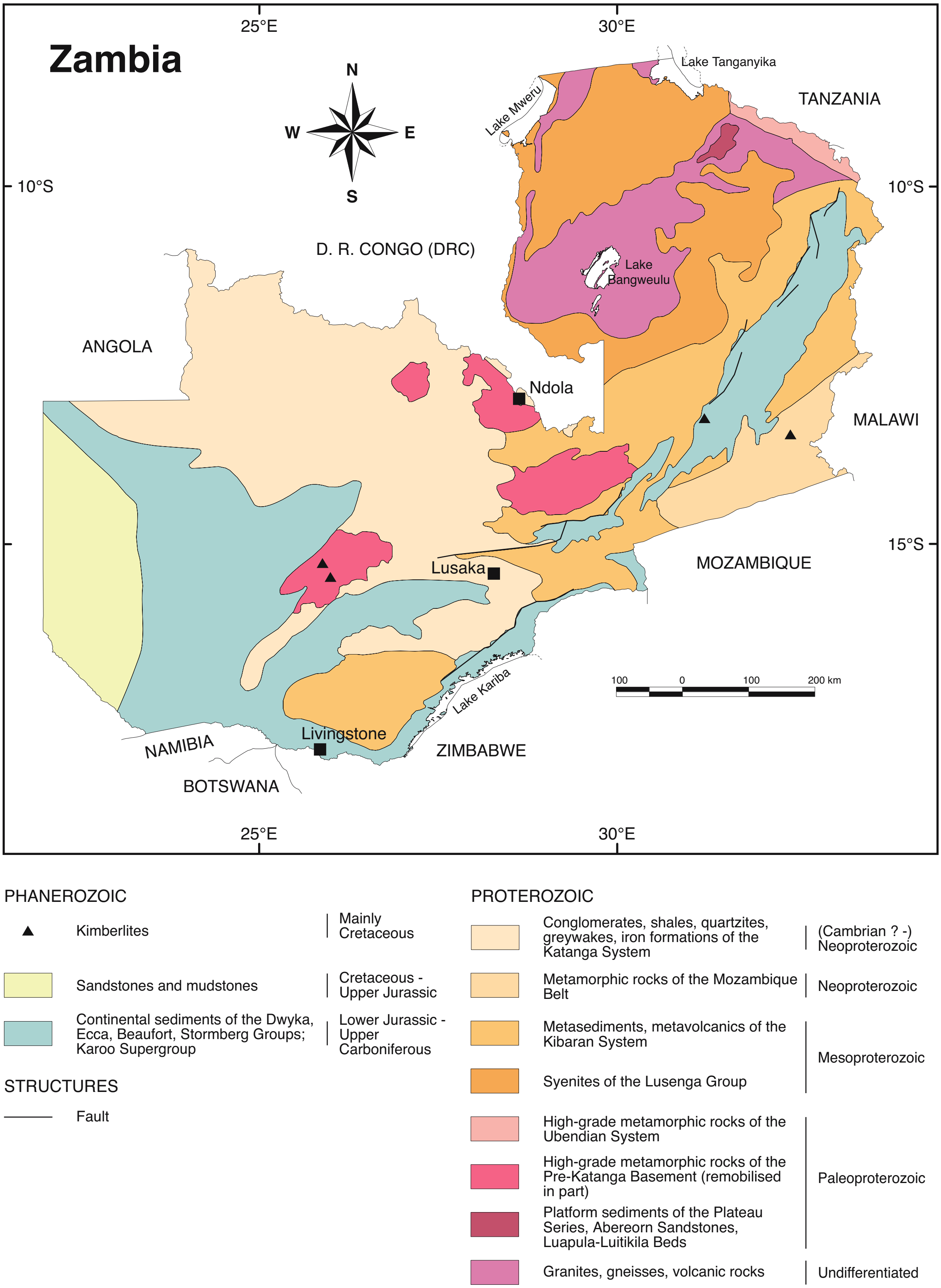

Fig. 239 Geological overview of Zambia (modified after Drysdahl et al., 1961, 1981 and Ng´Ambi et al., 1994)

Victoria Falls. Intrusions into the Karoo Supergroup are a few carbonatites and kimberlites.

Above the Karoo Supergroup are sandstones and mudstones of Late Jurassic to Cretaceous age. The Kalahari Group, consisting of poorly consolidated sandstones and unconsolidated windblown sands, mantles the greater part of the Western Province, together with smaller areas of the Northwestern, Central and Southern Provinces. These sands originated during the later Tertiary and Pleistocene periods. They were deposited during an arid phase, when the limits of the Kalahari Desert were greatly extended. Alluvial deposits occur most extensively along the upper Zambezi River and its tributaries, on the Kafue Flats, the Lukanga and Bangweulu Swamps and along the upper Chambeshi River.

4 Tectonics

The main structural provinces of Zambia are the Bangweulu Block, the Ubendian Belt, the Irumide Belt, the Kibaran Belt, the Mozambique Belt and the Zambezi Belt, the Lufilian Arc and the Mwembeshi Shear Zone. The Bangweulu Block, a craton of Proterozoic age, covers a large portion of northern Zambia. The Ubendian Belt has a NW-SE orientation and is probably of Paleoproterozoic age. The Irumide and Kibaran Belts have a NE-SW orientation and are dated 1.1Ga. The Irumide orogeny affected pre-Katanga rocks, especially those of the Muva Supergroup. The Neoproterozoic Mozambique Belt forms the southern part of an orogenic belt extending from Ethiopia and cutting across the Irumide Belt in southern Zambia. The Zambezi Belt is probably a southern extension of the Mozambique Belt. The Lufilian Arc is an arcuate belt that stretches from Angola through the Democratic Republic of Congo and Zambia, giving NE-SW and NW-SE structures, being formed by a northward movement between 840 and 465Ma. The about 550Ma old Mwembeshi Shear Zone is a ductile shear zone associated with a sinistral strike slip movement. Karoo rifting formed the Luangwa, Zambezi and Luano-Lukasashi Valleys.

5 Economic Geology

Zambia has a great mineral potential in various geological environments. Mining for copper in the famous lower Roan Group (Copperbelt Province) is the most prominent feature and was the main economic backbone of the country till the 1970s when the demand and price for copper suddenly declined. Cobalt as byproduct of the copper production is now the major mineral export in order of importance. Other metal ore commodities include lead, tin and zinc. Mica was mined in pegmatites in Southern and Eastern Provinces. The Basement Complex hosts gemstones within pegmatites and veins, but are mined in Zambia only on a small scale. Emeralds occur in the Ndola area, aquamarines and garnets in Lundazi. Talc has been worked in Ndola. The Lower Karoo hosts economic coal deposits, whereas in the Upper Karoo a uranium mineralisation occurs.

Fig. 240 The Kariba Dam across the Zambezi River with a high of 175m and holding back one of the largest artificial lakes in the world. It lies between Zimbabwe on the right side and Zambia on the left (1964)

6 Geohazards

Pollution of surface and groundwater due to extensive mining in the Copperbelt Province is one of the major geoenvironmental hazards in Zambia.

7 Geosites

An inventory of potential geosites in Zambia has not yet been made. The Zambian part of the Victoria Falls as well as its Zimbabwean counterpart is already a UNESCO world heritage monument, but clearly also represents a geosite (Fig. 241 - 242).

Fig. 241 The Victoria Falls between Zambia and Zimbabwe

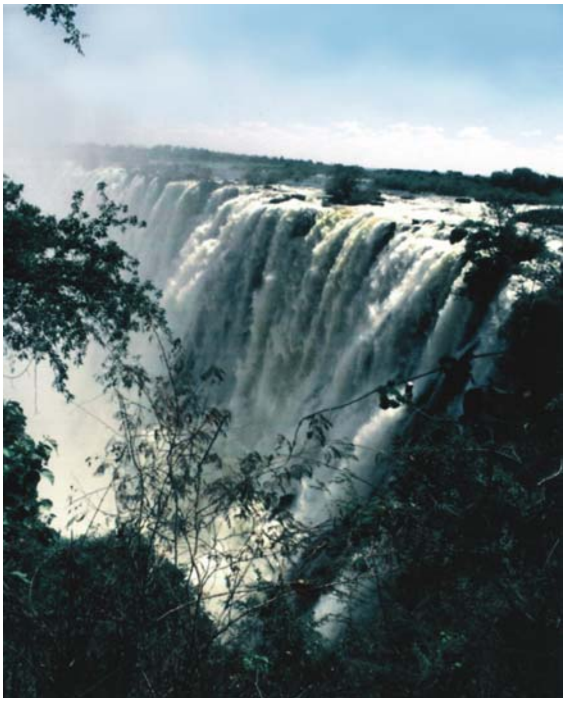

Fig. 242 The Victoria Falls seen from the Zambian side

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Zimbabwe

1 General

Area: 390,757 km²
Population: 11,920,000 (2001 estimate)

2 Summary of Geology

Zimbabwe is underlain by a core of Archean basement known as the Zimbabwe Craton, which is intruded by the famous Great Dyke, a SSW-NNE trending ultramafic/mafic dyke complex. The craton is bordered to the south by the Limpopo Belt, to the northwest by the Magondi Supergroup, to the north by the Zambezi Belt and to the east by the Mozambique Belt. The craton is principally composed of granitoids, schists and gneisses and greenstone belts. It is overlain in the north, northwest and east by Proterozoic and Phanerozoic sedimentary basins.

3 Stratigraphy and Tectonics

The Zimbabwe Craton is made up of vast areas of older Paleoarchean granitic gneisses and younger Neoarchean granitoids. The ancient gneisses have largely been recrystallized, which makes it difficult to distinguish between granitoids and gneisses. Greenstone belts are another geological feature located on the Zimbabwe Craton. Principally these belts are composed of mafic, ultramafic and felsic volcanics and associated intrusions, epiclastic sediments and iron formations. The greenstone belts are thought to have formed on the basement of older granitic gneisses and developed in three successive phases: the Sebakwian Group, the Bulawayan Group and the Shamvaian Group. They are separated from each other by granitoid and gneissic rocks. The Great Dyke is a unique geological feature on the Zimbabwe Craton. It is a long, narrow body of inward-dipping peridotites, with chromite bands, pyroxenites and norites consisting of separate but continuous elongate, gently inward-dipping masses emplaced from several intrusive centres aligned along a NNE-SSW striking graben structure. The Great Dyke, its two parallel satellite dykes on either side known as the Umvimeela and West Dyke, and the gabbro-filled Popoteke fracture zone further east, were intruded into basement complex greenstone belts and batholitic granites. The Great Dyke is divided into four sections; from north to south, teh Musengezi Complex (44km long), the Hartley Complex (314km long), the Selukwe Complex (97km long), and the Wedza Complex (80km long). These sections form a long synclinal structure, which has the same stratigraphic succession. In essence, the more than 500km long Great Dyke, is, however, not a dyke but a long stratiform complex composed of juxtaposed segments. The Magondi Basin was formed during an extension phase after the emplacement of the Great Dyke. This basin constitutes the northwestern margin of the Zambezi Basin. The southern part of the basin is covered by sediments of the Karoo Supergroup and younger formations. The sequence within the basin is divided into the Piriwiri Group, the Deweras Group, the Mcheka Group and the Chiwuyu-Godzi Group. The basin is filled with a thick sedimentary sequence with felsic and mafic volcanics interstratified near the base. These rocks are highly deformed and metamorphosed. Dolerite sills were formed during a magmatic episode on the craton, the so-called Mashonaland igneous event. The sills are concentrated in the northwestern part of the craton. The Zimbabwe Craton is separated from the Kaapval Craton to the south by a zone composed of rocks showing ubiquitous penetrative deformation and a high degree of metamorphism. This zone is called the Limpopo Mobile Belt. The Limpopo Belt runs SSW-NNE in the south of the country and consists of metamorphosed cratonic rocks containing gold deposits, corundum and magnesite occurrences. It has a complex polyphase history spanning Paleoarchean to Mesoproterozoic times.

The Karoo Supergroup is made up of sediments and volcanics, which were laid down in three basins: the Middle and Lower Zambezi basins in the west and north, and the Save-Limpopo basin in the south and southeast of Zimbabwe. The basins developed on two ancient suture zones known as the Zambezi and Limpopo Mobile Belts. The Zambezi Basin is the thicker of the two and was developed in the axial zone of a rift structure fringed by parallel sub-vertical faults and extends southwards onto the craton. The Save-Limpopo Basin in the south is relatively thin. The Karoo rocks are generally composed of terrestrial detrital sediments (feldspathic sandstones, grits, shales, coal beds, etc.), which are overlain by basaltic flows.

The Kalahari Group of Neogene to Recent age consists of poorly consolidated sandstones and sands, which occur in the northwestern part of the country between Bulawayo and Victoria Falls.

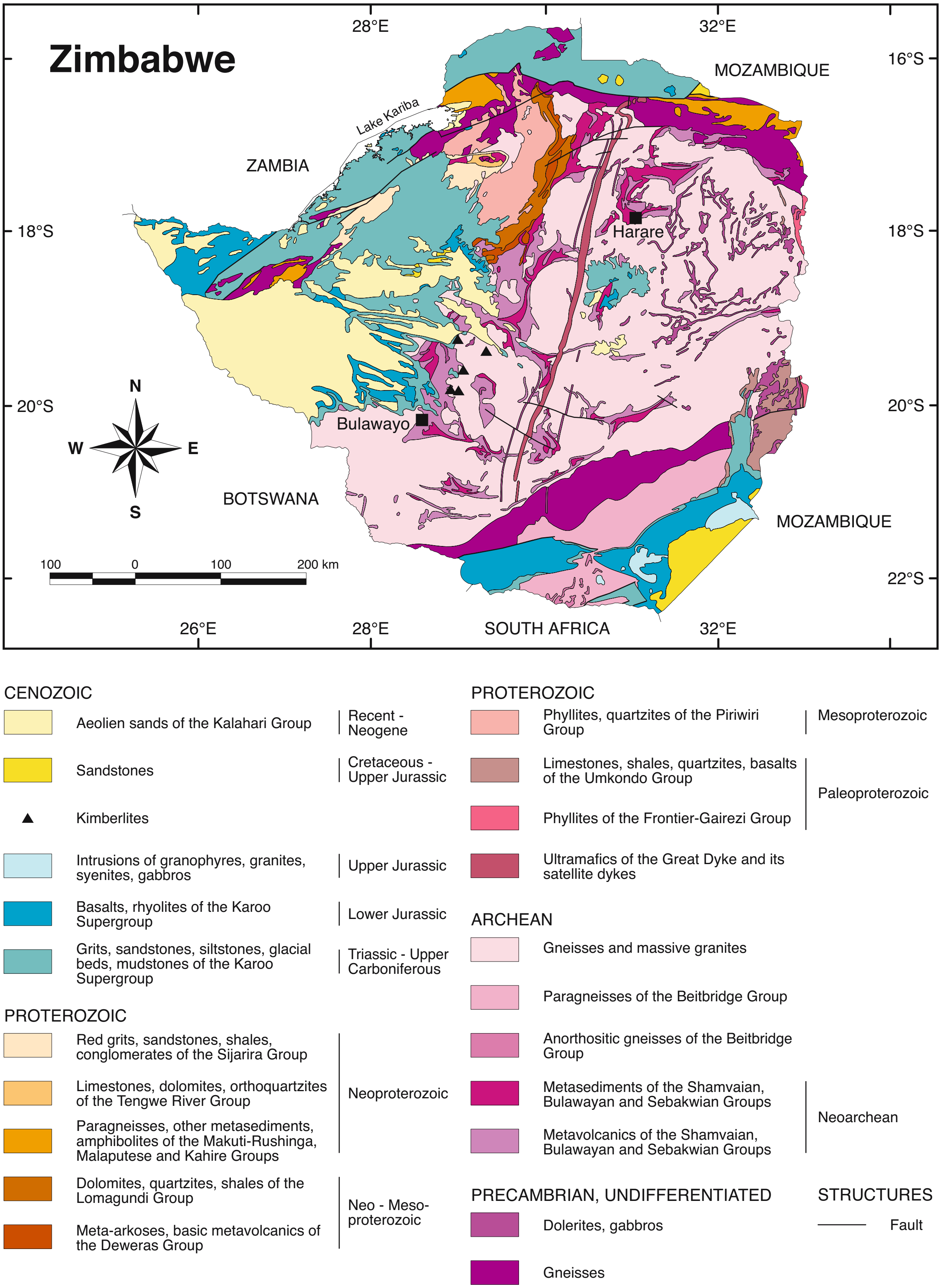

Fig. 243 Geological overview of Zimbabwe (modified after Campbell et al., 1991)

Fig. 244 The Victoria Falls from the west in a painting of Thomas Baines (1862)

Fig. 246 A dried-out arm of the Zambezi River over granitic rocks close to the Victoria Falls

4 Economic Geology

Non-fuel minerals such as chromite, gold and nickel will remain the mainstays of the economy for the near future. A special case is asbestos, which has been for several years a major contributor to the economy of Zimbabwe. But asbestos is now generally under threat of ban by some countries due to health risks associated with its use. Although uncertainty about the future of asbestos continues, it has been noted that a better understanding of the health risks associated with the different varieties of asbestos will lead to the continued use of Zimbabwe's chrysotile deposits.

It has been stated that the Archean terrain of Zimbabwe, in terms of gold yield per km^2, is the most productive of its kind in the world. Gold production remains the backbone of the country's mining industry with over 2000 operating mines scattered around the country. Evaluation of industry views about the future of the platinum group metals (PGM) generally indicate positive perceptions, for instance it is estimated that the Great Dyke contains a resource of over 4,500Mt of platinum-bearing material. The production of base metals in Zimbabwe in the last few years reflects significant structural changes that have occurred. While chromite ore, nickel and cobalt metals indicate steady output levels, those of copper and tin have declined. In terms of gross value to the country nickel occupies the number three position after gold and the PGM. Chrome ore production was in the range of 500,000-700,000t/y in the late 1990s. The precious stones industry had until the 1990s been dominated by emeralds production at the Sandawana Mine, but the country's production has been erratic, ranging from as low as 276kg to as high as 2209kg from one year to the next. River Ranch in the Limpopo Mobile Belt, Zimbabwe's only diamond mine, commenced production in 1991 and a steady production improvement from about 40,000ct in 1992 to a peak of 437,000ct in 1996, before registering a decline prior to closure. The industrial minerals sector in Zimbabwe is diverse ranging from asbestos through vermiculite, graphite, mica, limestone, lithium to black granite. Asbestos has in recent years been ranked second after gold in production values, the bulk of which is exported. Within Zimbabwe there is a thriving downstream industry based on chrysotile asbestos, as the manufacture of water pipes, roofing tiles, insulation products etc. are all based on the asbestos fibre mined in the country.

Fig. 245 Zambezi River close to the Victoria Falls

Zimbabwe has huge coal reserves. Currently about 5.5Mt are produced by the Wankie Colliery at Hwange to meet the thermal power plant needs of the country, as well as the industrial and agricultural sectors. A second mine, at Sengwa, is planned to commence production and supply the Gokwe North power plant. During the last decade Zimbabwe has seen a considerable exploration interest in coal bed methane as a potential energy source.

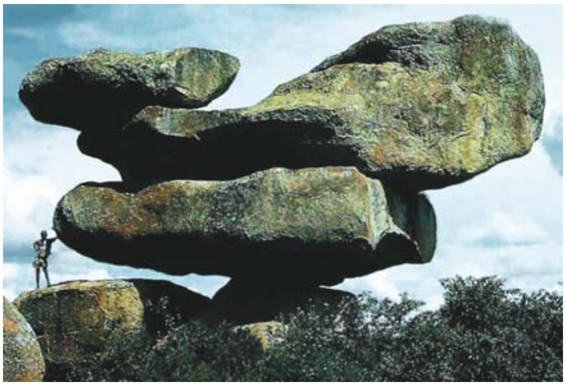

Fig. 247 Balancing rocks, an inselberg of granite boulders, at Epworth, southeast of Harare

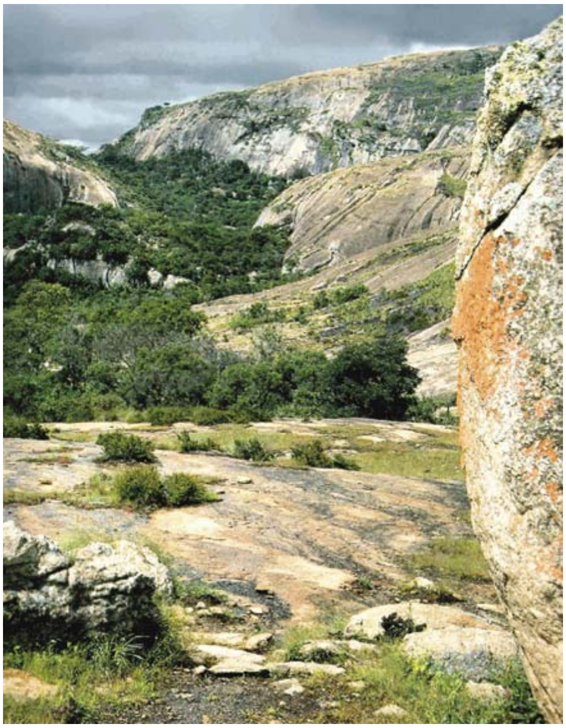

Fig. 248 Exfoliated granitic rocks in Mashonaland, often exhibiting stone age paintings and engravings

5 Geohazards

The mining sector faces a number of issues concerning environmental degradation during mining, the disposal of waste products and their potential use as well as local community conflicts.

6 Geosites

An inventory of potential geosites has not yet been made, but Zimbabwe offers various geological features of scenic beauty, for instance the Victoria Falls (Fig. 244 - 249).

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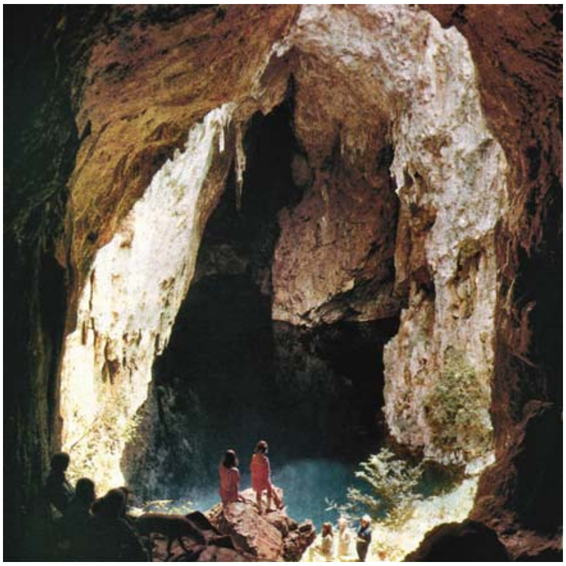

Fig. 249 The Chinhozi Caves in northwestern Zimbabwe

Index

Geographical and Subject Index

Geographical Index

E

G

H

I

J

K

L

M

N

O

P

R

N

T

U

V

W

Y

Z

Subject Index

A

B

C

D

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

T

U

V

W

Y

Z