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Martha Demas
Neville Agnew
Fan Jinshi

Strategies for Sustainable Tourism at the Mogao Grottoes of Dunhuang, China

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Martha Demas • Neville Agnew • Fan Jinshi

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With contributions by
Shin Maekawa, Lorinda Wong, Wang Xudong,
Su Bomin, Chen Ganquan, Wang Xiaowei, and Li Ping

Springer

Martha Demas
Getty Conservation Institute
Los Angeles, CA, USA

Neville Agnew
Getty Conservation Institute
Los Angeles, CA, USA

Fan Jinshi
Dunhuang Academy
Dunhuang, China

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Preface

This publication addresses a complex and multifaceted problem at an iconic World Heritage site in far northwestern China. The site, the Mogao Grottoes near the oasis town of Dunhuang in Gansu Province, has experienced an explosive rise in tourism over the last 10–15 years. Pressure from visitors for access to the cave temples containing sublime Buddhist art dating from the fourth to the fourteenth centuries CE has reached crisis dimensions and threatens the fragile cave paintings and sculpture while simultaneously degrading the visitor experience through overcrowding in the confined spaces of the rock-cut caves and along narrow access walkways. Congestion management is an important element of visitor management at heritage sites, but often sites are sufficiently robust and durable to withstand a degree of overcrowding—it is the visitor who is disadvantaged. At the Mogao site, the driving force for the present study was preservation of the art and the need for a better understanding of the causes of deterioration and whether and to what degree the number of visitors and the act of visitation itself, that is groups entering and occupying the cave temples, were responsible for or contribute to the many kinds of decay and damage found in the wall paintings. Working within the framework of the master plan for the Mogao Grottoes, itself structured to comply with professional guidelines issued by China ICOMOS (the *Principles for the Conservation of Heritage Sites in China*), the visitor study strived essentially to understand natural and human-induced deterioration as a prerequisite to determining safe levels for visitation while also endeavoring to provide a good visitor experience. To achieve this required a wide range of expertise and input of many disciplines, involving analytical and laboratory investigations, environmental research, analysis of visitation to the site, assessments of physical condition, development of visitor flow simulation models and visitor management systems. This study is part of comprehensive visitor planning undertaken by the vested authority for site, the Dunhuang Academy (DA), which includes a new visitor center, to be opened in 2014, with state-of-the-art presentation and interpretation. It provides an opportunity for the DA at the present critical juncture to manage tourism growth at

Mogao in a sustainable manner and from a position of strength, rather than one on the defensive against tourism pressure. For the field of cultural heritage management at large, this study provides a methodology applicable, in whole or in part, to many other sites faced with debilitating tourism growth.

Los Angeles, CA, USA Martha Demas
Los Angeles, CA, USA Neville Agnew
Dunhuang, Gansu, People's Republic of China Fan Jinshi

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The visitor study for the Mogao Grottoes is an outcome of many years of work and successful collaboration between the Getty Conservation Institute (GCI) and the Dunhuang Academy (DA). Among DA staff members who have contributed to this study the authors wish in particular to thank Deputy Director of the Dunhuang Academy Wang Xudong* and director of the Conservation Institute Su Bomin for support throughout the project; and to recognize the efforts of Chen Gangquan, with assistance of Qiao Hai, who supervised monitoring of wall painting condition in the four test caves and with Fan Yuquan ran the accelerated deterioration experiments on replica wall painting test coupons; Xue Ping undertook maintenance of the environmental monitoring equipment in the field testing caves and processed data for transmission to the GCI; Wang Xiaowei, Xu Shuqing, and Zhu Wanyu contributed to the compilation of information and the assessment of the 112 priority visitation caves; and Li Ping, director of the Visitor Reception Department, and her staff provided input and information on visitor management practices and policies and the development of visitor management tools. The DA provided many of the photographs used in this publication.

Shin Maekawa and Lorinda Wong have been core members of the GCI visitor study team from the beginning and contributed substantially to this publication. Maekawa has provided years of environmental monitoring and analysis that are central to the study, described in Sect. 4.2.3; Wong developed and led the cave assessment process, described in Sect. 4.2.4. GCI former staff member Jonathan Bell provided valuable support and input in all aspects of the work and was especially instrumental in carrying out and assessing the results of field testing. GCI staff Michael Schilling and Joy Mazurek contributed to chemical analytical work for the study; and Vincent Beltran, working under Shin Maekawa, further analyzed environmental data. Former intern Shuya Wei did initial studies on the humidity-salt

* For Chinese names we have retained the standard practice of placing the family name first followed by the given name.

relationship. Kiernan Graves contributed to the risk assessment of caves as a GCI intern and later as consultant. Valerie Greathouse undertook bibliographic searches and verified citations. Peter Barker undertook oral translation and formal written translation of documents. Special acknowledgment is due to Po-Ming Lin who, throughout the GCI's long relationship with the Dunhuang Academy, has been a lynchpin in the productive partnership.

Contents

List of Figures

Chapter 1
Introduction

A physical map of northwest China shows the Hexi Corridor of Gansu Province, a narrow area connecting heartland China with Central Asia. To the south are the Qilian Mountains, the easternmost spur of the Himalayan massif, to the north the Ordos and the Gobi Desert, and to the west the Taklamakan Desert of Xinjiang Province (Figs. 1.1 and 1.2). At a glance one can see how physical geography has determined migration and trade routes between China and western regions through Xinjiang and beyond. In these regions of deserts and mountains the source of water to sustain agriculture, settlement and trade has been snow clad ranges and the oases created by summer melting of snow and glaciers. A string of oases between present-day Lanzhou in Gansu Province and Kashgar in Xinjiang Autonomous Region define China's western portion of the famed Silk Road, a pattern of trade routes with Central Asia and the west that flourished in antiquity. Of these oases, the most historically significant in China is Dunhuang.

Dunhuang was founded as a military outpost in 111 BCE to guard the northwest frontier against nomad raiders and to protect and regulate trade routes. The ancient name itself reflects this: Dunhuang means "Blazing Beacon" (though this has been questioned by scholars) ostensibly referring to the string of watchtowers to the north and west that served to spread the alarm by lighting bundles of dry brush at the approach of the nomad enemy. By the late fourth century, Dunhuang had become an important oasis and trading center. It was nearby that the wandering Buddhist monk, Yuezun, had a vision and excavated the first cave in a cliff face above the Daquan River, in what were to become the Mogao Grottoes (Fig. 1.3). Over the next 1,000 years and many dynasties, from the Northern Liang (419–440) to the Yuan (1279–1368), until the decline of the Silk Road in the Ming Dynasty (1368–1644), hundreds of caves, some quite large, some mere niches, were excavated and decorated with brilliant wall paintings and sculpture.

Over time Dunhuang has seen many transformations: its name was changed to Shazhou (City or District of Sand) and back again; it declined during the Ming Dynasty when imperial influence contracted, but began to recover during the expansion under

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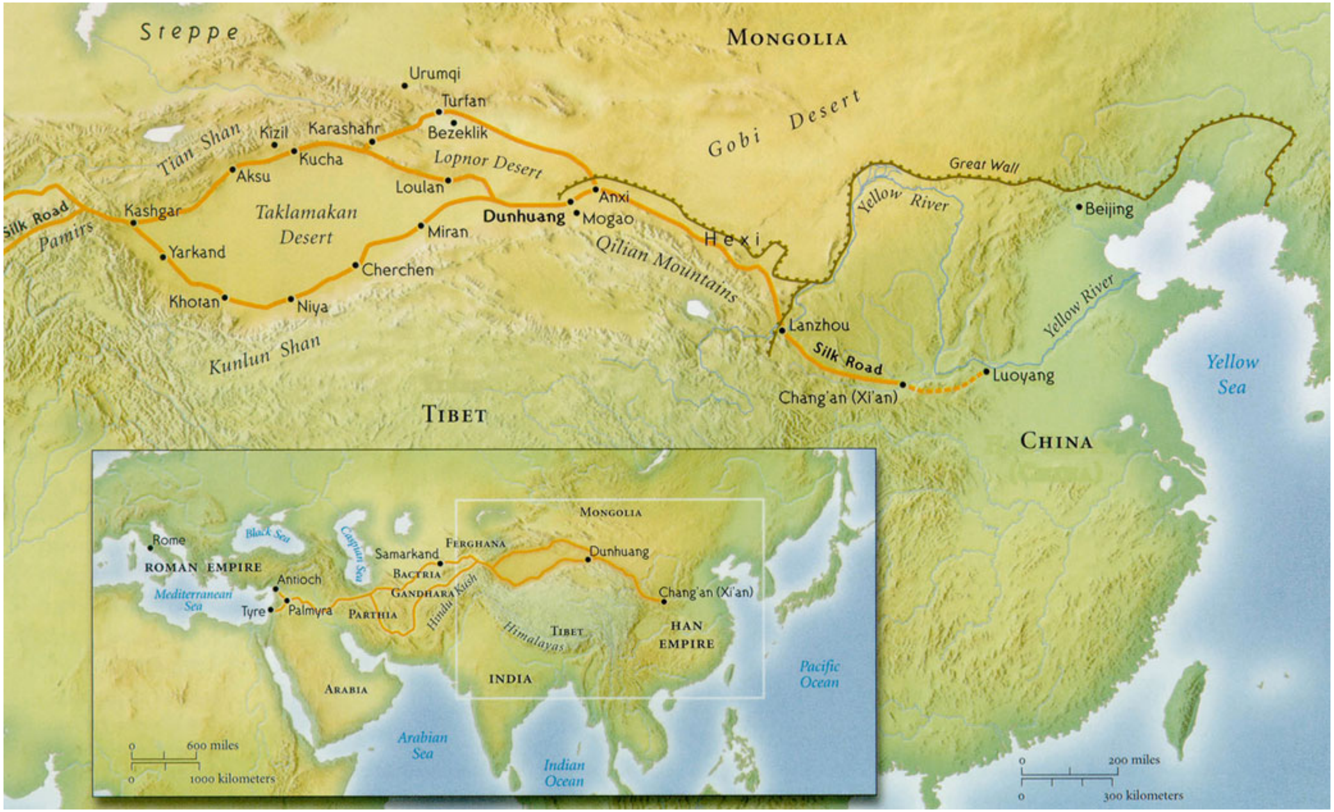

Fig 1.1 Location of Dunhuang and the Mogao Grottoes on the ancient Silk Road. Dunhuang was an outpost marking the western end of China proper. To the west, the Silk Road split into northern and southern branches encircling the Taklamakan Desert

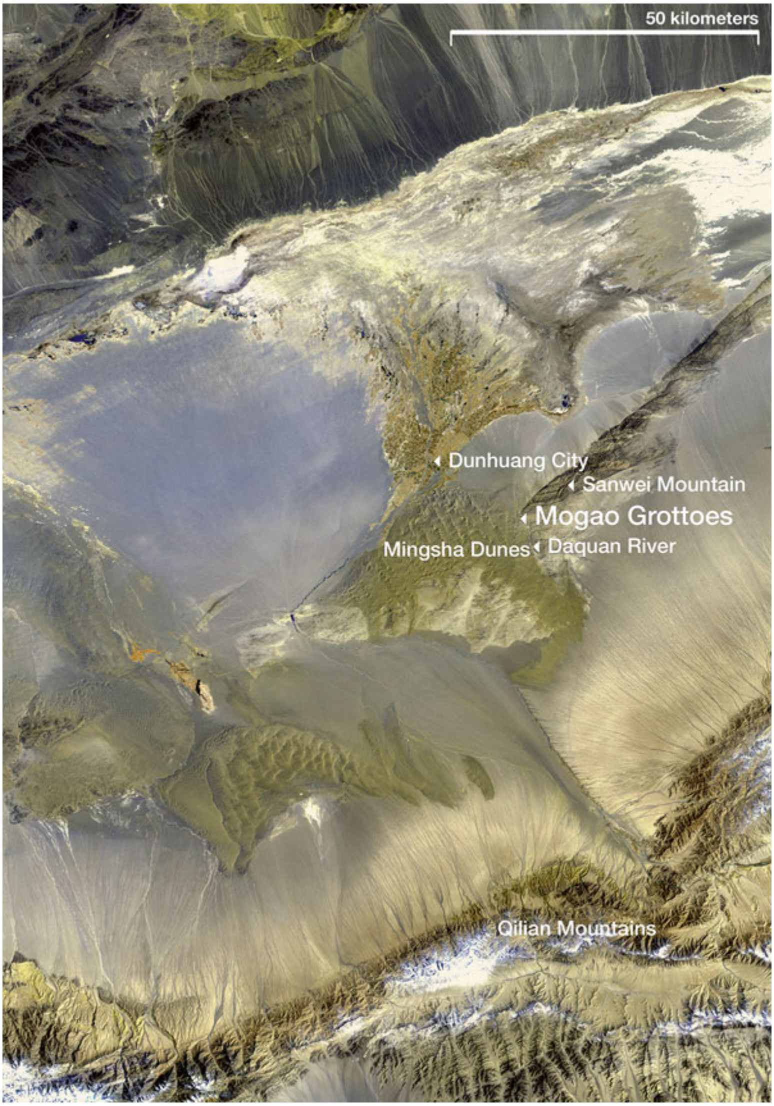

Fig. 1.2 Satellite image of the Dunhuang region showing geological features of mountains, sand dunes, and river (©1989USGS Landsat image courtesy of the U.S. Geological Survey)

the Qing Dynasty (1644–1911). Photographs from the first decade of the twentieth century convey an impression of a provincial town with mudbrick buildings and town wall—perhaps not all that different than its appearance during the pinnacle of Chinese imperial power in the Tang Dynasty when trade with western regions flourished—all of it passing through Dunhuang, including some famous travelers and monks such as Xuan Zang en route to India to obtain Buddhist scriptures.

Dunhuang today is a thriving, tourism-driven city, small by Chinese standards with a population of around 200,000, having grown rapidly from a small agricultural town largely as a result of expanding tourism to the Mogao Grottoes, and spurred by the influx of development funding from government and private sources.

Tourist numbers at heritage sites in China, and particularly at World Heritage sites, have grown rapidly since the Open Door policy of 1979. At the Mogao Grottoes, there is inherent conflict between the fragile nature of this extraordinary site and ever more visitors. The beauty of the art, its spiritual, religious and artistic attributes, and the striking landscape (Figs. 1.3 and 1.4) have drawn visitors for decades to this desert oasis, but now pressures from an increasingly mobile population with money to travel and from local and regional government and business interests who are eager to exploit the economic potential of tourism threaten what is most valued about the site.

As a "pillar industry" of the nation, tourism has been one of the means of bringing economic benefit to the poorer "Western Regions" of China, which include the Silk Road provinces of Gansu and Xinjiang. In expectation of commensurate returns from both domestic and international tourism, local large-scale infrastructure investment has been made through hotel development, an expanded airport, and a new rail link. In the city itself all vestiges of its ancient origins and its traditional architecture have fallen to development. Today the city looks like most other modern, anonymous Chinese cities; public art, in the form of flying celestial beings (*apsaras*) fancifully based on the Buddhist iconography of Mogao, provide the only visual clues as to the reason for the growth of the city as a tourism center. There is constant and mounting pressure for more development and tourism to the site. Arrayed against this are the national authority (State Administration of Cultural Heritage) and the Cultural Heritage Law of the PRC, together with the *Principles for the Conservation of Heritage Sites in China*, a set of national guidelines issued by China ICOMOS,[1] and professionals and citizens concerned to protect their heritage.

Understanding the impact of tourism at heritage sites is essential to developing management practices capable of safeguarding the resources, providing a satisfactory visitor experience and achieving long-term social, educational, and economic benefits that derive from the industry. Although concerns about irreparable damage to the Mogao Grottoes from rapidly increasing visitor numbers were frequently expressed by DA staff, direct and indirect effects of visitation on the primary cultural resource of the site, the 492 painted Buddhist cave temples (excavated into the cliff face and decorated between the fourth to the fourteenth centuries), had not been determined nor systematically studied. This was the initial purpose of a visitor study, began in 2001 and completed in 2013 as part of a larger initiative and long-term collaboration between the Dunhuang Academy (DA) and the Getty Conservation Institute (GCI).[2]

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[1] The *Principles for the Conservation of Heritage Sites in China*, developed through a collaboration of China's State Administration of Cultural Heritage, the Getty Conservation Institute, and the Australian Heritage Commission, were issued by China ICOMOS in 2000 and later published in a bilingual edition (Agnew and Demas 2004; see also Agnew et al. 2004).

[2] Under a collaborative agreement with China's State Administration of Cultural Heritage (SACH), the GCI has been working with the DA since 1989 on conservation at the Mogao Grottoes.

Fig. 1.3 Green oasis marks the cliff face, with the distinctive Nine-level Pagoda at its center, amid the desert sands (*top*). Contrasting with the stark desert are the vibrantly decorated cave interiors, here the Late Tang Dynasty Cave 85 (*bottom*) (Courtesy Dunhuang Academy)

The first years of collaboration addressed site-related issues. Since 1997, the collaboration has focused primarily on the conservation of wall paintings at Mogao and application of the *China Principles* (for an overview, see Agnew et al. 2012).

Fig. 1.4 The extraordinary beauty of the cave paintings illustrated in Cave 285, Western Wei Dynasty (*above*) and detail from Cave 61, Five Dynasties (*below*) (Courtesy Dunhuang Academy)

Associated with the DA's focus on visitor management over the last decade there have been two international workshops organized at Mogao. In 2009 a workshop entitled *Advancing Sustainable Tourism at Natural and Cultural Heritage Sites* was organized by the Australian and Chinese governments, the Getty Conservation Institute and the Dunhuang Academy with support from the Asia Pacific Economic Cooperation (APEC) Tourism Working Group. The aim was to discuss guidelines and propose principles as they relate to managing tourism at World Heritage sites; a set of recommendations emerged from this workshop (APEC 2010). A smaller, more focused colloquium on *Carrying Capacity and Visitor Management at World Heritage Sites in China* was organized at Mogao by the Dunhuang Academy and the Getty Conservation Institute in 2013. The colloquium engaged managers of World Heritage sites in China as well as international experts in presentations and discussion of practical solutions based on best practice and real-world experience of managing visitor impacts to heritage sites (for an overview and extended abstracts from the colloquium, see Agnew and Demas 2014).

Within the existing visitor management policy and framework for Mogao, the goal of the visitor study seeks to optimize visitation and sustainable use of the site while ensuring that no deleterious effects to the art result. The study also provides an understanding of the complex interplay of issues affecting the visitor, the site's management, and the site itself and affords information about the fragility and significance of the site as a means of outreach to the public and authorities.

It has become the norm to talk of cooperation between tourism and conservation. Though cooperation is essential, it is necessary to consider also the oppositional natures of tourism and conservation: economic benefit from tourism creates a drive to increase visitor numbers, build more facilities, provide opportunities for local vendors, and so forth, which, if unchecked, leads ultimately to degradation of the resource and an unsatisfactory experience for the visitor. China's rise as an economic power and the raised living standards of its people has led to huge increases in domestic tourism to heritage sites. The results of rampant tourism can be readily seen at iconic cultural heritage sites like the Forbidden City, the Badaling section of the Great Wall, and the Xi'an Terracotta Warriors, but also at lesser known World Heritage sites such as Longmen Grottoes in Henan Province, where congestion and crowding can be overwhelming, but where the impact is primarily to the visitor experience (Fig. 1.5). At these sites management has not yet adequately grappled with the problem of mitigating congestion and crowding although well-established guidelines and strategies exist (for example, WTO 2004), but the situation is more complex at a site such as Mogao. Congestion and overcrowding are indeed a problem at Mogao that directly affect the visitor experience (Fig. 1.6), not least because of bad air quality in the confined and enclosed spaces of grottoes, but the impact of visitors on the preservation of the cultural resource (i.e., the wall paintings and sculpture) is the first and foremost concern. Congestion and overcrowding must be considered since they impact the visitor experience and can be a principal contributor to mechanical (physical) damage by visitors, but these are ultimately management problems and can be solved with management solutions. The problems faced at Mogao are not unlike those at Paleolithic cave sites, such as Lascaux or Altamira, where visitation has an impact, direct or indirect, on the rock paintings by way of the environment. In these situations understanding the environment and its relationship to visitation is key to understanding the mechanisms of deterioration and thus the long-term preservation of the resource. At Mogao this has required extensive research, testing, and monitoring that began in a targeted way with the visitor study in 2001, but has built on two decades of collaborative work on these issues by the DA and GCI (see Agnew 1997, 2010).

Fig. 1.5 Congestion and crowding are problems at most of the important heritage sites in China, as seen here at the World Heritage site of the Longmen Grottoes during the 2012 October Golden Week. (Courtesy Longmen Grottoes Academy)

Fig. 1.6 Congestion and crowding at Mogao during peak visitation are problems that affect the visitors' experience of the site, as shown here on the narrow walkways outside the entrance to a cave. (Courtesy Dunhuang Academy)

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Chapter 2
Conceptual Frameworks for Managing Visitor Impact

The writing of a draft master plan for Mogao, beginning in 1999, proved to be a prescient undertaking. As a systematic exercise probing the strengths and weaknesses of the staff and management, it exposed a number of critical issues, not least of which were the need for integrated planning and implementation of management and conservation and contending with the emergent juggernaut of mass tourism. The latter confronted the site authorities with a practical management conundrum and put into conflict two of the goals of the master plan: preservation of the resource on the one hand and public access on the other. While the *China Principles* provided a framework for master planning, more specific models were sought for managing the impact of visitors. The methodology ultimately decided upon for the Mogao Grottoes visitor study (see Chap. 4) was adapted from models prevalent in the U.S. National Park Service and other land use agencies that grew out of earlier carrying capacity frameworks and their critiques, discussed in this chapter.

2.1 Concept of Visitor Carrying Capacity

Among the frameworks developed for managing tourism in protected areas, the concept of visitor carrying capacity has perhaps the longest continuous history of use, having been traced back to the 1930s with more systematic applications in the U.S. National Park Service (NPS) beginning in the 1960s (Manning 2002; Manning and Anderson 2012). Since then the concept has evolved to incorporate modern trends in outdoor recreation management. Several new frameworks or paradigms have emerged in the course of this evolution and seem now to have converged in a basic consensus of approach, although without a convergent naming system. Limits of Acceptable Change (LAC), Visitor Impact Management (VIM),

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and Visitor Experience and Resource Protection (VERP) are now widely used models that incorporate similar planning and decision-making processes for managing the evolving and complex relationship between visitors and the places they visit (NPS 1997).

The LAC planning methodology was developed in the early 1980s for wilderness protected areas in the USA as a response to the perceived weaknesses of the "numerical carrying capacity" models for limiting visitors (McCool and Lime 2001). Carrying capacity paradigms have been critiqued as being too focused on quantifying the number of visitors (how many is too many?) in order to mitigate (bio)physical and social impacts without a clear "understanding of conditions, trends in these conditions, and the management actions needed to keep conditions within acceptable limits" (McCool and Cole 1998, 72). Too much emphasis is placed on limiting numbers as the key to limiting impact, without consideration of other management strategies. Carrying capacity has also been seen as impractical in terms of the level of control and resources required. McCool and Lime argue that it is a fallacy to think we can determine carrying capacity in "the face of largely untested and often implicit assumptions" (McCool and Lime 2001, 373). Cole (2004) has critiqued the role of science in establishing carrying capacity, arguing that decisions about carrying capacity (i.e., "park purpose, the clienteles to be served, and experiences and conditions to be provided") are values-based and science is not well equipped to make decisions about values, which are ethical rather than science questions (Cole and David 2004, 44f). The criticism of science-based policy, and of carrying capacity, is overstated in our view. A more nuanced view is that managers are constantly needing to make informed judgments, based both on values and science (Hall 2004; Manning 2004). Cited as an example is the debate in natural resource circles over whether visitor access or preservation of the resource should be privileged; these decisions are indeed based on value judgments, but insofar as they relate to significant cultural resources such as the Mogao Grottoes, there is no question of compromising on preservation of the resource. The uncompromising policy decisions by the managers of Mogao (and most cultural heritage sites) to privilege preservation of the cultural resource over visitor access is a judgment that requires informed decision-making about the values of the site, but may depend on scientific data to determine how this can best be done.

The LAC approach addresses the many issues related to tourism in a more holistic manner that emphasizes, in particular, the identification of desired or acceptable conditions before deciding on management actions to limit use and the role of monitoring in ensuring that acceptable limits are maintained. It does so by asking the question "what conditions are acceptable and how can they be achieved?" which is intended to elicit a clear relationship between use, impacts, and management responses (McCool and Cole 1998). Further development of LAC by the NPS in the early 1990s resulted in the VERP process, which is the principal visitor planning and decision-making framework for the NPS (1997). Increasingly, aspects of these models—particularly the use of indicators and monitoring—are being adapted and applied by international organizations in the context of sustainable tourism policies (see e.g., UNEP and WTO 2005; WTO 2004a, 2004b, 19–20, 79ff; Pedersen 2002, 56ff).

Both LAC and VERP address the criticisms that McCool and others have leveled at simplistic numerically dependent models (the "magic number" approach). They require managers to define the values being protected, set specific management objectives, identify desired conditions and indicators of change, and monitor and respond to these indicators through management actions. They emphasize bringing the public into the process to achieve sustainable results and educating visitors as a means of influencing social behavior at sites. Moreover, in their decision-making process these approaches make explicit what values are given priority in setting limits on use or visitor numbers and what tradeoffs are being made among competing values or objectives. In essence, these approaches thus require transparent decision-making in which values, judgments, and standards of quality are made explicit. Indeed, this approach mirrors the values-based decision-making model which has been the predominant paradigm used internationally in cultural heritage management for over 20 years (Sullivan 1997; Mason and Avrami 2002; Demas 2002).

Since these critiques of carrying capacity and new approaches were first put forth in the 1990s they have dominated the discourse on this subject. Without question this debate has resulted in a more powerful and pragmatic tool for addressing visitor impact. Nevertheless, the concept of "carrying capacity" or "visitor capacity," has remained relevant and useful and appears to be regaining currency. Two recent comprehensive overviews of the subject have begun to reset the balance in favor of the utility of the concept. Whittiker et al. (2011) present the results of two years of meetings and discussions among professionals with long practice in the U.S. National Park Service and other agencies responsible for managing outdoor protected areas; these were intended to build consensus and document the current understanding of visitor capacity. The accepted definition of capacity that emerged—"the amount and type of use that is compatible with the management prescription for an area"—highlights the consensus view that capacity is dependent on "management prescriptions," that is, on the goals, values, financial resources allocated, and standards of quality determined by management. This is the understanding of practitioners who continue to use the term "carrying capacity" within the VERP framework in National Parks (e.g., Manning 2002; Manning and Anderson 2012). Since one of the outcomes of these processes for managing visitor impacts often leads to setting limits on use of the resource, despite employing the best management alternatives, the term has utility if understood in the context of LAC and VERP models.

A European perspective is expressed in Coccossis and Mexa (2004). While acknowledging that the role of carrying capacity is changing and becoming more nuanced and responsive to the complex environment in which it operates, Coccossis argues for its centrality in sustainable tourism policy and planning (2004, 3ff). In their review of trends in carrying capacity, Mexa and Cocossis (2004) point out that the alternative approaches (i.e., LAC, VERP, VIM) suffer from some of the same limitation as capacity frameworks, as they also must contend with subjective judgments by decision-makers and with the complexity of environmental and socioeconomic constraints. Carrying capacity, Mexa and Coccossis argue, has emerged from decades of criticism as a powerful concept in large part because it has been able to incorporate the management approaches of LAC and other frameworks (47ff).

Writing in the same volume, Butler addresses the argument about carrying capacity being a moral choice not a scientific question (put forth by McCool and Lime 2001, 386; Cole and David 2004), underscoring that society has both a moral and scientific obligation to protect significant places from overuse or over visitation (Butler 2004, 146). He also laments the fact that the very researchers who were responsible for such important work and "splendid research" on carrying capacity, were prepared to dismiss the concept (2004, 136).

In 2001, McCool and Lime advocated "burying" the concept of carrying capacity and focusing instead on approaches that "determine which of many plausible futures are desirable, what social, economic and environmental conditions are involved in tourism development, the acceptability of the tradeoffs that would occur, and how people affected can be given a voice to articulate the concerns and values involved" (2001, 385f). This shift was largely effectuated in the following decade and has taken carrying capacity out of the realm of a purely quantitative, science-based undertaking into the realm of a more qualitative, comprehensive, values-based approach that characterizes the VERP and other frameworks. Science-based research nevertheless has an important role to play in the new paradigms. It is also salient to remember that this approach emerged out of the context of recreational use of wilderness areas, not one of extreme pressures and consequent negative impacts resulting from mass tourism. It is in those latter contexts that managers feel besieged and numerical carrying capacity looks to be a very attractive defense. There is little doubt that uncertainties about when and how to use numerical capacities will continue to be debated, but attempting to coax further clarity or consensus out of the complexity of these approaches is not productive for our purposes. Suffice it to say that for the Mogao study, in which limits on visitor numbers to the caves have always been part of the management prescription, we have retained the use of the term "carrying capacity" or "visitor capacity" with its meaning following that used by Manning (2002, 2007, 2012), Whittaker et al. (2011), and Coccossis and Mexa (2004) within the VERP framework as a methodology for sustainable visitation.

2.2 Application of Visitor Impact Models to Cultural Heritage Sites

In considering the larger context in which visitor impact models (VERP, VIM, LAC) have been developed over several decades, it is important to note that the majority of scientists and practitioners dealing with these issues come from a natural science background and the application of the models has been mainly to managing outdoor recreation in wilderness and protected natural heritage areas. Exceptionally little work has been done to apply these models to cultural heritage sites, other than simple capacity studies undertaken for historic houses or buildings based on physical capacity of the spaces or loading capacities, much as one applies capacities to cargo ships or elevators. These are straightforward applications based on considerations of safety and congestion.

Valliere and Manning discuss the difficulties in applying the methodology to cultural sites. The authors struggle to define the limits of acceptable change: "The 'bottom line' for the allowable amount of impact may be a point at which the cultural resource is no longer eligible for the National Register [U.S.criteria for national-level significance];" and argue that an "implied zero tolerance" for impact may represent a barrier to determining appropriate indicators and standards of quality (2003, 237). The VERP model has been applied to the cultural heritage sites of Alcatraz Island in San Francisco and Mesa Verde in Colorado, but in both cases the indicators of quality relate to crowding, not impact to the cultural resource itself (Manning et al. 2002; Manning 2007, 181ff).

At the site of Petra in Jordan a NPS model was used to undertake a carrying capacity analysis and develop a monitoring program, but was never fully implemented by the authorities (Araoz et al. 1997; Akrawi 2012, 55ff). Petra exemplifies the strong countervailing forces in much of the region that make implementation of good site management measures so difficult. Many of these are related to economic conditions, but at heart are the absence of the institutions and administrative structures (systems of governance), visitor management systems and expertise within cultural heritage organizations at the national and site level, and trained personnel that will support good management. The relentless focus on tourism as an economic benefit to the detriment of the resource itself is well illustrated at Petra, but as Comer points out in his in-depth case study of Petra, this is often to the disadvantage of small local businesses (Comer 2012, 18ff, 169; Akrawi 2012, 170ff). These forces were formerly prevalent in China, and are still operative, but this is fast changing, as the example of Mogao itself demonstrates.

The parallels and differences in approaches between cultural and natural sites are illustrated in countless examples of restricted visitation to certain areas of natural sites for a period of time to allow flora or fauna to recover. Despite the prevalent misconceptions encountered in China, and elsewhere, that closing caves or tombs periodically so they can "rest" is beneficial, there is in fact no equivalent for cultural sites to the natural site approach of closing or restricting access to places to allow regeneration. Cultural sites cannot "regenerate" once damage has been inflicted; at best deterioration can be slowed by closing a site or one of its parts—a way of simply delaying the inevitable—but this is not a substitute for measures aimed at preventing the conditions that lead to deterioration in the first place. For this reason, the limits of acceptable change, which is an important concept in the VERP methodology, is far more difficult to apply to cultural heritage, and we would argue that in many cases it is an inappropriate measure to apply to the cultural resource itself. Where it remains applicable and useful is to the quality of the visitor experience.

Unrelated to the frameworks discussed previously are many Palaeolithic cave sites, whose carrying capacity has been determined by scientists and site authorities to be zero, that is, any public visitation is deleterious to the cave paintings. Consequently some of these caves have been completely closed to visitors, or subject to severe limits, and replicas built. The first and most famous replica is Lascaux (created in 1983). The long history of interventions and crises in this world-renowned cave demonstrates all the issues under discussion—fragility and vulnerability of cave sites, hyper-demand for access, and the critical need for scientific data to guide decisions, as well as the misguided application of scientific studies. In the attempt to balance access and preservation, it is fortunate that the latter has won out, based on a value judgment about the significance of the cave paintings, but one supported by scientific data demonstrating the harmful effects of visitors (for a fulsome overview of the Lascaux saga, see Coye 2011). A more recent example is the Altamira cave in Spain. In both these caves, the issue of concern was the negative impact on the painted rock, specifically a change in the cave environment due to the presence of visitors or changes made to allow visitation (e.g., to the entrance, or in the use of lighting). For Altamira, environmental monitoring led to establishing a very low annual visitation in 1982 to maintain a stable microclimate and eventually, beginning in 1993, the creation of a replica and museum to satisfy visitor demand and the pressures on site authorities to increase tourism to benefit the region economically (Lasheras et al. 2006). Now, as reported in the scientific literature, there is consideration of the cave once again being opened to visitors in the belief that this will boost the local economy (Saiz-Jimenez et al. 2011). It is symptomatic of the depth of the problem that after more than 100 years in the case of Altamira (the cave was discovered in 1879), the access-preservation debate has yet to be definitively settled. Kaminski (2014) discusses Palaeolithic cave sites in the context of both replicas and digital presentations or virtual reconstructions, which he argues are indispensable tools for educating the public and preserving these fragile sites, and as we shall see in the case of Mogao, these virtual replacements to access are an important strategy for limiting access.

The impact of tourism on the microclimate of natural caves, that is, ones without the cultural significance of painted decoration, has been more widely studied and the NPS frameworks applied in some cases. Such is the case for the Jenolan caves in the Greater Blue Mountains World Heritage Area in Australia, where the VIM model was used as the framework for determining carrying capacity. This work resulted in an understanding of the "complex interrelationship among visitor behavior, site management, and physical and biological impacts" and a program of extensive social and environmental monitoring without attempting to arrive at a specific number of visitors (Mackay 2010, 171). Other examples from natural cave systems are discussed in Sect. 4.2.3 in relation to environmental monitoring. The cave examples have in common strong science-based research components aimed at understanding the impact of visitors on degradation and deterioration of the resource. Resource protection is primary; the social and experiential dimensions for visitors are secondary. Both natural cave systems and manmade caves (and subterranean tombs) have fragile ecosystems and microclimates that are especially vulnerable to the impact of visitors, unlike open archaeological sites or historic houses where congestion, crowding, and physical abrasion or damage are often the main issues.

Understanding the cause and effect relationship between visitors and environmentally induced deterioration is a challenging task and one that requires a strong science component. Compared with decades of research on natural and wilderness areas, such research in a cultural heritage context is in its infancy, other than the Palaeolithic cave examples cited above. For this reason, we consider the research and assessment strategy that was developed for the Mogao study in order to understand the impact of visitors on the grottoes to be an important and innovative aspect of this study.

2.3 The Chinese Context

The general characteristics of tourism in China differ markedly from Western contexts. Tourism in China is a recent phenomenon (beginning only in the 1980s) and is overwhelmingly domestic, with foreign arrivals accounting for a small percentage (for an overview of domestic tourism see WTO 2013). As of 2010 China's domestic trips numbered 2.1 billion (WTO 2013, 75); according to the 2011–2015 National Development Plan for the Tourism Industry, domestic tourism is projected to reach a staggering 3.3 billion trips by 2015 with an average annual growth rate of 10 % (China Scope 2013; CNTA 2010). At major sites (World Heritage and many sites of national importance, and those designated as "scenic spots") tourism is large scale and can be categorized as mass tourism. Time of travel is dictated largely by government sanctioned holiday periods of limited duration rather than personal preference. A recently announced tourism policy aims to institute an annual leave system for employees by 2020 (General Office of the State Council 2013). This would relieve some of the extreme pressure placed on sites during the October Golden Week if it is implemented. Until very recently, Chinese tourism has been almost exclusively in the form of packaged, guided tours, organized mainly by work-units in the 1990s and early 2000s; independent visitors have been the minority, but are now growing along with the use of private vehicles. Due to the rapid increase in outbound tourism in recent years, there has been attention focused in the local and international press, and most recently referenced in China's first Tourism Law, on lack of understanding by Chinese tourists of the social norms when traveling abroad, but this also applies to domestic tourism.[1] Certainly social norms are in flux as visitors become more discerning and desire a better experience when traveling. What is important to underscore is that the situation in China is fluid and is changing very quickly, making tourism planning unpredictable. An example was the spike in already excessively high visitor numbers during the 2012 October Golden Week as a result of the substantial increase in use of private cars, the government's decision to suspend tolls on the roads during the vacation period, and reduced ticket pricing at some

[1] Initiated in the mid-1980s (according to Airey and Chong 2009, 304), the Tourism Law was finally published in June 2013 (http://en.cnta.gov.cn/html/2013-6/2013-6-4-10-1-12844.html). The Law references international norms in Article 13: "Tourists shall observe public order and respect social morality in tourism activities, respect local customs, cultural traditions and religious beliefs, care for tourism resources, protect the ecological environment, and abide by the norms of civilized tourist behaviors." Article 41 is similar but references domestic tourists, requesting guides to "explain to the tourists norms of civilized tourist behaviors…."

"scenic spots." Despite the chaos that ensued and the complaints publicly voiced, this phenomenon was repeated in 2013.[2]

The venerable tradition of "scenic spots" (*mingcheng*) in travel writing by the literati and in gazetteers has been perpetuated in a modern tourism context. The National Tourism Administration designates and ranks sites as "scenic spots" but a heritage site must apply for the designation, which many heritage sites desire because it translates into more visitors. The Mogao Grottoes has refrained from applying for the designation because of these implications and the theme park atmosphere that tends to prevail at such sites. But like quantification, ranking is seen as desirable and hard to avoid (see e.g., Nyíri 2006, 50ff).

Tourism can be a substantial contributor to the local economy of communities associated with heritage sites, especially in rural areas. The population in these areas is more than eager for a piece of the economic pie, having been impoverished for generations. The impact that tourism-driven development, interventions, and travel have on heritage sites cannot be overemphasized. The pressures on local government to keep the economy growing are real and significant and are transferred down to pressures on site authorities. Local and provincial government departments often operate quite autonomously from regulations and guidelines that are sanctioned by the central government. Until very recently local governments have been evaluated by central government based on their ability to generate income and jobs. This has now been superceded by a greater emphasis on quality of life issues and this in fact may bode well for heritage sites, depending on how it is interpreted and implemented.

Sofield and Li (2011) provide an overview of China's government policy on tourism and sustainable development. Of particular interest is the government's attempt to reconcile the concept of sustainability with China's policy that "[i]t is only through mass tourism that modernization can be obtained and demonstrated" (Sofield and Li 2011, 517). Shepherd and Yu discuss the role of decentralization of the management of heritage sites and the desire of local governments to benefit economically from tourism by placing their heritage sites on the World Heritage list (2013, 57f); however, see also Wang and Zan 2011 for the difficulty of obtaining data and analyzing impacts of World Heritage listing on tourism and the local economy. This situation differs markedly from the context and intent behind the nomination of the Mogao Grottoes to World Heritage status in 1987 as part of the first group of sites listed in China. At that time the economics of heritage tourism was not the motivating factor. Rather, it was the pride of the nation in its culture. In today's mass tourism context both the World Heritage and "scenic spot" brand have been subverted to economic goals. Wang and Zan also note the dramatic increase in expenditures made as part of the nomination process (2011, 4).

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[2] As example, see 2013 CCTV report (http://www.youtube.com/watch?v=UMXSIrwI6Bc), reports in the China Daily (http://europe.chinadaily.com.cn/business/2013-10/06/content_17010846.htm) or any number of online news reports (e.g., http://www.ibtimes.com/chinas-golden-week-national-holiday-creates-tourism-chaos-photos-1415092).

In the mid-1990s, a movement prominent in Italy received widespread enthusiasm from business and tourism interests and equally vigorous opprobrium from heritage authorities and conservationists. This was the "privatization" initiative which held that state cultural assets could be sold, or rented, to private interests who would manage and market them for profit (Palumbo 2006). The danger, an almost inevitable outcome, is development in response to the tourism market with loss of authenticity. China has not escaped privatization efforts. The demand for 'utilization" of sites for the public good combined with development pressures and increased tourism, especially at World Heritage sites, has been an issue long debated in China (for some context from the Chinese perspective of the challenges to reconciling sustainable tourism with social and economic forces, see Xu 2003 and WTO 2009).

Shepherd and Yu describe three management models prevalent in China: government control, joint ventures between local governments and private management companies, and private management contracting, all of which are contrasted with a "national park model" (2013, 50ff) Such joint management structures are becoming more common, especially for "scenic spots," and there have been many attempts to parcel out management to private contractors and even to list sites on the stock exchange (see e.g., Pomfret 2001). One of the earliest and most prominent attempts at privatization of management was the World Heritage site of Qufu (Temple and Cemetery of Confucius and the Kong Family Mansion in Qufu) where wall paintings were reportedly damaged (China Daily 2001a, 2001b; Gittings 2002; Wei 2005, 41) following the establishment of a joint venture between an economic development company and the local government. Mogao has not been immune to attempts to take over income generating aspects of management of the site, leaving the site authorities to handle its research and conservation, but such incursions have been resisted by the leadership at Mogao, which has been strong enough to counter them. Elsewhere, however, this trend toward private management ("enterprise style management"), and even corporate sponsorship, appears to be increasing at cultural heritage sites (see e.g., Daming Palace National Heritage Park in Forte 2013, 503).

The notion that site authorities have the power to restrict use of a site and control visitor numbers is wishful thinking; more often than not, site authorities find themselves in a weak position in the face of powerful tourism and development forces. Scientifically derived data is one tool for buttressing the case of cultural heritage against business interests and tourism pressure, and this is especially true in China, where the concept of "scientific management" (*kexue guanli)* (however erroneously understood) prevails in all sectors and where great attention is paid to numbers and to quantifying the world. Capacity numbers have long been required of site authorities and are frequently referred to on TV reports as having been surpassed during the Golden Week. Article 45 in the new Tourism Law, issued in June 2013, specifies that "A scenic spot shall not receive more tourists than its maximum capacity as approved by the tourism authority. It shall make public its maximum capacity as approved by the tourism authority, develop and implement a tourist flow control plan, and control the number of tourists in ways such as ticket reservation." But as noted above these sites experienced the worst overload in October 2013, with visitors stranded on mountain tops and enmeshed in traffic gridlock.

The State Administration for Cultural Heritage recently issued its own document requiring cultural heritage sites to assess the impact of visitors, develop actions to improve visitor management and minimize adverse impacts from visitors; the document further calls for managers of World Heritage Sites, popular "scenic spots" and sites whose material remains are especially vulnerable to visitor impact to undertake carrying capacity studies and implement reservation systems to distribute visitors throughout the day, and calls for local governments to pass regulations respecting the limitations on tourism.[3] While this represents an important step in the direction of creating policy related to visitor management, the methodologies, models, and mechanisms for implementing these goals are sorely lacking. Where they do exist is on the nature side of the nature/culture divide. As in the West, professionals involved in natural heritage in China tend to adhere around different government agencies (Ministry of Construction vs Ministry of Culture), academic departments, and management paradigms. They also tend to be more advanced in terms of planning methodologies and protection strategies, although realities on the ground may be different. Huangshan Scenic Area (Yellow Mountain), a World Heritage site and "scenic spot," exemplifies both the greater sophistication in planning but also the trend, noted above, toward joint public-private management models (for Huangshan see WTO 2009, 31–60; 235–269; Shepherd and Yu 2013, 51, 61), in which exploitation of the resource is a real risk.

The Jiuzhaigou Valley Scenic and Historic Interest Area (Jiuzhaigou Biosphere Reserve) precisely illustrates the problems encountered in trying to apply visitor management methodologies. The place is inscribed as a natural World Heritage site and is a designated highest ranked "scenic spot," being one of the first in the country to get this designation (or according to Nyíri 2006, to have recreated itself as a scenic spot). The site receives very large and growing numbers of tourists. In a recent publication on Jiuzhaigou, the authors forthrightly discuss the many efforts at establishing capacities over many years, none of which have been adhered to or established on the basis of solid data, and they note that the capacities increased with time (essentially the capacity is raised to match the increase in visitors). The difficulties of adhering to established capacities are attributed to the pressures from local government to increase revenues, the difficulty in denying entry to arriving visitors, and the problem of developing and applying management actions rather than reverting to carrying capacity numbers (Yong et al. 2013). These obstacles are symptomatic of more systemic problems relating to governance, reliance on tourism as an economic engine, and lack of familiarity of the public with the norms of traveling, such as relying on reservations. While the weaknesses of this approach illustrate some of the critiques of McCool and others regarding the danger of relying on "the magic number," they also demonstrate the great need for well-founded methodologies to address the tourism behemoth.

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[3] Issued in June 2013 as *Notification on Improving Research on Visitor Carrying Capacity Studies for Heritage Sites* (in Chinese only: http://www.sach.gov.cn/art/2013/6/26/art_1690_107520.html).

Chinese planning and decision-making guidelines for cultural heritage sites incorporate internationally accepted principles such as put forth in the *Principles for the Conservation of Heritage in China* (emphasizing values and the assessment process), but they also differ somewhat from Western models. The requirement for the preparation of a master plan (*Conservation Master Plan for National Level Heritage Sites*, issued August 2004 by the State Administration for Cultural Heritage (SACH); see also Sect. 3.2) was an important step in attempting to systematize planning and ensure that heritage authorities were undertaking comprehensive planning. Due to lack of expertise and experience at the site level, however, these regulations required that master planning be done only by institutions certified by SACH to undertake this work. The product is typically a thoroughly professional physical plan for the site in which the boundary, buffer zone, use areas, buildings and infrastructure, and so on are mapped, protection zones are established, and compliance with the law and integration with local plans is ensured. But, a weakness of this system can be insufficient input from the staff who have knowledge and experience of the site and consequent lack of ownership of the plan by staff, inadequate understanding of the significance of the site and its conditions, and absence of a long-term commitment to the site and implementation of the plan. Agencies, institutions, and academic departments that undertake and support much of the research and expertise in managing visitors and presenting and interpreting heritage sites have not existed in China. They are, however, being formed rapidly as academic departments take on research agendas and training of new professionals, conferences are organized and bureaucratic institutions begin to address tourism issues in regulations and guidelines.

Cooperation between heritage place authorities and tourism agencies and companies is more common in sites designated as “scenic spots” that attain a high level of entertainment value, but has the potential to stray into dangerous territory of management of sites by private enterprises for economic exploitation. Ancillary activities at heritage sites such as festivals, religious or cultural performances and other events are common, some having a basis in local traditions and others purely opportunistic exploitation (see e.g., Ryan and Gu Huimin 2009). This creation of “tourism product” associated with heritage sites is demonstrated, for instance, at Datong (home of the Yungang Grottoes World Heritage site) where tourism exuberance on the part of local officials has led to ever more inauthentic reconstruction of the “ancient” city (Johnson 2011); at Jiuzhaigou where the appropriation of minority cultural traditions was used to that end (Nyíri 2006); and at Qufu where it has been part of the “brand Confucius” scene for some time (Ma et al. 2009).

What has yet to happen to any significant degree is coordination between the SACH (China’s State Administration of Cultural Heritage) and CNTA (the China National Tourism Administration). SACH falls under the Ministry of Culture and has legal, administrative authority over museums, archaeological sites and monuments, including World Heritage sites. (Natural sites come under the Ministry of Construction; mixed natural and cultural sites are jointly administered with Ministry of Construction as the lead agency) SACH has no jurisdiction over tourism, which is under the National Tourism Administration (equivalent in rank to the Ministry of Culture and therefore a tier higher than SACH), and has no well-developed or integrated policy with respect to tourism of cultural sites; in fact, in recent decades, as tourism has exploded, there appears to have been poor coordination of policy between the ministries and administrative entities with responsibilities for cultural heritage, natural heritage, and tourism.

This lack of coordination between ministries or departments is common in other countries and China has at least taken the first step by acknowledging the problem through a strategic cooperation agreement signed by SACH and CNTA in 2010. The ambitious six point agenda includes coordination to "solve the problems of cultural heritage tourism;" conducting joint research and investigation on cultural heritage tourism, establishing standards and new models of cultural heritage tourism, and evaluating the protection and tourism development of cultural heritage (China Hospitality News 2010). Such efforts at enhanced cooperation between these two sectors are sorely needed but to date apparently no further concrete developments have been made in pursuing these goals. Airey and Chong (2010) chart the rise of the CNTA from "new growth pole in the national economy" in 1998 to a "key industry "[pillar industry] in 2008 to one of five "hot consumption spots" in 2009 in response to government's recognition of its role in promoting economic development and job creation. It will not be easy for heritage sites to resist succumbing to what may be undue influence of the tourism industry over heritage sites in the future. All the more reason why heritage sites must hone their skills in managing visitors.

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Chapter 3
The Mogao Grottoes

3.1 The Mogao Grottoes: Past and Present

The fates of the Mogao Grottoes and the town of Dunhuang have been inextricably bound up with each other from the establishment of the grottoes to the present day. For a 1,000 years Dunhuang had thrived and enjoyed a unique status as an outpost guarding the westernmost regions of the empire, protecting trade and facilitating the flow of goods and knowledge between the heartland of China and regions to the west. It was already nearly 500 years old when, out of India, Buddhism entered along the Silk Road oases into China proper and beyond. The earliest caves at Mogao were excavated in the cliff face in the fourth century. Subsequently, artisans continued to construct grottoes at Mogao (*Mogaoku* in Chinese, literally meaning "peerless caves") and at smaller grotto sites in the Dunhuang region over a period of a 1,000 years. There are 735 numbered caves at Mogao excavated along the 1.6 km of cliff face at the site (Fig. 3.1); 492 of these are decorated caves. The undecorated caves at the northern end of the cliff face were used as habitation and meditation caves (Fig. 3.2).

With some 45,000 square meters of wall paintings and over 2,400 polychromed sculptures the caves comprise the largest body of Buddhist art in China (Fan and Zhao 2009; Wang 2013; Whitfield et al. 2000). The decorated grottoes (also called cave temples) are among the world's most important sites of Buddhist art and afford an unparalleled record of 1,000 years of Chinese wall painting and sculpture, depicting not only the religious practices of the period between the fourth and fourteenth centuries, but also life, customs, costume, music, agriculture, and a wealth of historical information of the times (Fig. 3.3).

The first use of the site dates to 366 CE, according to a Tang Dynasty (618–907) stele inscription, and the last grotto (undated) was made in the Yuan dynasty (1278–1368). Stylistically, one can trace the evolution of Chinese Buddhism through the wall paintings and sculpture from the early nomadic periods when China had

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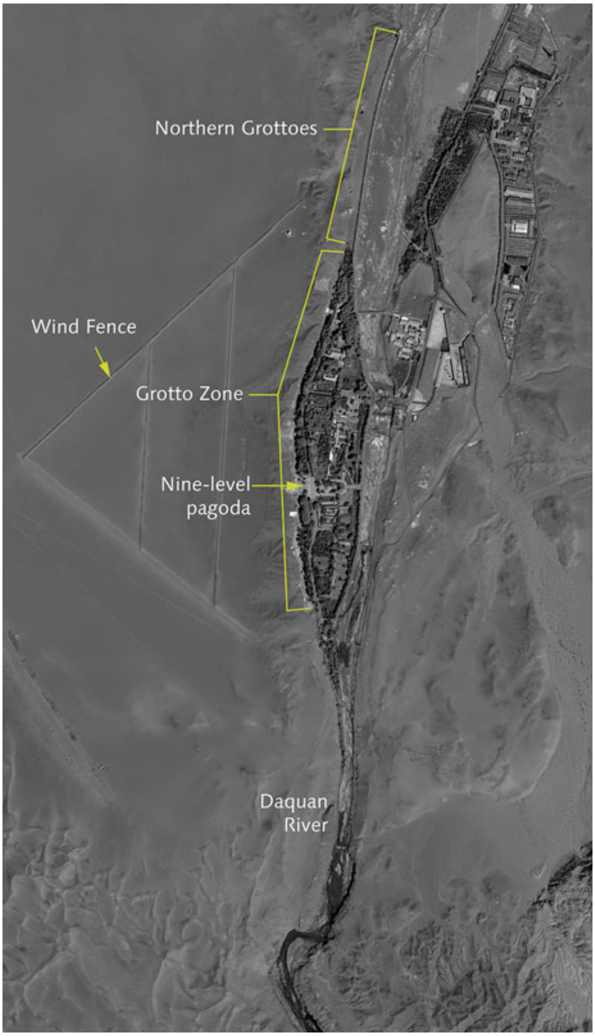

Fig. 3.1 Satellite image of the grottoes and associated buildings and features including the distinctive "A"-shaped wind fence above the cliff face (© 2003 DigitalGlobe, Inc.)

been disrupted after the Han dynasty (202 BCE–220 CE) through reunification in the Sui (581–618) to the golden age of the Tang dynasty. After the decline of the Silk Road during the Ming dynasty (1368–1644) China contracted upon itself and Dunhuang's status as a military garrison, a trading entrepôt, and a crossroads between East and West likewise faded. During this period, about which there is scant knowledge, the grottoes underwent decline and were virtually abandoned, serving only for local religious festivals.

The travails of China itself in the first half of the twentieth century are mirrored in the site. During the first decade foreign archaeologists and explorers began to arrive, among them Aurel Stein and Paul Pelliot, who removed to London (British Museum) and Paris (Musée Guimet) respectively, a significant portion of the now

Fig 3.2 The 248 caves of the Northern Grottoes were used for meditation and habitation and almost all do not contain paintings or sculpture

famed hidden "Library" of Cave 17, which contained some 50,000 items, mainly Buddhist scriptures (including the Diamond Sutra, the first dated (868) printed book, now in the British Library), documents of a nonreligious nature in several languages (including Tibetan, Uighur, and even Hebrew), drawings, embroidery, and painted silk. Other explorers came later, from Russia, Japan, the USA, and the documents they took away are now dispersed around the world. An active field of international scholarship continues to study the documents, exemplified by the International Dunhuang Project (http://idp.bl.uk) based at the British Library and in China at the Dunhuang Academy and the National Library of China. The activities of these early explorers brought the site to the attention of the Chinese authorities who eventually halted the removal of objects from the library cave.

The condition of the site is well documented beginning in the early twentieth century in photographs taken by the early explorers of the site and later by the Chinese authorities. These show collapse of most of the wooden facades that originally protected the cave entrances, buildup of sand and soil from wind and flood over the centuries, and exposed decorated caves (Fig. 3.4). This was the situation that faced the intrepid pioneers who were sent in the early 1940s to begin the daunting task of preserving and studying the site. These were the first staff of what was to become the Dunhuang Academy. The site as it looks today (Fig. 3.5) reflects that period of intensive work to protect the grottoes.

Fig. 3.3 The grotto wall paintings and sculpture are exuberant in their artistic expression, and the architectural forms are varied, as seen in Cave 428, Zhou Dynasty (*above*; courtesy Dunhuang Academy). The paintings display Buddhist sutras, costumes, music, agriculture, and a wealth of other historic information, as well as scenes of everyday life, such as this vignette of a butcher and his dogs on the ceiling of Cave 85, Tang Dynasty (*below*)

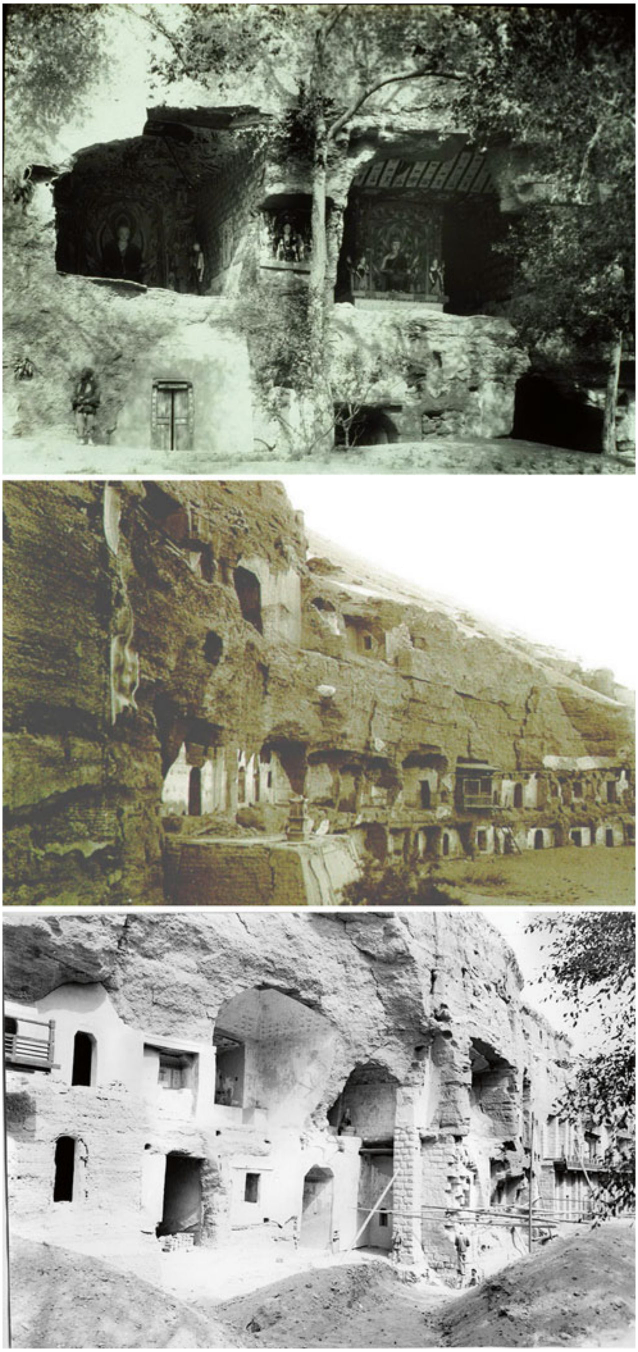

Fig. 3.4 Historic photos of the site taken by Aurel Stein in 1907 (*top* and *middle*; © The British Library) showing caves exposed to the environment, and below by the DA in 1950s as the first work began to protect the cliff face and the exposed caves (Courtesy Dunhuang Academy)

Fig. 3.5 Part of the cliff face with modern facade partly covering the conglomerate rock into which the caves were cut, with the iconic Nine-level Pagoda, visible in upper left of photo that houses the large seated Buddha

The Mogao Grottoes were listed by the State Council of the PRC as a nationally protected site in 1961. In 1987 it was among the first group of elite sites nominated by China to the World Heritage List of UNESCO. The other sites in this first listing spanned the history of China from its prehistoric past through the Qing Dynasty: the Peking Man site, the First Emperor's tomb at Xi'an, the Great Wall, Mount Tai, and the Forbidden City. Mogao was put forward as a cultural site under all six cultural criteria—only Mount Tai (a natural and cultural site) met all the cultural criteria. Today China has some 41 sites inscribed on the list, and many of these, certainly the Forbidden City, Great Wall, and Xi'an Warriors are iconic sites, known not only in China but also in the West. Outside of China, however, the Mogao Grottoes are not so well known. This is due in part to the site's geographic isolation and distance from the large coastal cities (see Fig. 1.1). The remoteness of Mogao and severe desert environment once protected the place from human interventions. Today, however, the site is fairly easy to reach, served by expanded air and road services and a new rail link, and these conveyances have brought with them the greatest risk to the integrity and values of the site—people. The infrastructure built to house these modes of transportation are oversized and, along with hotel and other development and signage, have impinged upon the landscape of traditional oasis agricultural fields and villages. All of this development, of course, represents progress for many, but it is the type of progress that degrades the traditional ways of life and historic values of the place.

3.2 Site and Visitor Management and the Master Planning Process

The Mogao Grottoes are the jewel in the crown of the five Buddhist grotto sites in the Dunhuang region. The other sites are the Western Thousand Buddha Grottoes, Five Temple Grottoes, Yulin Grottoes, and the Eastern Thousand Buddha Grottoes. With the exception of Yulin these other grotto sites are far smaller, some with little surviving painting, and are far less visited. Collectively, the sites are known as the Dunhuang Grottoes, all under the authority of the Dunhuang Academy (DA) whose mandate is to protect, preserve, study, and present the sites to the public (Fan 1997). The organization was founded in 1944 as the National Dunhuang Art Research Institute, becoming an academy in 1984. Since its founding it has grown in size and reputation and is now considered one of the leading cultural heritage research centers in China. Within the Academy are eighteen departments including Conservation, Reception (Visitor Management), Art Historical Research, Fine Arts, Archaeology, Documentation, Exhibitions, Security, and Maintenance. There are some 266 staff, 187 are professionals and technicians with qualifications in disciplines ranging from conservation, archaeology, and engineering to art history, fine arts, and photography. A very active publications program disseminates the results of research, mainly within China, but English-language publications are increasing. The DA also has joint programs with numerous institutions and universities in China and cooperative projects with a number of international organizations. One of the longest partnerships has been the multifaceted collaboration between the DA and the Getty Conservation Institute (GCI) beginning in 1989, of which the visitor study is one component.

The regulatory framework for Mogao consists of the Heritage Conservation Law of the PRC (Law of the People's Republic of China on Protection of Cultural Relics 2002), Regulations on the Conservation and Management of World Cultural Heritage Sites in China, and Gansu Provincial Regulations on the Conservation of Cultural Heritage, as well as the international covenant of the World Heritage Convention of UNESCO.

As a leader in conservation in China, the DA has been involved in both the development and application of the *Principles for the Conservation of Heritage Sites in China,* colloquially known as the *China Principles*. In 1999 the DA, the GCI, and the Australian Heritage Commission began work on the Mogao Conservation Master Plan using the methodology outlined in the *China Principles* (Fig. 3.6). The idea was to work simultaneously on both practice and principles so that each would inform the other. The Dunhuang Academy was thus the first cultural heritage organization to apply the formal planning methodology of the *China Principles* to the drafting of a master plan (Fan 2010; Agnew et al. 2004). Throughout 2000–2002, the three parties held several workshops to develop the plan, working with senior staff from the various departments of the DA who contributed information, and research for the assessments and developed the objectives and strategies. In 2003 the DA contracted with a nationally certified planning organization (the Architectural Design Institute of China, Beijing) to finalize the Master Plan and undertake physical planning to

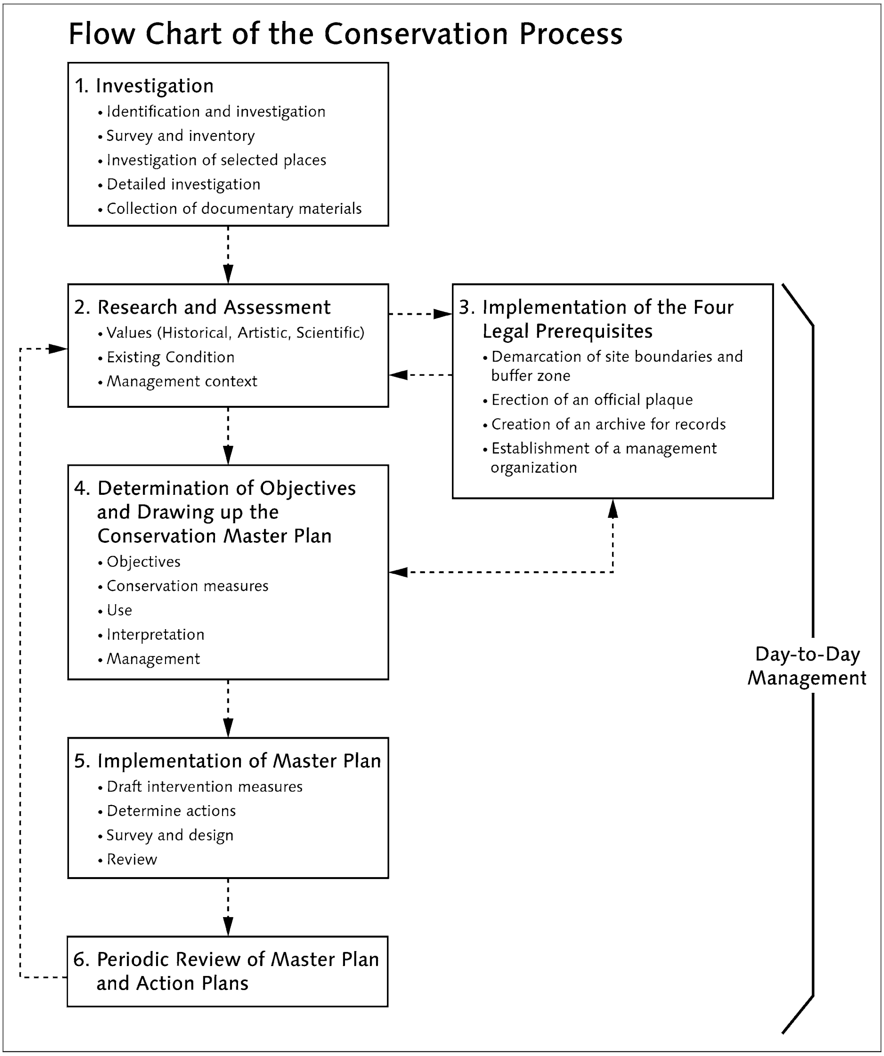

Fig. 3.6 The master planning process of the *China Principles* was followed for the Mogao Master Plan

ensure that it complied with the format of the newly issued regulations for master planning of national level heritage sites (China Academy et al. 2010).

The planning process outlined in the *China Principles* begins with investigation and identification of a site and its components. For Mogao, such investigation has been underway for over 50 years. Nevertheless, the planning process was an opportunity to assimilate and synthesize existing information on the art, history, geology, and environment, to undertake new surveys and photography to better document the resource, and to identify gaps in knowledge about the site. Among results from this process have been new digital photography and a photogrammetric survey of the cliff face, corrections to the site inventory and better integration of archival documentation.

Assessment is key to the conservation planning process since future objectives for conservation, management, and use of a site are based on these assessments. For this reason, more than 2 years were spent in carrying out research, assessment, and analysis of all aspects of the site prior to establishing the objectives of the plan. Although there was already extensive information and knowledge about values, condition and management context, additional research and compilation of this information was needed. In order to assess condition and management context, the planning team undertook an analysis of the site's strengths, weaknesses, opportunities and threats for each of the main programmatic areas of the plan (Conservation, Use, Research, and Management).

Assessment of significance. The exceptional historic, artistic and research values of the Mogao grottoes have long been recognized and are the bedrock of its significance. The preservation of these values remains the highest priority. There are, however, other values that had not been explicitly recognized in the past and these now form part of the vision for the site. The role of Mogao in informing, educating, and inspiring the visiting public and in providing economic benefit to the people of Dunhuang and Gansu province by attracting visitors are important values recognized by the DA and acknowledged in the plan. Though hitherto overlooked, the natural values of the site, particularly its pristine desert setting, are also explicitly recognized. Together, these values constitute the significance of the Mogao Grottoes and require protection and enhancement. They may also be subject to compromise, where one value competes or threatens to destroy another. Such is the case with one of the social values of the site, namely tourism, which is important to the economy of the region, but which threatens to destroy both the cultural and natural values if not managed, and, if need be, restricted. Prioritization thus becomes necessary. It is the bedrock values (historic, artistic, and research), from which others are derived, that receive priority in planning for the site.

Assessment of existing condition. This assessment identified the areas of greatest concern to be addressed in the master plan. Identifying these problems involved the DA conservation staff, who have long experience with the site. It also required new surveys of condition in order to categorize and visually map the current condition of the grottoes and prioritize future work. Major initiatives to address the principal environmental and geological problems affecting the site had began with the construction of the facade to protect the exposed caves in the 1950s and 1960s. Conservation of wall paintings was a focus of the 1970s, but was done under conditions of professional isolation from materials and methods being used internationally. One of the most important interventions to reduce daily maintenance of the site and cleaning of the caves was sand control (Fig. 3.7), which resulted in construction of the wind fence with the distinctive "A" design in the late 1980s and 1990s, seen in the satellite image (see Fig. 3.1). Flood control was addressed initially in the 1980s, followed by improvements in 2001 and is now being further improved following the

Fig. 3.7 Wind blown sand from the cliff top resulted in accumulation in the Grotto Zone and in the caves, requiring daily cleaning until the sand control measures were implemented beginning in the late 1980s

2012 flood, see Fig. 4.17. In the master plan assessment of priorities, conservation and protection of the wall paintings were identified as the highest priority. To achieve this required engineered stabilization of the weak and fissured cliff face, long-term investigation into causes of deterioration of the paintings, and planning for responses to natural disasters such as earthquakes and floods.

Assessment of management context. This type of assessment is rarely undertaken in China. Many problems confronting the site were revealed during the SWOT assessment (strengths, weaknesses, opportunities, and threats). Among those that emerged strongly were visitor management issues, such as the need for better expertise in this area, surveys to understand visitor behavior and expectations, understanding visitor impact, and enhancing visitor experience. Operational and infrastructure needs, often relating directly or indirectly to visitors, but also including the need for updating staff on-site housing as a means to improve morale, were also brought forth during the assessment. Incremental infrastructure development at the site over decades also had begun to seriously impinge on the site's setting. These issues made clear that the need to undertake comprehensive planning to reinstate the integrity of the landscape and to liaise with stakeholders, especially the tourism industry, whose goals and needs frequently clashed with those of the site authorities. Another area of need to emerge was wall paintings conservation education for professional staff, but opportunities were also identified, which led to the establishment of a master's degree program in conservation offered by Lanzhou University in cooperation with the Dunhuang Academy, the Courtauld Institute of Art (Conservation of Wall Painting Department) and the Getty Conservation Institute that incorporates theoretical and practical conservation teaching at the Grottoes.

The *China Principles* planning process involves establishing or reassessing the "Four Legal Prerequisites," which pertain to site boundaries and buffer zones, official public notification of the site's legal status, archival records, and a management organization. At Mogao, the four legal prerequisites were established in 1961 when the site was first designated a nationally protected site. Nevertheless, the planning process was an opportunity to review the state of the buffer and development control zones and take actions to enlarge them and strengthen their legal protection. This resulted in 2002 in the Gansu Provincial People's Congress adopting the *Regulations for the Conservation of the Dunhuang Mogao Grottoes,* which extended the buffer zone to protect the approach to Mogao, the nearby ancient and modern cemeteries, and the view sheds to the Sanwei Mts to the east and it further codified the special legal status of the Protection Zone of the site.

In the Mogao master plan the conservation and management decisions made about the future of the site derived from the assessments of significance, condition, and management context. These decisions were formulated in the plan as goals, principles, and objectives. Long-term goals encapsulate the core mission of the site in the areas of conservation, research, and education. The principles identify the most appropriate ways of preserving the site's significance and serve to guide decision-making about future care and development. Of particular importance were the general principles of preserving authenticity and integrity and the implementation principles of minimal intervention, not changing the historic condition, and using tried and proven technologies. The objectives specify actions to preserve the values, in accordance with the goals and principles, and are grouped under the main programmatic areas of conservation, use, research and management. Based on the assessments and objectives established in the initial phase of the master planning process, the Architectural Design Institute of China undertook extensive graphic mapping of the assessment results and physical planning on elevations of the cliff face and satellite maps of the site. These included condition, values (significance and integrity), geology, vegetation, setting, historic architecture, modern infrastructure, and use zones.

Conservation objectives addressed not only the grottoes themselves, but also the setting and natural environment, maintenance needs, and improvements in the quality of conservation work and in science and technology capabilities. Research objectives are a distinct programmatic activity at Mogao because of the importance of Dunhuang Studies since the founding of the Dunhuang Academy. Management Objectives targeted a broad range of issues such as enhancing staff motivation and professional capacity, establishing the partnership, noted earlier, with Lanzhou University to create a master's degree program in wall painting conservation, fostering international collaborations, and developing infrastructure both for tourism and staff needs.

The focus of the Use objectives (visitor management, interpretation, education) was to enhance the quality and diversity of the visitor's experience, while understanding and managing the negative impacts of too many visitors.[1] Among the principal objectives was a visitor impact study to determine a level of visitor use that would not diminish the values of the site and cause deterioration or damage to the caves and their paintings. The development of this objective is described in Chaps. 4 and 5.

From the DA's perspective, the need for a master plan was driven in part by the growing urgency to manage the ever increasing influx of visitors. Beginning in 2000 with the push of the central government to develop the Western Provinces, this need became even more compelling with the policy to make tourism a "strategic pillar industry" of the economy under the 12th Five-Year Plan (2011–2015). The master planning thus set the context and understanding for a comprehensive approach to tourism, one that considered the needs of visitors for safety, education, comfort, and even entertainment, but that would foremost protect the cultural and natural values. It was acknowledged from the outset that this was a tall order, one that would be subject to countervailing pressures to increase visitor numbers and one that would require a substantial commitment of time and staff to undertake the requisite research and implement the results. This has indeed proven to be the case, but the endeavor has been successful and stands as a model of what can be achieved with commitment and vision.

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[1] The Australian Department of the Environment and Heritage was centrally involved in the development of the visitor management plan and the initial visitor surveys (Altenburg et al. 2010; Li et al. 2010). See also Agnew et al. 2006 for application of the China Principles planning process to visitor management at the Mogao Grottoes and the Imperial Mountain Resort at Chengde.

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Chapter 4
The Mogao Visitor Study

4.1 Methodology of the Visitor Study

The methodological approach of the Mogao study (Fig. 4.1) was adapted from the Visitor Experience and Resource Protection (VERP) model discussed in Sect. 2.1, Chap. 2. The first phase—assessment and analysis—progresses from defining the problem to determining the conditions that require management responses and may limit visitation. The methodology begins with briefly defining the parameters of the study and identifying issues, indicators, and desired conditions. The most important and innovative part of this study was the research and assessment strategy developed to understand the impact of visitation on the wall paintings (Sect. 4.2). The research and assessment strategy incorporated four parts: analysis of visitation and visitor management practices; analytical laboratory investigations; environmental investigations; and assessment of condition and visitation potential for each of the caves. This investigative part of the study, which was carried out over a period of 6 years, led to defining the limiting conditions for visitation in the Grotto Zone from which were developed the monitoring and management tools and actions described in Chap. 5.

4.1.1 Parameters of the Study and Management Objectives

The visitor study identifies the conditions necessary to prevent deterioration while seeking to maintain a predetermined threshold of visitor satisfaction. This requires consideration of a range of variables, including the scope, extent, and significance of the site; the complex cause and effect relationship between environmental conditions, deterioration, and visitation; visitor services and infrastructure requirements; the degree of change that is acceptable and methods to monitor change; and the means by which the site's values and the visitor experience will be protected and enhanced, while still allowing flexibility to meet changing conditions. In the present

M. Demas et al., *Strategies for Sustainable Tourism at the Mogao Grottoes of Dunhuang, China*, SpringerBriefs in Archaeology,
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METHODOLOGY OF THE VISITOR STUDY

Assessment and Analysis Phase

- Define the parameters of the study and management objectives
- Identify issues impacting the site and visitors
- Identify key indicators to monitor change
- Define desired conditions
- Design and implement a research and assessment strategy
    - Visitor analysis
    - Analytical investigations
    - Environmental investigations
    - Cave assessments
- Define limiting condition

Response Phase

- Develop monitoring and management tools and strategies
- Define management actions to respond to monitoring

Fig. 4.1 The methodology of the visitor study for Mogao was adapted from the Visitor Experience and Resource Protection (VERP) model developed by the U.S. National Park Service

study, the inherent complexities required that clear parameters be established at the outset. These were framed in terms of the use zones of the site, values to be protected, visitor experience, time of greatest threat, and the limits of acceptable change.

The current use zones of the site are the 1 km long Grotto Zone, the section of cliff face with the painted caves (the unpainted Northern Grottoes extend another 0.6 km), and the Visitor Use Zone, where visitor facilities and exhibition buildings are located (Fig. 4.2). This study addresses primarily the Grotto Zone, which encompasses the primary cultural values of the site—the wall paintings and sculpture of the 492 decorated grottoes, representing the artistic and religious development of Buddhism in China over a 1,000 years. With respect to visitors, their safety and basic comfort were identified as a baseline condition of a satisfactory visitor experience. The time of greatest threat is May through October, which includes the summer peak visitation period (June–September), and major national holidays and

Fig. 4.2 The current use zones are the 1 km long Grotto Zone, where the primary cultural values of the site—the wall paintings and sculpture—are located and the Visitor Use Zone, where visitor facilities and exhibition buildings are located, seen here in an overview photograph (*above*) of the grottoes and in a corresponding graphic (*below*)

festivals in May and October. During this period, management staff and the grottoes themselves are often subjected to excessive visitor numbers, with consequent impact on the visitor experience, while ambient environmental conditions of high humidity pose the greatest danger to the art.

Limits of acceptable change specify the degree of change or impact that will be tolerated for the resource and the visitors. As discussed in Sect. 2.1, Chap. 2, for cultural heritage sites, which are nonrenewable resources, answering the question of how much change is acceptable is highly problematic. A "zero tolerance" policy (i.e., no change is acceptable) is acknowledged to be an unattainable ideal for cultural sites, but must be the goal for significant cultural resources since any loss is irreversible. Compromises as to what visitors see and under what conditions they experience a place, and some degree of degradation to renewable resources, may be tolerated as part of a management strategy in order to accommodate pressures to increase visitation, but a management objective that allows for any degree of change (that is, loss or attrition) to the physical fabric of a significant cultural resource is unacceptable. A deliberate policy of allowing deterioration followed by restoration is likewise contrary to the conservation ethic. Restoration diminishes authenticity and repeated cycles of restoration only exacerbate loss of authenticity. In some less significant sites, repair and replacement of historic fabric may be required, but once again, this would never be a management objective for a cultural site of antiquity and importance. Thus, for the Mogao Grottoes a "zero tolerance" policy means that no detectable change or degradation to the wall paintings and sculpture due to visitation is acceptable. This is a high but necessary bar if the integrity and authenticity of the art and significance are to be preserved, which is the highest priority and most important objective in managing the site.

For visitors, the limits of acceptable change were defined in two ways. Some level of impact to the quality of the visitor experience during peak periods of visitation is accepted as unavoidable, mainly as a result of greater congestion, in order to accommodate the greatest number of visitors. There can be no tolerance, however, for diminished safety and health.

Enhancing and protecting other values (such as the natural and cultural landscape) and other aspects of the visitor experience (such as quality of narration and interpretation and provision of visitor services) are also important. The desert landscape setting of the grottoes includes the natural environment (mountains, sand dunes, trees, river) as well as cultural features (stupas, historic buildings, and the few remaining temple fronts on the cliff face), all of which contribute significantly to an appreciation of the site and are integral to the experience of the visitor (Fig. 4.3). Less tangible values that derive from the environment are the clear air and night skies and the contemplative nature of the place, which are keenly felt on quiet days and in the off-season. It is part of the compromise that must be made to a satisfying visitor experience that these aspects are diminished during peak periods of visitation. Of course, not all visitors—indeed, probably not the majority—desire such an experience and those who do generally chose a different time to visit.

The landscape and setting of the site are impacted mainly by visual intrusions related to visitor services (buildings and parking lots), and there is a direct relationship between visitor numbers and the number and size of buildings needed to service

Fig. 4.3 The desert landscape of mountains, sand dunes, and cultural features such as stupas (*above*) are impacted mainly by service buildings in the Visitor Use Zone (*below*)

them. Intrusions and pollution to the environment due to mass tourism extend beyond the boundaries of the site to the villages and agricultural fields in the nearby oases, in the form of an airport, a huge railway station, hotels, signage, and associated developments.

The response of visitors to the cultural and natural values of the site, to the guides, and to the information and services provided, constitutes the visitor experience. Protection of the natural and cultural landscapes and the visitor experience are identified within the overall Master Plan for the Mogao Grottoes (Fan 2010). The Visitor Use Zone is part of a comprehensive plan being undertaken by the DA that addresses visitor services, exhibition spaces and interpretation, and the flow and distribution of visitors through the site (see Chap. 5). Current service buildings in the Visitor Use Zone that impinge on the cultural and natural landscape will be moved off site as part of this comprehensive plan. It is the protection of the individual caves in the Grotto Zone, however, that needs to be the start and end point for determining the limiting conditions and developing appropriate visitor management strategies. All other threats from visitation can be mitigated or reversed through good planning and management, but degradation of the wall paintings and sculpture is cumulative and irreversible.

The goals of the DA management in undertaking visitor planning are succinctly stated. They are to prevent any alteration or damage to the wall paintings and sculpture as a result of visitation and ensure visitor health, safety, and basic comfort, while endeavoring to maximize visitor numbers to the site and access to the caves. This reflects the willingness of DA management to accommodate increased visitation in order to satisfy the desire of the general public to visit the site; respond to the pressures from local and provincial government for continued economic gain from tourism; and to enhance their own revenue stream. These economic and social imperatives are openly acknowledged. But the goals equally reflect the values and priority of the DA, which is to preserve without further deterioration the wall paintings and sculpture of the grottoes and this takes precedence over visitor satisfaction and economic gain. Thus, while management is aimed at satisfying other interests, it does not accept a trade-off that will impinge on the preservation of the grottoes.

4.1.2 Issues, Indicators, and Desired Conditions

Issues impacting the site and visitors. The cave temples and their art have survived because of the remoteness of the site and arid climate, but over the centuries of use and abandonment, they have been negatively affected by their changing environment and use. In the past natural and human impacts—earthquake, flood, fires in some caves, windblown sand, vandalism and theft—have destroyed or degraded the wall paintings and sculpture in many caves. Most insidious, and ongoing, however, has been the slow accumulation of hygroscopic salts in and on the painted mud plaster. Today, the most critical issue for preservation of the wall paintings is active or ongoing deterioration caused by deliquescence and recrystallization of the salts as humidity fluctuates with consequent disruption or collapse of the painted plaster. Removal of the salts is not possible. This means that the mechanisms of decay can be activated under certain conditions. The problem of salt-induced deterioration had been previously investigated, but studies had not been definitive. In particular, sources of humidity in the caves, the critical humidity leading to deterioration, and the relationship to visitation remained unresolved and subject to conjecture. Investigations to address these questions were the main focus of the research strategy.

Mechanical damage from visitors touching or scratching the paintings has long been recognized by the management. This is a problem that requires constant vigilance and has been addressed with management solutions, ranging from glass barriers to prevent people from touching the walls to well trained guides who monitor behavior. Such efforts are essential methods of preserving the paintings. While the approach used for physical barriers was in need of a design overhaul, which was done as part of the overall presentation strategy for the caves (see Chap. 5), there was no need for a major research project to address the problems of physical contact. The solutions exist and need only be sensitively applied.

For visitors themselves, key issues were identified as overcrowding in the peak summer and holiday seasons and poor air quality in many of the caves (an unpleasant mixture of high carbon dioxide [CO_2] levels, heat and body odors) during periods of high temperature and heavy visitation.[1] These problems were known anecdotally and through the experience over time by the site guides, but had never been demonstrated through systematic visitor surveys or investigated scientifically (for an overview of visitor management issues at Mogao see Altenburg et al. 2010). They also formed part of the research and assessment strategy.

Key indicators to monitor change. Indicators measure the status or "health" (or otherwise) of the resource. For the wall paintings, the main indicator of ongoing problems is evidence of hygroscopic salt-related deterioration, but any detectable change in the wall paintings is indicative of undesired conditions and requires a management response. For visitors, the main indicators are a decline in satisfaction, as measured in surveys repeated over time, complaints to guides about crowding, and complaints or incidents of fainting in the caves due in part to high CO_2 levels and malodorous air.

Desired conditions. The desired condition for the wall paintings and sculpture is stability, meaning no change or further degradation. This requires a humidity environment that does not activate the mechanisms of deterioration, namely deliquescent salts, and prevention of physical damage by visitors. For visitor safety and comfort in the grottoes, CO_2 concentrations must be maintained at or below internationally accepted levels, the allocated space per person for visitation should be sufficient to ensure that crowding is not a factor, and walkways and caves must be structurally capable of handling visitor loads safely and without undue crowding as groups move from cave to cave. Achieving these conditions fulfills the management objectives.

[1] Outbreaks of infectious diseases in recent years and the speed with which they spread may become a concern in the future in confined spaces under crowded conditions such as those that prevail at Mogao.

4.2 Research and Assessment Strategy

The research and assessment strategy was designed to address the identified issues impacting the site and visitors, namely, the mechanisms of deterioration, any link between deterioration and visitation, and the health, safety, and comfort of visitors. This is the largest and most complex component of the study. The strategy integrates visitor-related research and analysis; analytical investigations in the laboratory; environmental monitoring and research; deterioration monitoring through field testing; and assessment of condition and visitation potential for each cave. Together, these components provide information about:

- The presence, types, and distribution of deterioration in the caves
- Conditions that activate deterioration
- The role of natural air change (i.e., not mechanically driven) with the outside in accelerating or mitigating deterioration through its influence on humidity (expressed as percent relative humidity, RH) and on CO_2 buildup
- The impact to the wall paintings from visitation, to visitors themselves from CO_2 buildup, and to the visitor experience from crowding and other factors
- The potential of individual caves to be visited, based on significance, size, safety, and access limitations
- The principal management conditions that affect the daily visitor capacity

The components of the research and assessment strategy, the questions they were designed to answer, and the key results are described in Sects. 4.2.1–4.2.4 below.

4.2.1 Assessment of Visitation to the Mogao Grottoes

Visitor research and analysis focused on understanding visitor profiles and behavior, patterns of visitation and current visitor management policies and practices, and establishing appropriate tour group size, occupancy numbers, and acceptable CO_2 levels for visitor health and comfort in each cave. The questions the visitor research was designed to answer and the principal methods employed are described below.

Research questions

- What are appropriate physical capacity and CO_2 limits to ensure visitor health, safety, and comfort?
- Which are the critical visitor management practices that will affect the capacity of individual caves (as distinct from the site as a whole)?

Methods of investigation

- Visitor surveys and observations of visitor behavior
- Research on personal space requirements and industry standards for CO_2
- Assessment of visitor management capacity and policies

Fig. 4.4 "Must-see" caves: Cave 16 with adjacent Library Cave 17 (*upper left*), Cave 96 with the large seated Buddha (*upper right*), Cave 148 with reclining Buddha (*lower left*), and Cave 130 with smaller standing Buddha (*lower right*) (Courtesy Dunhuang Academy)

Visitor context at the Mogao Grottoes. Among the 492 decorated caves are many niches (so-called "ear caves" adjacent to larger caves), very small caves, or poorly preserved caves with little remaining painted plaster or sculpture; others are deemed to have insufficient artistic value with little attraction for visitors (e.g., repetitive thousand Buddha motifs). Excluding these, there remain some 112 well preserved caves of highest significance, which have been open to visitors or special groups at one time or another in the last 30 years. It is from this elite group that visited caves are drawn and, although some are now judged too small or fragile to receive visitors, this is the priority group of caves investigated in this study.

Four of the caves have always been considered essential ones to be seen by visitors (Fig. 4.4). They are referred to as "must-see" caves. While they are large (each can hold two or more groups of 25 persons at once), they constitute a serious problem in distributing visitors rationally among the available caves since all visitors want to see them. Other constraints relate to achieving dynastic representation in a tour, and to the horizontal and vertical distribution of caves linked by narrow walkways and staircases on the cliff face (see Fig. 3.5).

The Reception Department of the DA has been managing visitors to the site since it opened in 1979. All visitors to the grottoes must be accompanied by a trained DA guide; most caves are unlit and viewed with flashlights. Tours are established for the season in advance with ten caves visited on a tour, which also includes the exhibition in the restored Abbot Wang Temple near the Library Cave 17. Typically 30–40 caves are available daily to accommodate eight tour routes.

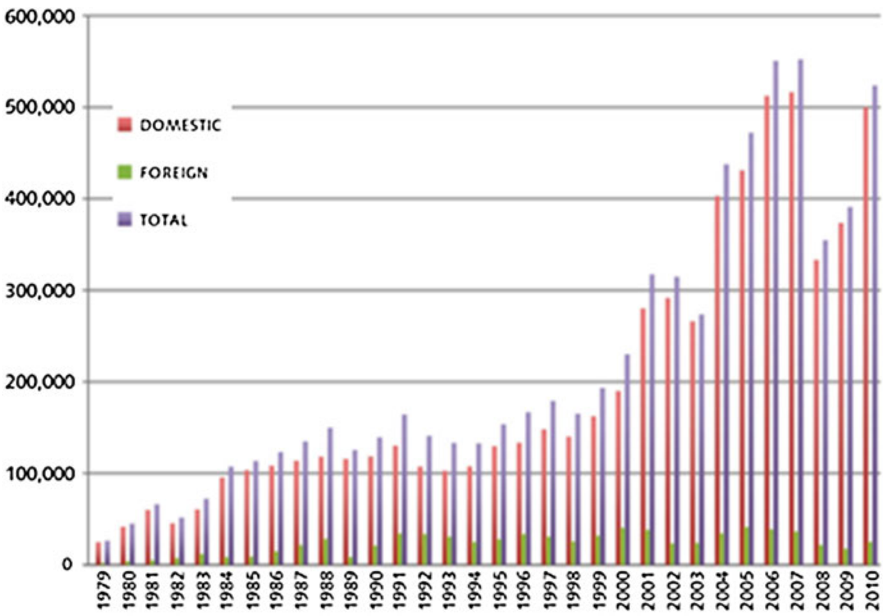

Fig. 4.5 Visitor numbers (domestic and foreign) to Mogao from 1979 to 2011; visitors rose to over 700,000 in 2013

Visitor numbers and profiles. Since 1979 the DA has kept records on the number of visitors and their origins. Visitor numbers have increased significantly, from 26,000 in 1979 to over 700,000 in 2013 (Fig. 4.5). The increase has been steady with only occasional dips, as a result of SARS in 2003 and the economic downturn in 2007–2008. Visitors are concentrated in the summer periods (June–September) and, until 2008, during the two national holiday weeks ("Golden Weeks") in May and October (the May 1 national holiday week was shortened in 2008 owing to the excessive pressure it placed on the travel and transportation industry). Celebration of Buddha's Birthday, which takes place on the eighth day of the fourth month of the Chinese lunar calendar (usually in May), is also a time of heavy visitation but mainly involves the local community, who use the setting of the site for picnics and visit only a few selected caves, typically the "must-see" caves (Fig. 4.6). Other holidays that lead to spikes in visitors are Dragon Day (*Duanwu*) Festival in May–June and the mid-Autumn Festival; the Chinese New Year occurs in the low, winter season at Mogao when there are few visitors.

During holiday periods and summer months, peak visitation ranges between 5,000 and 6,000 a day; however, with the opening of the train station in Dunhuang in 2008 daily visitation has sometimes exceeded 7,000 and in a spectacular week over the October 2012 holiday the grottoes were visited by up to 18,000 people in a single day, which was repeated in 2013 (Fig. 4.7). To provide some perspective, as recently as 10 years ago the Reception department had determined that 3,000

Fig. 4.6 Local visitors during the Buddha's Birthday celebration use the site for recreation and are interested principally in visiting the "must-see" caves, seen here in front of the Nine-level Pagoda

visitors per day was reaching maximum capacity that could be handled through normal daily tours. While a formal capacity was never established for the site, management gradually adjusted its idea of what was feasible to the increase in visitor numbers (as was noted at the site of Jiuzhaigou (see Sect. 2.3, Chap. 2). The October 2012 and 2013 scenarios were, however, more emergency response rather than adjustment, driven by the inability or reluctance to turn visitors (and the income they bring) away.

At these times of peak visitation, visitor management staff is overwhelmed and guided tours cease to operate. Instead, a select number of caves are kept open with narrators stationed inside and visitors move freely within the Grotto Zone. The result is overcrowding, poor narration, noise, waiting lines, and general visitor dissatisfaction. Daily peaks and troughs of visitors, the result of short stays in Dunhuang city and schedules dictated by tour operators, are also problematic. Even with the latest onslaught in 2012–2013, management found ways to handle the numbers, but the impact on the visitor experience was well beyond what anyone considered tolerable or within the limits of acceptable change.

Visitor profiles have changed more gradually. The vast majority of visitors has been and continues to be domestic, with international visitors making up only 5–20 % in any 1 year. Of these, Japanese visitors have always been the larger share, although they constitute an aging demographic, consisting mainly of middle aged and elderly visitors in organized tour groups. Domestic tourism has been predominantly in the form of large tour groups, but this is changing rapidly as private vehicles and road

Fig. 4.7 During peak periods of visitation the caves and the site are overwhelmed, as crowds lead to congestion in confined spaces of the caves (*above*) and the desert is turned into a sea of private cars (*below*). (Courtesy Dunhuang Academy)

trips become more common with visitors arriving in small groups; these groups are less predictable in terms of times of visit and duration of time spent on site (Li et al. 2010). In addition to large organized groups and independent travelers, there are local visitors, who only come to the site on special days, such as Buddha's Birthday (see Fig. 4.6). Education and knowledge levels, travel experiences, and expectations among these groups differ markedly and require different management responses, but all have in common an expectation to visit the caves.

Visitor surveys and observations. Between 2002 and 2004, visitor surveys were designed and conducted and observations were carried out by the Dunhuang Academy and the Australian Department of the Environment and Heritage to gather baseline information on visitor profiles, behavior, and satisfaction (Li et al. 2010). Visitor surveys are now undertaken annually by the DA. They provide essential information on the level of satisfaction of visitors. The surveys at Mogao have shown that complaints about overcrowding and "bad" air during peak periods coincide with a general decline in satisfaction about the visit.

Visitor behavior and the important role of guided tours, education, and barriers in protecting the paintings is illustrated from formal observations made by DA staff during peak holiday periods in Cave 16, from which the Library Cave 17 (a side chamber) is viewed (Fig. 4.8). At these times, this popular cave is very crowded as guided tours are replaced by an open-door system with guides stationed inside the caves for narration and monitoring of visitor behavior. During a 1-week period in May 2004, of the more than 18,000 visitors recorded, 708 people (3.9 %) were observed touching the wall paintings (Li et al. 2010, 148–150). Cumulatively over time this behavior would have a significant impact on the paintings. Protecting the paintings from such mechanical (physical) damage is addressed through good management, primarily by way of watchful DA guides in control of single tour groups and the use of protective barriers. Breakdown in the management systems occurs under these extreme conditions of crowding and congestion. Physical damage is also a potential consequence of maintenance of caves; visitors introduce dust and clothing fiber, and even food into the caves, requiring frequent maintenance.

Crowding. Tolerance and perceptions of crowding (perceived encroachment on personal space) vary among cultural groups, with generally lower levels of tolerance among Western tourists than Asian visitors. This is certainly borne out by anecdotal evidence of the Mogao guides, as well as by Western visitors to China. Tolerance levels are based on attitudes and perceptions that can and will undoubtedly change, especially with more independent travelers, who are less amenable to being in a large group. Social science research on tolerance levels and perceptions of crowding has tended to focus on residential or recreational (especially remote back country or wilderness) environments but more relevant to the present context is the discussion of crowding and analysis in a cave environment at the Waitomo Glowworm cave site in New Zealand (Doorne 2000). Also to be considered is "competition for the resource" (normally applied to ecological conditions) as visitors "compete" to see the artwork in confined spaces (Fig. 4.9). Directed studies examining Chinese perceptions of crowding, such as the visual research methods used in the USA are warranted in order to better understand domestic visitors. This technique utilizes visual simulations (computer edited photos) of various use levels, which are shown to visitors for acceptability ranking, thus providing a means of assessing crowding tolerance (Manning et al. 2002, 392; Manning 2007, 182–191). Based on current understanding and observations in the caves, the acceptable limits on physical capacity have been set at two persons per square meter. Crowding and congestion are thus at some level perceptual issues, but they also intersect with the problems of "bad air" quality in the caves, which leads us to the problem of CO_2.

Fig. 4.8 The corridor of Cave 16 leading to Library Cave 17 (*above*, entrance to the cave is above the semicircular modern steps). *Below*, visitors crowd to see the Library Cave through the narrow entrance. (Courtesy Dunhuang Academy)

The problem of CO_2. In order to improve air quality, determining acceptable CO_2 limits for the caves became an important component of the research and was to have an unexpectedly large impact on the visitor capacity of individual caves. Two aspects of CO_2 concentration are relevant to Mogao visitation. Foremost is the safety limit, but an equally important aspect of CO_2 is as an air quality indicator. CO_2 occurs as a

Fig. 4.9 Tour group in a medium sized cave. Although the cave is spacious, visitors tend to clump together during the guide's narration

component of the atmosphere, where its concentration is around 340 parts per million (ppm). In confined spaces with little ventilation very high levels of CO_2 are injurious to health. Industry standards for safe CO_2 limits have been established for commercial facilities and offices but standards vary and have changed over time. OSHA standards set 5,000 ppm as an occupational safety standard; ASHRAE standards use CO_2 as an indicator of adequate ventilation, or air quality, and are therefore set at a lower 1,000 ppm.[2] CO_2 levels higher than 1,000 ppm are only an indication of an inadequate amount of outside air being brought in; they are not hazardous or life threatening, but they often result in complaints of fatigue or headaches in a work environment and may indicate that other contaminants are present at elevated levels.

No such standards exist for human-made caves or tombs and environmental monitoring of human-made caves rarely takes CO_2 into consideration. Singh (2011) indicates 800 ppm as a high level of CO_2 in the caves at Ajanta and relates the impact mainly to the wall paintings not visitors. Environmental studies in the Hal Saflieni Hypogeum in Malta monitored CO_2 (Bonnici et al. 1993), but no upper limit is provided in the implementation of the visitor management system, which relies on mechanical ventilation to limit CO_2 (Pace 2000).

[2] ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers) Standard 62.1 (ANSI/ASHRAE 2007). European standards for air quality are somewhat higher at 1,200 ppm. OSHA (Occupational Safety and Health Administration) standards are averaged over a 40-h work week.

Natural cave systems have been subject to more systematic scientific investigations and monitoring of the environment. The 5,000 ppm limit has been cited for natural caves as a safe limit for visitors, but the emphasis in these studies is more on the impact of CO_2 on dissolution of carbonates in these limestone caves (see, for instance, Liñán et al. 2008; Lario and Soler 2010; Dragovich and Grose 1990; Doorne 1999, 7). It should also be noted that these are large cave systems, not individual caves or tombs (so-called "blind holes") with relatively small, confined spaces.

CO_2 health safety limits have never been exceeded at Mogao, but acceptable comfort conditions are problematic in certain caves where CO_2 levels frequently exceed 3,000 ppm in peak periods, often causing management to close the caves temporarily or, in the past, to install fans, which serve only to circulate the bad air in the cave rather than promote air exchange (Fig. 4.10). DA guides have known for years which caves are problematic in terms of air quality, many of which are the most popular to visit, but CO_2 levels had not been measured. While 3,000 ppm levels are not injurious to visitors' health, when combined with heat stress, physical exertion, dehydration, and body odors, they degrade the visitor experience and cause instances of fainting, particularly for elderly or unfit visitors. Comfort levels can be satisfied if ventilation results in CO_2 concentrations less than around 700 ppm above outdoor concentrations—that is, around 1,000 ppm. Since group visits are 2 h duration and do not involve continuous exposure to cave environments, the CO_2 limit for the Mogao caves has been set at 1,500 ppm. The relationship of CO_2 levels to air change rates and the impact on visitor capacity is discussed in Sect. 4.2.3.

Visitor management policies and practices. Assessment of the visitor context also focused on the ability of management to protect the caves and to service visitors by examining existing policies, practices, and capabilities of management (see also Altenburg et al. 2010). While there are many management issues that impact the visitor capacity of the site as a whole (e.g., water resources, visitor service facilities, parking capacity), those that affect the capacity of the Grotto Zone relate to guiding (tour group size, number of available qualified guides and number of tours per guide per day), number of caves per tour, duration of cave visit, and routing patterns of groups along the elevated, narrow walkways of the cliff face.

DA trained guides (Fig. 4.11), who interact daily with visitors, are an important source of information about visitor satisfaction and expectations and about their own ability to manage visitors effectively. Based on decades of experience, the nature of large group tourism at Mogao, and the logistical constraints of guiding on multi-tiered walkways, the DA Reception Department has established policies on all aspects of guiding and visitor management. Among the variables that must be considered, two are critical in considering the capacity of individual caves. The maximum number of persons in a tour group that a guide can manage has long been set at 25. The physical capacity number (2 persons per square meter), in conjunction with the tour group size, sets the threshold for cave size of 13 m^2. Smaller caves are not capable of accommodating a standard tour group. Very large caves are capable of accommodating more than one group at a time. For the practices and training of guides, based on a study and direct experience of DA guided tours, see Ku 2013.

Fig. 4.10 During the hot summer season visitors to caves with low air change rates become uncomfortable as CO_2 levels rise. To alleviate these conditions, fans were installed in some caves (*above*). However, this merely serves to circulate the air in the caves. More recently, management has taken to closing caves with very high levels of CO_2 (*below*). (Courtesy Dunhuang Academy)

The duration of an average cave visit on a standard 2-h tour has been 8 min (visiting ten caves), with the remaining time taken up traversing the 1 km length of the Grotto Zone. In order to meet increased visitation the DA has reduced this to 5 min. Duration of time in the cave is pertinent since it affects the calculations for "CO_2 capacity" of each cave, discussed below in Sect. 4.2.3. Other variables, such as duration of tour, number of caves per tour, the number of "must-see" caves per tour, and routing on the walkways, are also important to managing capacity within the Grotto Zone, but they

Fig. 4.11 The guides, professionally trained and attired by the DA, play an important role in managing visitors and ensuring a satisfactory visit

affect the Grotto Zone as a whole, rather than individual caves, and they can be changed to meet different visitation scenarios based on seasonal demand. What happens inside the cave is most critical to the preservation of the wall paintings and the satisfaction of the visitors.

Key Parameters that Emerged from the Visitor Research and Analysis
Five key parameters were identified from this research that have a direct bearing on the daily visitor capacity of individual caves:

1. **Tour group size**: Based on experience of the DA over several decades, 25 persons per tour group is the upper limit of what guides can handle both in terms of narration and regulating visitor behavior in the caves. This is an important parameter because it has implications for the number of caves of sufficient size (physical capacity) to accommodate 25 persons.
2. **Physical capacity**: Acceptable limits for physical capacity were set at two persons per square meter, while recognizing that perceptions of crowding vary across cultures and people tend to clump together in the cave to follow the narration, which makes for greater density and creates "competition for the resource" as visitors jostle to see the paintings.
3. **Cave size**: The physical capacity number, in conjunction with the tour group size, sets the threshold for cave size: 13 m^2 is the smallest cave size capable of accommodating a standard tour group. Very large caves are thus capable of accommodating more than one group at a time.

(continued)

(continued)

4. **CO_2 level**: CO_2 is a safety issue for visitors but with the contribution of heat stress and body odors it is also a general indicator of air quality and relates to basic comfort level. An acceptable CO_2 level was established at a not-to-exceed limit of 1,500 ppm based on research and modified industry standards, considering the short duration of the typical cave visit. The buildup of CO_2 in the caves and the implications of air exchange on visitor numbers are examined in Sect. 4.2.3.
5. **Duration of a cave visit**: In order to maximize visitor numbers the DA will reduce the average time spent in a cave from 8 to 5 min (with remaining time to be spent viewing exhibitions). This parameter was important to fix since it affects the length and components of a guided tour and is used in calculating the CO_2 capacity of each cave, discussed in Sect. 4.2.3.

4.2.2 Analytical Investigations

The presence of humidity and salts in the caves is key to understanding deterioration and was extensively investigated in this study and in many previous studies (see papers from the Mogao Cave 85 project in Agnew 2010, 397–501). These investigations showed that ongoing deterioration of the painted plaster, evidenced in many of the caves (Fig. 4.12), is due mainly to hygroscopic salts and their response to fluctuations in humidity (i.e., deliquescence of salts as humidity in the air rises and recrystallization as it falls). To understand the mechanism and effect of salt activation on deterioration, a methodology was developed and a series of laboratory investigations was undertaken by both the DA and the GCI. The research questions and methods of answering them are noted below.

Research questions	Methods of investigation
• What is the mechanism by which wall paintings deteriorate due to salts? • What is the response of salts to high humidity?	• Identify salt species in the caves and their deliquescent relative humidity • Understand the migration of salts through the conglomerate rock and plaster to the painted surface • Determine the response of earthen wall plasters with salts to high humidity conditions • Model the progression and rate of deterioration

Salt investigations. Salt was extracted from the conglomerate rock of the cliff face at the site and from earthen plasters and subjected to ion chromatography analysis to establish the species and determine their proportions. As the analytical method used only provides for identification of ions, salt species were determined by calculation based on total sample mass, salt molecular mass, and proportion of ions.

Fig. 4.12 Salt-related deterioration in Cave 85 showing characteristic conditions of detachment and loss (*above*), and powdering plaster and severe flaking (*below*)

Further analysis identified the presence of bicarbonates (HCO_3), which could not be identified by ion chromatography. These efforts resulted in the following breakdown with sodium and chloride indicated as the principal salt species:

Salt	Percentage by weight (%)
$NaCl$	70.1
Na_2SO_4	6.7
$NaHCO_3$	14.4
$NaNO_3$	1.9
KCl	1.7
$MgSO_4 \cdot 7H_2O$	1.3
$CaSO_4 \cdot 2H_2O$	3.9

The extracted salts were then exposed to changing relative humidities to determine the critical value at which absorption occurs (differing rates of absorption, as seen in the graph, Fig. 4.13, are due to variations in salt compositions). This was determined as 67 % in the laboratory. However, cave wall temperatures, being cooler than the cave air, result in a rise in RH at the walls (see Sect. 4.2.3 for impact of wall temperature). For this reason 67 % was considered too high a humidity to preclude absorption of water vapor in salt afflicted caves. A value not-to-be-exceeded of 62 % RH in caves with salts was therefore settled upon as being reasonable for the long-term protection of the wall paintings

Salt migration and accumulation. The conglomerate into which the caves were excavated contains small amounts of soluble salts, typically on the order of less than 1 %. It is surmised that during periods of sustained high humidity, as from flooding at the base of caves which occurred historically, the rock and atmospheric humidity within the caves equilibrated, resulting in salt enrichment at or near the surface during subsequent drying phases (Agnew et al. 2010). At the interface between the rock and the painted earthen plaster, and in the plaster itself, the salt content was found to be up to 4–6 % in some caves.[3] It seemed probable, therefore, that environmental conditions over the centuries had caused this accumulation of salts. What was not clear was the mechanism of transport and rate of accumulation in the absence of evidence of liquid water in the rock or of past infiltration through the rock. Laboratory experiments confirmed the facility with which sodium chloride can move through the rock under conditions of differential humidity (Agnew et al. 2010).

To confirm that environmental conditions in the caves could induce migration of salts through the conglomerate, with accumulation at the surface, testing was undertaken using blocks of conglomerate with and without painted plaster and salt applied to one side and then subjected to RH cycling (Fig. 4.14). Results showed that alternating high and low relative humidity was capable of readily causing salt migration through both the conglomerate rock and attached painted plaster. Since it is impossible to remove the accumulated salts in the cave walls, prevention of future salt damage to the wall paintings must depend on control of humidity in the caves.

Earthen plaster investigations. The effects of salt concentration at the surface and in the plaster (which ranges between 1 and 6 %) and the progression of deterioration involved two areas of investigation. Intact and powdered original plaster samples were subjected to 75 and 54 % RH to determine rate and amount of moisture uptake and loss, which leads to salt crystallization and deterioration. In both humidities the powdered samples responded faster, due to greater surface area, and showed that the loss of moisture can occur quickly and result in damage at least at the micro level. The results highlighted the existing dangerous situation in the caves and led to the second area of investigation to better understand the long-term progression and rate of deterioration on salt-laden plaster. This involved accelerated cycling of earthen test coupons whose results mirrored those of the original plaster samples.

[3] A method for spot-testing was developed (using chloride ion as the indicator) in order to determine salt content in the earthen plaster in situ, see Chen et al. (2010).

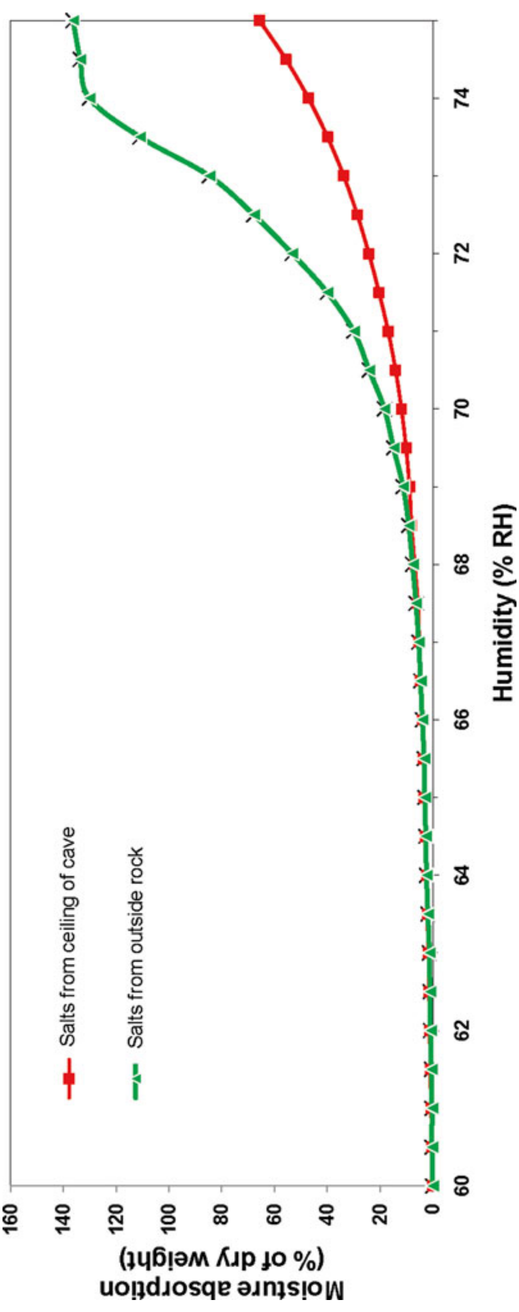

Fig. 4.13 Isotherms (25 °C) of salts determined by dynamic vapor sorption. Hygroscopic salts from within a cave and from external conglomerate rock differ somewhat in composition as shown by the different rates of absorption of water vapor. Both, however, begin to absorb moisture at about 67 % RH

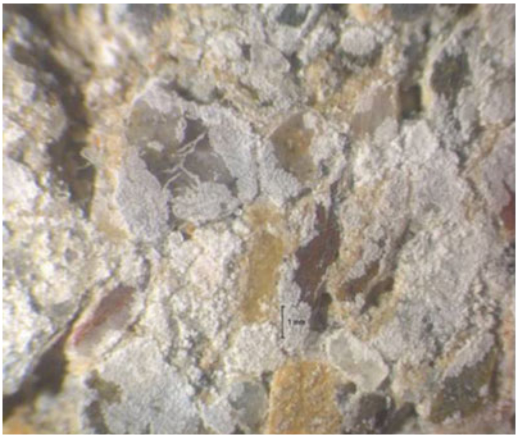

Fig. 4.14 Sample of conglomerate without plaster showing salt efflorescence on the surface (*whitish-grey*) after cycling between 43 and 85 % RH for only two prolonged cycles

Modeling progression and rate of deterioration using deterioration test coupons. Deterioration test coupons are painted earthen coupons that replicate the structure, composition, and pigments of the wall paintings and are loaded with different amounts of salts (1 and 6 %) (Fig. 4.15). Half of each coupon was also sprayed with a 2 % solution of polyvinyl acetate (PVAC), previously used at Mogao as a treatment for flaking wall paintings. Once complete, the coupons were subjected to accelerated cycling at 25 and 85 % RH in an environmental chamber allowing sufficient time to ensure thorough deliquescence and crystallization of the salts during each cycle. Coupons were examined after each drying (to constant weight) cycle, i.e., when recrystallization and resulting damage occur, and changes were recorded photographically and through written description. Coupons representative of progressive deterioration as seen in the caves were withdrawn and stored in a desiccator at a low RH to prevent further change. These representative coupons were assessed visually under the microscope to create an index of deterioration (on a scale of 1–6). Cycling of the coupons provided an opportunity to observe and document, phase by phase, progressive deterioration of painted plaster due to the interaction of salts and fluctuating humidity. PVAC, at a low concentration (2 %), neither accelerated nor slowed deterioration. Powdering was observed on the unpainted plaster.

This testing process resulted in conditions comparable to those seen in the wall paintings at Mogao (e.g., cracking, flaking, plaster powdering), validating the approach. By extrapolation, the rate of natural decay of cave wall paintings is inferred to be on the order of multiple decades or centuries depending on frequency and exposure to high humidity. It is clear that salt-related deterioration in the caves has been a slow, cumulative process, occurring over a time scale of centuries, but can be suddenly activated by environmental conditions.

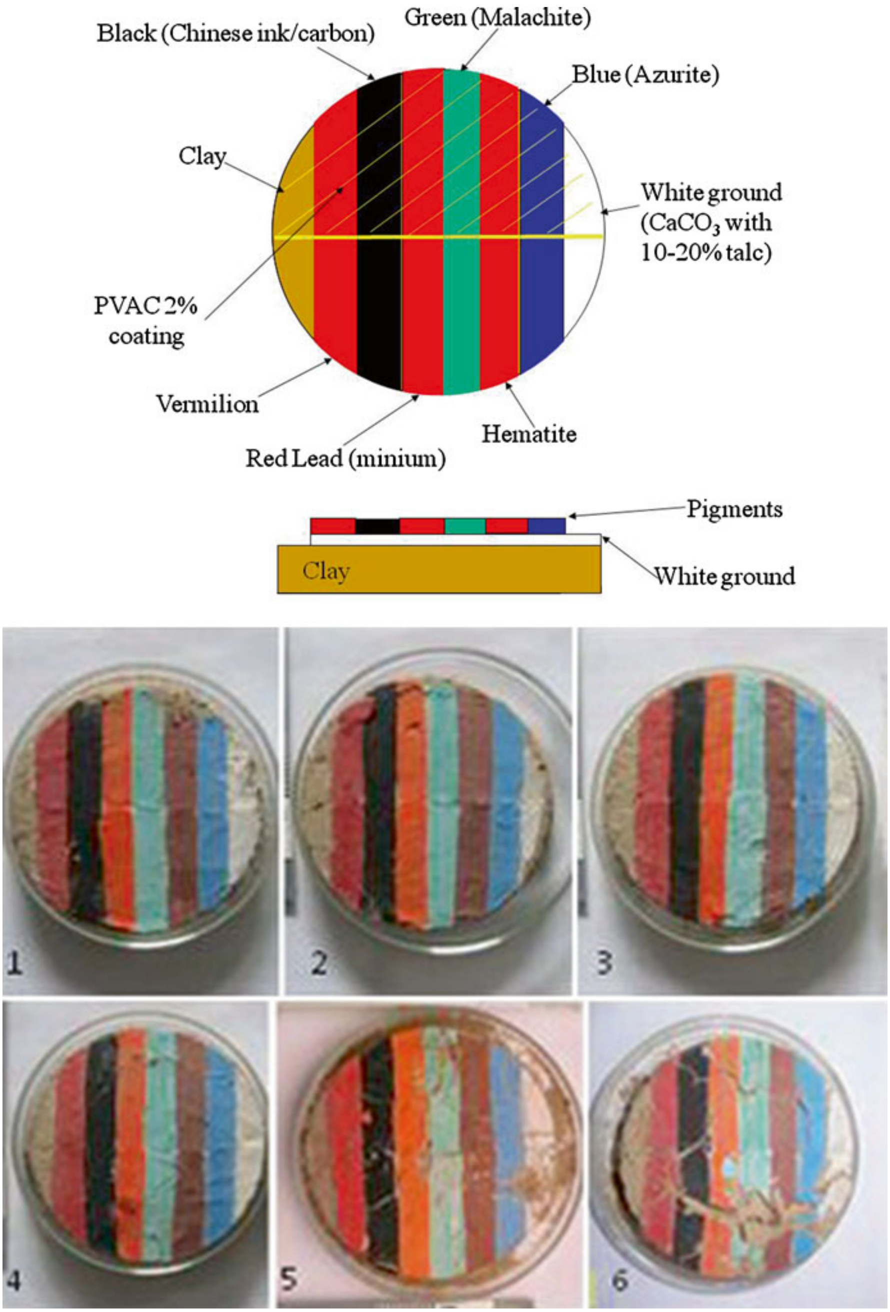

Fig. 4.15 Diagram shows placement of pigments and PVAC on coupons (*above*). *Below*, coupons representative of deterioration indices 1–6: (1) Hairline cracking; lifting of paint layer along edge. (2) Increased cracking and lifting; notable loss along edge; possible salt growth on and below paint. (3) Increased cracking; localized lifting along cracks. (4) Progressive cracking and crack widening; increased lifting of paint layer. (5) Severe cracking and loss along cracks; detachment. (6) Widening of cracks due to expansion of clay substrate; severe detachment and loss along cracks

Results of Analytical Investigations

Laboratory investigations determined several critical parameters as the basis for understanding deterioration of the wall paintings due to salts.

1. **Identification of salts**: Mogao salts are comprised primarily (approximately 70 %) of sodium chloride (NaCl) with minor amounts of other salt species including sulfates.
2. **Source and migration of salts**: Salts originating in the conglomerate rock are mobilized by elevated RH in the caves and have migrated through the rock to the plaster and painted surface over a time scale of centuries, resulting in a salt content in the range of 1–6 % by weight.
3. **Critical RH**: The Mogao salts mixture begins to absorb water vapor (at 20 °C) at 67 % RH (pure NaCl deliquesces at 75 %). Considering the influence of wall temperature (always lower then ambient cave air temperature) on RH means that around 62 % RH is the critical point at which deterioration could begin to be activated in susceptible caves. Time is also important—the longer the cave RH remains above the critical value, the more moisture is absorbed (depending on the amount of salts) and the greater the potential for damage. As deterioration progresses it also accelerates. Basal flooding of the exposed caves and periods of rain in past times when the Mogao caves were abandoned during the Ming Dynasty fulfill these conditions.
4. **Progression and rate of deterioration**: Investigations on earthen plaster and fabricated coupons containing salts showed that evaporation of moisture (leading to salt crystallization) occurs, causing damage within the earth matrix. The extent of damage correlates with the amount of salt. Cycles of deliquescence and crystallization result in porous, powdery plasters (common in some caves at Mogao), which have a larger surface area and respond faster to moisture uptake and loss, resulting in greater damage. Thus, the rate of deterioration is also a function of preexisting damage from salts.
5. **Deterioration Index**: A numerical index of deterioration was established for the fabricated coupons, which exhibited the same patterns and types of conditions present in the wall paintings and thus serve as a model for salt-related deterioration in painted clay. The index correlated with the number of accelerated laboratory cycles and percentage of salt content.

4.2.3 Environmental Investigations

In conjunction with the analytical results, environmental investigations were pivotal in making the link between visitation and mechanisms of deterioration in the caves. Building on previous environmental monitoring and testing at Mogao by the DA and the GCI, objectives were to investigate and determine the sources of humidity in the caves, and to understand the role of natural air change (ventilation) on the humidity and CO_2 levels in the caves.

Environmental monitoring at Mogao has been extensive and over the last 25 years has involved:

- Monitoring of the exterior climate since 1989 (using a weather station placed on top of the cliff and temperature and relative humidity sensors placed outside the caves)
- Installation of sensors recording air temperature, relative humidity, and surface temperature in four test caves for a period of 6 years
- Experiments to understand the effects of visitors on the microenvironment using varying size groups occupying a cave for different periods of time
- Experiments to measure the air change rate by natural ventilation under varying conditions: doors opened, closed; cave visited, not visited; hot vs. cold days; and the time required for the cave microenvironment to return to baseline
- Spot monitoring in selected caves of CO_2, RH, and temperature during periods of peak visitation

Taken together with investigations of moisture sources this extensive environmental monitoring of the caves has led to a refined understanding of the mechanisms of deterioration, the impact of visitation on deterioration, and the buildup of CO_2 in the caves. The research questions and the methods employed to answer them are indicated below.

Research questions

- What is the source of high humidity in the caves and is it related to visitation?
- How can buildup of CO_2 levels inside the caves be prevented?
- What is the role of natural ventilation in increasing humidity (RH) and mitigating CO_2 buildup?

Methods of investigation

- Extensive environmental monitoring of exterior climate and cave microenvironment
- Modeling of cave environmental conditions
- Measuring or calculating air changes rates for all priority caves

Source of humidity in the caves. Seven principal sources of moisture have been investigated in order to understand when and how humidity enters the cave (the sources of moisture discussed here are indicated on the moisture diagram, Fig. 4.16). The **Daquan River** (**1**) which lies at a distance of approximately 200 m from the cliff face is a trickle or dry for most of the year but can become a fast flowing torrent during the spring when the snow from the Qilian mountains melts. Historically, the Daquan River has occasionally flooded the site. Together with the accumulation of windblown sand during abandonment of the site from the fifteenth century, flooding and rain caused damage and loss of the paintings at the base of the walls in caves that had lost their protective temple fronts. Modern flood mitigation measures have largely eliminated this threat, but in the summer of 2012 and 2013 unusually severe rain storms caused flooding at the site (Fig. 4.17). Although the caves were not directly affected by the flooding, because of deepening and channeling of the river bed, this was a sober reminder that flooding remains a rare but potent threat.

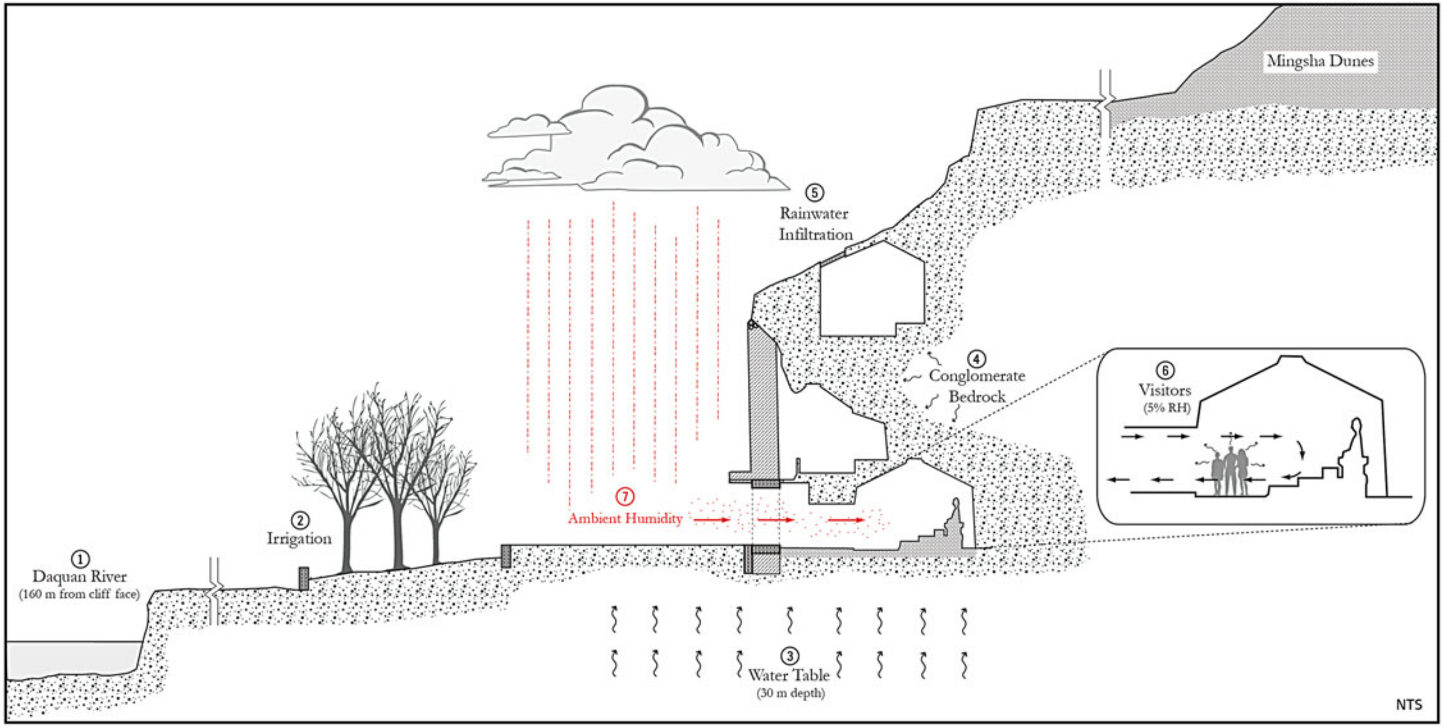

Fig. 4.16 This schematic section through the grottoes, from the Daquan River on the east to the Mingsha Dunes above the cliff face on the west, summarizes the results of investigations on the impact of sources of moisture in the past or currently on the caves and their art

Fig. 4.17 A rare flood event on the Daquan River, seen here in front of the Northern Grottoes, overcame flood control measures in 2011. (Courtesy Dunhuang Academy)

Poplar trees in front of the grottoes have been a traditional feature of the landscape at Mogao and in the oases. With the taming of the river and utilization of the area in front of the grottoes in modern times, plantings of trees have been confined to a specific zone and subject to irrigation. Subterranean migration of moisture from **irrigation of the trees** (**2**) was problematic when inundation irrigation techniques were used but these were replaced by drip irrigation several years ago. Subsurface moisture probes set at intervals between the caves and the zone of trees revealed no evidence of subterranean moisture affecting the caves.

The **water table** (**3**) was also considered as source of moisture in the caves. However, the water table is approximately 30 m below ground level, thus precluding capillary rise of liquid water through the bedrock, but allowing water vapor to diffuse upward through the sediments.

The c**onglomerate bedrock** (**4**) into which the caves are excavated has always been viewed as a potential source of humidity in the caves. As discussed in Sect. 4.2.2, salt accumulation in the west walls of many of the lower level caves is a major problem. Monitoring holes in the west wall of several caves show a humidity gradient from ambient at the wall surface increasing to 100 % RH at a depth of about 1.2 m. No liquid water is found. This indicates a water source deep in the conglomerate—the water table and possibly geological discontinuities or faults—from which water vapor diffuses through the porous rock. The RH gradient in the rock reflects the dynamic process of gaseous (air and water vapor) exchange between the cave atmosphere and the rock body to a depth of 1.2 m. Provided the humidity in the cave is less than that of the deliquescence of the salts at the surface, that is, in the painted plaster, the moisture at depth in the rock does not constitute a threat.

In the past direct **rainwater infiltration** (**5**) has affected a few upper tier caves where erosional thinning and collapse of the ceiling rock had occurred, but these holes have been sealed and the problem eliminated.

Fig. 4.18 Ambient humidity from rain or weather systems that occur between May and October is the principal source of moisture in the caves

Two final potential sources of moisture relate to visitors. They involve the separate effects of **visitors** (**6**) on the cave microenvironments (i.e., people in the caves) on the one hand, and visitation (i.e., the opening and closing of cave doors) on the other which allows **ambient humidity** (7) to enter the caves during periods of rain or high humidity weather systems in summer (Fig. 4.18). These two potential sources are discussed below in more detail in connection with the role of air changes.

Role of air change rate. Natural ventilation in a cave is measured as the number of air changes per hour (ACH), that is, the number of times in 1 h that the interior air mixes with an equal volume of exterior air. Air change rate is measured by decay in the concentration of a tracer gas released in the cave (a tracer gas dilution technique was used initially employing CO_2 and subsequently SF_6 gas). There is no single, fixed value for a cave's ACH. The range of ACH values for a particular cave depends on whether the doors are opened or closed, the temperature difference between exterior and interior (largest in the summer), exterior wind speed and direction, and cave characteristics such as size of chamber and door opening, and architectural configuration of the cave. Natural ventilation of caves is most influenced by the opening and closure of the entry doors. Cave air can freely exchange with the outside when the doors are wide open; with doors closed ventilation is limited to door vents and through gaps and cracks of the doors and bulkhead. This results in an order of magnitude smaller ACH than with the doors open; ACH is also affected when visitors block the entrance. During summer, outside air is warmer than inside where air is cooled by the cave walls. Since cooler air is heavier, a downward circulation develops in the main chamber and air flows from the main chamber through the lower half of the corridor to the cave entrance and the outside.

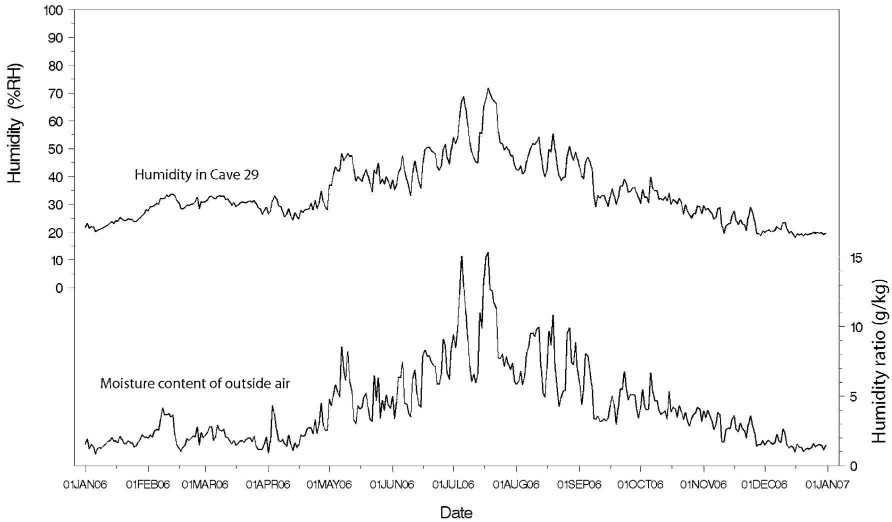

Fig. 4.19 Graph 1. Influence of external moisture on microclimate as measured in Cave 29 in 2006

Air change with the exterior purges the cave of water vapor and CO_2 emitted by visitors and, likewise, may bring in high humidity from outside until the process equilibrates interior and outside air. During high season, a continuously visited cave has its doors open throughout the visitation day (an 8-h period) such that a return to the cave's environmental baseline (i.e., the situation without visitation and the doors closed) is possible only during the closed period at night (16 h). In fact a cave with a low air change may not equilibrate completely, remaining at around 5 % RH above baseline (Maekawa et al. 1997); CO_2 likewise may remain above ambient. Although the Mogao Grottoes are situated in a desert environment, during the summer period the external atmospheric humidity rises and experiences periodic spikes due to occasional rain events or weather fronts passing through, reaching as high as 85 % RH. Elevated RH may persist for several days depending on duration of the rain and humid conditions, resulting in a greater quantity of moisture absorbed by deliquescent salts in the conglomerate and plaster and, consequently, greater damage to the wall paintings upon drying.

Graph 1 (Fig. 4.19) plots the daily mean values of external moisture (expressed as "humidity ratio," grams water per kilogram of air) over a year (2006) and the relative humidity inside a cave open to visitors (Cave 29). The influence of moisture entering the cave is evident in summer when external humidity is higher. As noted in Sect. 4.2.2, the surface temperature of cave walls, always substantially cooler than exterior air in summer, also affects the RH at the surface of the paintings and thus the potential for salt deliquescence. As air temperature cools at the wall surface, RH rises, meaning that exterior air does not need excessive humidity to create undesired conditions for the paintings. For example, a 1 °C difference between ambient in the cave and the wall temperature could mean approximately a 4–5 % RH increase at the surface. For this reason, 62 % RH, rather than 67 % based solely

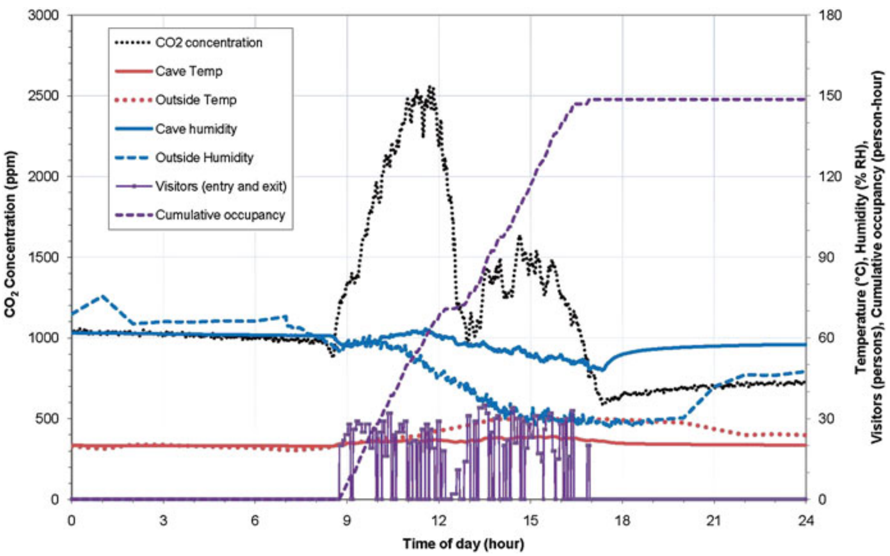

Fig. 4.20 Graph 2 shows external climate, interior microclimate, visitors, and CO_2 concentration over a 24-h period (August 19, 2007) in Cave 29 (volume 210 m^3)

on the salt deliquescence, was set as a not-to-be-exceeded value, in order to eliminate, over the long term, the threat of salt-related deterioration.

For management to better understand the potential impact of setting a RH limit, which requires closing some caves to visitors, and to assist in long-range planning, statistical analysis derived from environmental data collected over 5 years was undertaken. The result indicates that the number of days per month in July and August that caves with active deterioration will likely require closure because of infiltrating high humidity is less than 5 % (36 h) on average. Although a relatively small percentage, in any single year a RH higher than 62 % can occur for a longer period with annual variations in the climate or extreme events such as flooding.

Graph 2 (Fig. 4.20) illustrates the complex interplay of humidity, temperature, visitor numbers, and CO_2 on a typical peak summer visitation day in Cave 29. Visitation was continuous between opening and closing (8:00 am–5:00 pm); visitor numbers were counted manually (150 person hours and a total visitor count of 1,528). Apart from the dip during mid-day lunch, visitation was high throughout the day. The higher CO_2 from the previous day persisted overnight due to closure of doors at the end of the day. During morning visitation CO_2 rose to 2,500 ppm, while in the afternoon it peaked at 1,600 ppm when the natural air change is typically higher due to high external air temperature (approximately 30 °C). Internal air temperature is hardly affected by the doors being opened and the presence of visitors because of the buffering effect of the cool cave walls. RH increase in the morning hours, on the order of 5 %, is due to visitors and low air change. RH is slightly affected by infiltration of dry outside air when the cave is first opened and to a much greater extent subsequently by higher air change in the afternoon.

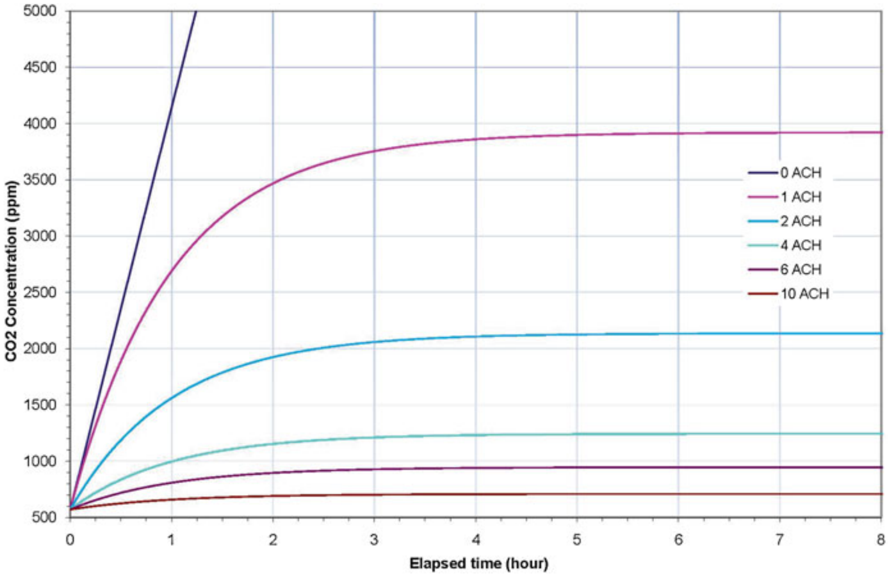

Fig. 4.21 Graph 3 shows calculated CO_2 concentrations as a function of air change per hour in Cave 29 (Volume of cave: 210 m^3; Ambient CO_2 : 350 ppm; CO_2 production rate: 500 cc/person/min)

Environmental modeling and CO_2 capacity. Caves with high air exchange may be expected to override the influence of visitors on RH and CO_2 buildup. However, in caves where air exchange is low, the increase in RH and CO_2 can be significant during peak visitation months. The relationship between ACH and CO_2 accumulation is illustrated in Graph 3 (Fig. 4.21). For each visited cave, the lowest ACH value, either directly measured in situ or calculated from an empirical formula (using measured ACH values as a function of cave volume for similar caves), was used to determine the potential for elevated CO_2 levels. The "CO_2 capacity" of a cave is defined (for purposes of this study) as the number of groups (of 25 persons) per hour at 5 min visit duration that a cave can accommodate such that the CO_2 concentration does not exceed 1,500 ppm (see Sect. 4.2.1 for determination of acceptable CO_2 limits).

Graph 3 illustrates the calculated CO_2 concentrations in Cave 29 as a function of ACH during continuous occupancy by groups of 25 persons. The smaller the number of air changes, the faster CO_2 concentrations rise. The amount of CO_2 emitted per person per minute (500 cc) is typical for mild exercise, such as walking. As shown in Graph 4 (Fig. 4.22), this model was verified by comparing the measured CO_2 in Cave 29 with calculated CO_2 concentrations and applying measured ACH values of 1.9 for the morning and 3.0 for the afternoon. The estimated overnight ACH when the cave is closed is 0.01. The low morning ACH of 1.9 resulted in excessive CO_2 buildup from nearly continuous visitation. In the afternoon the higher ACH of 3.0 was capable of maintaining a not-to-exceed value of 1,500 ppm.

The model was then used to estimate CO_2 levels with a distributed visitor load. Graph 5 (Fig. 4.23) shows the calculated CO_2 concentration over an 8-h day during

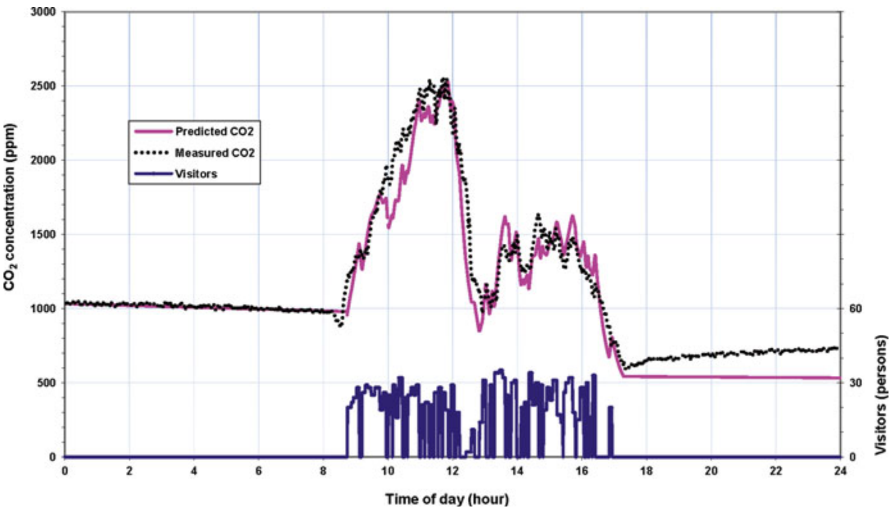

Fig. 4.22 Graph 4 compares measured and predicted CO_2 concentrations in Cave 29 on August 19, 2007 (Volume of cave: 210 m^3; ACH in morning: 1.9; ACH in afternoon: 3.0)

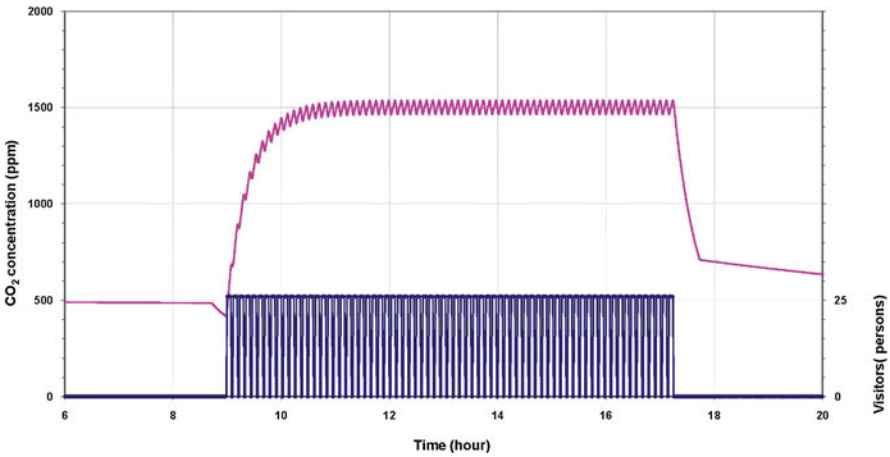

Fig. 4.23 Graph 5 shows estimated CO_2 levels with a distributed visitor load in Cave 29 over an 8-h day during which 25 people occupy the cave for 5 min followed by a 2-min interval, with doors open continuously (volume of cave: 210 m^3; ACH: 2.4; Ambient CO_2: 350 ppm; CO_2 production rate: 500 cc/person/min)

which 25 persons occupy the cave for 5 min followed by 2 min intervals, with the doors remaining open. In this scenario the CO_2 concentration does not exceed 1,500 ppm because the visitors are distributed and the ACH (the mid-range value of 2.4 was used) can cope with the production of CO_2.

The effect of occupancy time per group (25 persons) of visitors and the consequences for the CO_2 capacity are shown in Graph 6 (Fig. 4.24) where they were

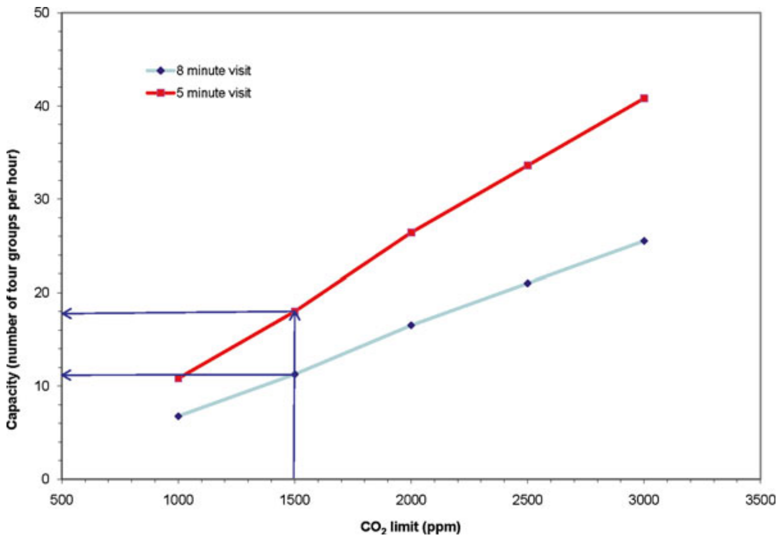

Fig. 4.24 Graph 6 shows the effect of visit time and CO_2 limits of 1,500 ppm on the number of groups in Cave 148 (volume of cave: 1,022 m^3; ACH: 1; CO_2 production rate: 500 cc/person/min)

calculated for Cave 148, a large cave (1,022 m^3) with a physical capacity that can accommodate up to four groups at a time (100 persons), but with a very low air change (ACH 1). Graph 6 shows the reduction in number of groups imposed when limiting the CO_2 level to 1,500 ppm and varying the visit time (5 vs. 8 min). At an 8-min visit, the cave can only handle about 11 groups per hour in order to remain below 1,500 ppm; if the visit time is decreased to 5 min, 18 groups can visit the cave. As one of the "must-see" caves at Mogao, this difference has a significant impact on visitation numbers.

Field experiments. Monitoring the impact of visitation on the environment was undertaken in four test caves, two open to visitation, two closed. In each cave environmental monitoring consisted of two air temperature (T), surface temperature (ST) and relative humidity (RH) sensors, located inside and outside the caves. Data was collected at 5-min intervals, recording daily fluctuations of RH and T in the caves for comparison with external weather conditions and humidity. From this, the influence of exterior conditions on the cave microenvironments is discernible, particularly as exacerbated by visitation to the two caves open to visitation. Visitation is defined as the period of time between opening of door, allowing ingress of exterior air (with the visitors), and closing of the door after visitors have left. Comparison between open and closed caves on a continuous basis for a period of 6 years has aided in quantifying the impact of visitation on the microenvironment, particularly during high season, which is also the period of high RH and greatest rainfall.

Graph 7 (Fig. 4.25) shows RH maxima plotted for the four test caves in 2007 with two caves (25 and 35) closed to visitation, and two (26 and 29) open to visitation.

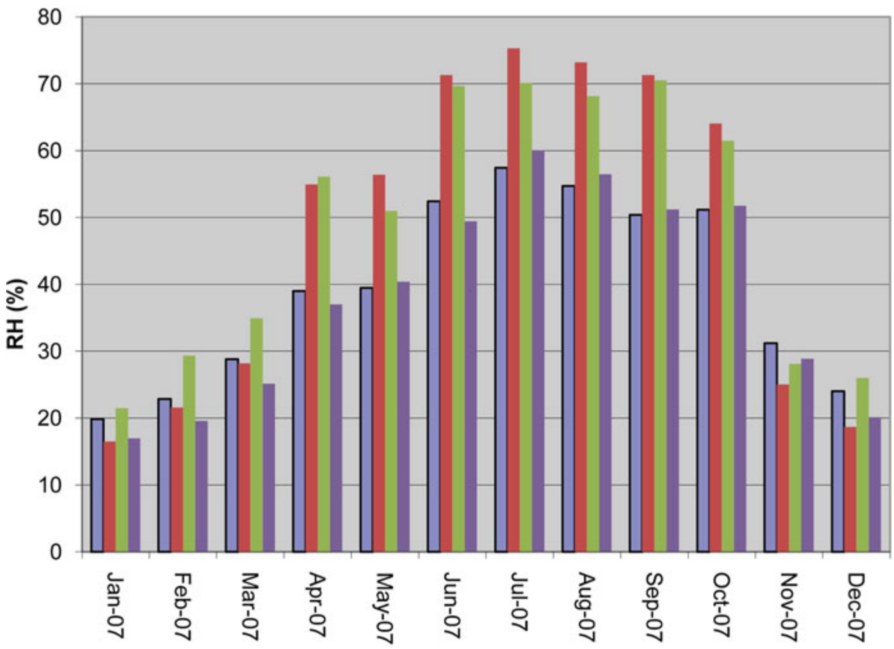

Fig. 4.25 Graph 7 shows RH maxima for the four test caves in 2007 (*orange* and *green* columns are caves open to visitation)

Closed caves never exceeded 60 % RH because of the low air change with doors closed (since doors are not tightly sealed some infiltration of outside air does occur); open caves frequently exceeded this value, rising up to 75 %, due to the intrusion of humid summer air under conditions of visitation. Seen over the course of a year, the chart shows the natural increase in humidity as temperature rises in the summer.

Graph 8 (Fig. 4.26) shows the same RH data plotted as monthly standard deviation which illustrates the microclimate variability about its mean caused by visitation, i.e., open doors, over the summer. The peaks correspond to holiday periods in spring and fall. Closed caves have significantly less variation. By contrast, in the winter, under conditions of little or no visitation, there is negligible difference between open and closed caves.

Also field tested were small paper sachets ("sentinels") with deliquescent salts (NaBr; KI; NaCl) mixed with soluble dyestuff that indicate elevated humidity (59, 70 and 75 % RH) by staining the paper when the particular RH has occurred. The paper sachets have proven a low-cost, easy method for indicating that a particular RH level was reached in a cave. They have been successfully correlated with peaks in RH recorded by the instrumentation in the caves. Such simple tools may be useful for other grotto sites that do not have the resources to engage in sophisticated environmental monitoring

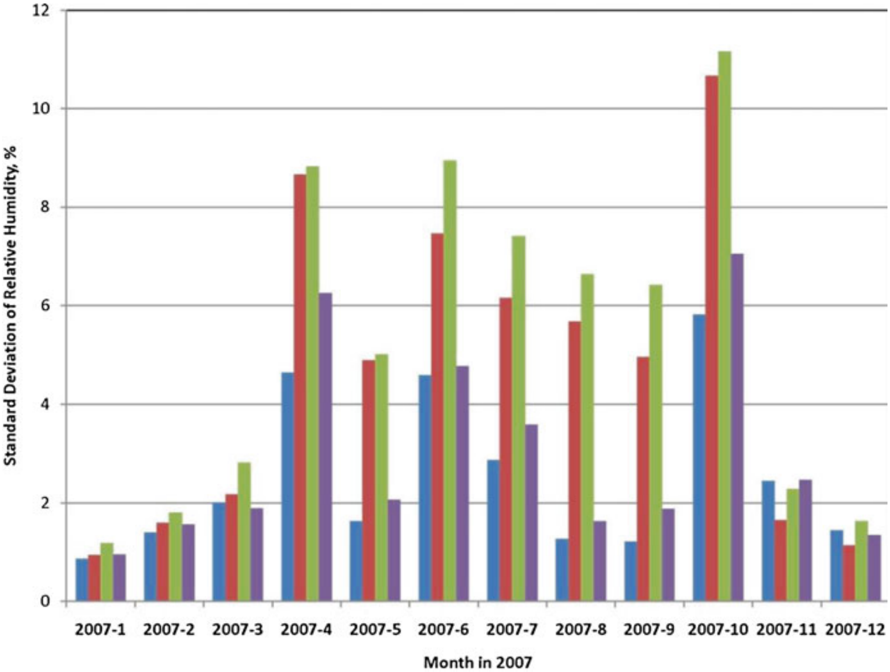

Fig. 4.26 Graph 8 shows monthly standard deviation of RH illustrating the microclimate variability about its mean (*orange* and *green* columns are open to visitation)

Results of Environmental Investigations

Key environmental parameters that will affect visitation to the caves were identified from the environmental investigations:

1. **Source of humidity in the caves**: The main source of moisture in the caves is from intrusion of outside air when it is humid or raining outside. Humid air enters the cave when the doors are open for visitation. It is thus the act of visitation, rather than visitors per se (who contribute only about 5 % of moisture through breath and perspiration), that is the cause of high humidity in the caves and puts caves with salts at risk of deterioration.
2. **Closure of caves under conditions of high humidity**: Natural ventilation (air change) mitigates the buildup of both humidity and CO_2 on a hot dry summer day, but on a humid or rainy day, open-door natural ventilation is the source of increased humidity in caves. This means that caves at risk of salt damage must be closed to visitation during periods of high humidity.
3. **Field experiments**: The results from the environmental monitoring in four test caves comparing caves open and closed to visitors clearly showed:

(continued)

(continued)

- Over the 6-year test period closed caves (25 and 35) never exceeded 62 % RH.
- Open, visited caves (26 and 29) frequently exceeded 62 % RH and often exceeded 70 % RH in the summer months. High RH relates directly to the opening of the door for visitation, which allows an influx of humid air into the caves during periods of high external RH. With 62 % RH as the threshold value at which salt damage begins to be activated (allowing for the influence of wall temperature on RH), this means that caves with salts are vulnerable to continued deterioration during periods of high humidity.

4. **Environmental modeling**: Modeling showed that cave visit time has a significant impact on the CO_2 capacity of a cave, with a 5-min visit allowing a greater number of groups, and that distributing visitors equally throughout the day will increase capacity.
5. **CO_2 capacities**: CO_2 has been established as a determining factor in visitor capacity of individual caves. Capacities set for each cave, based on measured or calculated ACH rates, determine the number of groups (maximum 25 persons per group) per hour at 5-min visit duration that a cave can accommodate such that the CO_2 concentration does not exceed 1,500 ppm. By projecting CO_2 values and the number of groups allowable, a visitor management system for peak periods can be put in place.

4.2.4 Assessment of Condition and Visitation Potential

Since opening of the Mogao site to visitors in 1979, some 112 caves have been accessible to the general public or special groups at various times. The remainder of the 492 decorated caves have been closed for a variety of reasons (too small, little extant wall paintings, poor condition, low significance). Beginning in 2005, an assessment of physical condition and visitation potential was undertaken for each of these 112 priority caves (Fig. 4.27). The objective was to determine which caves may be opened to visitation based on their physical condition (risk to the paintings and sculpture) and their visitation potential (significance, access and safety, size). In particular, the assessment of risk identified caves affected by salt-related mechanisms of deterioration. As will be discussed in Chap. 5, these caves will require more regular monitoring and temporary closure under conditions of high external humidity. Additionally, the assessment provided the indicators for regular monitoring and periodic re-evaluation of risk status. The questions posed by the assessment and the methods employed to answer them are noted below.

Fig. 4.27 The risk assessment team, consisting of staff from both documentation and conservation departments, undertook in situ investigation of conditions for the visitor study in 112 priority caves

Research questions

- Which caves are at risk of deterioration from visitation?
- Which caves have visitation potential (based on defined criteria of significance, access and safety, size)?

Methods of investigation

- Collection of historical information and baseline cave data
- In situ assessment of condition and risk level
- Determination of visitation potential based on significance ranking, safety and access issues, and useable visitor space

Historical overview of conditions. Knowledge of the history of the caves informs our understanding of existing conditions, their nature and possible causes, and ultimately whether or not they may be ongoing and affected by visitation. Historic redecoration within caves was common and can be seen in many of them. These modifications can often help explain the condition of the wall paintings and sculpture that exists today, such as plaster cracking and detachment found around many of the rebuilt entrance corridors and detachment and loss attributed to a later scheme of painted plaster being applied directly over the earlier paintings. The use of the caves for devotional practice is evidenced by wax and oil drips on niches and altar platforms and in some cases soot blackening from the burning of incense.

We know relatively little about the history of the caves from the abandonment of the site in the Ming period up until the 1940s when the Dunhuang Academy was founded. Historic photographs from the early part of the twentieth century show that caves did endure different lengths of exposure to environmental conditions during this period (see Fig. 3.4). Over time parts of the cliff face eroded or collapsed, and doors and wooden cave fronts were lost leaving the caves open and exposed to the elements. Windblown sand caused erosion and also buried parts of lower tier caves, abrading the paintings and leading to loss of antechambers. Flooding of the Daquan River and wetting of the accumulated sand banked up against cave walls over extended periods also led to basal loss and instability of painting in most of the ground level caves (Fig. 4.28).

Other types of activity in the twentieth century have left their mark on the caves. Of the many explorers in the early 1900s, only Langdon Warner desecrated the caves by removing paintings and sculpture in several caves. Some caves were inhabited by White Russian troops in the early 1920s, and possibly by unknown others. Graffiti and other damages such as fire blackening, heat-induced flaking, and alteration of paint layers caused by stoves being used in a number of caves are visible today (Fig. 4.28). Acts of iconoclasm are also evident where faces of Buddhas and Bodhisattvas have been gouged and in a number of caves the gold leaf decoration was deliberately scraped off.

Modern interventions at the site include the systematic protection and security of caves through the construction of the concrete façade beginning in the 1950s and 1960s (Sun 1997). This was a major engineering feat and provided much needed protection to the caves, but it also necessitated changes to the caves to accommodate the façade and to construct supports for the walkways. The construction of the walkways, in particular, anchored directly into the rock, added weight and may be the cause of structural cracking in a few caves (Fig. 4.28). The vibration and weight caused by groups of visitors on these walkways, though determined to be safe, may still be causing problems in caves that are already unstable.

The caves have multiple and varied treatment histories, from the work undertaken mainly on statuary by Abbot Wang, the resident monk in the late Qing and Early Republic periods, to more systematic stabilization work of cave wall paintings and sculpture by the Dunhuang Academy starting in the 1940s. Work in the 1970s included anchoring of detaching painted plasters with cross braces and treatment of flaking paint layers and plaster disruption with various synthetic materials, such as PVAC and polyvinyl alcohol emulsions.

All of these problems and interventions have disfigured the paintings and impacted the aesthetic integrity of the art, but for the most part they are of the past and are not ongoing or active conditions. This is not to say they do not require monitoring and

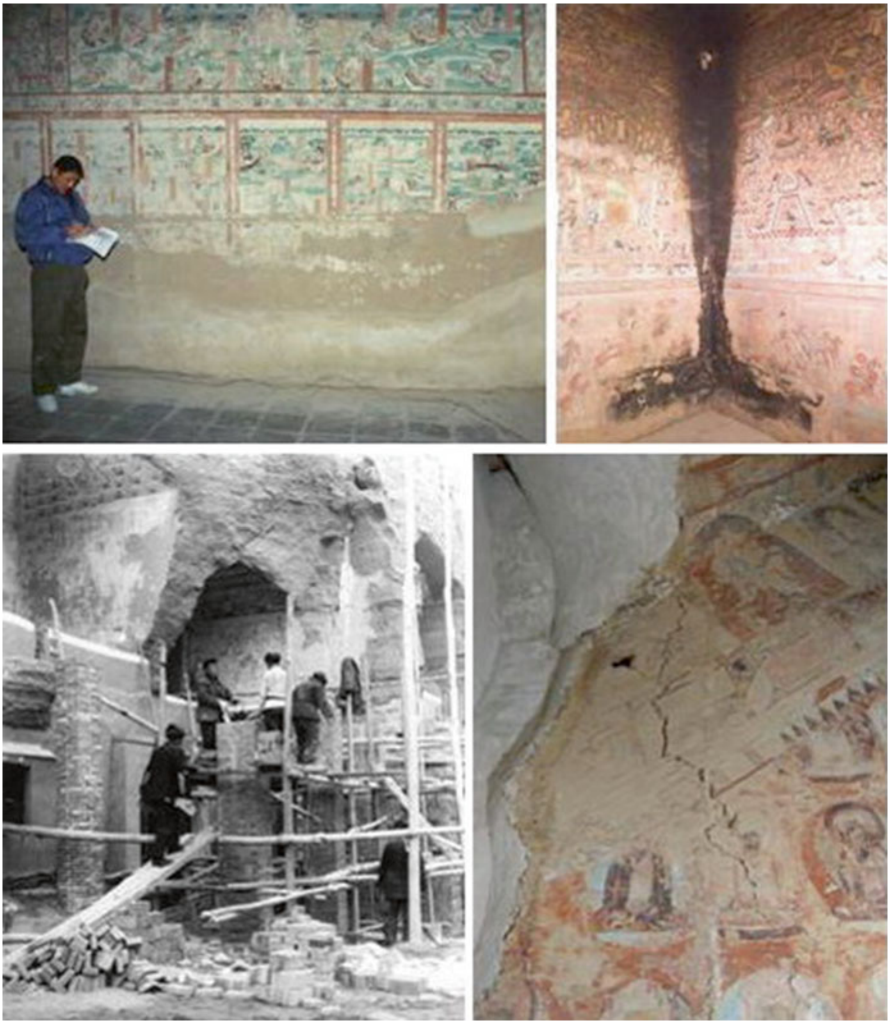

Fig. 4.28 Damage and deterioration related to the period of abandonment, past use or interventions include basal loss of paintings in ground level caves (*top left* in Cave 85, the loss extends on average 1 m up the wall); fire blackening (*top right* in Cave 156) caused by a stove being used during a period of inhabitation in the 1920s; and construction of a facade and walkways may have caused structural cracking, as shown here in Cave 260 (*below*). (Courtesy Dunhuang Academy)

preventive measures to ensure they remain stable, but these conditions are not caused by the intractable problem of salts. Salt-related deterioration, especially in ground level caves, has been ongoing for centuries in some cases and it continues to be a mechanism of decay if environmental conditions are not controlled.

Determination of risk. Assessment of physical condition of the caves began with review of historical information from archival documentation held by the DA as well as photographs from other institutions, some of which date back over a

100 years. This was followed by in situ inspection of each cave to document evidence of ongoing deterioration and other priority conditions.

Determining risk level requires both an understanding of the past history and conditions and rate of change of the wall paintings and sculpture, and also how these conditions could be susceptible to further deterioration from visitation. This is dependent on the experience and knowledge of the assessment team to be able to assimilate information on the caves' physical history and to correlate it with current condition and potential risk. The involvement of both documentation and conservation department staff in this process was therefore important.

The principal risk to the wall paintings related to visitation is environmentally driven, salt-related deterioration such as powdering of the plaster (disruption) and plaster detachment (Fig. 4.29), as a result of high external humidity entering the caves when they are opened for visitation. Other visitor-related conditions include the potential impact of humidity fluctuations and air movement on fragile flaking paint layers, the susceptibility of pigments and colorants to color change, and damage from visitors touching the paintings (Fig. 4.29).

The assignment of a risk level contributes to establishing the limiting conditions for visitation to caves and is the first stage in a process to prevent future impact from visitation. A risk level between 1 and 4 was assigned to each of the 112 priority caves. The risk ranking must be periodically reassessed as part of a long-term monitoring program. Definitions of risk levels and results of the baseline assessment of the 112 priority caves are briefly outlined below:

Risk Level 1—LOW. In these caves, current condition and documentary evidence indicate that the painting and sculpture are stable or at minimal risk of deterioration as a result of visitation. Risk Level 1 caves can be opened to visitors and will require only yearly monitoring of any identified problem areas. There are only nine caves assigned to Risk Level 1 (8 % of the total caves assessed), but it is likely that through condition monitoring, some Risk Level 2 caves can be changed to Risk Level 1.

Risk Level 2—MEDIUM. For medium risk caves current condition and documentary evidence indicate that the painting and sculpture exhibit problems that are more serious and/or widespread than Risk Level 1, such as paint flaking, structural cracking, and plaster detachment, but that do not show evidence of being ongoing. These problems are not salt-related, but may still be exacerbated by humidity, air movement, or loading as a result of visitation. Risk Level 2 caves can be opened to visitors, but may require more frequent monitoring of identified problem areas, further investigation, and a plan for conservation. There are 58 Risk Level 2 caves (52 % of the total caves assessed)—currently the largest risk level group.

Risk Level 3—HIGH. In these caves current condition and/or documentary evidence indicate that the painting and sculpture are vulnerable to environmentally driven, salt-related deterioration. These conditions are exacerbated when moist air enters the cave as a result of the door being opened for visitation during periods of high humidity (62 % RH or higher). These caves can be opened to visitors on a controlled basis (i.e., the cave must be closed during these periods to limit air exchange and maintain a stable environment). Risk Level 3 caves will require

Fig. 4.29 Principal risks to the wall paintings related to visitation include environmentally driven salt-related deterioration, such as powdering and plaster detachment (*top*, Caves 26 and 61). Other conditions include widespread and severe flaking and loss shown in Caves 386 and 85 (*middle*); and color change to pigments and colorants susceptible to light and humidity, as seen in Caves 85 and 260 (*bottom*). (Courtesy Dunhuang Academy)

detailed monitoring of salt-related deterioration or other active conditions. Twenty-four caves were assigned to Risk Level 3 (21 % of the total caves assessed).

Risk Level 4—HIGHEST. Current condition and documentary evidence indicate that the painting and sculpture in these caves are at highest risk due to anticipated loss or undesirable change as a result of visitation. These caves exhibit conditions such as plaster disruption, plaster detachment, and paint flaking that are currently severe, widespread, and ongoing or they retain unaltered or partially unaltered areas of painting that risk imminent loss (i.e., of original color) if open to visitation. These caves should be closed to visitation. Following conservation measures, their visitation status may change. Risk Level 4 caves will require yearly detailed monitoring of identified problem areas, further investigations to understand problems and, if necessary, a plan for conservation. Twenty-one caves were assessed as Risk Level 4 (19 % of the total caves assessed).

Determination of visitation potential. Information used to assess visitation potential includes the cave's significance ranking, which was established for all caves by the DA as part of their master planning process, and basic data such as size, dimensions, floor area, volume, and volume-to-door area ratio. The useable visitor space within the main chamber was determined for each cave (1 m from the walls subtracted from floor area) (Fig. 4.30). Volume and volume-to-door ratios were needed for interpolating air exchange rates.

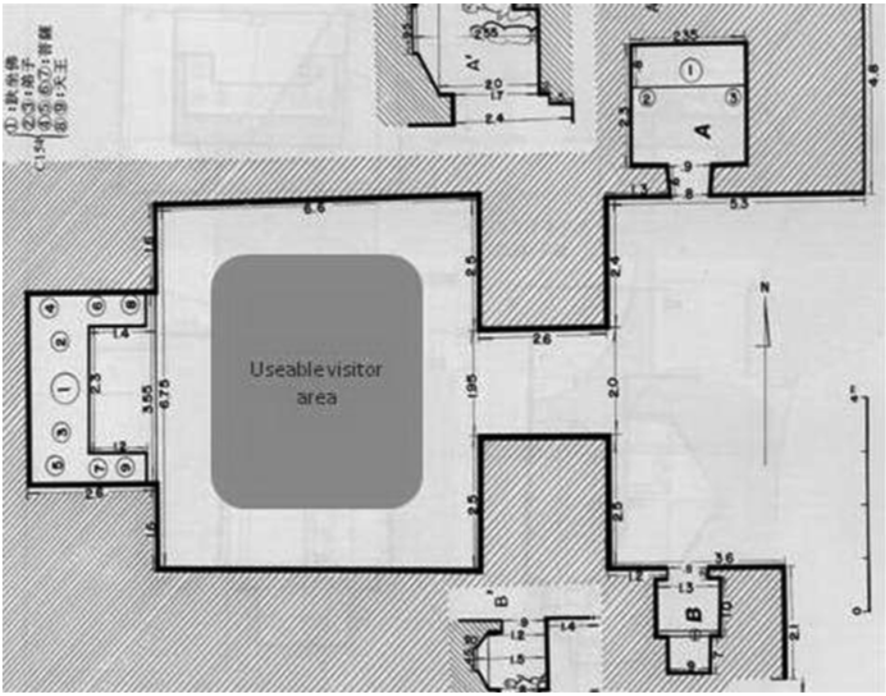

Fig. 4.30 Assessment of visitation potential involved measuring the useable visitor space within the main chamber of each cave (1 m from the walls subtracted from floor area), as well as volume and volume-to-door ratio required for calculating air change rates

Access and safety issues, such as structural loading of caves and walkways, and steep stairways or narrow entry corridors were recorded or assessed. The DA has undertaken assessment of structural stability of all caves and since 2010 has begun replacing sections of the external walkways to ensure safety. Visitor-related infrastructure, such as protective glass barriers, railings, and lighting were recorded.

Results of the Cave Assessment
The assessment process has provided key information on the condition and visitation potential for the 112 priority caves, as follows:

1. A **portfolio** for each cave was compiled with information on dynasty, location, dimensions, significance, visitation history, access and safety issues, previous interventions, and current physical condition. Specific inputs to the visitor study for each cave are:
    - A risk level (between 1 and 4) assigned to each cave; those that have direct bearing on whether the cave can be visited are Risk Level 4 (risk of imminent loss) and Risk Level 3 (susceptible to salt-related decay)
    - Useable visitor space, defined as 1 m from the cave walls, to decide whether a cave meets the physical capacity threshold for a standard group
    - A significance ranking (A–D) following the DA's ranking system, based on age and rarity, dynastic representation, integrity (degree/extent of preservation of the paintings and sculpture), artistry, Buddhist iconography, historical depictions of everyday life, and inscriptions
    - Issues of safety or access either within the caves or related to the walkways
2. **Monitoring indicators**: The assessment defines the conditions that need to be monitored (key indicators of change) and monitoring protocols, and serves as the basis for periodic re-evaluation of risk status.
3. **Summary condition report**: Synthesis and interpretation of the assessments provide a global understanding of current status and risks
4. **Future priorities**: Results of the condition assessment form the basis of conservation planning for the grottoes.

4.3 Defining the Limiting Conditions

The research, investigation, and assessments described in Sect. 4.2 are the core of the visitor study. Results of that work allow us to define the limiting conditions that may restrict visitation to each cave and thus to the Grotto Zone as a whole and that may require management responses in order to ensure that desired conditions are achieved. We have characterized these conditions as either "eliminating," "restricting," or "management" conditions.

Eliminating conditions, based on significance, safety and access, physical capacity, and level of risk to the wall paintings, provide clear thresholds that must be met for caves to be open to visitors. These conditions separate caves currently suitable for visitation from those that are not. Thus caves of low significance, with safety issues, inadequate physical capacity, or at highest risk are eliminated from the roster of potential caves.

Restricting conditions are applied to caves that pass the elimination threshold. These conditions will restrict visitation in certain caves under specific conditions, but do not preclude their use. Caves with low CO_2 capacity are subject to restrictions on the number of groups in order to keep CO_2 below 1,500 ppm. The method developed for setting CO_2 capacity allows for a preset number of group visits per hour using measured or projected ACH rates for caves with doors left open. Caves at Risk Level 3 are subject to closure under conditions of high external humidity (above 62 %) and will trigger specific management actions, most importantly, closure of the cave. In the event a cave is closed it will be substituted by a lower risk cave.

Management conditions, limited by factors such as tour group size, number of guides, hours of opening, number of caves visited per tour, number of caves open, duration of tour visit, and routing of tours, will also play a role in restricting the number of visitors that can be accommodated in a single day. Tour group size (25 persons) and duration of cave visit (5 min) are the two management conditions that have a direct bearing on the daily capacity of individual caves and if changed would have a domino effect.

All of these limiting conditions are potentially amenable to mitigation strategies, which might allow higher visitation. Some of these strategies may be viable in the short term. The use of smaller tour group size to allow for visitation of small caves or reduction in the number of caves on a tour are readily available options, but such options may have implications for routing on walkways, staffing, and potentially on visitor satisfaction, although there are ways to compensate for what would appear to be a loss of access. The 5-min visit could be increased in the future or for special tours, but would require a recalculation of CO_2 values since it is the basis for calculating CO_2 capacity.

Other mitigation strategies may require a period of investigation, testing, and monitoring to determine their efficacy. Such is the case for the use of fans or ventilation systems in caves to increase air change, which may create new risks. Emphasis in this study has been on working within the constraints of natural ventilation. In general, forced air exchange is not considered practicable or desirable because of the potential negative consequences of changing the environment and due to the requirements of electrical supply and ducting, and resulting noise and aesthetic impact to the site. Other strategies related to how visitors access high-demand cave are being tried, discussed below in Sect. 5.2.1, Chap. 5.

Conservation of caves with a Risk Level 4 may allow them to be opened to visitation, but this might require years of monitoring, assessment and conservation, as was the case for instance with Cave 85 (Wong and Agnew 2013) (see Fig. 4.31). Other mitigation strategies, such as opening less significant caves in order to interpret other aspects of Mogao's history and conservation issues, may only appeal to a small targeted audience, but if developed into an appealing interpretation program, would provide additional available caves for a specialized audience. All these options are possible, but require understanding of potential consequences for the

Fig. 4.31 Cave 85 is an example of a cave that is now Risk Level 3, having undergone extensive investigation and conservation, but the wall paintings remain vulnerable to environmentally driven salt-related deterioration. Prior to conservation, this cave would have been classified as Risk Level 4

preservation of the caves, the capacity of management, and the interests and demographics of visitors.

The limiting conditions respond to the management objectives and the desired conditions set forth at the outset, as summarized below:

Desired conditions and management objectives	Limiting conditions that address the desired conditions and management objectives
The desired condition for the wall paintings and sculpture is stability, meaning no change or further degradation. This requires a humidity environment that does not activate the mechanisms of deterioration, namely deliquescent salts, and prevention of physical damage by visitors	• Eliminating caves of Risk Level 4 from visitor roster • Closing Risk Level 3 caves if RH exceeds 62 % • Keeping tour group size to manageable numbers (25 pax) for guides to monitor visitor behavior • Other management practices such as physical barriers and DA guide-led tours largely eliminate mechanical damage to paintings and sculpture

(continued)

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The desired condition for visitors was defined as a baseline condition of a safe, healthy, and comfortable environment in the grottoes. This requires an acceptable air quality, an allocated space per person for visitation sufficient to ensure that crowding is not a factor, and walkways and caves must be structurally capable of handling visitor loads safely and without undue crowding	• Eliminating caves with safety and access issues • Keeping CO_2 limit to below 1,500 ppm • Restricting tour group size to 25 pax to enhance visitor experience with guides and within the caves • Using only caves of 13 m^2 or larger in order to allow space requirements of two persons per square meter • Eliminating caves of low significance begins to address other aspects of the visitor experience relevant to interpretation
A further objective of management in undertaking the visitor study was to maximize visitor numbers without negatively impacting the resource	Setting a minimum standard of quality for visitation to accommodate more visitors and reducing the cave visit duration to 5 min helps achieve this goal. While the visitor management plan will strive to achieve visitor satisfaction beyond this basic level, the quality of the visitor experience may be compromised during peak periods to allow maximum visitor numbers

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Chapter 5
Strategies for Sustainable Tourism

5.1 Developing Monitoring and Management Tools and Strategies

The limiting conditions for visitation were the end result of the research and assessment phase of the visitor study discussed in Chap. 4. Responding to the research and assessment phase through the development of monitoring and management tools constituted the second phase of the study. The correlation and interpretation of the data generated in the first phase is complex, but essential to developing a comprehensive understanding of the impact of visitation and a rational visitor policy during periods of high visitation. In order to most effectively manage and use the matrix of data that emerged from the study an integrated visitor management system was developed (Fig. 5.1). The Tour Management system (an operational management tool) and the simulation models for the Grotto Zone and a new Visitor Center (currently under construction 12 km from the grottoes) incorporate the results of the visitor study. The purpose of the Grotto Zone simulation model is to determine the visitor capacity under different scenarios, while adhering to the limiting conditions established in the visitor capacity research. The model allows scenarios to be tested based on variables such as opening hours, the number of "must-see" caves on a tour, the number of standard tours available, the number of caves per tour, and walking speed of the groups, and hence the walking time, between caves. It quantifies defined service levels, such as wait time and queue length and visually depicts the visitor flow and distribution within the Grotto Zone during the course of the day. Remaining fixed in the model are the restrictions imposed by CO_2 capacity, but the model allows for changing the duration of cave visit on which CO_2 capacity is calculated. This model is linked with a simulation model for the Visitor Center, which determines the most efficient way of moving visitors through the Visitor Center, to the site and Grotto Zone by shuttle and back again at the end of the tour. The Grotto Zone Model can be run separately or as part of the Visitor Center Model.

M. Demas et al., *Strategies for Sustainable Tourism at the Mogao Grottoes of Dunhuang, China*, SpringerBriefs in Archaeology,
DOI 10.1007/978-3-319-09000-9_5

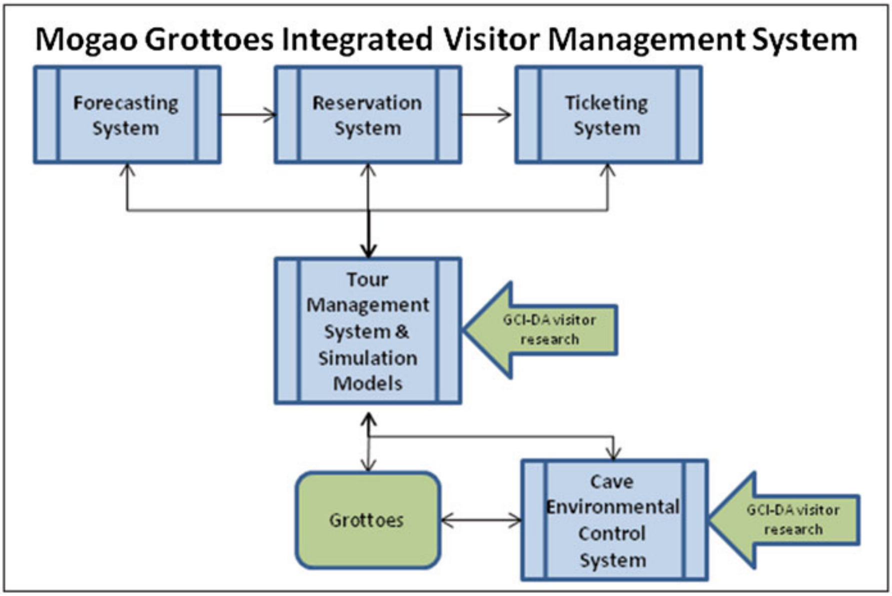

Fig. 5.1 Diagram shows the main system components and data sources of the visitor management system developed for Mogao

The operational management tool allows visitor management staff to plan itineraries by searching and creating tours and easily modify them when conditions require a selected cave to be closed, such as when high external humidity necessitates closing at-risk caves or when caves are added or removed to the roster due to a change in risk level. The main criteria used in tour selection are those that have always been the basic building blocks by which tours were created at Mogao (that is, dynastic representation, the inclusion of "must-see" caves, and the significance and size of caves). These criteria were formalized in the course of the study and the new data generated by the visitor study were added (i.e., the physical capacity of each cave, the CO_2 capacity, and the risk level based on the condition assessment). With these criteria tagged to each cave, selection of cave tours calculates capacities for individual tours (consisting of ten caves typically) and for an aggregate of tours (consisting of eight to ten tours typically). The aggregate of tours defines the total daily capacity for the Grotto Zone. A capacity allocation algorithm in the system eliminates as much as possible common caves among tours, thereby decreasing congestion and bottlenecks that limit the sum of the tour capacities along the walkways and increasing daily capacity. Once tours are selected, they can be tested in the simulation model to determine how they will be affected by variables such as operating hours, walking speed, sequencing and routing, and with actual reserved bookings in the system.

The simulation models and operational tool have been incorporated into a web-based system that includes a forecasting system, reservation and ticketing system, and a real-time environmental monitoring system, which uses Wi-Fi technology, to measure humidity and temperature, and additionally CO_2 in those caves susceptible to high levels. The Forecasting Module is used to accurately predict the hourly visitor arrival volume based on the time of the year, weekday, time of the day, and the visitor language. The output is used for planning purposes and to design the visitor tours (Fig. 5.1)[1].

A danger of these sophisticated systems is that they can divert attention away from real management weaknesses and become a substitute for hands-on management of a site. As a tool they are useful in creating different scenarios to meet varying visitor levels and in managing and tracking tours and reservations. But their output is only as good as the data input. In this we believe that the in-depth analysis and monitoring undertaken at Mogao has proved its value. DA staff have been performing the management tasks for decades now and are highly attuned to what is needed and what works; however, the complexity resulting from huge visitor numbers and the requirements for preservation of the caves necessitates computerized systems such as those developed for Mogao.

5.1.1 Applying the Management Tools

When the Simulation Model for the Grotto Zone first became operational and the limiting conditions were initially established and assigned, trials were conducted to assess options for visitation in the Grotto Zone and the level of impact that the limiting conditions would have on the current and projected visitation levels. These were based on the limiting conditions (fixed in the system) and current management policies and practices (which can be varied), but assumed a mandatory reservation system in place that distributed visitors evenly throughout the day and a unidirectional flow of visitors:

Limiting conditions

- Significance (A and B ranking)
- No safety issues
- Physical capacity of 13 square meters or larger
- Risk Level 1–3 (assuming a RH below 62 %)
- CO_2 capacity (number of group visits per cave per hour not to exceed 1,500 ppm)
- Duration of cave visit: 5 min
- Tour group size: 25 persons

Current visitor management parameters

- 8.5 h operating day for the Grotto Zone
- 30 caves open for tours
- Eight standard tours used equally
- Ten caves per tour
- 2 h tour (including exhibitions)
- 80 guides available
- Four "must-see" caves per tour
- Walking speed (50 m/min)

[1]The simulation models, utilizing Arena® software, and the operational tool were developed by Kiran Consulting Group (San Diego, CA); the web-based visitor management system is being developed by Kiran Consulting Group and QWARE Corporation (China); the real-time environmental monitoring system was developed by Zhejiang University (China), all under contract to the DA.

Different scenarios were run in the model, varying the visitor management parameters (e.g., operating hours, number of “must-see” caves on a tour, and number of caves per tour), which provided a range between 2,800 and 5,600 visitors per day. In the scenario based on current management practice the visitor capacity was 2,800 with a high percentage of waiting time (34 %). This was due to “must-see” Cave 148 becoming a blockage point due to its low CO_2 capacity (this cave routinely reaches 3,000 ppm during the summer months). A visitor capacity of 5,600 could only be achieved if the bottleneck Cave 148 was removed from the “must-see” cave list, operating hours were extended, walking speed between caves increased, and the number of caves per tour reduced. These trials thus brought to the fore the unanticipated impact of keeping CO_2 levels at a safe and comfortable level. With this understanding, new methods of visiting some of these high-demand, high CO_2 caves began to be developed (see e.g., Cave 148 in Sect. 5.2.1).

The Simulation Model for the Visitor Center, where all visitors will start their tour and see an orientation film about the site and virtual tours of caves, showed that it is capable of handling a maximum of 6,000 visitors, subject to certain conditions and assumptions (increased staffing levels, including guides, and longer operating hours). To accommodate this number of visitors in the Grotto Zone, management will need to implement a scenario for the Grotto Zone that will alter many of the current visitor management practices. The main options to increase visitation that emerged from the simulation testing are:

- Decreasing the number of caves per tour with more time spent at exhibitions or other activities
- Reducing the number of “must-see” caves per tour during peak periods or providing alternative methods of visiting these caves (currently the total capacity of the Grotto Zone is limited by the capacity of these caves, with Cave 148 being the greatest obstacle)
- Increasing the operating hours during peak periods
- Optimizing tours by opening a greater number of caves to reduce the number of common caves among tours
- Reducing walking distance by better tour routing (this, however, will be difficult given the need for dynastic representation and visits to at least some of the “must-see” caves)
- Decreasing the visit time in caves from 5 to 3 min (this will entail recalculating the CO_2 capacity for each cave and would certainly curtail the experience of the visitor)

With the management tools in place, these options can be explored through the model and special scenarios can be implemented during periods of excessively high visitation. There is no doubt that some of these scenarios will result in a less satisfying visitor experience, but if visitor numbers are to be maximized then compromise and trade-offs are mandatory. And these trade-offs can only be targeted at the visitor experience, not at preservation of the art. Strategies for compensating visitors for some loss of experience in the caves are discussed in Sect. 5.2.

5.1.2 Monitoring Indicators and Management Actions

Methods of monitoring the indicators of change in condition of wall paintings, the cave microenvironments, and levels of visitor satisfaction were developed and tested during the course of the study. Automated environmental stations for exterior environment are critical for alerting staff to dangerous RH levels and thus triggering a management response. As the real-time monitoring system being developed becomes fully operational, such alerts will be made automatically. The cave CO_2 capacities have been calculated such that the limit of 1,500 ppm is not exceeded, but these will require verifying and refining over time. Spot monitoring of problematic caves during peak visitation using portable CO_2 instruments, and ultimately, the real-time monitoring system, will serve this purpose. Specific protocols for monitoring ongoing deterioration in caves susceptible to salt decay are based on the risk assessments and will become part of routine condition monitoring undertaken by DA staff. The reservation system will be the means by which group numbers for touring the grottoes are controlled. Issues of crowding, poor air quality, and wait times will continue to be monitored through visitor surveys, but new and more sensitive methods of assessing visitor satisfaction may be required. As always, the DA guides play an important role in monitoring visitor satisfaction and bringing problems to the attention of management.

When monitoring indicates change from desired conditions, or if undesirable conditions are improved, specific management actions are set in motion. Depending on the changing conditions, these may include closing those caves with salt-induced, active deterioration (Risk Level 3) when exterior humidity rises above 62 % RH, and reassigning alternative caves to a tour; adjusting the risk level of caves higher if condition monitoring indicates deterioration is active in low risk caves, or lower if conservation treatment allows visitation to a high risk cave; reducing the number of daily tours or the time between visits (while keeping doors open to allow natural ventilation to flush the cave) if CO_2 limits are exceeded or adjusting calculations if real-time monitoring shows that the calculated number of tours per hour is exceeding the CO_2 capacity; and adjusting the number of tours to a cave if tested and proven mitigation measures allow a higher CO_2 capacity.

5.2 Enhancing and Diversifying the Visitor Experience

As was made clear with the simulation model tests, the visitor capacity of the grottoes is not a static condition. It needs to be seen as a dynamic and responsive system, one that will require different scenarios that respond to seasonal peaks of visitation and continuous re-evaluation and assessment of both the condition of the caves, the level of satisfaction of visitors and the visitor management operations. Changing visitor patterns and demographics in the future will undoubtedly influence visitation potential and require new management strategies. Currently, the vast majority of visitors to Mogao are Chinese nationals most of whom arrive in large tour groups and have somewhat parochial interests, such as wanting to visit all the "must-see" caves. The trends for the future are, however, already discernible—younger and better informed visitors, use of private vehicles as part of the growing road trip phenomenon, and a more sophisticated and nuanced appreciation of the artistic and religious significance and the landscape values, as well as an awareness of conservation. These changes in visitor profiles and patterns will open up visitation options as they also create new challenges for management.

In order to meet evolving visitor expectations and patterns of travel and to address the challenges of increasing visitation in the future, the DA is implementing and exploring a number of visitor management, presentation and interpretation strategies. These are intended to enhance and diversify the visitor's experience at Mogao while also compensating for what may well be limits on direct access to the art of the caves.

5.2.1 *Enhancing Presentation of the Caves*

Presentation and interpretation concepts were developed for Cave 85 at the completion of the conservation (Wong and Agnew 2013) and have subsequently been adapted for other caves. These involved establishing criteria and selecting light sources, new designs for physical barriers to prevent visitors touching the paintings, and a platform concept to allow for better viewing of very large caves (Fig. 5.2).

Fig. 5.2 Presentation of Cave 85 established a basic design scheme for the caves. In this large cave the viewing level was raised on a platform 1.30 m above floor level allowing visitors to better see the exquisite ceiling paintings. Guides and visitors still use flashlights to point to specific areas as can be seen here on the ceiling panels

Lighting The need for lighting the caves has long been debated among DA staff. Some of the caves receive ambient light from outside when the doors are open, while other large caves are dark even with open doors. Visitors see the paintings in the caves with the use of flashlights carried by guides. Over the years the quality of flashlights has improved somewhat and large polluting D-size battery torches with poor light have been replaced by slimmer, more powerful versions with longer battery life. Guides find flashlights useful in directing the attention of visitors to the scenes being described, but alternatives such as laser pointers are being considered and rechargeable flashlights are being investigated to reduce battery consumption and disposal. Even with this improvement, there remain significant problems in viewing the paintings by flashlight. A flashlight illuminates only the specific details of the sutra or *jataka* stories being narrated by the guides, leaving the viewer literally in the dark about the larger context of the scenes and unable to grasp the overall composition and beauty of the paintings.

Based on visitor surveys, visitor perceptions of lighting were ambivalent, with over half believing that it would not be appropriate to install lighting as it might affect the wall paintings. These responses were better understood when placed in the context of the DA guides' informal conversations with visitors over the years. The responses reflect, on the one hand, a lack of understanding about the effects of lighting and a desire to experience the caves as they may have been seen originally (in low light), counterbalanced, on the other hand, by a desire to see the paintings clearly.

Lighting criteria were based on considerations of aesthetics, conservation (no further change of both pigments and organic colorants), and easy maintenance. Tests were undertaken, comparing various LED sources with tungsten and fluorescent lamps. LED sources were favored and have the additional advantage of stable output over the life of the lamp (Druzik and Michalski 2011). The following criteria were established for the lighting:

Lighting Criteria

Color temperature: Color temperature is measured in degrees K (the unit of absolute temperature, the Kelvin). In practical terms, it may be understood as the color of the light source: warm white (2,600–3,200 K), bright white (3,200–4,500 K), and daylight (4,500–6,500 K). This range covers the red to blue ends of the visible spectrum.

Based on trials of different color temperatures in the cave, it was decided that light sources should have a warm color temperature (around 3,000 K or slightly lower). The appearance of the paintings was best at this color temperature; higher color temperatures created an unpleasing, "cool" artificial effect.

Color rendering index: Color rendering index (CRI) measures, on a scale of 100, the ability of a light source to reproduce the colors of objects faithfully in comparison with an ideal or natural light source. While it is generally agreed that a CRI of 85 is suitable for museum display, the best white LEDs measure above 90 when evaluated against a 3,000 K incandescent reference source.

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Aesthetic effect: Uniform lighting of the walls and ceiling was not necessarily desirable since the cave would not have been created, viewed, or used originally under even illumination; however, mitigating areas of high illumination, especially at the lower parts of the walls was an important requirement.

UV and IR emission: No UV and little IR.

Lux levels: Lux is a measure of the illuminance at the surface of an object. Formally, it is the illuminance occurring when 1 lumen falls on a square meter of surface. Based on research, 50 lux is an accepted standard for viewing of the most light sensitive materials in museums. Illumination of 70–100 lux was considered safe for the wall paintings since it is likely that color change of pigments and organic colorants has reached a plateau over the centuries since the caves were made. Damage is a function of light intensity multiplied by duration of exposure, and the cave will be lit only intermittently for tours. Nevertheless, long-term monitoring of the stability of the wall painting colorants is being undertaken using ISO Blue Wool standards. These consist of eight swatches of blue dyed wool of different light sensitivity that fade at known rates when exposed to light over a given time (Wong and Agnew 2013, 315, 449).

Heat emission from the light source: Negligibly low.

Longevity: Care and maintenance of lighting is an important management issue. It was essential that the light source be long-lived.

Power consumption: Low electrical power consumption.

The Peking University Center for Wide Gap Semiconductor Research was contracted by the DA to design, provide, and install LED sources that met all the criteria established. The results are largely successful, although shadows cast by statues and transitions, especially at the wall and the sloped ceiling, could not be fully avoided.

Physical barriers. Existing physical barriers at Mogao to prevent visitors touching the paintings are heavy glass screens in aluminum framing, with wheeled bases (Fig. 5.3). The glass screens serve a protective function both against deliberate and inadvertent contact, but they are cumbersome, take up excessive space within the caves and are a visual intrusion on the interior; however, experimentation with alternative railing systems has not been successful (the barrier with flat bases seen in Fig. 5.3 is one example). Moreover, the glass accumulates dust, and is frequently flawed by surface irregularities. A better method of isolating the walls has been, and still is, needed for the majority of caves. Visitor surveys about perceptions of the barriers found an ambivalence similar to that for lighting, with visitors recognizing that some form of barrier is required to protect the paintings, but disliking the visual intrusion this imposes. Cave 85, with a large floor area, enabled a different solution.

Fig. 5.3 Example of glass and aluminum frame barrier in Cave 148 to prevent visitors touching the walls, prior to implementing new presentation scheme

A wooden railing system at 1.10–1.20 m from the wall prevents visitors from touching the walls but allows an unobstructed view of the paintings (see Fig. 5.2). Because of this cave's size, this still allows a large viewing area for visitors.

Platform concept and design. An additional consideration for Cave 85 was to be able to better view the art from a raised platform in adequate light. While the large size of this cave is an advantage for solving the barrier problem, it is an impediment to viewing the upper areas of the walls and pyramidal ceiling with its central panel, which is at a height of 13 m from the floor. In particular, the many small vignette paintings (for example, the butcher and his dogs in Fig. 3.3) on the ceiling slopes are one of the delights of the Cave 85 paintings but are very difficult to see from the floor level. A further consideration in favor of a viewing platform is due to the complete loss or deterioration of paintings in the lower parts of the walls (see Fig. 4.28) from intrusion of flood water and sand in the past, which means the visitor is confronted mainly with loss and deterioration when viewing the cave at eye level from the floor. The steel structure of the platform and its steps rests on the cave floor. The railings, which incorporate a tempered glass safety panel, define a platform space of 7.18 × 4.88 m. The platform also serves to carry the LED lighting system and interpretive panels.

Interpretation. The objective for interpretation in Cave 85 was to convey a conservation message and enhance an understanding of what conservation entails and how

Fig. 5.4 Presentation scheme for Cave 148 followed basic design principles established for Cave 85 for lighting and use of wood frame barriers, but without the raised platform. Removable stanchions, visible at center of viewing area, allow visitors to be streamed in single file during peak periods

it is done through creating a special experience. Visitors to the site have only a rudimentary understanding of deterioration processes and how they may be mitigated by a systematic conservation, management, and monitoring program. To this end, five interpretive panels were created for the cave. They focus especially on conservation issues and messages and therefore supplement the normal tour provided by the DA guides, which is principally related to history and iconography (although the guides also received special training about the conservation of Cave 85).

The DA has now adopted the basic design criteria used for Cave 85 to other high-demand caves, such as Cave 148 and the Library cave 16/17. In Cave 148, which has a narrow viewing area, physical barriers were required adjacent to the walls. These conform to the basic design used in Cave 85 and are attached to the platform, which minimizes the space required (the glass can be removed for cleaning). In this cave, as in most caves, a raised platform would not be appropriate. The platform that holds the glass and wood panels is thus only slightly above floor level (Fig. 5.4). Since low air exchange was severely limiting the number of groups allowed in Cave 148 (see discussion in Sect. 5.1.1), the development of a presentation scheme was also a time to reconsider visitor flow. The DA is now experimenting with streaming visitors in single file through the narrow viewing area, with all narration taking place outside the cave. This reduces the visitation time of any one group and prevents congestion and clustering at the entrance which further hinders air exchange.

5.2.2 Visitor Management and Interpretation

In Sect. 4.3 we noted the potential for mitigation strategies for conditions that will limit visitation to the Grotto Zone and thus potentially allow greater visitation, while keeping preservation of the grottoes as the overriding goal. Outside the Grotto Zone a greater range of strategies is possible.

Visitor Center. The new Visitor Center (Fig. 5.5) outside the boundaries of the site, scheduled for opening in 2014, will serve an important orientation and interpretation function for visitors and will allow management to better control heavy visitor loads. It will be the point of departure for all visitors to the site and will include a film and virtual tours of caves. Vehicle parking and visitor services (such as restaurants) and all merchandizing activities will be re-located from the site to the Visitor Center.

The design of the Visitor Center (Cui Kai, principal of the China Architecture Design and Research Group, lead architect) takes its inspiration from the Mingsha sand dunes on the plateau above the cliff face of the grottoes. This design, so compatible with its environment, contrasts starkly with that of the nearby enormous new railway station at Dunhuang, which is overweening in scale and size (Fig. 5.6). Its location, close to the airport at the T-junction in the road, confronts the visitor to the site, while the Visitor Center is discreetly situated behind the poplar trees. These two

Fig. 5.5 The new Visitor Center under construction 12 km from the site takes its design inspiration from the sand dunes (Courtesy Dunhuang Academy)

Fig. 5.6 The architectural design of the train station, opened in 2008 and located less than a kilometer from the Visitor Center, takes its design cues from bureaucratic architecture and is not compatible with the desert landscape

contrasting designs symbolize the contrast between mass tourism as a business and bureaucratic enterprise and cultural tourism as a sustainable enterprise—like so much else, a question of values. Limiting the impact of buildings on the landscape is an important value for the DA and one that the Visitor Center building design respects.

Virtual Dunhuang. The Visitor Center is equipped with theaters to show a film about the history of the site and virtual tours of some of the caves that may not be open to the public or be able to be seen by all visitors. Over the past decade the DA has given a lot of attention to an extensive and varied program of digital reconstructions of the caves and experimentation with different forms of virtual tours. This has been a deliberative process with multiple objectives. Very high quality digitization aims not only to document for the future the state of the caves but importantly to bring forth the beauty of the art and allow the interpretation of the many stories they tell in a manner that is not possible because of time constraints in the caves themselves. These stories will include highlighting the fragility of the site and the centrality of conservation. This initiative is also a deliberate strategy to compensate visitors for limited access to caves, which will be required during peak visitor periods. Thus, before setting foot on the site, visitors will already have heard important messages and been exposed in a dynamic way to many of the most spectacular caves.

Replication. Replica caves are a traditional method of understanding and presenting the art of the caves (Fig. 5.7). Beginning in 1944 when an official organization was first established at Mogao to oversee the task of protecting and preserving the site, artistic re-creation of the cave art has held a high place in the activities of the DA. It was the famous Chinese artist Zhang Daqian (Chang Ta-ch'ien) who made the first

Fig. 5.7 Replication of the existing condition of wall paintings by hand is a long-established tradition at the DA (*above*) and continues to be practiced today, as in the example of a painting being finalized for exhibition below (Courtesy Dunhuang Academy)

artistic representations of the paintings in 1942 and brought them to the attention of a wider audience in China (Fan and Zhao 2009, 37). Since then, many generations of artists have carried on the tradition with an emphasis on creating meticulous copies of the art in its present condition. Unlike replicas such as those of Lascaux or Altimira, the replication process at Mogao is one that has traditionally been a way of studying, understanding, and immersing oneself in the art and Buddhism. Twenty full-scale replicas now exist, some of which are displayed in the Exhibition Hall, which allow visitors to explore the art more intimately and at their leisure. Other replica and digital reconstructions are used in exhibitions throughout the world.

Exhibition. The Exhibition Hall, built in 1994, is the largest exhibition venue at the site. In addition to the hand-painted replica caves, it offers changing exhibits that provide greater depth and variety of interpretation and the efforts to preserve the site (Fig. 5.8). These complement other exhibits, such as that in the Abbot Wang Temple (Fig. 5.9), which tells the story of the Library Cave, and the so-called Upper and Middle Temples that house exhibits on the early days of the DA and its first director, Chang Shuhong. All of these exhibits significantly enhance the understanding and experience of the site for visitors who have the interest and are willing to spend the time. Until recently, exhibitions had not attracted many visitors for several reasons; most visitors were in the hands of tour operators who work to a schedule that typically allows one day at the grottoes and other local attractions, such as the Crescent Lake; additionally, the DA has not marketed the exhibitions; and some of the venues, such as the Upper and Middle temples, are quite small and would not accommodate groups. This is now changing somewhat with an increase in individual travelers with more time to spend and greater interest in the context of the site.

Fig. 5.8 The Exhibition Hall houses ten replica caves (entered from the bays on the *right* of photo) and changing exhibits in large gallery spaces provide greater depth of interpretation and information on the efforts to preserve the site

Fig. 5.9 The so-called Abbott Wang Temple, where the Daoist monk Wang Yuanlu who discovered the Library Cave lived, now houses an exhibit about the discovery and contents of the cave whose entrance is in the cliff seen to the left of the building (Courtesy Dunhuang Academy)

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Conclusions

Around the world iconic heritage sites attract ever growing numbers of visitors. First to fall victim to the onslaught of unchecked mass tourism is the quality of the visitor experience, but ultimately, even the most robust of sites will be degraded in a variety of ways, from new infrastructure and transportation development to service more visitors, to noise, pollution, crowding, and so forth. At the vulnerable end of the spectrum are places like the Mogao Grottoes in which, absent good management measures, there is little latitude for over-visitation without irremediable damage to the cultural resource.

Efforts to maximize visitors to cultural heritage sites are driven by many forces. There is the desire of heritage managers, and often the legal mandate, to make sites available to the public, and there are pressures from government authorities for heritage managers to generate income to fund their operations and from the tourism industry and local governments to increase visitor numbers for economic benefit of the community and the industry. The constraints on site managers in the face of powerful interests and expectations of the local community for benefit are huge. Lack of information and an understanding about what is degrading the resource is one fundamental limitation on the ability of management both to make good decisions and to educate and convince the public and those who wield power that tourism at cultural sites must be firmly rooted in a preservation ethic and backed by effective management policies and governance if it is to be sustainable and a long-term benefit to society.

Logic would suggest that there must be ways whereby visitor numbers can be maximized while protecting the resource and striving to ensure a quality visitor experience. These are the objectives to be met at most visited cultural sites, and certainly these are the objectives established by the DA in the master plan for the Mogao Grottoes. It has been argued that indirect management approaches, especially educational programs, have proven successful in reducing impact and are preferable to regulations and direct management actions, such as physical barriers

M. Demas et al., *Strategies for Sustainable Tourism at the Mogao Grottoes of Dunhuang, China*, SpringerBriefs in Archaeology,
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or limiting visitors, since they are minimally intrusive and allow visitors to retain their "freedom of choice" (Marion and Reid 2007).

For those who have visited the Forbidden City in Beijing or the Terracotta Warriors in Xi'an during high visitation season such indirect approaches will seem to be optimistically naive. Sites that might benefit from indirect or "soft" approaches, such as educational messages, are geared toward fairly sophisticated, educated visitors who are sufficiently experienced in travel to understand and absorb the messages being conveyed. Mass tourism, wherever it occurs, is not amenable to such indirect approaches and in China, in particular, given its exploding domestic tourism, site managers must contend with visitors who have little experience of being a visitor to cultural sites, and the responsibilities entailed. That being said, visitor surveys at Mogao have shown that the public is generally aware of the fragility of the wall paintings, though not necessarily of specific causes of deterioration, and is supportive of efforts to preserve the caves. This is undoubtedly due in part to the DA guides who promote a conservation message as well as to frequent television documentaries about the site. Communicating messages on conservation and the effects of visitation will find better acceptance as they become consistently integrated within site interpretation.

Based on decades of experience and research and utilizing numerous case studies in the U.S. National Park Service, Manning and Anderson (2012) selected six tried and true management practices (with accompanying case studies) for reducing the impact of visitors. These provide a systematic approach to thinking about practical actions and options that can be taken to mitigate visitor impacts or problems (e.g., to water, wildlife, trails, night sky, crowding, conflict, depreciative behavior, facilities). Among these management practices are information and education so that visitors understand the impact and are provided with options (as noted above); rules/regulations; law enforcement; zoning; facility/site design/maintenance; and rationing or allocation, utilizing pricing, queuing, reservation or lottery systems. With regard to rationing or allocation strategies, the authors conclude: "Use rationing is controversial and is generally considered to be a management practice of last resort because it runs counter to the basic objective of providing public access to parks and recreation areas…. However, limits on use may be needed to maintain the quality of the recreation experience and to protect the integrity of critical park resources." This statement reflects the trends in managing visitor use today and the ambivalence among practitioners about setting limits and reducing access that was discussed in Chap. 2. It is our experience in cultural heritage management outside of the USA and in contexts of mass tourism, especially in developing countries, that limits on use are almost always a necessity.

The difficulty in relating visitor use to impacts has been cited as the primary challenge of applying carrying capacity planning to cultural resources, as distinct from impacts to natural ones which, as a result of long scientific study of the resource, can be quantified (Valliere & Manning 2003). In fact, the Mogao Grottoes, with its confined spaces, lends itself to a quantitative approach. A strength of the visitor study for the Grotto Zone at Mogao is that, while not ignoring soft approaches, it provides an objective, scientific basis for understanding, assessing and demonstrating the impact of visitation on the principal cultural resource (the wall paintings and sculpture), while striving to maximize visitation. Environmentally imposed limits have been subject to a fundamental misconception at Mogao (and this applies to other sites as well); succinctly stated, this is that visitors have a significant influence on humidity in the caves—and thus on salt-related deterioration—whereas it is the intrusion of humid air through doors opened for visitation that is the overriding effect.[1] While this finding in no way takes the visitor out of the equation, it changes in a fundamental way how management responds to the impact of visitors. Although we cannot yet quantify the impact of visitation on the wall paintings in the grottoes, we can use the scientifically validated theoretical model of deterioration to mitigate or prevent decay. Continued research and monitoring will undoubtedly refine an understanding of the causes of deterioration and their relationship to visitor use.

A second strength of the study is that it addresses the quality of the experience of visitors. Given the management structure and commitment of the DA it has been relatively easy to impose physical limits (cave size, group size, guided and scheduled tours) and address the problem of mechanical (physical) damage to the wall paintings. More problematic is the temptation to ignore CO_2 levels in the caves. It cannot be ignored, both for visitor comfort and health reasons; in fact, CO_2 provides a reasonable indicator by which to judge air quality. The impact of visitation on air quality is more easily quantifiable than deterioration and, as concluded in this study, it is the major limiting determinant for many caves at Mogao. This is not surprising given the spatial configurations of the caves, which restrict natural ventilation, combined with high visitor numbers (in this case it is the visitors themselves who introduce the problem). The CO_2 problem does, however, present a real challenge to the management of the site since the options are either to limit visitation significantly in some of the more popular caves or install a mechanical ventilation system, which may be problematic for a number of reasons discussed previously, and in any case would require further investigation.

In spite of these strengths, which we believe are significant and pioneering for China, the visitor management system that has been developed for Mogao will neither be sustainable, nor effective, without regular monitoring and integration into daily operations. Internally, its success will depend on staff trained in the operations of the visitor management system and complying with its requirements and, externally, on working with the tourism authorities to understand the objectives, rationale, and results of the study. The efforts that have gone into the visitor study and the results of the scientific investigations will ensure that restrictions on visitor numbers and access are more effectively communicated to tourism authorities and the public.

The Mogao Grottoes, as other World Heritage sites, will undoubtedly face many challenges in the future. These may arise from climate change, from changing visitor demographics, from national or global economic upturns and downturns, or from other sources that we are not even contemplating today. In planning for such

[1] Environmental monitoring of the Urn Tomb at Petra shows a sharp rise in humidity when visitors enter the tomb and this has been attributed to the visitors themselves (Comer 2012, 88ff).

an uncertain future Mogao's management has laid a solid foundation through the building blocks of master planning, visitor management, and conservation work in which it has been engaged over the last two decades.

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Author Bios

Neville Agnew is a principal project specialist at the Getty Conservation Institute (GCI) in Los Angeles. Prior to joining the Getty in 1988, he headed the conservation section at the Queensland Museum, Australia. Previously his career had been in academic and research chemistry. Agnew has led and participated in many of the international conservation projects of the GCI and has authored and edited numerous publications. He is a former member and chair of the U.S. National Park Service's National Center for Preservation Technology and Training and is on the editorial boards of the journals *Conservation and Management of Archaeological sites* and *Historic Environment*. Agnew organized the conservation theme at the 5th World Archaeological Congress in 2003 and co-edited the subsequent publication. His long association with cultural heritage conservation in China has resulted in a number of awards: The Friendship Award of the State Council in 2000; the International Scientific and Technology Cooperation Award of the PRC in 2005; and awards from Gansu Province and the Dunhuang Academy. His current projects include continuing work at the Mogao Grottoes of Dunhuang; revision of the *Principles for the Conservation of Heritage Sites in China*; conservation and management of the Valley of the Queens and Tutankhamen's tomb, Egypt; and the Southern African Rock Art Project.

Martha Demas is a senior project specialist at the Getty Conservation Institute (GCI) in Los Angeles. She received her doctorate in Aegean Archaeology from the University of Cincinnati. After several years engaged in archaeological excavation, research, and publication on Late Bronze Age sites in Cyprus, she returned to the USA to pursue an M.A. in Historic Preservation at Cornell University, specializing in conservation of the archaeological heritage. Demas joined the Getty Conservation Institute in 1990 where she has worked on the development of training courses and undertaken research and publication in conservation and management of archaeological sites. She has principally been involved in archaeological site conservation and management projects in Central America, Africa, the Middle East, and the USA. Since 1997 Demas has

M. Demas et al., *Strategies for Sustainable Tourism at the Mogao Grottoes of Dunhuang, China*, SpringerBriefs in Archaeology,
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been actively involved in China in the development of the *Principles for the Conservation of Heritage Sites in China* and their application at the Mogao Grottoes and the Chengde Imperial Mountain Resort, as well as on research into the history of conservation in China. In 2010, she received the Friendship Award of the State Council of the PRC in recognition of her work in China.

Fan Jinshi is the Director of the Dunhuang Academy in Gansu Province. After graduating in 1963 from Peking University where she studied archaeology, she joined the Research Institute of Dunhuang (later renamed the Dunhuang Academy). She was appointed as Deputy Director of the Academy in 1984, Executive Deputy Director in 1993, and Director in April 1998. She is an adjunct professor at Lanzhou University in Gansu Province. Fan has dedicated herself to the archaeological study, conservation and management of the Dunhuang Grottoes for over five decades. She has strengthened international cooperation to ensure the preservation of Dunhuang heritage and is now working on a "Digital Dunhuang" project to expand accessibility to research materials and safeguarding them for future generations. Fan Jinshi has overseen numerous projects relating to the protection and use and documentation of the Dunhuang Grottoes, and a long-term, overall conservation plan for the Dunhuang Grottoes. She has published widely on the Dunhuang Grottoes and also compiled and edited *The Complete Collection of Dunhuang Grottoes* (26 volumes). Fan has served as a Member of the Chinese People's Political Consultative Conference since 1993. She was named as one of the "Most Outstanding Professionals of the Nation" by the Ministry of Science and Technology in 2002. In 2013 she was awarded the degree of Doctor of Social Sciences *honoris causa* by the University of Hong Kong in 2013.

Index

M. Demas et al., *Strategies for Sustainable Tourism at the Mogao Grottoes of Dunhuang, China*, SpringerBriefs in Archaeology,
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