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Questions of Risk and Relocation: Developing a Conservation Program for the Gateway of the Sun, Tiwanaku, Bolivia

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Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of Master of Science in Historic Preservation 2006.
Advisor: Frank G. Matero

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Comments
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QUESTIONS OF RISK AND RELOCATION: DEVELOPING A CONSERVATION PROGRAM FOR THE GATEWAY OF THE SUN, TIWANAKU, BOLIVIA

Leslie A. Friedman

A THESIS

In

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Chapter 1: Introduction

All that we are we owe to the past
- Yi-Fu Tuan, Space and Place

1.1 Project Justification

The archaeological site of Tiwanaku, located close to the southern shore of Lake Titicaca near the border between Bolivia and Peru, served as one of the first great capitals of the Andes from approximately A.D. 400–1000. Listed as a World Heritage site in 2000, UNESCO declares that “the buildings of Tiwanaku are exceptional examples of the ceremonial and public architecture and art of one of the most important manifestations of the civilizations of the Andean region.”¹ The site of Tiwanaku is a symbolic homeland for indigenous people, a source of national pride and identity for Bolivians, a destination point for international tourists, as well as a critical source of income for the local valley’s inhabitants. A complex site, Tiwanaku is also a current source of conflict between the local Aymara people, the national Bolivian government, local and foreign tourists, as well as competing interests from archaeologists, conservators, and UNESCO.

One of the most famous structures at the site of Tiwanaku, the monumental Gateway of the Sun has become an important cultural symbol to Bolivians, and especially to the region’s indigenous peoples. The Gateway is the most significant single feature at the pre-Columbian site. Likely created from between A.D. 200–400, the Gateway is a monolithic doorway, originally carved from a single block of andesite stone. The earliest

visual documentation from mid-19th century traveler accounts shows the Gateway broken into two pieces.

Questions have arisen concerning the Gateway of the Sun’s current location, in terms of the structure’s “original” location at the site. Additionally, concerns have been raised over the monument’s state of preservation. Archaeologists and preservationists have suggested moving the Gateway to other locations, including another outdoor location at the site; inside to the site’s museum; or retaining the structure in its current location, with the possibility of installing a shelter or implementing other protective measures. Additionally, the Gateway’s current presentation—surrounded by a barbed-wire fence and set in concrete—is detrimental; not only to the stone, but to the context and reception of the monument and the interpretation of the site as a whole. The Gateway’s material and structural stability, however, must first be ascertained before a decision can be made concerning the monument’s possible relocation and representation to the public. Specifically, an assessment of the Gateway’s past and present conditions, rates of decay, and current state of risk are imperative for determining if, or where, to move the monument, and what new conservation and preventative measures should be undertaken.

This thesis will explore the conservation options for the Gateway of the Sun. An investigation of the Gateway’s present conditions through contemporary photographs and site records will be conducted. By comparing historical and contemporary photographs, the monument’s apparent weathering will be evaluated and mechanisms of stone decay will be assessed utilizing the known history of the Gateway and environmental information about the site. The aim of this study is to determine the Gateway’s current
and future state of risk in order to aid the decision-making process regarding the conservation and presentation of the monument. Further, a conservation program for the Gateway of the Sun has the potential to serve as a model for the other monuments, sculpture, and structures at the site of Tiwanaku, as well as for the advancement of a comprehensive conservation plan for the site as a whole.

1.2 Methodology

Phase one of this project is to present the background and context for the Gateway of the Sun. Chapter 2 provides an overview of current and future trends within the discipline of archaeological site conservation and management. Chapter 3 reviews the cultural, archaeological and conservation history, and current context of the site of Tiwanaku. National and international charters, site records, published literature, personal interviews with archaeologists and conservators working on the site, environmental and geographical information, current presentation of the site, cultural heritage and management in Bolivia, and the current political climate, are utilized to provide the background history and current context. A description of the Gateway of the Sun, including its construction, conservation and excavation history, significance, and current presentation are provided in Chapter 4. The background and context of the site of Tiwanaku and the history of the Gateway are fundamental components to this conservation program.

Phase two of this thesis is the analysis of the current conditions of the Gateway of the Sun. Chapter 5 provides an overview of general mechanisms of stone deterioration and methods of measuring stone decay are reviewed in Chapter 6. Using published...
research and case studies, the material properties and deterioration mechanisms of andesite and related rock are discussed in Chapter 7. Utilizing the literature on stone decay, published and unpublished site records, and interviews with site archaeologists and researchers, an analysis of the conditions of the Gateway of the Sun is presented in Chapter 8. Integral to this investigation is a comparative study of historical photographs with present-day photographs for a qualitative evaluation of the conditions and a description of the material deterioration over time. The concluding chapter, Chapter 9, submits recommendations concerning the conservation and presentation of the Gateway of the Sun. This chapter further recommends future avenues of research for the Gateway of the Sun and the site of Tiwanaku.
A wealth of literature has been published on the subject of archaeological site conservation and management. Beginning in the 1970s, the discipline of archaeological site conservation developed more fully in the 1980s and 1990s. A journal devoted solely to the topic was started in 1995. The field of archaeological site conservation was largely divided between object conservators and architectural conservators. More recently, archaeologists have become involved with the responsibilities regarding the conservation and management of sites. Conservators have tended to research and publish on particular materials and conservation techniques and while archaeologists have begun to view site conservation as part of their professional responsibility, the emphasis remains on artifacts. In recent years, public archaeology and cultural resource management professionals have become concerned with conservation and preservation, while archaeologists are engaging in larger conversations regarding the politics of presentation and the interpretation of cultural heritage.

This chapter reviews the trends in archaeological site conservation and management over the last twenty-five years with particular emphasis on the last ten years, identifying current, and future, movements in the field. This chapter does not provide a comprehensive assessment, as a 1998 review on the current trends in the conservation of

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2 The journal Conservation and Management of Archaeological Sites, 1995–.
archaeological sites was written by Matero et al.\textsuperscript{5} and the Getty Conservation Institute produced a lengthy annotated bibliography on the topic in 2003.\textsuperscript{6} This chapter further focuses the research on the developments that are most applicable to the study of the site of Tiwanaku. Research on specific materials, such as earth or masonry, and particular deterioration mechanisms, such as moisture, salt, or biodeterioration, are eliminated from this review. Although useful for the study of specific conditions and the degradation of particular features, this literature does not shed light on the issues of site conservation. Moreover, specialized bibliographies and reviews on these topics are available and usually categorized by material. Additionally, specialized subjects with their own extensive literature, such as rock art or underwater archaeological sites are not included in this review. Although a vast collection of literature exists on the conservation of mosaics, some of this research is included here, as relevant to site conservation.

Certain key trends are identifiable in the recent research of archaeological site conservation and management. These trends can be categorized into broader movements within the field, although these developments are not isolated from one another. One broad theme is developments in archaeological site conservation as a discipline, including the roles of conservators and archaeologists, the need for an integrative approach to site conservation, and the process of decision-making regarding the conservation and management of sites. The second broad movement is the importance of conservation planning, including the preparation of pre- and post-excitation conservation and preservation, the critical role of documentation in site conservation, and the need for in-


situ preservation methods, such as shelters and reburial. Related to post-excavation concerns are the presentation and interpretation of sites. The third major movement within the field of archaeological site conservation comes from other disciplines such as archaeology, geography, and cultural heritage studies. Issues of cultural landscape studies and cultural tourism are being discussed by conservators in relation to the presentation, interpretation, and long-term preservation of sites.

2.1 Developments in the Practice of Archaeological Site Conservation

The discipline of archaeological site conservation and management has developed into a distinct discipline, a sub-specialty of architectural conservation and separate from archaeological object conservation. As the professionals in the field progressively define themselves and their profession, conversations in the literature continue to discuss the place of archaeological site conservators. These conversations include the role of conservators at archaeological sites, the need for an integrative and sustainable approach to site conservation, and the utilization of a values-based methodology.

2.1.1 Role of Conservators in Archaeological Excavations

The role of conservators at archaeological excavations is well discussed in the literature, particularly as a comparison to the role of archaeologists. A 2003 conference devoted to the contributions of conservators to archaeological investigations and the role of archaeologists in conservation is one of the most recent examples of this discussion. Within these proceedings, Buccellati argues that conservation needs to be an integral part

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7 Agnew and Bridgland, eds., Of the Past, for the Future: Integrating Archaeology and Conservation.
of archaeology conceptually, not just logistically, and that archaeologists and conservators need to inform one another. Matero points out that archaeology, as subtractive and destructive, is inherently opposite from conservation, which is protective. However, the two need to coordinate in order to effectively protect and manage exposed remains. As an offshoot of architectural conservation, archaeological site conservators are calling for a distinct role throughout all stages of excavation planning, pre-excavation, excavation, and post-excavation. Archaeological site conservators are defining a specialized place at archaeological sites and cementing their discipline as an integral part of all archaeological research.

2.1.2 Integrative and Sustainability Approach

An understanding of the agencies behind the conservation decision-making process is critical for the vitality and development of the field of conservation. Conservators need to constantly examine what is chosen for preservation as well as the conservation methods employed. Archaeological site conservators are arguing for a more holistic approach, one that stresses the importance of understanding the full-range of historical and current meanings of monuments and sites. The concept of sustainability encompasses the notion of valuing the present and the future, as well as the past. Any

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conservation intervention must take into account the site and monument history, as well as its current significance and context. Conservation must be practiced in a sustainable manner, but conservation can also be a tool for sustainability, acting as a bridge between the past and the present.  

2.1.3 Values-Based Methodology

A number of terms have been used in conservation and cultural heritage management over the last five years, signaling a shift in approach. *Values-based assessment*, *stakeholders*, and *significance*, are tied to larger currents across many disciplines that are arguing for greater inclusiveness, cultural perspective, and multiple voices. Attempting to provide a framework for the management of sites, a values-based methodology offers a common vocabulary for conservators and site managers.

Identifying the values associated with a site in order to make thoughtful conservation and management decisions is a useful tool to insure the inclusion of all interested parties. Consideration of the values and the stakeholders of a site is particularly crucial with sites of a sacred nature and those sites associated with indigenous peoples.

Management Planning for Archaeological Sites; Ladron de Guevara et al., “Cultural Heritage as a Basis for the Development of Social Capital”; Nixon ed., *Preserving Archaeological Remains in Situ?*. 13 Conservation as a means for sustainability was the subject of a conference in 2001 held at the University of Pennsylvania. Teutonico and Matero, eds., *Managing Change: Sustainable Approaches to the Conservation of the Built Environment*; The papers by Batchelor and Castellanos discuss the issue of sustainability within the context of archaeological sites and propose inclusive management approaches that take into account the site’s history and current context: Batchelor, “Toward a Sustainable Management Plan”; Castellanos, “Sustainable Management for Archaeological Sites.”
The incorporation of a values-based methodology has become well accepted within the field of cultural heritage and architectural conservation.\textsuperscript{14} The application of this approach to archaeological sites is more recent and, arguably, does not always succeed.\textsuperscript{15} Inclusiveness, the basis of a values-based approach, is aligned in ways with post-colonial, post-modern theory, or post-processualism in archaeology. These movements have been criticized within their own disciplines and this criticism may be applied to values-based assessment in conservation. One criticism that can be applied to conservation is Smith’s critique of the concept of inclusiveness in post-processualism.\textsuperscript{16} Inclusiveness in the study of archaeological sites and the conservation decision-making process is fine as long as the conservator or archaeologist is deciding who is included. The identification of the values associated with a site is a useful tool; however, the conservator in charge decides whose values are ultimately given priority.

Additionally, any methodology which is formulaic in its approach does not work equally well for every case. A values-based approach is a useful framework; however, a systematic application of this approach will not be successful in every situation. Further, one could argue that employing a corporate-client model for the conservation and management of cultural heritage is, simply, a bad idea. Applying a corporate model to the conservation and management of places filled with history, symbolism, and cultural meaning may leave little room for nuance or creative approaches. By focusing on the

\textsuperscript{14} Avrami et al., \textit{Values and Heritage Conservation}; de la Torre ed., \textit{Assessing the Values of Cultural Heritage}; Teutonico and Matero, eds., \textit{Managing Change: Sustainable Approaches to the Conservation of the Built Environment}.
\textsuperscript{16} Smith, \textit{Archaeological Theory and the Politics of Cultural Heritage} offers a critique of post-processualism in archaeology.
needs and desires of the stakeholders, a values-based model can overemphasize the “client” rather than on the needs of the site. The needs of different stakeholders are often in conflict, not only with each other, but sometimes with the requirements of a long-term preservation of the site.

Moreover, archaeological sites present a unique set of dilemmas that differentiate them from buildings, singular monuments, or historic districts. Archaeological sites, in addition to being locations of current research, possess long histories and have often been utilized by different groups through time. Any methodological approach to archaeological sites needs to take into account complex temporal and spatial changes that occur on a site. A values-based approach, therefore, may or may not be successful for archaeological sites, particularly those in developing countries or in places with different types of economic and social concerns. The critique of values-based assessment, however, is yet to be forthcoming in the conservation literature.

The term stakeholders, associated with values-based assessment and planning, is frequently used in the conservation literature. A 2003 conference discussed the need for inclusiveness in conservation planning and the value of incorporating all of the stakeholders in the process, especially local communities. Nordby points to this critical issue, particularly when working on sites that are associated with living or ancestral communities. Miura takes the topic of inclusiveness a step further and addresses the notion of a ‘living heritage’ site and the importance of incorporating local stakeholders.

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18 Nordby, “Mesa Verde”. 
that are direct descendents of the previous inhabitants. Joyce also argues for inclusiveness of all who claim a place, even commonly dismissed groups such as New Age believers and tourists.

A critique of the use of significance in assessing the value of sites has been better approached by archaeologists. Although beyond this literature review, a few recent works are worth noting. The issue of significance is tied intrinsically to the concept and identification of ‘site.’ To label a place as an archaeological site immediately imbues the location with a certain set of values and level of significance. Tainter, Dunnell, and Fotiadis are three archaeologists who have debated the meaning and definition of site in recent years. Although coming from different approaches, each critiques the use of site to denote archaeological significance.

2.2 Importance of Conservation Planning

Increasingly, conservators are focusing their attentions on preventive conservation and risk-management. Although still a major component of conservation, emergency conservation measures are becoming viewed less favorably than preventative actions. Archaeological site conservators are increasingly calling for conservation planning and implementation throughout the excavation process, from beginning to end. Conservation should be incorporated in every excavation plan and budget. The critical role of documentation has been recognized, but increasingly, documentation is serving a more

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19 Miura, “Conservation of a ‘Living Heritage Site: A Contradiction in Terms?’”
important function in conservation. More advanced and computer-aided documentation methods are being developed and utilized for analysis in addition to recording purposes. In-situ stabilization and preservation methods are another aspect of the conservation planning. Reburial and the installation of shelters are vital for the protection of some archaeological remains and should be planned in advance where needed. As the final step in the conservation planning process, the presentation and interpretation of the site needs to be fully considered, as these requirements directly affect the conservation approach. Additionally, an exit strategy for the site needs to be planned in advance.

2.2.1 Pre- and Post-Excavation Conservation

Preventive conservation measures and long-term conservation planning are increasingly discussed in the literature on archaeological site conservation. Conservation professionals are calling attention to the need to plan for future risks, such as natural disasters, as well as climatic concerns like global warming. Embedded within these discussions is the argument for thoughtful, long-term conservation planning and management. Some authors acknowledge that short-term emergency stabilization is unavoidable; however, setting a conservation plan in place even before excavation will greatly reduce that need. Palumbo discusses the main threats to archaeological sites today and cites archaeological activity itself as one of the most common causes of damage.

A lack of planning, poor or non-existent coordination with local agencies, and lack of

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interest on the part of archaeologists, results in sites and structures that are abandoned and deteriorating.
2.2.2 Critical Role of Documentation

The role of documentation and recording is considered increasingly important in archaeological site conservation and management. Due to the inherent destructive nature of archeological investigation, and a growing trend in the general conservation literature that emphasizes the importance of documentation before any conservation decision or intervention, a proliferation of literature about documentation exists. With the continual development of computer-aided means, faster, more precise documentation is possible. ArcGIS, CAD, 3D laser scanning, photogrammetry, GPS and GPR are methods being used in archaeology and conservation. These computer applications are being utilized in the development of conservation plans and the presentation of archaeological heritage. Documentation techniques, used for more than recording, are being employed in condition analysis, predictive modeling, and condition assessments.

2.2.3 In-Situ Preservation Methods

In-situ preservation measures such as reburial, shelters, structural reinforcement, and relocation (with perhaps subsequent replacement) are topics in the archaeological site conservation literature. The subject of shelters is discussed since the early 1980s. A
1996 conference presented a number of papers that brought attention to the use, and sometimes misuse, of shelters. A number of papers presented at the conference argue for a more thorough research and design process before installing shelters at archaeological sites. Shelters may interfere visually with the presentation of the site and detract from the experience of visitors. Additionally, a poorly designed structure may cause damage to the material the shelter is intended to protect.

Reburial has, in recent years, become a topic for debate. Reburial may be used positively to protect previously exposed structures and architectural remains at archaeological sites. However, often the soil used for refill is not carefully analyzed, or studied at all, and the detrimental affects of placing fragile materials in an untested environment has led to more damage. Once considered a panacea, the method of reburial is now controversial and has been shown to cause problems with the long-term stability of objects.

29 Mosaics make a site: the conservation in situ of mosaics on archaeological sites 1996.
31 Volume 6 (3-4) 2004 of Conservation and Management of Archaeological Sites was devoted to the topic of reburial. In particular, see Demas, “Site Unseen”: The Case for Reburial of Archaeological Sites”; Rivera, “Partial reburial of West Ruin at Aztec Ruins National Monument.”; English Heritage Conservation Bulletin also devoted an entire issue to reburial in 2004. In particular, see Stewart, “Reburial of Excavated Sites.”
2.2.4 Presentation, Interpretation and Display

Issues of presentation, interpretation and display have received increased attention in the literature on the conservation of archaeological sites in the last ten years.\(^32\) Related to values-based assessment and the call for integrated conservation, debates over presentation result from the differing needs of multiple stakeholders. According to Matero, conservation of archaeological sites begins and ends with interpretation as each conservation solution (stabilization, reconstruction, anastylosis, reburial, protective shelters, and material conservation) directly and immediately affects the visual legibility, authenticity, and perception of the site.\(^33\) Although the primary objective of conservation is to protect cultural heritage from deterioration, these conservation choices are made based on the values of the site and the needs of the associated stakeholders.

How to preserve, present, and interpret archaeological heritage remains a well-debated topic; no consensus exists within the discipline, and even larger variation exists cross culturally. According to Emory, a more creative approach to the presentation of archaeological sites should be taken, which involves partial reconstructions to increase the legibility of the site to visitors.\(^34\) This attitude was in direct opposition to the long-held standards of English Heritage that ruins be left as found.\(^35\) Since Emory’s publication in 1987, many authors have discussed the issue of presentation and debated whether archaeological heritage should be left in situ for the sake of context and legibility or be moved inside museums for the purpose of preservation. Additionally,

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\(^32\) Thompson, *Ruins: Their Preservation and Display*, 1981 is one of the earliest works concerned with the display of archaeological heritage. Thompson reviews the history of monument preservation philosophy in Britain and provides a description of the theory and practice of monument restoration from the late 1970s.

\(^33\) Matero, “Making Archaeological Sites: Conservation as Interpretation of an Excavated Past”, 55-63.

\(^34\) Emery, “The Presentation of Monuments to the Public.”

\(^35\) Thompson, *Ruins: Their Preservation and Display*.
archaeological site conservators and architects have discussed the extent of reconstruction and anastylosis that should, or should not, occur at archaeological sites. The cultural variations in the approach to presentation becomes quite apparent in the literature, as conservators and architects from different regions often present varying views on the topic.36 Additionally, many archaeological sites have been so heavily manipulated for the purpose of visual display and increased legibility that the preservation of the site has been compromised. A loss of place and damage to the architectural remains has often been the result of an overly interpreted site.37

2.3 Broader Trends: Cultural Landscape Studies and Cultural Tourism

Broader trends regarding the concepts of site, place, and space, come from other fields such as archaeology, geography, landscape architecture, and cultural heritage studies. These trends are beginning to be discussed by conservators, who work intimately with issues of place and identity. The concept of viewing archaeological sites as cultural landscapes, and preserving them as such, rather than as traditional sites, is an outgrowth of cultural landscape studies in geography and the archaeology of landscapes. Additionally, the preservation of landscape has become another sub-specialty of architectural conservation. The study of cultural tourism and cultural heritage are recently developed disciplines, the focus of which greatly impact the preservation of

36 Sivan, “Presenting Mosaics to the Public” compares the pros and cons of displaying archaeological heritage in situ versus presentation in museums; Ranelluci, “Strutture Protettive e Conservazione dei Siti Archeologici” discusses some of the theoretical issues surrounding presentation of archaeological remains to the public; De la Torre, ed., The Conservation of Archaeological Sites in the Mediterranean Region presents a number of papers that address issues of presentation, reconstruction, and interpretation; Inoue et al., “Conservation and Utilization of Archaeological Heritage in Germany” compares Japanese and German concepts of preservation, authenticity, and presentation.
archaeological sites. Global tourism and the growth of world heritage are directly affecting the conditions of archaeological heritage.

2.3.1 Cultural Landscapes

The concept of cultural landscape has been in the literature since the 1920s and has been embraced recently as a potential framework for conservation efforts. The application of the notion of cultural landscape to archaeological sites is a significant development for conservation. Viewing an archaeological site as a cultural landscape aids in the understanding of a site’s larger context and places the site in time and space. The conservation of archaeological sites, as opposed to single monuments or buildings, must embrace the larger whole. Related to the notion of archaeological sites as cultural landscape is the movement towards conserving the larger site context, rather than simply the objects found within the boundaries of the site. Matero further argues that approaching archaeological sites as cultural landscapes could be helpful in mediating the palimpsest of histories, including “destruction, reuse, abandonment, rediscovery, and even past interpretations.” According to Bender, in her discussion regarding the archaeological site of Stonehenge, the landscape is not merely a backdrop for the stones; rather the stones need to be part of the landscape to facilitate understanding of the monument through time.

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38 The pioneer cultural geographer, Carl Sauer, began writing about cultural landscapes in the 1920s.
40 Hadjisavvas, “Developing a World Heritage Site.”
41 Matero, “Conservation as Interpretation of an Excavated Past”, 62.
42 Bender, Stonehenge, 7.
Unfortunately, the archaeological site conservation literature is lacking a real discussion of cultural landscape. Perhaps it is an accepted notion that archaeological sites are easily defined as, and accepted as, cultural landscapes. According to landscape archaeologists, cultural landscape is an important class of cultural heritage. Arguing that the commitment to the concept of ‘site’ in archaeology ignores the significance of landscapes, Erickson maintains cultural landscapes should be recognized and managed (if not ‘preserved’) as any traditional archaeological site or monument. UNESCO added cultural landscapes to its *Operational Guidelines for the Implementation of the World Heritage Convention* in 1992. The properties inscribed as World Heritage Sites cultural landscapes, however, are usually nominated “because of their association with important buildings, monuments, or natural features rather than their intrinsic value.”

2.3.2 Cultural Tourism and World Heritage

Due to an increase in the number of visitors, tourism is a major source of damage to archaeological sites. In addition to the number of visitors, damage to sites results from inappropriate behavior, such as harming monuments through touching and contributing to erosion problems. Visitors, unless otherwise instructed, pay little attention to the conditions of the monuments. Looting and social unrest are additional causes of damage to archaeological sites. Widespread looting is supported by the international demand for antiquities, mistrust of foreigners and archaeologists, and local poverty.

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43 Erickson, “Agricultural Landscapes as World Heritage: Raised Field Agriculture in Bolivia and Peru”, 181-182.
44 UNESCO World Heritage Centre http:\\whc.unesco.org.
45 Erickson, “Agricultural Landscapes as World Heritage: Raised Field Agriculture in Bolivia and Peru”, 183
Increased global travel and public access have raised interesting debates about the advantages (usually economic) and disadvantages (damage to the sites and integrity of the experience) of increasing tourism to archaeological sites. This increase of tourism to archaeological heritage areas has been greatly accelerated by the phenomenon of heritage listing. Recent articles have addressed the flip sides of cultural tourism and the delicate balance required between the preservation of historic sites and cities, the economic and social development of the associated towns, and access to foreign visitors.\textsuperscript{46} The proliferation of World Heritage sites has added another layer to this conflict. From UNESCO’s World Heritage and World Monuments Fund to national, local, state and city levels, listing sites has become commonplace.\textsuperscript{47} So commonplace, that perhaps the benefits are being lost. We can not inscribe everything nor can everything be saved. A critical evaluation of these lists needs to occur. The affect and impact of the list-making needs to be addressed and the afterlife of these inscribed sites needs to be assessed.

2.4 Conclusion

Much of the research on the conservation and management of archaeological sites has been sponsored or conducted by the Getty Conservation Institute and English Heritage. English Heritage has recently been concerned with underwater or waterlogged site preservation. Most of the publications are from the United States and England, with some from Italy and Australia. Significant articles are often published by the \textit{Journal of} 

Cultural Heritage, the English Heritage Bulletin, World Heritage Review, and Conservation and Management of Archaeological Sites. Recent key conferences and proceedings are Managing Change: Sustainable Approaches to the Conservation of the Built Environment, Management Planning for Archaeological Sites, Mosaics Make a Site, and The Conservation of Archeological Sites in the Mediterranean Region. The World Archaeological Congress’s latest symposium proceedings, Of the Past, for the Future: Integrating Archaeology and Conservation, is one of the most recent publications to address the conservation of archaeological sites. 48

A number of key trends have been identified from the literature on archaeological site conservation and management. The discussion about the field of archaeological site conservation and management continues as the discipline itself develops. Conversations about the role of conservators and the relationship between conservators and archaeologists, the need for an integrative and holistic approach to conservation, and the incorporation of a values-based assessment model can be viewed as one movement within the field. A second broad movement constitutes the call for increased conservation planning through all stages of the excavation process, including the afterlife of the site. A third movement can be seen in the appropriation of concepts and terminology from the study of cultural landscapes applied to archaeological sites and the debates surrounding cultural tourism and world heritage.

The discipline of archaeological site conservation continues to develop and to take inspiration from other related fields such as object conservation, architecture, and archaeology. Conservators of archaeological sites are establishing their place within the

field of conservation and as critical contributors to archaeological excavations. Only an interdisciplinary approach among conservators, archaeologists, anthropologists, and other scientists, however, will result in successful archaeological site conservation and management. Additionally, self-critique is necessary in order to insure the vitality and viability of this field.
Chapter 3: History, Significance, and Current Context

In order to assess the condition of any one monument at an archaeological site, and to make recommendations concerning its conservation and presentation, the site must be viewed as a whole. Taken out of context, or viewed singularly, the Gateway of the Sun is not much more than an impressive piece of cut stone. The Gateway’s meaning and symbolism comes from its context within the site and the interplay between it and the rest of the architecture, as well as the landscape. An archaeological site is not a moment frozen in time; rather it is a place constantly made and re-made. The site of Tiwanaku is still in the process of being created. Indigenous cultural claims, ongoing excavations and, hopefully, the beginnings of conservation work and a long-term management plan, continue to transform the site. Therefore, although this thesis is concerned mainly with the Gateway of the Sun, any conservation analysis or program for this monument must be grounded in an understanding of the history of the site, as well as the current political environment in which the site of Tiwanaku is surrounded.49

3.1 Cultural History

Intended and designed to impress its visitors, the sacred site of Tiwanaku was the location of state-sponsored religious ritual and public ceremony. As a major urban center,

49 The historical review is taken from a number of sources in which the same information or dates are often repeated. Key sources have been: The University of Pennsylvania Museum. http://tiwanaku.museum.upenn.edu/Tiwanaku.htm; Isbell and Vranich, “Experiencing the Cities of Wari and Tiwanaku”, 167-182; Young-Sanchez, Tiwanaku Ancestors of the Inca.
the site of Tiwanaku dominated the Central Andes between A.D. 500 and 1000. The site of Tiwanaku developed into the first true city-state of the south-central Andes; its cultural and artistic influence spreading far into what is present day Peru, Chile and Argentina. The architectural and technological developments at the site of Tiwanaku were later utilized by the Inca Empire, and indeed Tiwanaku’s architectural remains were appropriated to support the Inca’s own creation myth. The stonework and monuments amazed both the Spanish, who used the stone to build their own monuments, and later European visitors who documented and wrote about the mysterious abandoned site. Tiwanaku continues today to be a site of contention and multiple visions—claimed by the Aymara people who consider it their ancestral home; considered a place of national pride and importance to the state of Bolivia; visited by thousands of foreign tourists a year, many of whom come to experience a newly created version of a traditional solstice festival; and highly valued by archaeologists hoping to understand the true nature of this civilization.

By approximately 2000 B.C. farmers began to settle the area around the shores of Lake Titicaca. Raised-field agriculture, which began in the region about 1300-500 B.C., supported increased food production, encouraged population growth and the

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50 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 168, 173-174.
51 Janusek, Collapse as Cultural Revolution: Power and Identity in the Tiwanaku to Pacajes Transition, 176.
54 By some estimations, the number of annual visitors is 50,000. See Vranich, Coping with Chaos, 62-66.
development of organized labor, leading to the development of large settlements, social
stratification, and craft specialization.  

Beginning as a small settlement around 1200 B.C. and located on a flat Altiplano
about 20 km from the south shore of Lake Titicaca,\(^57\) (Fig. 3.1) the site of Tiwanaku
rapidly expanded into a small town. Progressively increasing in size and power, the city
of Tiwanaku dominated the Tiwanaku Empire and the Andean region by A.D. 500.\(^58\)
During the Formative Period, the Tiwanaku culture coexisted with the Pukara, the
Sillumoco, and the Chiripa polities, but by A.D. 400, the Tiwanaku culture dominated the
region. As early as 500 B.C., the population of Tiwanaku began to overtake that of their
neighbors and the town began to increase in complexity. From 200 B.C. to A.D. 200,
Tiwanaku and Pukara were the largest polities in the area. Pukara, however, collapsed as
a political center about A.D. 200 and, as a result, Tiwanaku became the strongest empire
in the Titicaca Basin.\(^59\)

State-sponsored religious ceremonies and practices transformed the site of
Tiwanaku into a vast ceremonial center that materialized into a distinct artistic style,
expressed in architecture, sculpture, textiles, metalwork, and ceramics.\(^60\) Recent
investigations support the interpretation of the site of Tiwanaku as a major planned city
with a large urban and regional population.\(^61\) Tiwanaku’s cultural influence, however,
extended even farther than the boundaries of the site. Ceramic and other evidence of its

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\(^56\) Binford et al., Climate Variation and the Rise and Fall of an Andean Civilization, 235.
\(^57\) Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 168.
\(^58\) Janusek, Collapse as Cultural Revolution: Power and Identity in the Tiwanaku to Pacajes Transition, 181.
\(^59\) Stanish, Ancient Titicaca: The Evolution of Complex Society in Southern Peru and Northern Bolivia, 137.
\(^60\) Young-Sanchez, Tiwanaku Ancestors of the Inca, 19, 28-29.
\(^61\) Stanish, Tiwanaku Political Economy, 185, 188.
role as a major civic and religious center can be found throughout the Titicaca Basin.\textsuperscript{62}

For reasons still not understood, and debated, the site of Tiwanaku began to decline by A.D. 1000. A century-long drought is often suggested as the cause of the decline,\textsuperscript{63} but scholars have put forth competing explanations.\textsuperscript{64} Regardless, the inhabitants of the city dispersed, although the regions around the city did not depopulate.

By the fifteenth century, the most important political powers in the region were the Aymara-speaking Colla and the Lupaka groups. Not until the Inca and Spanish conquests did the region have a major political power on the scale of Tiwanaku. In addition to the Aymara, the region was also home to Quechua, Pukina, and Uruquilla speakers.\textsuperscript{65} Today Aymara and Quechua are still widely spoken.\textsuperscript{66}

Abandoned for hundreds of years by the time the Inca came to Tiwanaku in the middle of the 15\textsuperscript{th} century, the architectural remains of Tiwanaku were used by the Inca to justify their claims for divinity and initial creation, relegating the site of Tiwanaku, in essence, the place of their birth.\textsuperscript{67} Creating a mythic story, the Inca believed the sculptures of human forms were the first Andes people created by their deity Viracocha, who made the first Incans of clay.\textsuperscript{68} Appropriated by the Inca people, the region around Lake Titicaca became an important center for Incan power. In fact, the Inca built a palace

\textsuperscript{62} Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 167-182.
\textsuperscript{63} Binford et al., \textit{Paleoecology} and Tiwanaku Agroecosystems.
\textsuperscript{64} Erickson, Neo-environmental determinism and agrarian “collapse” in Andean prehistory; Janusek, Collapse as Cultural Revolution: Power and Identity in the Tiwanaku to Pacajes Transition.
\textsuperscript{65} Janusek, Collapse as Cultural Revolution: Power and Identity in the Tiwanaku to Pacajes Transition, 177.
\textsuperscript{66} Arnold and Yapita, Strands of Indigenism in the Bolivian Andes: Competing Juridical Claims for the Ownership and Management of Indigenous Heritage Sites in an Emerging Context of Legal Pluralism, 141.
\textsuperscript{67} Kolata, \textit{The Tiwanaku: Portraits of an Andean Civilization}, 4.
\textsuperscript{68} University of Pennsylvania Museum of Anthropology and Archaeology. http://tiwanaku.museum.upenn.edu/Tiwanaku.htm
among the ruins of Tiwanaku in order to associate themselves with the status of the
Tiwanaku Empire.69

When the Spanish arrived in 1525, they were amazed at the scale and age of the
monumental architecture at the site of Tiwanaku. By the 1570s, the Spanish mined the
site for precut stone to build the church (Fig. 3.2), among other structures, in the modern-
day town of Tiahuanaco.70 Over the next few centuries, numerous European visitors
came to visit the site and scientific investigation, including the first archaeological
research, began in the mid-to-late 19th century, fueled by growing European interest in
natural history and ancient cultures.71 Some early examples are Ephraim George Squier’s
field report of Tiwanaku, published in 1877 and the 1892 publication by Max Uhle and
Alfons Stübel, The Ruins of Tiahunaco in the Highlands of Ancient Peru.72 In later
years, Tiwanaku’s origins became fodder for the strange. The creation of the site was
attributed to aliens and a moon crashing, among other theories.73

The site of Tiwanaku was inscribed on UNESCO’s World Heritage List in
2000.74 The site is a symbol of Bolivian national pride and identity, particularly the
monument of the Gateway of the Sun, and is visited by schoolchildren, Bolivian political
figures, foreign researchers, and thousands of tourists every year, including New-Agers,
who come every summer solstice to watch the sun rise over the monuments.75 (Fig. 3.3)
Different cultural, political and research groups are invested in the site. The most vocal

70 Janusek, Collapse as Cultural Revolution: Power and Identity in the Tiwanaku to Pacajes Transition, 192.
71 Young-Sanchez, Tiwanaku Ancestors of the Inca, 16-17.
72 Young-Sanchez, Tiwanaku Ancestors of the Inca, 17.
75 Vranich, Coping With Chaos, 65.
has been Bolivia’s Aymara-speakers, who lay claim to Tiwanaku as their ancestral home and perform sacrifices and religious rituals at the site. But despite violent confrontations between local populations with national authorities and the strong presence of outsider researchers, the site of Tiwanaku remains emblematic to the identity of all Bolivians. On January 21, 2006, the new Aymara Bolivian president, Evo Morales, dressed in traditional robes, held his ceremonial swearing-in at the site of Tiwanaku.76 (Fig. 3.4)

3.2 Architectural History

Tiwanaku was nominated for World Heritage status by meeting two of six categories:

*Criterion (iii):* The ruins of Tiwanaku bear striking witness to the power of the empire that played a leading role in the development of the Andean prehispanic civilization.

*Criterion (iv):* The buildings of Tiwanaku are exceptional examples of the ceremonial and public architecture and art of one of the most important manifestations of the civilizations of the Andean region.77

78Visitors at Tiwanaku, from the Inca to modern travelers, have reacted to the monumentality of the architecture. The prehistoric Tiwanaku constructed their ceremonial and monumental structures, remnants of which survive today, of andesite and sandstone, while they used more ephemeral material of adobe brick for their other buildings and domestic structures. The masonry construction and carved details of the architecture, such as the Putuni Platform and Semi-subterranean Temple, display the skill and technology of the Tiwanaku people which the ancient Inca observed and arguably

76 Forero and Rohter, Bolivia’s Leader Solidifies Region’s Leftward Tilt.
78 The architectural history section was written with Emily Lanza.
attempted to copy with their own monuments. The stonemasonry, “technically accomplished and aesthetically sophisticated”, includes symmetric and geometric arrangements of various sizes of dressed stone as seen in the walls of the Semi-subterranean Temple. The Spanish later used these perfectly cut-stones to construct their own monuments and buildings, including the church in the town of Tiahuanaco.

Knowledge of the site’s early construction history is limited. During the earliest construction period, ca. 800 B.C. – A.D. 200, during the Yaya-Mama religious tradition of the southern Titicaca Basin region, stone sculpture and Tiwanaku’s first sunken temple were probably created. This earliest temple was likely successively reconstructed, resulting in the Semi-subterranean Temple at the site today. Small mound structures were possibly created in the locations now occupied by the Akapana Pyramid and the Kalasasaya Platform.

Around A.D. 200–400, about the time that Tiwanaku became the most important polity in the region, larger, more elaborate, architecture began to be constructed, continuing previous architectural traditions of temples with sunken courts. Tiwanaku, unlike earlier settlements in the area, was centrally planned; the structures oriented to cardinal directions. The core of the city, containing both public buildings and elite residences, was surrounded by a constructed moat of subterranean canals and drains that supplied fresh water and carried away waste. Beginning about A.D. 700, a major new

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79 Protzen and Nair, Who Taught the Inca Stonemasons Their Skills? A Comparison of Tiahuanaco and Inca Cut-Stone Masonry, 146.
81 Protzen and Nair, Who Taught the Inca Stonemasons Their Skills? A Comparison of Tiahuanaco and Inca Cut-Stone Masonry, 150.
construction campaign started. Many existing structures were demolished and new buildings constructed, developing Tiwanaku into even more of a monumental city. This building campaign corresponded with the expansion of the Tiwanaku Empire which included the establishment of colonies and growth of its urban population.

Some scholars believe that the buildings at the site of Tiwanaku were constructed on an east-west axis to correspond with the path of the Sun across the sky. The eastern staircases of Akapana Pyramid and Pumapunku Complex are more elaborate and monumental than the western staircases, implying the religious significance attributed to the sunrise. Eastern and western entryways also are found on the Kalasasaya Platform.

The site of Tiwanaku also represents superb examples of ceremonial and public architecture of the Andean region and prehispanic period. Monuments such as the Akapana Pyramid and Putuni Platform were the locations of ceremonial and ritual activity as well as residences of the elite. The Akapana Pyramid appeared as a significant architectural feature in the site throughout the history of Tiwanaku. With a base measuring 194 meters by 194.4 meters, the Tiwanaku people constructed the Akapana as seven superimposed platforms. Archaeologists have interpreted the Akapana Pyramid as a temple and a sacred mountain resembling the surrounding mountain peaks. Current excavations have revealed complex drainage systems around the Akapana Pyramid.

Located near the Akapana Pyramid, the Templete or Semi-subterranean Temple developed as another ceremonial and architectural feature of the site of Tiwanaku. A

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83 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 172.
84 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 172.
85 Benitez, A Unique Lunisolar Observatory and Calendar in Precolombian Bolivia; Kolata, Tiwanaku Ceremonial Architecture and Urban Organization, 179.
87 Kolata, The Tiwanaku: Portraits of an Andean Civilization, 10.
sunken court excavated into the ground, the Semi-subterranean Temple is constructed of sandstone and contains an assemblage of various stone steles and sculptures of carved stone heads set into the wall.

As another major temple on the site, the Kalasasaya Platform was constructed according to a cosmological orientation. The standing pillars of the Kalasasaya Platform walls were aligned to make astronomical observations. The Pumapunku Complex is connected with the Kalasasaya Platform with a series of canals. Probably intended as a duplicate structure of the Akapana Pyramid during initial construction, the Pumapunku Complex provides views of the sacred mountain of Quimsichata to the south. A residential and ceremonial structure of the elite, the Putuni Complex contains a raised platform and a sunken central courtyard.

The builders of Tiwanaku were masters in the use of stone as a building material and the precision with which the stones were cut and assembled was unsurpassed. The regularity of dimensions and proportions indicate that a system of measurements and proportions was used by the stone-cutters, suggesting that they were mass produced. Some stones exhibit holes cut into them that are connected within the stone. Some archaeologists hypothesize that these holes were an ingenious way to thread the rope that was used to lift the stones into place without disrupting the overall external shape of the

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89 Benitez, A Unique Lunisolar Observatory and Calendar in Pre Columbian Bolivia; Kolata 1993, 143
93 Protzen and Nair, Who Taught the Inca Stonemasons Their Skills? A Comparison of Tiahuanaco and Inca Cut-Stone Masonry, 156.
94 Protzen and Nair, Who Taught the Inca Stonemasons Their Skills? A Comparison of Tiahuanaco and Inca Cut-Stone Masonry, 159.
stone. The tools used by the people of Tiwanaku to cut, shape, and decorate their stonework have yet to be found in the archaeological record.\(^{95}\)

While past excavations have yielded significant information concerning the culture, recent studies of Tiwanaku’s architecture are directed towards the interpretation that the buildings were not themselves the focus of attention; rather, they were vantage points from which to interpret the surrounding landscape and celestial sphere.\(^{96}\)

A valuable example of pan-Andean history, the site of Tiwanaku was a spiritual and political center for hundreds of years, the capital of an empire that dominated a large area of the southern Andes and beyond. The distinctive ceremonial and monumental architecture testify to the significance of this civilization. The historical significance of Tiwanaku, does not, however end with the abandonment of the city and decline of this culture in A.D. 1000. Utilized by the Inca in the 15\(^{th}\) century and appropriated to justify their own powerful empire; a source of awe and material to the conquering Spanish in the 16\(^{th}\) century; the subject of inspired travelers’ accounts for hundreds of years; the focus of Bolivian pride since the 20\(^{th}\) century; and more recently, the symbolic location of Aymara identity, the site of Tiwanaku is a place that has continually been created and re-created. Its historical significance began almost 3,000 years ago but persists through the present day.

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\(^{95}\) Protzen and Nair, Who Taught the Inca Stonemasons Their Skills? A Comparison of Tiahuanaco and Inca Cut-Stone Masonry, 153-165.

\(^{96}\) Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 171-172.
3.3 Archaeological and Conservation History

The appearance of the site of Tiwanaku today is the result of a millennium of growth and construction, including several building campaigns, centuries of abandonment, extensive looting of stone for building materials, and reconstructions. During the early 20th century, a railroad was built through the site of Tiwanaku, further denigrating the site and increasing the rate of pillage. (Fig. 3.5) A combination of severe destruction through looting, uncontrolled and unmanaged development surrounding the site, lack of management of the site itself, and irresponsible excavations and reconstructions have resulted in a site with serious problems of erosion, illegibility, and poor management.

When the site of Tiwanaku declined around A.D. 1000, many of the site’s monuments and ritual complexes were intentionally dismantled and destroyed, including important religious symbols, gateways, and sculpture. When the Spanish arrived in the 1500s, the sculptures, considered expressions of paganism, were systematically dismantled or removed. Janusek, however, argues that the amount of ritualized destruction undertaken by the Spanish is unclear and suggests that much of the systematic defacement and destruction occurred long before the Spanish arrived. The precisely-cut stonework, however, was highly desirable, and stones were taken to construct the Spaniards’ own monuments, such as the church that still exists today in the modern-day

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97 The archaeological and conservation history were written with Emily Lanza.
98 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 169.
99 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 169.
100 Janusek, Collapse as Cultural Revolution: Power and Identity in the Tiwanaku to Pacajes Transition, 191-192.
101 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 169.
town of Tiahuanaco. Two sculptures taken from the site still flank the entrance to the church (Fig. 3.6). The looting of the stones and monumental works continued for centuries, and were used by both the Spanish and Bolivians to construct buildings, private houses, and bridges.\textsuperscript{103}

The archaeological studies of Tiwanaku began with Ephraim George Squier’s visit and survey of the site in the 1860’s. Squier, an American journalist and archaeologist, represented the United States in Latin America as a diplomat. In 1877, Squier published a monograph entitled *Peru: Incidents of Travel and Explorations in the Land of the Incas*. The monograph contains a map and a few drawings of the archaeological remains of the site of Tiwanaku. Focusing on the monuments, Squier interpreted the site as a “sparsely populated ceremonial center,” a theme that dominated Tiwanaku studies until the middle of the twentieth-century.\textsuperscript{104}

Max Uhle and Alphonse Stübel, with the aid of B. von Grumbkow, an engineer who photographed the site in 1876, published *The Ruins of Tiahuanaco in the Highlands of Ancient Peru* in 1892. Compared to Squier’s monograph, Uhle’s study presented a more scientific and detailed account of the site of Tiwanaku. Today, Uhle’s 1894 photographs and documentation of the site, the town, and the sculpture and architecture provide important information to study the state of preservation and decay of certain monuments.\textsuperscript{105} In 1894, Uhle, distressed at the looting and state of conservation of the

\textsuperscript{103} Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 169; Janusek, Collapse as Cultural Revolution: Power and Identity in the Tiwanaku to Pacajes Transition, 192.
\textsuperscript{105} Young-Sanchez, *Tiwanaku Ancestors of the Inca*, 17.
site, in addition to perhaps other motives\textsuperscript{106}, wrote a letter to the Bolivian government in which he discussed seeing stonework from Tiwanaku used for the church, private houses, and other buildings in town, and requested permission to bring stonework back to Berlin for safekeeping. Even more shocking to Uhle, however, was witnessing the Bolivian army using the “best figure” at the site of Tiwanaku as a mark for target practice.\textsuperscript{107}

By the beginning of the 20\textsuperscript{th} century, a railroad was constructed through the site of Tiwanaku, essentially turning the architectural remains into a quarry for its construction.\textsuperscript{108} In 1910, the Bolivian government invited the participants of the Seventh International Congress of Americanists to visit the site of Tiwanaku. Max Uhle was among the delegates. Uhle was shocked at the amount of devastation that had occurred at the site in the few years since his earlier visit in 1894. Whole areas of stonework, both cut and carved, had disappeared from the site.\textsuperscript{109}

In 1903, Arthur Posnansky, a German born Bolivian citizen, began studying the site extensively by mapping, photographing and studying the artifacts, architecture, sculpture, and the monuments of Tiwanaku. His 1945 publication, \textit{Tiahuanacu: The Cradle of American Man}, introduced the theory that American civilization originated from Tiwanaku and disseminated throughout South, Central and Northern America. This theory greatly differed from previous interpretations of the site of Tiwanaku as solely a

\textsuperscript{106} Museums in both European and the United States wanted to acquire sculpture and monuments from the site of Tiwanaku and Uhle wanted to bring some of the monoliths back to Berlin. Loza, \textit{Max Uhle in the Bolivian Highlands}.

\textsuperscript{107} Loza, \textit{Max Uhle in the Bolivian Highlands}.

\textsuperscript{108} Loza, \textit{Max Uhle in the Bolivian Highlands}.

\textsuperscript{109} Loza, \textit{Max Uhle in the Bolivian Highlands}.

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religious center. Posnansky also expressed his distress at the vandalism of Tiwanaku.

During the 1930s, Wendell Bennett, who studied the Wari Empire of Peru, began excavations within the monumental precincts of the site. His excavations severely limited by the Bolivian government, Bennett focused on the monuments. His finding of a massive stele in the center of the Semi-subterranean Temple became the subject of a political struggle. This stele, referred to as the Bennett Stele or Monolith, was moved into downtown La Paz on July 3, 1932, despite outrage by the local Aymara. After years of conflict and protests by the Aymara, the Bennett Stele was finally returned to the site of Tiwanaku on March 16, 2002 in an elaborate processional, culminating in a traditional ceremony at Tiwanaku. While the stele was in La Paz, however, the monument was severely damaged by heavy air pollution and traffic, pigeon guano, as well as deliberate abuses. Bullet marks from Bolivia’s revolutions and uprisings during the more than 60 year period also scarred the monolith, which has, since its return to Tiwanaku, been located inside the museum on site. (Fig. 3.7)

Native Bolivian supervision and involvement in archaeological research at the site of Tiwanaku did not occur until the 1950s with excavations directed by the Instituto Nacional de Arqueologia de Bolivia (INAR). As a direct response to the National

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110 Young-Sanchez, Tiwanaku Ancestors of the Inca.
111 Loza, Max Uhle in the Bolivian Highlands.
113 Enever, Spiritual Return for Bolivian Monolith.
114 Arnold and Yapita, Strands of Indigenism in the Bolivian Andes: Competing Juridical Claims for the Ownership and Management of Indigenous Heritage Sites in an Emerging Context of Legal Pluralism, 141-149.
Revolutionary Movement (MNR), which gained control of the Bolivian government in 1952, the excavations, led by party member and archaeologist Carlos Ponce Sangines, focused on the architecture and the monuments and on creating a national emblem for Bolivia. The ultimate goal for the excavations was to systematically document and expose the structures in order to promote tourism. Propelled by governmental request as well as his own staunch nationalistic ideology, Ponce Sangines reconstructed certain architectural elements and discarded any architectural features that were not considered sufficiently monumental.\(^{117}\) A new interpretation of the site arose from these excavations (1950s–1970s). Ponce Sangines declared the site of Tiwanaku a major pre-Inca urban center by calculating the total area of occupation and the estimated population density, discarding the previous perception of the site as only a religious center.\(^{118}\) Ponce Sangines, overall, wanted to present the site of Tiwanaku as a monumental apogee of Bolivian civilization and history—a site that could compare with Peru’s Machu Picchu.

In 1978, Alan Kolata began a project sponsored by the Bolivian National Institute of Archaeology (INAR) to explore Tiwanaku’s hinterland. This multidisciplinary study investigated technology and agricultural production through the excavations of smaller hamlets, subsidiary sites, and raised fields in the Tiwanaku area. This project extended into the 1980s during which excavations spread into the high plateau area and the regions around the site of Tiwanaku to understand the nature of this civilization.\(^{119}\)

\(^{117}\) Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 169.
In 1987, the Getty Conservation Institute (GCI) offered a course at the site of Tiwanaku in the field conservation of objects and buildings.120 DINAR produced a summary document of this workshop, which included a description of the conservation of some of the stone monuments, a proposal for the conservation of the Pumapunku Complex, an analysis of the current tourist flow and its impact on the site, and recommendations for improving the visitor experience. This report also provides a summary of any treatment interventions conducted during the workshop.121 Unfortunately, none of these recommendations were developed any further than this initial survey. The descriptions of the treatments conducted during the course are brief and incomplete; therefore exactly what interventions were implemented, how, and on which objects or monuments, remains unknown.

The Getty Conservation Institute also sponsored the installation of a microenvironment monitoring station at the site of Tiwanaku in 1990.122 This project culminated in a paper that analyzes the environmental decay mechanisms that are affecting the sandstone and andesite monuments at the site.123

Presently, archaeologists of the University of Pennsylvania expedition are integrating and applying the methods and recommendations established by the Getty Institute in the late 1980’s. The conservation work includes supporting exposed excavation trench walls with adobe. This method protects the structure from rain but does not sufficiently aid conservation. While excavating and researching the site,

123 Maekawa, et al., Environmental monitoring at Tiwanaku.
DINAR is also filling in gaps of the architecture with adobe. Both groups are conserving with the adobe material so that future visitors and researchers can observe the difference between ancient and modern construction and material.124

In 1995, the University of Pennsylvania and National Department of Archaeology of Bolivia began excavations of the Pumapunku Complex. Presently, grants from the National Science Foundation support excavations of the Lakarana and west of the Akapana Pyramid. Recent studies have also included geophysical survey and excavation of the Akapana Pyramid.125

Besides excavation, other anthropological research has occurred at the site of Tiwanaku. Deborah Blom of the University of Vermont is currently researching the health, nutrition, and identity of the people of Tiwanaku. Couture has studied elite residences and the social uses of space and is currently excavating a cemetery on the site of Tiwanaku.126 While most of these projects are conducted by international researchers, more and more research is being conducted at the site of Tiwanaku and the surrounding area by Bolivian scholars. Juan Albarracin has conducted surveys to research Tiwanaku settlement patterns and spatial relationships between these patterns.127

While the site has been studied and excavated for over one hundred years, very little attention has been directed towards the conservation of the site or its monuments. An ICOMOS statement of September 2000 declared that “little, if any, conservation has

124 Vranich, personal interview with the author, April 2006.
125 Vranich, National Science Foundation Grant application, 2006.
taken place.” ¹²⁸ ‘Conservation work’ has been focused on the confiscation of specific artifacts deemed important works of art and the reconstruction projects of certain monuments. The Kalasasaya Platform was reconstructed by Ponce Sangines in the 1950s and 1960s (Fig. 3.8), as a direct response to the Bolivian nationalist movement to create a national site that would serve as Bolivia’s Machu Picchu and attract tourism. Some scholars, however, question the accuracy of this reconstruction and particularly, its authenticity is broadly doubted.

Likewise, the Gateway of the Sun has been partially restored by the Ponce Sangines excavation team in the 1950s, and the authenticity of its present location questioned. Recent archaeo-astronomical research has indicated that the Gateway of the Sun was likely originally located within the main axis of the Kalasasaya Platform, not relegated to the corner in which it is currently placed.¹²⁹

Most recently, the Foundation for the Research and Conservation of Andean Monuments conducted a study trip in 2004 to Tiwanaku to evaluate the current conditions of the stone monuments at the site.¹³⁰ Conservation architect Gionata Rizzi produced a brief conservation assessment of the major stone structures, determining that many of the monuments and artistic sculptures, particularly those composed of red sandstone, are at great risk. Already severely damaged, further deterioration will rapidly occur unless conservation interventions are undertaken. In addition, Rizzi noted that

¹²⁹ Benitez, personal interview with the author, March 2006.
¹³⁰ De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present, 6.
(reportedly) some of the stone structures, including the Gateway of the Sun, had received silicate treatments in the 1930s for the purpose of consolidation.\textsuperscript{131}

The lack of conservation efforts has greatly influenced the preservation and presentation of the site of Tiwanaku. While visitors to the site of Tiwanaku during the nineteenth-century observed the decay, deterioration, and destruction of the site and its monuments, serious conservation plans were not formed until the later half of the twentieth-century. Early conservation included reconstructions which may not have been historically accurate and encouraged incorrect interpretations of the site for the visitor. Presently, these reconstructions and the original material need immediate conservation and care. Future conservation plans and interventions will be needed in order to stop the effects of the natural processes and human influence that contribute to the decay and deterioration of the site. Therefore, prospective conservation plans and procedures should include both short-term and long-term perspectives.

\textbf{3.4 Environment and Land-Use}

\textsuperscript{132}The site of Tiwanaku is situated on the Altiplano, about 20km from the southern shores of Lake Titicaca, at an elevation of about 3,850 meters above sea level.\textsuperscript{133} The site is located approximately 150 km inland.\textsuperscript{134} The weather can be extreme in the Andes, but the area surrounding Lake Titicaca is regulated by the warmth and

\footnotesize{\textsuperscript{131} The information regarding the silicate treatment was reported to Rizzi from the current site conservator, Marcello Maldonado. This information, however, is undocumented (Rizzi, personal interview with the author, April 2006). Rizzi, Tiwanaku: Notas Sobre Conservación y Presentación.\textsuperscript{132} The environmental and land-use section was written with David Artigas.\textsuperscript{133} ICOMOS, \textit{Advisory Board Evaluation Tiwanaku (Bolivia)}. No 567rev.\textsuperscript{134} Maekawa, et al., Environmental monitoring at Tiwanaku, 885-891.}
humidity from the lake. The current lake-wetland relationship creates a kind of microclimate in the area that raises near-ground temperatures by a few degrees C. Even with the moderating influence of the lake, however, frosts occur in almost every month of the year and snow is not uncommon. The climate in the area is, on average, 9 °C, but there are sharp differences in daily temperature. Average highs during the day can be from 15 °C to 20 °C; at night, however, the air retains little heat and temperatures rapidly drop to just above freezing. In the summer months, the temperatures drop to below freezing only briefly, but in the winter temperatures fall below freezing every night. The climate overall is dry and cold, typical of any high plateau zone. Seasonal cloud cover results in a clear atmosphere the majority of the year, increasing daytime insolation effects on the soil and the stone structures, and nighttime loss of heat. Therefore, a significant difference between daytime and nighttime temperatures occurs at the site of Tiwanaku.

The environmental monitoring study conducted by the Getty Conservation Institute at the site of Tiwanaku over a 22-month period beginning in 1990 found that summer rainfalls, coupled with dry cold winters, are responsible for the seasonal variations in relative humidity (RH) at the site. The repeated occurrence of high humidity is not due to frequent rain but to the normal drop in night-time temperature to around freezing. During the day, a more conventional rise and fall in RH, typical of high desert-

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136 Binford, et al., Climate Variation and the Rise and Fall of an Andean Civilization, 245.
138 Binford, et al., Climate Variation and the Rise and Fall of an Andean Civilization, 237.
140 Maekawa, et al., Environmental monitoring at Tiwanaku, 885-891.
141 Villegas, Factors that Cause Deterioration of the Land in Province ‘Los Andes’ (North Bolivian High Plateau), 47.
like climates, was noted by the scientists. The supposedly dry mountain climate of Tiwanaku has almost as many periods above 80% RH as below 40% RH. As expected, the atmospheric water content decreases during the drier months and increases during the rainy period. The water content during a 24-hour day does not significantly change, indicating the rise and fall of the relative humidity are due only to solar heating of the air.\textsuperscript{142}

Extreme seasonal changes, ranging from prolonged droughts to torrential rain, cause the water table to rise and fall drastically throughout the year. Modern day Tiwanaku alternates between an arid period, generally lasting from April to November, and a wet period from December to March, during which 85% of the total rainfall occurs.\textsuperscript{143} The soil becomes saturated by February or March. The rainfall during the wet period is not distributed evenly; rather the precipitation falls in short intense bursts.\textsuperscript{144} Most of this rain is brought by winds approaching from the east;\textsuperscript{145} however, the annual rainfall is only about 750 mm.\textsuperscript{146} The level of Lake Titicaca has been relatively stable during the 20\textsuperscript{th} century, rising on average, 80 cm/yr during the rainy season and falling 78 cm/yr during the dry season.\textsuperscript{147}

The site of Tiwanaku is also located on a windy plateau, subject to cool winds all year round, but more intense in the summer months. The wind is varied-directional but the west wind predominates throughout the day and evening.\textsuperscript{148} The composition of the

\begin{footnotesize}
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\item \textsuperscript{142} Maekawa, et al., Environmental Monitoring at Tiwanaku, 888.
\item \textsuperscript{143} Maekawa, et al., Environmental Monitoring at Tiwanaku, 888.
\item \textsuperscript{144} Preston, et al., Grazing and Environmental Change on the Tarija Altiplano, Bolivia, 142.
\item \textsuperscript{145} Binford and Kolata, The Natural and Human Setting, 30-32
\item \textsuperscript{146} Binford, et al., Climate Variation and the Rise and Fall of an Andean Civilization, 237.
\item \textsuperscript{147} Binford, et al., Climate Variation and the Rise and Fall of an Andean Civilization, 237.
\item \textsuperscript{148} Maekawa, et al., Environmental Monitoring at Tiwanaku, 889.
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\end{footnotesize}
soil is 8% sand, 37% silt, and 55% clay. The pH of the soil is almost neutral and the total nitrogen is low. Soils in the region are characterized as sandy soils, saline soils, argillaceous soils, black earth, peat, and wetlands.

This environment allows the cultivation of corn, barley, wheat, quinoa, oats, potato and alfalfa. The majority of highland farms consist of minifundia, or small private land holdings, using raised bed agriculture. The raised fields are elevated earthen mounds from 3 to 10 meters wide and up to 200 meters long, which are believed by some scholars to have first been constructed to raise the root zone above the water-saturated soils. The raised fields prevent crops from becoming water logged when the water table rises and help maintain moisture in the soil during the dry season. Raised bed farming also protects crops from freezing by absorbing solar insolation and conserving heat, retain dissolved and particulate nutrients, enhance nitrogen fixation, and may decrease soil salinity; contributing greatly overall to the amount of food production.

The major problems affecting current land use in this region are the lack of fuel for cooking, soil erosion, and the depletion of fertile soils. The land surrounding Tiwanaku has been largely cleared of trees to produce more land for grazing. Therefore, in order to collect cooking fuel the roots of trees must be removed from the earth, adding to problems of soil erosion. The traditional fallow period for Aymara-farmed fields is

149 Argollo, et al., Geology, Geomorphology, and Soils of the Tiwanaku and Catari River Basins, 81
150 Villegas, Factors that Cause Deterioration of the Land in Province ‘Los Andes’ (North Bolivian High Plateau), 47.
151 Villegas, Factors that Cause Deterioration of the Land in Province ‘Los Andes’ (North Bolivian High Plateau), 46.
152 Binford and Kolata, The Natural and Human Setting, 53; Villegas, Factors that Cause Deterioration of
the Land in Province ‘Los Andes’ (North Bolivian High Plateau), 47.
153 Binford, et al., Climate Variation and the Rise and Fall of an Andean Civilization, 236.
154 Binford, et al., Climate Variation and the Rise and Fall of an Andean Civilization, 236-237.
155 Villegas, Factors that Cause Deterioration of the Land in Province ‘Los Andes’ (North Bolivian High Plateau), 47.
seven years, but this number has been shortened more recently to three years. More nutrients are being taken from the soil than are being returned. In addition, the over-grazing of cattle, sheep, llamas, alpacas, donkeys and similar beasts can cause the soil to loose fertility, becoming more dry and compact. These issues, along with insufficient vegetation, are contributing to severe problems with erosion. Additionally, there is a moisture deficit in the soil due to water evaporating faster than it is absorbed, leading to high salinity in the soil. Also, salts in the system tend to remain and are not washed away.

3.5 Presentation of the Site

3.5.1 Geographical Context—“Sacred Geography”

The site of Tiwanaku is largely defined by and revered for its remote location. (Fig. 3.9) Despite the harsh environment, some researchers believe the site of Tiwanaku’s location is deliberately due to the site’s orientation to four major geographical features, as well as its arrangement among countless other cerros, or peaks, that contribute to the dramatic vistas. These four geographical features are situated in the four cardinal directions: the mountain of Illampu to the north, Sajama to the south, Illimani to the west, and Lake Titicaca to the east.
The site of Tiwanaku sits along an approximate North/South axis with Illampu and Sajama, with the mountain peak of Quimsichata as the southward gateway to Sajama. Although the peaks of Illampu and Sajama are not visible from the site, Tiwanaku’s positioning between the two would appear deliberate. As the highest peak near the site of Tiwanaku, Quimsichata is visible from the site, serving as both the anchor to south and the vantage point from which all other peaks are observed. The cardinal directions create a protective boundary around Tiwanaku, four parts establishing a unified whole.\footnote{Reinhard, Tiahuanaco, Sacred Center of the Andes, 210.}

Illimani, considered the King of Mountains by Aymara, rises to nearly 21,208 feet and serves as the most widely worshiped geological deity among indigenous peoples. The largest monuments at the site of Tiwanaku, the Akapana Pyramid and the Pumapunku Complex, point towards Illimani and are assumed to symbolize the ‘cosmic’ mountains of the area.\footnote{Reinhard, Tiahuanaco, Sacred Center of the Andes, 205.}

Lake Titicaca, believed to be an \textit{achachila}, or spiritual ancestor, of the mountains,\footnote{Reinhard, Tiahuanaco, Sacred Center of the Andes, 203.} plays a major role in rituals regarding rain, harvest and welfare, and serves as the most prominent economic and religious stimulus for the present-day Aymara.\footnote{Reinhard, Tiahuanaco, Sacred Center of the Andes, 204.}

Although not formally oriented to the site of Tiwanaku, Ccapia is the highest mountain along Lake Titicaca. The view of Ccapia from the Kalasasaya Platform corresponds to the solstice sunset.\footnote{Benitez, A Unique Lunisolar Observatory and Calendar in Precolumbian Bolivia.} Ccapia is believed to affect the weather, much like Illimani and the lake. Many of the geographic features in the region are thought to regulate weather phenomena, as erratic conditions are the greatest concern for the
inhabitants of the Altiplano. Severe hail and electrical storms have not only destroyed crops, but have killed people and livestock as well.

3.5.2 The Monumental Complex (Fig. 3.10)

Today’s visitors to the site of Tiwanaku encounter a rather empty expanse of reconstructed temples and fields of large stones. (Fig. 3.11) The site of Tiwanaku, composed mainly of a monumental core, contains architectural remains that, while certainly impressive, do not necessarily inspire great awe, as they once did. A combination of extensive looting, periodic dismantling of architecture considered unimportant, the use of ephemeral adobe for many of the structures (long ago eroded) and partial, and perhaps inaccurate, reconstructions have left a degraded site.\textsuperscript{167}

Recent research hypothesizes that the role of the architecture was not to inspire visitors on its own; rather the role of the monuments was to harmonize with the landscape and the magnificent views of the mountains and the then-nearby lake.\textsuperscript{168} Looking out at the views from within the monumental architecture was a major purpose of these ceremonial structures, the remains of which are still being uncovered and deciphered.

3.5.3 The Architecture

The Akapana Pyramid is the single most imposing structure at the site of Tiwanaku. Some archaeologists believe that the Akapana Pyramid resembles the Andean cross which symbolizes the four human areas of the world. The Tiwanaku created the Akapana Pyramid by transporting earth, clay, and gravel onto seven superimposed

\textsuperscript{167} Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 169.
\textsuperscript{168} Vranich, National Science Foundation grant application 2006, 2-4.
terraces cut into the natural stone. Archaeologists hypothesize that the upper terraces once displayed symbolic texts and plaques, likely made of precious gold or silver and textiles. Recent excavations have discovered a system of surface and subterranean drains. This sophisticated water system includes buried tanks that may have enabled water to spring from the summit. As the sacred mountain of the site Tiwanaku and local protector deity, the Akapana Pyramid probably served a religious and civic function for the site.  

Now, however, after centuries of looting of the stone from its façade and resulting erosion, the Akapana Pyramid appears as not much more than an earthen mound.

A sunken court excavated into the ground and constructed of sandstone masonry, the Semi-subterranean Temple contains an assemblage of stone steles and sculptures inserted into the masonry walls. To the west of the Semi-subterranean Temple, the Kalasasaya Platform is likely the monument that replaced the Semi-subterranean Temple as the focal point for the city. A large platform, the Kalasasaya Platform is elevated above surface level and is believed to have been constructed for making astronomical observations. The west wall of the structure, in conjunction with the Gateway of the Sun, may have served as a calendar. The walls are constructed of rough-cut sandstone pillars alternating with smaller, precisely-cut ashlar blocks. Within the Kalasasaya Platform are a series of stone stele placed in the center of the platforms. Perhaps inaccurately reconstructed by Ponce Sangines in the 1950s and 1960s, the Kalasasaya Platform today presents an imposing and monumental structure.

170 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 172.
172 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 172.
The Gateway of the Sun was found and re-erected in the northwest corner of the Kalasasaya Platform. (Fig. 3.12) The monumental Gateway exhibits an elaborately carved stone façade and may once have stood either in the Pumapunku Temple complex or within the main axis of the Kalasasaya Platform. The Gateway’s current location, unfortunately, does little to enhance the monument’s spectacular carvings or give much indication as to its significance, both past and present.

Like the Akapana Pyramid, the Pumapunku Complex was likely an impressive monumental structure designed to collect water through a drainage system. Possibly intended to act as a duplicate of the Akapana Pyramid during initial construction, the Pumapunku Complex provides views of the sacred mountain of Quimsichata to the south. The Pumapunku Complex, along with the Akapana Pyramid, is thought to have represented the “cosmic mountains.” Current excavations are focused on this feature and some archaeologists believe that the Pumapunku Complex functioned as the official entrance to the site of Tiwanaku.

Uncontrolled development of the modern town of Tiahuanaco is threatening the view sheds from the pre-Columbian site. Additionally, partial, and perhaps inaccurate, reconstructions, ongoing excavation, and poorly planned visitor accoutrements, such as modern staircases, barbed wire fences, and cement platforms, not only create an unattractive site, but an inauthentic one as well. If one of the original intents of the site during the height of the Tiwanaku Empire (and the period considered most significant) was to view the unobstructed land and astronomical occurrences, including the path of

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173 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 199.
174 Benitez, personal interview with the author, March 2006.
176 Isbell and Vranich, Experiencing the Cities of Wari and Tiwanaku, 171-172.
the sun as it moved across the buildings, sculpture, and mountains—from within a carefully planned monumental setting—the presentation of the site as it currently exists certainly, undoubtedly, does not offer this experience.

3.6 Cultural Heritage in Bolivia

Any conservation interventions or conservation program for the site of Tiwanaku must comply with national and local laws and take into account a variety of international conservation charters. This section provides an overview of the legal context of Bolivia as well as a summary of the national Cultural Heritage Policy and international charters that affect the management of archaeological sites in Bolivia.

3.6.1 Bolivian Government Structure

The structure of the Bolivian government can be divided into Executive, Legislative, and Judicial branches, in addition to the local government.177 The purpose of this section is to provide an understanding of the decision-making process in Bolivia at the national and local level. Of particular importance is the evolution of political influence and power held by the indigenous populations in Bolivia. This evolution gives subtext to the history of the management of the site of Tiwanaku, including the 2001 revolt during which the local Aymara population literally wrested the site from the national government.

Executive power resides in the President and the Ministers of State, who conduct the day-to-day business of public administration in Bolivia. Because of a recurring

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177 The source of the information regarding the structure of the Bolivian Government is the Library of Congress Country Studies.
executive-legislative split with Congress, real power, or the effective capacity to rule, had eluded democratically elected presidents until 1985. The President heads a Council of Ministers (representing sixteen ministries) and various other councils. The power of appointment enables the president to exercise control over the large number of public servants at all levels of government. The president appoints the ministers of state, members of the bureaucracy, and prefects (prefectos) of departments (departamentos).

Although Congress generally plays a passive policy-making role, it is a major actor in national politics. Congress's political powers include the right to create new provinces, cantons (cantones), and municipal districts. Congressional members, or deputies, are elected through universal suffrage based on a complex proportional representation system. Bolivia has adopted the Spanish tradition of electing alternates (suplentes) as well. This arrangement ensures minority representation in the upper house. A recurring problem is the prevalence of obsolete rules of procedure dating back to the 1904-05 legislative year that slow the approval of bills and have contributed in large measure to making Congress's legislative function obsolete.

In 1989 Bolivia was divided into nine departments, which were subdivided into ninety-four provinces. Provinces, in turn, were divided into sections and sections into cantons. The president's power of appointment created a system of patronage that reached down into the smallest administrative unit. Under democratic rule, local government reflected the pattern of job struggle present in the national bureaucracy.

The principal local structure is the municipal government system. Theoretically, municipal governments are autonomous. Autonomy refers primarily to the direct and free election of municipal authorities, the power to extract and invest resources, and the
power to implement plans and projects. Four types of municipal government exist in Bolivia. In the capitals of the departments, municipal governments function under the direction of a mayor (*alcalde*), who should be subject to a municipal council, which consists of twelve members. The capitals of the provinces also function under the direction of a mayor, as well as a six-member municipal board (*junta*). In the cantons, municipal governments function under the direction of municipal agents. Mayors and council members are elected in each department and province for two-year terms. Because councils are elected on the basis of proportional representation, minority parties have a significant degree of influence in local politics.

3.6.2 National Cultural Heritage Legislation and Policy

178 The earliest cultural heritage preservation legislation in Bolivia was a Supreme Decree adopted on 11 December 1825, the year of Bolivian’s independence. Two articles of this decree mention the use and adaptation of old buildings for educational purposes. In 1906, a Legal Regime, as a Law of the Republic, was enacted for the site Tiwanaku, ruins on Lake Titicaca and ruins from the Inca and preceding ages. Article 1 of this law classified the ruins as state property and mandates governmental care and an annual budget. Article 2 prohibited the export of art from the ruins and Article 3 allows the government to delegate preservation and restoration activities to corresponding geographical societies. In 1909 a Supreme Decree established an Excavation Regime for Tiwanaku and the ruins on Lake Titicaca in accordance with the 1906 law. The National

178 Unless otherwise noted, the information regarding Bolivia’s cultural heritage laws is summarized from Torres, *Chronological Overview of Developments in Bolivian and Latin American Cultural Heritage Legislation with a Special Emphasis on the Protection of Indigenous Culture*. 53
Monument Act was enacted in 1927, which created a National Gallery of Fine Arts, History and Archaeology, under the Ministry of Education, which was in charge of classifying and protecting artistic and historical heritage. Another Supreme Decree in 1930 declared a number of temples and important civilian and administrative buildings in La Paz, Sucre, and Potosi as national monuments, including those at Tiwanaku. In 1945 the town of Tiahuanaco and a region of 5km around the town was designated a National Monument. In 1958, the Archaeological Excavation Regulations were issued, to be enforced nationwide by the Ministry of Education’s Department of Archaeology. The Center for Archaeological Research at Tiwanaku (CIAT) was founded also in 1958. The 1961 edition of the Bolivian Constitution stipulated in Article 199 that:

Archaeological monuments and objects are property of the State. Colonial, archaeological and historical goods, as well as objects related to religious worship, are part of the nation’s cultural treasure, are protected by the State and cannot be exported. The State shall protect buildings and sites that are declared as being of artistic and historical value.

A November 1961 Supreme Decree reemphasized that the State was to protect the nation’s artistic and cultural heritage as well as supervise the proper conservation of artistic, historical, and archaeological patrimony from pre-Columbian, Colonial, and Republican eras. This Decree, No. 05918, complemented existing legislation and is still considered the most complete set of regulations protecting Bolivia’s cultural heritage. It encompasses architecture, cities, paintings, murals, sculpture, fine art and jewelry,

179 ICOMOS. Advisory Board Evaluation Tiwanaku (Bolivia). No 567rev.
180 ICOMOS. Advisory Board Evaluation Tiwanaku (Bolivia). No 567rev.
181 Viceministerio de Desarrollo de Las Culturas, Bolivia.
182 Quoted in Torres, Chronological Overview of Developments in Bolivian and Latin American Cultural Heritage Legislation with a Special Emphasis on the Protection of Indigenous Culture, 124.
furniture, textiles, ceramics, and books and manuscripts. It also classifies all pre-Hispanic monuments or archaeological objects as including monuments, ruins, agricultural terraces, sites, cemeteries, and a range of objects. The Decree prohibits the export of all of these items and makes it criminal to do so. A Ministerial Resolution gave the enforcement of this Decree to the Directorate of Fine Arts and National Monuments and the Directorate of Anthropology of the Ministry of Education.

Another Supreme Decree was enacted in 1965 that established norms for archaeological excavation and prohibited the sale of archaeological objects. Perhaps in response to the 1966 General Conference of UNESCO, at which the Declaration of the Principles of International Cultural Cooperation was adopted, the Bolivian Constitution was amended in 1967 to make the State responsible for cultural heritage conservation and in 1973 the Ministry of Education and Culture was made responsible for the preservation of Bolivia’s anthropological heritage. ICOMOS-Bolivia was also established at this time and today still provides important training and advice regarding conservation and restoration of historic structures.

In 1975, CIAT became the National Institute of Archaeology (INAR) as part of the Bolivian Institute of Culture, and overseen by the Ministry of Education and Culture. In perhaps the first international collaboration, the Organization of American States adopted the Convention on the Protection of the Archaeological, Historical and Artistic Heritage of the American Nations to identify, protect, and safeguard the cultural heritage of the American nations in 1976. ICOM-Bolivia was established in 1986 and also beginning in the late 1970s, a series of both International Declarations and Supreme

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183 Viceministerio de Desarrollo de Las Culturas, Bolivia.
Decrees were adopted that began to focus on protecting indigenous culture. By the end of the twentieth century, the subject of ethics and the recovery of cultural objects became the focus of the international community and also on a national level.

Since the 1990s, a large number of resolutions and laws have been adopted in Bolivia, mostly as a response to international trends and charters established by ICOMOS and UNESCO. In 1994, a number of far-reaching reforms occurred in Bolivia, including changes to the Constitution which affirmed the cultural rights of indigenous peoples. In 1995, the Sucre Historical Sites Rehabilitation Plan began, preserving Sucre’s urban heritage which had already been declared a World Heritage Site by UNESCO. In the 1990s the Potosi Plan became the model for all urban architectural preservation plans in Bolivia and acquired several financial backers including the Spanish Agency for International Cooperation, the municipal government of Potosi, and the Potosi Development Corporation (later taken over by the Prefecture of the Department of Potosi).

In 1996, the National Secretary of Culture called for the unification of the Bolivian Institutes of Archaeology and Anthropology to create one National Direction of Archaeology and Anthropology of Bolivia (DINAAR). In 1997, a Regulations on Excavations Resolution was issued stating that no individual or institution may undertake prospecting, excavation, or archaeological restoration in Bolivia without formal authorization by DINAAR. DINAAR is also responsible for enforcing a Resolution issued in 1997 regarding the Basic Regulations for Anthropological Research. From 3-5 December 1998, the First National Workshop-Seminar on the Protection and Rights of

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184 Viceministerio de Desarrollo de Las Culturas, Bolivia.
Traditional Culture and Folklore was held in Bolivia which aimed to define Bolivia’s position on the protection of traditional culture and folklore, both tangible and intangible.

In 1998, Bolivia and Mexico signed a General Collaboration Agreement on Archaeological, Anthropological, Cultural Heritage Protection and Conservation Issues and also that same year, Bolivia and Peru signed an Agreement for Recovery of Cultural Property. However, a group of organizations published a document, also in 1998, asserting that current Bolivian law does not protect the cultural rights of indigenous peoples and put forth a number of recommendations and policies for this protection.

In 1998 and 1999, Bolivia passed a number of regulations regarding the recovery of stolen property and professional ethics for museum staff. In May 1999, The Andean Council of Foreign Ministers adopted a measure on the Protection and Recovery of Cultural Artefacts of the Andean Community’s Archaeological, Historical, Paleontological and Artistic Heritage which is intended to promote common policies and regulations. Also in 1999, the Bolivian government officially submitted a request to the US government, in accordance with the UNESCO Convention, that seeks to protect Bolivia’s cultural heritage and halt illegal trafficking.

In recent years, there have been more concerted efforts to work internationally and regionally with other Andean States, South American countries, as well as the Americas of large, for the protection of cultural heritage and cultural diversity. However, internal bureaucracy and swift authority turnover makes the effective implementation of these resolutions a difficult task. Additionally, rapid agency re-organization complicates the situation even further. While DINAR is responsible for overseeing the technological and methodological aspects of archaeological research, as well as approving excavation
permits, UNAR is a governmental agency that is responsible for regulating and supervising archaeological work on a national level, while the Vice-Ministry of the Development of Culture is the institution in charge of the defense and conservation of Bolivia’s Cultural Heritage.\textsuperscript{185}

Overall responsibility for the management of the archaeological remains at Tiwanaku generally fell to DINAR. Other areas of the UNESCO World Heritage nominated area are still managed by the Roman Catholic Church as well as private individuals (ICOMOS Advisory Board Evaluation, 2000). However, in 2001, the Aymara peoples reclaimed the site of Tiwanaku in a violent uprising and the Municipality of Tiwanaku now makes all management decisions regarding the site, including the approval of excavation permits after they are issued and approved by DINAR.\textsuperscript{186}

\subsection*{3.6.3 International Cultural Heritage Policy}

\textsuperscript{187} A brief summary of the international charters that are applicable to the conservation and management of archaeological sites follows: The International Charter for the Conservation and Restoration of Monuments and Sites (otherwise known as the Venice Charter), adopted by ICOMOS in 1965, lists 16 Articles, describing Definitions, Conservation, Restoration, Historic Sites, Excavations, and Publication mandates. An extension of the 1931 Athens Charter, the Venice Charter calls for international standards for any conservation or restoration work.

\textsuperscript{185} Viceministerio de Desarrollo de Las Culturas, Bolivia.
\textsuperscript{186} Vranich, personal interview with the author, March 2006.
\textsuperscript{187} ICOMOS (\textit{International Charters for Conservation and Restoration}) provides an overview of the major international charters and resolutions.

The Nara Document on Authenticity, published in 1994, is not an internationally adopted charter, but lists Articles discussing the importance of cultural and heritage diversity and authenticity.


The Australian Burra Charter of 1999 is the adoption of 34 Articles on cultural heritage management, including, but not limited to, Definitions, Conservation Principles, Maintenance, and Recording and remains the standard for the management and conservation of cultural heritage sites.

Last, the 2003 ICOMOS Charter – Principles for the analysis, conservation and structural restoration of architectural heritage, delineates three Principles: General Criteria, Research and Diagnosis, and Remedial Measures and Controls.

These charters, some of which have influenced the evolution of cultural heritage law in Bolivia, are not routinely or uniformly enforced. However, any conservation plan must be guided by these internationally adopted principles.
3.6.4 Other Archaeological and Cultural Heritage Sites in Bolivia

To complete the context of the management of cultural heritage in Bolivia, the site of Tiwanaku must be situated along with other heritage sites in the country (FIG). Briefly, six other heritage sites, four of which are also World Heritage listed, were found publicized for Bolivia. (Fig. 3.13)

El Fuerte de Samaipata (World Heritage listed, 1998) is an archaeological site dating from the 14th–16th centuries. The justification for inscription was: Criterion ii: The sculptured rock at Samaipata is the dominant ceremonial feature of an urban settlement that represents the apogee of this form of pre-Hispanic religious and political centre. Criterion iii: Samaipata bears outstanding witness to the existence in this Andean region of a culture with highly developed religious traditions, illustrated dramatically in the form of immense rock sculptures.188

Jesuit Missions of the Chiquitos (World Heritage listed, 1990) is a living heritage site on the former territory of the Chiquitos. Between 1696 and 1760, six ensembles of settlements of Christianized Indians (reducciones) inspired by the 'ideal cities' of the 16th-century philosophers were founded by the Jesuits in a style that married Catholic architecture with local traditions. Only six remain – San Francisco Javier, Concepción, Santa Ana, San Miguel, San Rafael and San José.189

The City of Potosi (World Heritage listed, 1987) was regarded as the world's largest industrial complex in the 16th century. The site consists of the industrial monuments of the Cerro Rico mine, where water is provided by an intricate system of aqueducts and artificial lakes; the colonial town with the Casa de la Moneda; the Church

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of San Lorenzo; several patrician houses; and the areas where the workers lived (*barrios mitayos*).\(^{190}\)

The Historic City of Sucre (World Heritage listed, 1991) was the first capital of Bolivia, founded by the Spanish in the first half of the 16th century. Its many well-preserved 16th-century religious buildings, such as San Lázaro, San Francisco and Santo Domingo, illustrate the blending of local architectural traditions with styles imported from Europe.\(^{191}\)

### 3.7 Political and Economic Climate

#### 3.7.1 Political Climate of the 1950s

Since independence from Spain in 1809 and the birth of the Bolivian Republic in 1825, the country’s political situation has been filled with instability.\(^{192}\) The 1950s, in particular, was a decade of massive upheaval and change in Bolivia. For the purpose of better understanding the political context in which Bolivian led excavations began at the site of Tiwanaku, this section will briefly describe Bolivia’s political climate of that era.

Between the years 1938–1939, Colonel Germán Busch was president of Bolivia. Busch’s policy and vision for the country have been described as largely influenced by Germany. He died in 1939 in what was officially ruled a suicide, but Busch’s supporters insisted that he was assassinated. Busch’s death motivated his supporters to organize the National Revolutionary Movement (MNR). The 1940’s was a time of successes and failures for the MNR, as well as a period of overall political instability that culminated in

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the Revolution of April 9, 1952.\textsuperscript{193} The MNR took power with Víctor Estenssoro Paz as president and Juan Lechín (who had been an important mine-workers’ organizer) as the Minister of Mines.

The MNR is described as having “come into office committed to the nationalization of the mining industry, the emancipation of the underprivileged native population, the parceling of the land among the native agricultural workers and the introduction of advanced social and labor legislation”.\textsuperscript{194} For example, on August 2, 1952, all Bolivians were given the right to vote, repealing a previous law that had determined eligibility based on literacy or income.\textsuperscript{195} Subsequently, individual and group ownership of land was severely limited by the government through legislation passed on August 2, 1953 in an effort to redistribute land more fairly among the poor indigenous communities throughout the country.\textsuperscript{196}

Within this political climate and due to the strong nationalist beliefs of the directing archaeologist (and MNR member) Carlos Ponce Sangines, large-scale reconstructions occurred at the site of Tiwanaku. According to Kolata,\textsuperscript{197} the use of the site of Tiwanaku as a nationalist symbol of identity and the notion of the ‘Stone at the centre’ of the site as a world cosmological axis only began with the 1952 Revolution.

\begin{footnotesize}
\begin{enumerate}
\item Osborne, \textit{Bolivia: A Land Divided}.
\item Osborne, \textit{Bolivia: A Land Divided}, 71.
\item Osborne, \textit{Bolivia: A Land Divided}.
\item Osborne, \textit{Bolivia: A Land Divided}.
\item Kolata, \textit{The Tiwanaku: Portraits of an Andean Civilization}.
\end{enumerate}
\end{footnotesize}
3.7.2 Current Political Climate

Currently, many conflicting interests and competing claims exist over the site of Tiwanaku. The indigenous group, the Aymara, consider the site of Tiwanaku their ancestral homeland, while the national government views the site of Tiwanaku as a place of national identity and, indeed, almost every Bolivian schoolchild visits the site.\footnote{University of Pennsylvania Museum of Anthropology and Archaeology. http://tiwanaku.museum.upenn.edu/Tiwanaku.htm.}

In the year 2000, Tiwanaku was listed by UNESCO as a World Heritage Site.\footnote{UNESCO World Heritage Centre. http://whc.unesco.org.} Soon after in 2001 the site was taken over by the Aymara in a violent struggle with the government\footnote{Vranich, Coping With Chaos, 63.} as part of the Aymara demand for recognition of their autonomous territory and Aymara Nation.\footnote{Arnold and Yapita, Strands of Indigenism in the Bolivian Andes: Competing Juridical Claims for the Ownership and Management of Indigenous Heritage Sites in an Emerging Context of Legal Pluralism.} The Aymara claim that the site of Tiwanaku is their ancestral homeland is widespread. As Arnold and Yapita write, “Even young urban musicians of Aymara descent like to flaunt themselves in front of Tiwanaku’s ‘Gateway of the Sun’ in their digital videos”.\footnote{Arnold and Yapita, Strands of Indigenism in the Bolivian Andes: Competing Juridical Claims for the Ownership and Management of Indigenous Heritage Sites in an Emerging Context of Legal Pluralism, 146.} The incorporation of this nationally significant monument by young Aymara artists, in such a contemporary medium, illustrates the competing uses of the site of Tiwanaku. Worldwide attention has been brought to the site by UNESCO, contributing to the national pride felt by Bolivians about their site. This international and national recognition has also perhaps prompted a renewed interest by the Aymara and their entitlement to the site of Tiwanaku.

In the year 2000, a year before the site of Tiwanaku was taken over by the local Aymara, Bolivia’s government arranged a deal with the U.S. company by the name of
Bechtel to privatize the water supply of the country’s third largest city, Cochabamba. National protests erupted after the price of water tripled, and eventually the contract was revoked. Bechtel then filed a lawsuit against the Bolivian government in 2001 seeking USD $25 million in lost profit. In January 2006 Bechtel dropped the case. (To help put things into perspective, consider the fact that Bolivia’s national budget in 2004 was USD $2.9 billion. In the same year, the Bechtel company earned USD $17.4 billion in revenue). This event helped to strengthen the indigenous community’s call for change and contributed to the political climate responsible for bringing an indigenous president to power in 2006.

Bolivia’s current political situation may be further illuminated by two events. During the 1930s, Wendell Bennett’s excavation of a massive stele in the center of the Semi-subterranean Temple became the subject of a political struggle. The stele was moved into downtown La Paz on July 3, 1932 despite outrage by the local Aymara. After years of conflict and protest by the Aymara, the Bennett Stele was returned to the site of Tiwanaku in March 2002 in an elaborate processional culminating in a traditional ceremony at the site. In January 2006, Evo Morales of the Movement Towards Socialism party (MAS) became president of Bolivia. Of Aymara descent, Morales held his inauguration ceremony at the site of Tiwanaku, dressed in traditional ceremonial robes, and standing in front of Tiwanaku’s monuments.

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203 Harris, Bolivia Resolves Dispute, Company Drops Demand over Water Contract Canceling.
205 Enever, Spiritual Return for Bolivian Monolith.
207 Arnold and Yapita, Strands of Indigenism in the Bolivian Andes: Competing Juridical Claims for the Ownership and Management of Indigenous Heritage Sites in an Emerging Context of Legal Pluralism.
208 Forero and Rohter, Bolivia’s Leader Solidifies Region’s Leftward Tilt.
Despite the competing claims over the site of Tiwanaku, some recognition exists by the Aymara of the benefits offered by other groups. Although the Aymara attempt to defend their political and cultural interests in the site of Tiwanaku against competing nationalist and World Heritage claims, the Aymara acknowledge that “if it were not for the vigilance of international organizations that have claimed the site [Tiwanaku] as World Patrimony, ‘it would have been dismantled already,’” 209

Chapter 4: The Gateway of the Sun

The Gateway of the Sun is considered the most significant single monument at the site of Tiwanaku and of all Bolivia. The cracked structure has become an icon to Bolivians, and the monument’s symbolism is often compared to that of the Liberty Bell. Indeed, the image of the Gateway was featured on a stamp produced by the Bolivian government in 1925, and re-issued again in 1960 with an edition of more than 14,000,000. The Gateway’s image has also been used on Bolivian money (Fig. 4.1) as well as appropriated by popular advertisements, such as one for a La Paz beer company, which uses the (imagined) vision of the sun rising over the Gateway of the Sun every June 21 on the day of the solstice.

4.1 Architectural Description and Construction

Made from a single block of andesite, the Gateway of the Sun is the grandest of the site of Tiwanaku’s portals. A large, precisely cut, rectangular stone block with a narrow doorway in the center, the Gateway was cracked into two pieces. As evident from the earliest visual documentation (Fig. 4.2), the Gateway of the Sun has been fractured since at least the early 19th century; however it is possible that the monument was broken hundreds of years earlier.

210 University of Pennsylvania Museum of Anthropology and Archaeology. http://tiwanaku.museum.upenn.edu
211 De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present, 6.
212 Vranich, Coping with Chaos, 65.
213 De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the
The Gateway was carved to form a large portal with niches on each face. The upper portion of the east façade exhibits an elaborately carved bas-relief frieze (Fig. 4.3) depicting a central deity, standing on a stepped platform, wearing a head-dress and holding a staff in each hand. The central “staff god,” as this figure is commonly called, is flanked by rows of anthropomorphic animals and a series of human faces. (Fig. 4.4) As with the other grand monuments at the site of Tiwanaku, the Gateway of the Sun was likely originally painted and inlaid with gold.

The Gateway’s reverse face, or east façade, is quite different than the front. The central doorway is flanked by two large niches on either side and above those niches are four smaller niches, two on each side. (Fig. 4.5) The niches are all framed by stepped molding, as is the doorway. The similar structures and forms found at the Pumapunku Complex have led some researchers to suggest that the Gateway of the Sun was intended to be the main entrance into that complex. The construction date of the Gateway is debated. Archaeologists generally accept that the Gateway was created late in the Tiwanaku period, after A.D. 550 However, stylistically, some researchers argue that the Gateway was constructed earlier between A.D. 200–400. The unfinished state of the Gateway is not understood. Possibly, construction on the Gateway was abandoned just before completion, or the detailed carving was intentionally conducted in phases.

In addition to the famous Gateway of the Sun, a number of other gateways, or remnants of gateways, have been found at the site of Tiwanaku, including the Gateway of

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the Moon. (Fig. 4.6) At the Pumapunku Complex, fragments of gateways similar to the Gateway of the Sun have been found. Sharing a number of characteristics with the Gateway of the Sun, these doorways were also monolithic, are plain on one side, and divided by a step molding on the other. This step molding wraps around the upper half of the Gateway in two steps. The Gateway of the Sun is set in a double-set recessed frame. The jambs and doorheads are beveled, so that the opening of the doorway is larger on one side than the other. Using an analogy to the niches found on a number of the stones, the researchers Protzen and Nair posit that the plain side with the smaller opening is the front or outside and the modulated side with the larger opening is the back or inside. The bas-relief frieze on the Gateway of the Sun, however, appears to be unique, as this type of elaborate carving does not appear on the other gateways. Although the form of the rectangular doors, windows, and niches, framed by one or more stepped frames is typical and repeated on many of the monuments at the site of Tiwanaku.

Protzen and Nair also argue that the Gateway of the Sun, despite being monolithic, is not a complete composition. The niche on the upper left is missing a section which would have been completed on another stone. The authors further suggest that pockets on either side of the doorway were intended to hold clamp sockets, suggesting that more building blocks would have been, or were intended to be, added to the Gateway in either plane, indicating that the Gateway was part of a more extended

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219 Protzen and Nair, On Reconstructing Tiwanaku Architecture, 364.
220 Protzen and Nair, On Reconstructing Tiwanaku Architecture, 154.
221 Protzen and Nair, On Reconstructing Tiwanaku Architecture, 364.
222 Protzen and Nair, On Reconstructing Tiwanaku Architecture, 364.
223 Young-Sanchez, Tiwanaku Ancestors of the Inca, 29.
224 Protzen and Nair, On Reconstructing Tiwanaku Architecture, 365.
Additionally, the similar carvings on the backs of the gateways found at the Pumapunku Complex has led some scholars to suggest that the Gateway was originally located there and not at the Kalasasaya Platform where the monument is currently located.

4.2 Excavation and Conservation History

The site of Tiwanaku was largely abandoned by A.D. 1000. Archaeological evidence has been found indicating ritual destruction and/or dismantling of the religious monuments at the site around the time of decline. No direct evidence, however, exists regarding the particular destruction of the Gateway of the Sun. The Spanish also were responsible for systematic destruction, although the extent to which this was practiced at the site of Tiwanaku is unclear. Archaeologists do not know whether the Gateway of the Sun was intentionally damaged.

The site of Tiwanaku was abandoned for hundreds of years when the Inca arrived, who were impressed by the scale and technique of the stonework at the site. By the time of the Spanish conquest, the Gateway of the Sun had become a source of interest and fascination. The Gateway of the Sun has long been documented and described. Perhaps the first record is from Cieza de Leon, who, in 1585, remarked upon the size of the Gateway and commented on the precise engravings of the sculptures. During the 19th century, a series of European travelers wrote about and documented the Gateway. (Fig. 4.7) Alcide d’Orbigny and Léonce Angrand from France completed a series of drawings.

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225 Protzen and Nair, On Reconstructing Tiwanaku Architecture, 365.
226 Young-Sanchez, Tiwanaku Ancestors of the Inca, 32.
227 De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present, 1.
and descriptions of the Gateway. D’Orbigny traveled to the site of Tiwanaku in 1833 and produced a number of drawings about the iconography and the monuments at the site. According to Andean Art Historian, Georgia de Havenon, d’Orbigny was the first to consider the symbolism of the Gateway’s carvings. Angrand visited the site of Tiwanaku in 1848 and produced a set of drawings, published in 1866, that are considered more accurate and precise than d’Orbigny’s depictions.

The next set of visual documentation was produced by Richard Inwards, a geologist from Britain, who traveled to the site of Tiwanaku in 1866. His illustrations of the Gateway were published in 1884 and present detailed sectional views as well as speculations on the Gateway’s iconography. Additionally, Inwood commented on the condition of the Gateway, noting that the monument has held up well to weathering.

The Germans Max Ulhe and Alphonse Stübel produced more detailed descriptions and visual documents, including the first known photographs of the Gateway. Perhaps the most accurate account of the 19th century was the monograph published by Ulhe and Stübel in 1892. The photographs were taken by Georges B. von Grumbkow during a visit to the site of Tiwanaku from 1876-1877. Uhle, who extensively photographed the site in 1894, also wrote a letter to the Bolivian government after being appalled by the looting and the lack of management at the site of Tiwanaku. Concerned about the conservation of the monuments at the site, Uhle desired the

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228 De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present, 1.
229 De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present, 3-4.
230 De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present, 6.
231 De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present, Die Ruinenstatte von Tiahuanaco.
deconstruction of the Gateway, along with a number of other monoliths, so that the monuments might be shipped to Berlin for their protection. Calling attention to the Gateway, Uhle writes,

> It is beyond comprehension that the officers of the Army can use the best architectural figure as a target practice. It is incomprehensible that it still stands there with innumerable bullet marks, that the children climb over the scaffolding destroying the precious reliefs of the Puerta del Sol, and the Indians destroy the cut stones that are truly works of great masonry.

Although Uhle’s letter seemed to attract some attention, mostly from the ruling elites, a scandal had erupted three years prior. In 1891 a secret sale of the Gateway of the Sun was attempted in an effort to take the monument to the Chicago Exposition of 1893, of which Bolivia participated. In response to the subsequent debate regarding ownership of the site of Tiwanaku, Uhle was forbidden to export the monoliths but was allowed to take “replicas” to Berlin. Additionally, many of the archaeological and cultural heritage laws that Bolivia passed around this time were in response to these scandals and debates about protection and ownership concerning the site of Tiwanaku and the increase of foreign interest in the site.

The Sintich Brothers were local photographers working in La Paz and were hired by Georges Courty of the Mission Scientifique Francaise a Tiahuanaco to photograph the site in 1903. The Sintich photos offer a valuable record of these excavations.

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233 Loza, *Max Uhle in the Bolivian Highlands*.
235 Loza, *Max Uhle in the Bolivian Highlands*.
236 Also at this time, many museums in Europe and the United States were interested in acquiring the Gateway of the Sun. Loza, *Max Uhle in the Bolivian Highlands*.
237 De Havenon, *The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present*, 4-5.
caption of the photograph of the Gateway of the Sun states that the relief was coated in chalk, presumably to allow easier photographing of the frieze.\textsuperscript{238}

The Bolivian-born Austrian, Arthur Posnansky, began studying the site in 1904 and published a thorough treatise on the site of Tiwanaku in 1945, which includes a number of images of the Gateway.\textsuperscript{239}

In the 1950s, the nationalist archaeologist Carlos Ponce Sangines began large-scale excavations of the site. The authenticity of his reconstruction of the Kalasasaya Platform remains questionable. Ponce Sangines is also responsible for the re-erection of the Gateway of the Sun and the presentation of the monument today. Erecting the two sections of the Gateway exactly where he found them in the northwest corner of the Kalasasaya Platform, Ponce Sangines fitted the pieces back together and then secured the entire structure in a base of concrete.

Although other archaeologists have worked on the site since, little attention has been given to the conservation of the Gateway of the Sun. Environmental monitoring was conducted at the site of Tiwanaku in 1990 by The Getty Conservation Institute and the Bolivian National Institute of Archaeology in response to the deterioration of the sandstone and andesite monuments and architecture at the site.\textsuperscript{240} The results of this monitoring program contend that the aggressive environment at the site of Tiwanaku greatly affects the deterioration and stability of the sandstone and andesite monuments. The andesite monuments, including the Gateway of the Sun and the Ponce Monolith, exhibit vertical cracks and extensive surface degradation. The authors concluded that

\textsuperscript{238} De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19\textsuperscript{th} Century to the Present, 5.
\textsuperscript{239} Posnansky, \textit{Tiahuanco: the Cradle of American Man}.
\textsuperscript{240} Maekawa, et al., Environmental Monitoring at Tiwanaku.
three main environmental factors contribute to the decay of the stone monuments at the sites: wind, water, and temperature. In combination, these factors are incredibly detrimental to the stone.

Most recently, the Foundation for the Research and Conservation of Andean Monuments conducted a study trip in 2004 to the site of Tiwanaku to evaluate the condition of the stone monuments at the site. In conjunction with DINAR, a preliminary examination revealed that the Gateway was not deteriorating at a rapid rate and appeared to be stable.\(^{241}\) Conservation architect Gionata Rizzi recommended that conservation interventions be undertaken to remove the biogrowth (likely algae and lichens) from the west façade of the Gateway, as well as consider the consolidation of the small pits found all over the monument. Rizzi also suggested future measures, including a complete condition assessment, photogrammetric documentation and laser scanning, and the making of a rubber mold, in addition to careful monitoring. Also noted was a report, of unknown source, that the Gateway of the Sun had been treated with a fluoro-silicate in the 1930s.\(^{242}\)

### 4.3 Iconography, Interpretation

Different interpretations have been posited concerning the iconography of the Gateway’s carvings. Archaeologist Alan Kolata has argued that the central staff figure represents “a celestial high god that personified various elements of natural forces intimately linked with the productive potential of the altiplano: the sun, wind, rain, hail—

\(^{241}\) De Havenon, The Power of an Icon: References to the Gateway of the Sun from the 19th Century to the Present, 6.

\(^{242}\) Rizzi, Tiwanaku: Notas Sobre Conservación y Presentación; Rizzi, personal interview with the author, April 2006.
in brief, a personification of atmospherics that most directly affect agricultural production in either a positive or negative aspect.” 243 Kolata contends that this high god was a representation of the Aymara weather god, Thunupa. He interprets the stepped platform on which the figure is standing as the Pumapunku Complex or the Akapana Pyramid. All of the frontal human faces on the relief are images of Thunupa, while the figures running or kneeling in profile are subsidiary.

These carvings were interpreted by Posnansky, on the other hand, as a calendar; each of the twelve masked front-facing figures represent each of the twelve months in the year.244 Most recently, archaeo-astronomist Leonardo Benitez has carried out experiments based on the interpretation of the Gateway as a solar calendar and has related the pillars of the west wall of the Kalasasaya Platform to this calendar.245

The carvings have been variously interpreted as a calendar, records of the lunar and solar cycles, and a system of writing. One of the most accepted current interpretations is that the engravings relate to a calendrical system.246 However, many scholars have argued instead that the central staff god figure is Viracocha, the creator god of the Inca.247 For example, archaeologist Johan Reinhard offers a thorough discussion of the anthropomorphic figures carved into the Gateway’s lintel and contends that the central staff god figure can be interpreted as a representation of a deity that controlled meteorological phenomenon as well as the fertility of plants and animals.248

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244 Kolata, Tiwanaku Ceremonial Architecture and Urban Organization, 200.
245 Benitez, personal interview with the author, March 2006; Benitez, *A Unique Lunisolar Observatory and Calendar in Precolumbian Bolivia*.
246 Benitez, A Unique Lunisolar Observatory and Calendar in Precolumbian Bolivia.
247 Reinhard, Tiahuanaco, Sacred Center of the Andes, 211.
248 Reinhard, Tiahuanaco, Sacred Center of the Andes, 213-217.
Regardless of the interpretation, this deity figure has a long history in the Andes and is found throughout the region. The symbols on the Gateway of the Sun have been found throughout the site of Tiwanaku, including on ceramics, textiles, stone, and bone carvings; and across the Andean region both before and after the Tiwanaku era.

### 4.4 Current Presentation

Currently, the Gateway of the Sun sits in the northwest corner of the Kalasasaya Platform, the front facing east into the Kalasasaya Platform. Based on earlier photographs and drawings, the Gateway was re-erected in the exact location in which it was found by Ponce Sangines in the 1950s. Further excavated and exposed, the Gateway was erected, the two broken pieces fitted together, and the entire base of the monument inserted into a cement slab. A relatively recent barbed wire fence divides the Gateway platform from the rest of the Kalasasaya Platform. (Fig. 4.8)

A number of different options have been suggested for addressing the presentation issues of the Gateway. One, the original Gateway may be moved inside the museum on site and a replica may be situated in its current location. Two, a shelter may be constructed over the monument if the Gateway is determined to be at risk for further deterioration. Three, the Gateway could simply be left as is. Four, the Gateway should be moved to a location deemed more appropriate based on archaeological and archaeoastronomical research. And five, some conservation interventions should occur, such as removing the lichens, cleaning the stone, or removing the stone from its concrete

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250 Young-Sanchez, *Tiwanaku Ancestors of the Inca*, 32.
encasement. Removing the stone from the concrete, if the structure is deemed to be stable, is not just aesthetic as encasing stone in concrete can cause serious conservation problems and accelerate other decay mechanisms. Additional aesthetic adjustments might include removing the barbed wire fence or designing an alternative boundary to restrict access to the Gateway.
Chapter 5: Mechanisms of Stone Decay: An Overview

Stone deterioration is a continuous and complex process influenced by physical, chemical, and biological mechanisms. As determined by various agents, the deterioration of stone is the overall result of many interacting factors between the stone and the environment. The importance of each mechanism varies according to the environmental conditions, the stone type, and the stone’s state of preservation. Moreover, the combined affect of multiple mechanisms is greater than the impact of any one mechanism. The most common deterioration mechanisms for stone in general are discussed in this chapter: salt damage; atmospheric pollution; freeze-thaw and thermal cycling; wind erosion; chemical weathering; biodeterioration; and human influences. The purpose of this section is to provide an overview of the most frequent causes of stone decay. An analysis of the specific deterioration mechanisms affecting the Gateway of the Sun are discussed in Chapters 7 and 8.

5.1 Salt Damage

The presence of salts is extremely destructive to porous materials and is commonly considered the most dangerous decay mechanism for stone.\textsuperscript{251} Salts originate

\textsuperscript{251} Many researchers have studied the mechanisms of deterioration of porous materials due to the presence of salts. Thousands of articles on the topic have been published but the phenomenon is still poorly understood. For recent research advances see Charola, “Salts in the Deterioration of Porous Materials: An Overview”; Charola and Pühringer, “Salts in the Deterioration of Porous Materials: A Call for the Right Questions”; Colston, Watt, and Munro, “Environmentally-Induced Stone Decay: The Cumulative Effects of Crystallization-Hydration Cycles on a Lincolnshire Oopelsparite Limestone”; Lewin, “The Mechanism of Masonry Decay Through Crystallization”; Pühringer, “Hygrothermic Deterioration of Materials by Salts: A Technical Approach”; Scherer, “Stress From Crystallization of Salt in Pores”; Snethlage and Wendler, “Moisture Cycles and Sandstone Degradation”; For a useful background on salt damage see Winkler,
from various sources including air pollution, deicing salts, sulfates and chlorides from groundwater rising through the masonry, sea spray, inappropriate treatments, or interaction among materials.\textsuperscript{252} The effectiveness of salt action depends on the kinds of salts present, the size and shape of the capillary system of the stone, the moisture content, and the degree of exposure to solar radiation.\textsuperscript{253}

Understanding moisture movement through porous materials is necessary in identifying the impact of salts and moisture.\textsuperscript{254} Water enters and moves through a porous material in liquid or vapor forms. In the liquid state, two mechanisms operate: capillarity and/or infiltration. Capillarity is the result of the surface tension of liquid and the attraction of water to the capillary material. Infiltration requires hydrostatic pressure and depends on the permeability of the material. In the vapor state, water may enter a porous material through surface condensation, micro-condensation, (capillary condensation in pores) or hygroscopicity.\textsuperscript{255} Hygroscopicity broadly covers different processes for absorbing or attracting moisture from the air. The stone material can absorb or adsorb a certain amount of moisture. Salts may additionally absorb moisture, particularly when the relative humidity increases over the equilibrated relative humidity of the salts. Specifically, soluble salts are then able to absorb sufficient vapor to form a saturated solution. Salt solutions have a lower vapor pressure than pure water and tend to

\textsuperscript{253} Winkler, “Weathering and Weathering Rates of Natural Stone”, 88-89.
\textsuperscript{254} Salts enter and move through porous bodies only when dissolved in water, therefore understanding moisture movement is extremely important as the combination of salts and moisture impact porous materials together.
condense water vapor from the environment in order to reach equilibrium. Changes in relative humidity will cause partial crystallization and dissolution of the salts. A salt solution that contains different salts will have a wider range of relative humidity. The effect of a mixed solution within the pore system of a stone will be compounded by the hygroscopicity and capillary condensation ability of the stone, further increasing the deterioration potential of the salt.

Ground moisture, which includes components from the soil and rain, travels from the ground upward through capillary action. Salts are transported up to the capillary fringe, where the moisture tends to evaporate, leaving the salts behind. A “wetline” can develop, often associated with a rim of efflorescence and invisible subflorescence beneath the stone’s surface. Concentration of hygroscopic salts around the wetline can lead to further attraction of moisture, especially at high relative humidity. The deposition of salts close to the surface of the stone will manifest in the form of blistering, spalling, flaking or powdering. The actual distribution of moisture within stone depends on the rock’s porosity and pore-size distribution, and the environmental conditions.

A complex phenomenon that researchers do not fully understand yet, several deterioration mechanisms are associated with the presence of salts, including hydrostatic pressure, linear crystal growth pressure, and hydration pressure. Salt damage, however, is

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257 Snethlage and Wendler, “Moisture Cycles and Sandstone Degradation”, 9
largely attributable to two mechanisms: the crystallization of salts from solution and the hydration of salts. A third mechanism is the process of thermal expansion. 262 Any salt is capable of creating crystallization damage, whereas hydration damage can be caused only by salts that exist in more than one hydration state. Sodium chloride, for example, can only cause crystalline damage, while sodium sulfate can cause both crystalline damage and hydration damage.263

These mechanisms vary among the different types of stone and among salts with different solubilities.264 Hydration pressure occurs from the volume increase upon the wetting (and expansion) of the salts.265

Salt crystallization is viewed by some researchers as an oversimplification.266 The deterioration of stones due to the presence of salts is not the result of a single “salt crystallization” mechanism but rather several mechanisms operating simultaneously.267 Crystallization of salts in stone causes pressurized stresses when a growing crystal encounters a pore wall.268 Four stages of crystal growth have been identified which depend primarily on the humidity of the stone.269 The expansion and contraction experienced by stone, particularly those that contain clay are enhanced by the presence of

267 Such mechanisms include the formation of salt-films and the resulting stresses they induce in the substrate or the wedge action exerted by growing crystals in fissures. Charola and Pühringer, “Salts in the Deterioration of Porous Materials: A Call for the Right Questions”, 433.
269 Arnold and Zehnder, “Salt Weathering on Monuments”. 80
salts. Salts exhibit the opposite action, contracting upon wetting and expand upon drying.\textsuperscript{270}

If the stone contains soluble salts, those salts will become mobile if sufficient water or vapor moisture is present to affect dissolution. A decrease in the ambient relative humidity at the exposed surface will cause the dissolved salts to migrate towards the surface, while surface water evaporates in the attempt to equalize with the change in relative humidity. At some point, the salt concentration will be sufficient enough such that should crystallization occur, the pressure exerted against the pore walls will deteriorate the stone. However, other factors such as thermal and moisture cycling, temperature, and relative humidity will affect the patterns of deterioration.\textsuperscript{271}

The growth of salt crystals within the pores of a stone can generate stresses powerful enough to overcome the stone’s tensile strength and turn the stone into powder. The site of crystallization on the stone is determined by the balance between the rate of escape of water from the surface and the rate of re-supply of solution to that site. This balance determines the form of the decay. If the rate of re-supply keeps pace with the rate of evaporation, the solute deposits on the surface will effloresce. If the rate of resupply is slower than that of evaporation, a dry zone develops just beneath the surface. Solute is deposited within the stone at the boundary between the wet and dry regions, causing spalling, flaking, or blistering.\textsuperscript{272} The site of crystallization can be predicted by the physical-chemical laws governing capillarity, viscous flow, and diffusion. These laws

\textsuperscript{270} Snethlage and Wendler, “Moisture Cycles and Sandstone Degradation”, 9; Charola, “Salts in the Deterioration of Porous Materials: An Overview”.
\textsuperscript{272} Lewin, “The Mechanism of Masonry Decay Through Crystallization”, 120.
govern the quantitative relationship between porosity of the masonry and the dimensions of the flakes, blisters, or spalls that develop as well as the manner in which the decay progresses.\textsuperscript{273} The damage will generally occur in the area of maximum moisture content and the type of deterioration will depend on the location of the moisture in the stone. For example, if the area of maximum moisture content is at the stone surface, the type of damage that will occur results in scaling and disaggregation.\textsuperscript{274}

Wetting and drying cycles are part of the processes leading to damage by salt crystallization even if the moisture is in vapor form rather than liquid water.\textsuperscript{275} Repeated wet-dry cycling can cause material fatigue.\textsuperscript{276}

\subsection*{5.2 Atmospheric Pollution}

Air constituents and contaminants determine the rates of some forms of chemical attack and are often a precursor to physical or chemical decay of porous materials. Natural constituents, such as carbon dioxide and sea-salt aerosol play a role in stone deterioration in addition to manufactured pollutants.\textsuperscript{277}

Acid precipitation originating from air pollution can occur as wet and dry deposition.\textsuperscript{278} Dry deposition results from the transfer of pollutant gases and/or particles from the atmosphere to the stone surface in the absence of rain.\textsuperscript{279} This type of deposition generally originates from nearby sources, therefore is also referred to as short-range

\textsuperscript{273} Lewin, “The Mechanism of Masonry Decay Through Crystallization”, 120.
\textsuperscript{274} Snethlage and Wendler, “Moisture Cycles and Sandstone Degradation”, 17.
\textsuperscript{275} Porous materials exhibit hygric and hydric expansion and contraction as a result of moisture changes.
\textsuperscript{276} Snethlage and Wendler, “Moisture Cycles and Sandstone Degradation”, 9.
\textsuperscript{277} Tombach, “Measurement of Local Climatological and Air Pollution Factors Affecting Stone Decay”.
\textsuperscript{278} Charola and Ware, “Acid Deposition and the Deterioration of Stone: A Brief Review of a Broad Topic”, 393.
\textsuperscript{279} Charola and Ware, “Acid Deposition and the Deterioration of Stone: A Brief Review of a Broad Topic”, 393.
deposition. The deposition of pollutants occurs in the boundary layer at the surface of the stone and the rate of deposition is affected by the level of concentration of the pollutants, air turbulence, roughness and heterogeneity of the surface, chemical affinity of the surface for the pollutant, and surface moisture.

Wet deposition consists of pollutant substances incorporated in cloud droplets, otherwise called ‘acid rain.’ Dry deposition is of greater importance than wet deposition, which affects only the exposed stone surfaces. Dry deposition, on the other hand, can affect all structural surfaces. Although atmospheric pollution has garnered increased attention and the role of acid rain in stone deterioration has been well documented, the impact and study of dry deposition has not been as well investigated despite its severe impact.

5.3 Freeze-Thaw and Thermal Cycling

Freezing and frost shattering and the associated effects are extremely detrimental to stone material. The loss of water by evaporation and by “cryosuction” (movement of an ice-water mixture from the interior towards the object’s surface) during freezing

280 Charola and Ware, “Acid Deposition and the Deterioration of Stone: A Brief Review of a Broad Topic”, 393.
281 Charola and Ware, “Acid Deposition and the Deterioration of Stone: A Brief Review of a Broad Topic”, 394.
282 Charola and Ware, “Acid Deposition and the Deterioration of Stone: A Brief Review of a Broad Topic”, 397-398.
283 Charola and Ware, “Acid Deposition and the Deterioration of Stone: A Brief Review of a Broad Topic”, 395.
284 The role of acid rain in the deterioration of stone has been well researched. See for example Amoroso and Fassina, Stone Decay and Conservation; various Sadeghi and Pancellia, eds., Proceedings of the 1995 LCP Congress 1995; International Conference on Stone Weathering and Atmospheric Pollution (SWAPNET) 2001; Smith and Warke, eds., Processes of Urban Stone Decay; Winkler, Decay of Stone, Monuments and Buildings: The Role of Acid Rain.
285 Camuffo, “Perspectives on Risks to Architectural Heritage”, 69-70.
cycles is a major cause of stone deterioration.\textsuperscript{286} Inherent mineral inclusions in the stone can cause stress on the surrounding stone during freeze-thaw cycles.\textsuperscript{287} When water freezes in the capillary spaces, the resulting expansion causes the stone to crumble along the interfaces of the inclusions. Once begun, these fissures continue to increase in size, facilitating further deterioration due to other mechanisms such as air pollution, salt re-crystallization, and mechanical damage, thus increasing the rate of decay over time.\textsuperscript{288} These mineral inclusions retain liquid water. Upon freezing, the inclusions and any surface of the stone that may be covering the inclusion will rupture. The ruptured stone surface can appear as blistered or pitted.\textsuperscript{289} The results of freeze-thaw damage can also manifest as deep cracking, surface scaling, and exfoliation.\textsuperscript{290}

The impact of freeze-thaw cycling results from a combination of factors, including volumetric expansion of the ice phase; degree of saturation of the pore system; pore size distribution; continuity of the pore system; relative humidity; and the presence of salts.\textsuperscript{291} Temperature variations around the freezing point cause more serious damage than continuous freezing. Therefore, the number of freeze-thaw cycles is important to estimate.\textsuperscript{292} Many studies have shown the importance of solar radiation on weathering. Temperature is one of the most significant factors in stone deterioration, “operating indirectly through its control on moisture movement and processes such as salt weathering and freeze-thaw and, possibly, directly through ‘insolation weathering’.

\textsuperscript{287} Lewin and Charola, “Stone Decay due to Foreign Inclusions”, 205.
\textsuperscript{288} Lewin and Charola, “Stone Decay due to Foreign Inclusions”, 205.
\textsuperscript{289} Lewin and Charola, “Stone Decay due to Foreign Inclusions”, 210.
\textsuperscript{290} Amoroso and Fassina, Stone Decay and Conservation: Atmospheric Pollution, Cleaning, Consolidation and Protection, 23.
\textsuperscript{291} Winkler, Stone in Architecture, 250-252.
\textsuperscript{292} Winkler, Stone in Architecture, 250.
(structural deterioration of stone by repeated thermally induced expansion and contraction of surface material).” Sunlight has a great impact on heating-cooling cycles and moisture availability, which may accelerate rates of surface recession. Stone can be heated on one side so rapidly that parts of the surface will break away from the cooler underlying mass. If repeated often enough, thermal cycling by solar radiation can lead to surface decay. Repeated thermal cycling can also lead to microcracking at the mineral boundaries, making an otherwise durable stone susceptible to salt crystallization.

Temperature is characterized by two main frequencies, yearly and diurnal. Yearly averages alone are of little importance. Rather, the seasonal variation should be represented with monthly averages and the diurnal with the daily range. Especially in areas where solar radiation is intense and nocturnal cooling leads to very low temperatures (like at the site of Tiwanaku), diurnal cycles occur for several months a year. The resulting weathering can be very intense. The temperature of the air affects stone deterioration, causing damage to occur when the freezing point is crossed. Additionally, most chemical reactions proceed more quickly as temperature increases. Solar insolation (the radial cooling of stone at night) can cause the condensation of water on an otherwise dry surface.

295 Honeybourne, “Weathering and Decay of Masonry”, 164.
296 Honeybourne, “Weathering and Decay of Masonry”, 164.
297 Camuffo, Environment and Microclimate, 41.
298 Camuffo, Environment and Microclimate, 42.
299 Camuffo, Environment and Microclimate, 42.
Solar insolation and the resulting expansion and contraction can be a direct cause of surface decay. Important factors influencing thermal cycling are the absorptive capacity of the surface, the thermal expansion coefficient, and the elasticity of the material. The heating of the stone surface also depends on the rate of evaporation, which is in turn affected by relative humidity, wind strength and moisture content.\textsuperscript{300} A surface’s absorption capacity is further influenced by chemical contamination or biological origin, as well as coverage of biogrowth.\textsuperscript{301}

Changes in temperature induce differential expansions in the materials and tensile strengths between the surface and the subsurface structure. Temperature cycles induce a number of mechanical weathering mechanisms and accelerate fatigue failure. More rapid cycles produce a greater temperature gradient inside the material, resulting in faster damage in the surface layer.\textsuperscript{302} Additionally, shorter fluctuations in temperature affect thinner layers of the stone surface. For this reason, daily or shorter temperature cycles are more important than seasonal cycles.\textsuperscript{303} Cycles are dangerous when they create gradients inside stone. In addition to cycling, spatial gradients and time rates are also important. Quick variations generate differential expansions on the outer layer of the monument, causing mechanical stress and fatigue. Therefore, daily cycles can be extremely detrimental.\textsuperscript{304}

Thermal cycles cause mechanical disaggregation of outer surface layers, beginning at the discontinuities included in the rock and at the interfaces between the

\textsuperscript{300} Rosvall, “Air Pollution and Conservation”, 216.
\textsuperscript{301} Rosvall, “Air Pollution and Conservation”, 216.
\textsuperscript{302} Camuffo, \textit{Microclimate for Cultural Heritage}, 10-11.
\textsuperscript{303} Camuffo, \textit{Microclimate for Cultural Heritage}, 11.
\textsuperscript{304} Camuffo, Perspectives on Risks to Architectural Heritage, 68.
different minerals that form the stone. Water activity is superimposed on top of this disaggregation. Additionally, granules of greater size will deteriorate faster from the internal tension. Granular disintegration is often found on stones with granular or crystalline texture, like andesite, where stresses generated between grains or large crystals are differently oriented and have different expansion coefficients, producing fatigue failure along the grain or crystal interfaces.

Building orientation can influence the impact of climatic extremes on different facades, such as freeze-thaw cycles, heating-cooling, and wetting-drying cycles. All of these cycles create stresses in stone, although freeze-thaw cycles are potentially more damaging. Temperature and moisture conditions are key parameters in the mechanical weathering processes of stone. Rather than simply an issue of extreme climatic conditions, cyclic changes have greater affects on stresses and strains in stone and their deterioration over time. Further, the combination of freeze-thaw and thermal cycling is extremely detrimental.

5.4 Wind Erosion

Wind affects the abrasion or impact of particles on a stone, as well as increasing the evaporation rate of moisture. Dry winds can cause mechanical stress and erosion

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due to windborne abrasive particles and force evaporation in monuments, causing salt efflorescences.\textsuperscript{310}

Wind can also cause rain to impact on vertical surfaces by generating driving rain.\textsuperscript{311} Moreover, wind affects the absorption of moisture into a monument. Wind can drive water into the monument and the lift displaces the moisture along the surface. Additionally, wind gusts will cause a fluctuating pressure between the interior and exterior of the monument, which may force water in the layer running over the surface into the cavities and pores of the structure.\textsuperscript{312}

\subsection*{5.5 Chemical Weathering}

Physical and chemical weathering have usually been studied as separate processes; recent research, however, has shown that most processes are physiochemical in nature. Physical weathering is generally defined as alterations caused by freeze-thaw action, solar insolation, salt crystallization and hydration pressures, plant root action, and heat. Chemical weathering is generally defined as alterations caused by the dissolution of carbonates and sulfates, followed by oxidation and hydration. However, the process is more complex and not readily separated into distinct physical and chemical categories. For instance, crystallization and hydration pressure are both physical and chemical processes. There is also evidence for chemical reactions between salts and masonry leading to the formation of new compounds.\textsuperscript{313}

\textsuperscript{310} Camuffo, “Environment and Microclimate”, 41.
\textsuperscript{311} Winkler, \textit{Stone in Architecture}, 138.
\textsuperscript{312} Camuffo, \textit{Microclimate for Cultural Heritage}, 174.
\textsuperscript{313} Winkler, “Weathering and Weathering Rates of Natural Stone”, 85
Alteration of primary minerals by chemical weathering can create areas that are more susceptible to physical weathering processes such as freeze-thaw action. Mineral alteration may also change other important stone properties such as porosity and permeability. Increases in pore size resulting from chemical dissolution may alter a stone’s response to mechanical weathering processes such as freeze-thaw action by enhancing moisture penetration.\footnote{McGreevy, et al., “Controls on Stone Temperatures and the Benefits of Interdisciplinary Exchange”, 261-271.}

5.6 Biodeterioration

Biodeterioration damage is caused by microbes, including bacteria, algae, fungi, and lichens and higher organisms including mosses, plants, insects, and mammals, which may cause mechanical and chemical damage to stone.\footnote{Koestler, et al., “Biodeterioration: Risk Factors and Their Management”, 25.} Biodeterioration is especially important in areas where air pollution is not too elevated\footnote{Camuffo, “Perspectives on Risks to Architectural Heritage”, 71.} (such as at the site of Tiwanaku).

Bacteria affects stones only chemically, whereas higher plants and animals attack stone both physically and chemically. Bacteria has little impact upon sound stone; upon initial weathering, however, fungi begin to attack and a weathered rock may develop a large bacterial population among the cracks and along the surfaces.\footnote{Winkler, \textit{Stone in Architecture}, 218.}

Little is known about the extent of damage that lichens can cause on stone structures, but they do play an important role as pioneer organisms in colonizing rocks.\footnote{Kumar and Kumar, \textit{Biodeterioration of Stone in Tropical Environments}, 20.} The affects of lichens are both chemical and physical, although researchers disagree as to...
which kind of attack is more detrimental. Lichens contribute to the mechanical
weathering of rocks in four ways. Lichens penetrate the stone through their mycobiont
hyphae and rhizines into existing cracks and crevices, enlarging the existing fissures and
creating new ones. Expansion and contraction of the lichen thallus from daily and
seasonal changes in ambient temperature and humidity causes stress inside the stone.\textsuperscript{319}
Surface stresses can also result from the shrinking of the lichens upon drying.\textsuperscript{320} Further,
lichens produce organic salts which swell and lichen thallus fracture and incorporate
mineral fragments.\textsuperscript{321}

Chemical damage, however, may be more critical through the secretion of oxalic
acid, the generation of carbonic acid, and the formulation of other acids capable of
chelating metal ions.\textsuperscript{322} Damage to the stone can result from the chemical changes caused
by the corrosive action of carbon dioxide emitted by respiration and to the chelating
effect of some metabolic products.\textsuperscript{323}

Lichens can survive in a wide range of habitats, including those normally hostile
to other life forms. However, the ultimate affect of lichens varies according to the stone
type and structure. Lichen attack on silicate stones, such as andesite, appears to mainly be
on micas. Removing lichens through biocide treatment is not always successful, and may
cause more harm. Even after biocides are applied, the thallus hyphae remain embedded in

\textsuperscript{319} St. Clair and Seward, “Biodeterioration of Stone Surfaces: Lichens and Biofilms as Weathering Agents
of Rocks and Cultural Heritage”, 1-8.
\textsuperscript{320} Honeybourne, “Weathering and Decay of Masonry”, 168.
\textsuperscript{321} St. Clair and Seward, “Biodeterioration of Stone Surfaces: Lichens and Biofilms as Weathering Agents
of Rocks and Cultural Heritage”, 1-8.
\textsuperscript{323} Romao, “Understanding Lichens Colonisation on Granitic Substrata”, 305.
the stone. If the hyphae are removed, the stone is weakened, allowing the entrance of acid rain and other pollutants.\textsuperscript{324}

Other low plant forms such as algae, fungi, and mosses, also extract ions from the stone through the production of carbonic, nitric, sulfuric, and other weak acids. Physical damage from higher plants includes axial and radial pressures and advanced animals may bore into stones either by mechanical action or chemical secretions.\textsuperscript{325}

5.7 Human Influences

Humans negatively impact the condition and longevity of stones in many ways. Direct damage can be caused by quarrying, construction, tooling, previous conservation interventions, and use. Indirectly, human impact on environmental conditions, climate, development, and poor management can greatly affect the deterioration of stone.

Directly, the way a structure or object is constructed may result in damage. Humans cause unique weathering agents such as quarrying and the production of organic wastes.\textsuperscript{326} The extraction method used for quarrying stone can sometimes be a cause of deterioration. Additionally, carving using too much force or dull tools can create microscopic fissures inside a stone. Tooling and other forms of working stone can cause the formation of microcracks.\textsuperscript{327} Inaccurate positioning of cramps and dowels can lead to fractures and an increase in stress concentrations.\textsuperscript{328}

\textsuperscript{324} Camuffo, “Perspectives on Risks to Architectural Heritage”, 72.
\textsuperscript{325} Animals that bore by chemical secretion only affect carbonate rocks, not silicate rocks like andesite. Winkler, \textit{Stone in Architecture}, 220-230.
\textsuperscript{326} Pope and Rubenstein, “Anthroweathering: Theoretical Framework and Case-Study for Human Impacted Weathering”, 248-249.
\textsuperscript{327} Amoroso and Fassina, \textit{Stone Decay and Conservation: Atmospheric Pollution, Cleaning, Consolidation and Protection}, 7.
\textsuperscript{328} Honeybourne, “Weathering and Decay of Masonry”, 171.
Indirectly, humans exert widespread influences on the environment, greatly affecting the weathering and decay of materials. A variety of human activities affect the mechanical and chemical processes associated with stone deterioration, including industry, habitation, agriculture, commerce, and recreation.\textsuperscript{329} The impacts of agriculture, excavation, construction, and conservation have a major effect on weathering.\textsuperscript{330}

The history of human use of an object or structure greatly affects the weathering of the stone. Tourism, including casual touching from visitors, additions to humidity, pollution, and waste, all contribute to the deterioration of stone. Moreover, inappropriate use, lack of care or maintenance, and inadequate or poor past preservation actions, may all cause damage to stone material. Other human-related damage includes war, vandalism, looting, neglect, economic development, uncontrolled tourism, careless management, lack of governmental policy or lack of enforcement of protective legislation.

\textit{5.8 Importance of Moisture}

The mechanisms of stone decay almost always require the presence of water in either liquid or gaseous form and many of the mechanisms require the presence of foreign materials in the stone or on its surface. These impurities come from wet or dry atmospheric deposition or are the chemical by-products of reactions with atmospheric

Moisture is critical for the chemical reaction of stone constituents, the transportation of soluble salts, and the wet deposition of atmospheric pollutants. Most of the damage to stone occurs not during the absorption process, but rather during the drying processes. The drying, or evaporation, of moisture is governed by environmental conditions such as temperature, relative humidity, and the velocity of air near the stone surface, in addition to internal factors such as the pore system.

5.9 Intrinsic versus Extrinsic Mechanisms

Factors affecting stone decay are often categorized as either extrinsic or intrinsic, although they are inherently interconnected and facilitate one another. Internal factors affecting stone decay, in addition to the type of stone itself, include the clay mineral content, which greatly affects the longevity of stone. Pore space is the other major intrinsic factor in the deterioration of stones, but is still a subject that needs to be more fully understood. For instance, pores are prevalent in highly porous sedimentary rocks while fissures predominate in low-porosity igneous and metamorphic rocks. Porosity, capillary rise, permeability and pore size distribution are also important parameters regarding a rock’s susceptibility to frost. For example, damage by frost and freeze/thaw is more likely to occur in materials that show a prevalence of small pores in the pore size distribution. In small pores, condensation occurs at a lower relative

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331 Tombach, “Measurement of Local Climatological and Air Pollution Factors Affecting Stone Decay”, 198.
332 Amoroso and Fassina, Stone Decay and Conservation: Atmospheric Pollution, Cleaning, Consolidation and Protection, 12.
humidity due to the curvature of the meniscus, therefore stones with small pores have a greater probability of being filled with water and then experiencing freeze-thaw cycles.\textsuperscript{335}

Countless extrinsic deterioration mechanisms include atmospheric conditions, faulty design, excessive loads, improper use, seismic action, landslides, foundation settlement, excessive heat, and volume change due to hydration of minerals, water absorption, thermal expansion and swelling of clay minerals.

Tombach and Winkler are two authors who have categorized weathering agents.\textsuperscript{336} Tombach classifies atmospheric conditions into available moisture (rain, fog, humidity); temperature of the air; cooling and heating of surfaces (by wind and radiation) and evaporation and condensation of moisture on them; motion of the air (wind); presence of air constituents and contaminants (gaseous and aerosol).

Winkler classifies stone weathering mechanisms into three factors: atmosphere, moisture, and the presence of salts. A fourth mechanism is plants, bacteria, and animals that can cause damage and add to the effects of deterioration already in process. Atmospheric agents include solar and ultraviolet radiation, carbon dioxide and monoxide, ozone, sulphates, chlorides, nitrates, acid rain, relative humidity, fog, and wind action. Moisture is available the form of rain, relative humidity, ground moisture, leaking pipes and gutters, and construction moisture. Capillary movement and the suction of moisture into the capillary system and the pore structure of the stone is another, significant, source and entry point for moisture. Additionally, related cycling including wet-dry cycles and heating-cooling cycles contribute to case hardening and spalling. Salts, perhaps the most

\textsuperscript{335} Camuffo, “Environment and Microclimate, 42; Sherer, Stress From Crystallization of Salt in Pores”.
\textsuperscript{336} Tombach, “Measurement of Local Climatological and Air Pollution Factors Affecting Stone Decay”; Winkler, \textit{Stone in Architecture}. 

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damaging, come from different sources and can cause both efflorescence and subflorescence. Damage by salt action occurs from crystallization pressure, hydration pressure, erosion from deicing salts, and differential thermal expansion.\textsuperscript{337} The environment affects masonry on the mesoscale, microscale, and macroscale levels through the amount of precipitation (in total and throughout the year), temperature as conditioned by solar radiation, cloud cover and advection, as well as the altitude of the site.

5.10 Conclusion

A multitude of intrinsic and extrinsic factors impact and accelerate the natural weathering of stones. Internal mechanisms, such as porosity and clay content, are greatly affected by extrinsic agents. The extent and rate of damage from external mechanisms, in turn, is largely controlled by the inherent properties of the stone. In addition to atmospheric pollution, the influence of humans on stone deterioration has been clearly shown. Stone deterioration mechanisms are traditionally categorized as either extrinsic or intrinsic and as physical or chemical processes. Although helpful for understanding the matrix of factors affecting the deterioration of stone, these mechanisms clearly interact.

Smith et al. provides a useful summary of stone weathering.\textsuperscript{338} Weathering processes are polygenetic—the result of more than one process. Weathering may be divided into two categories: high frequency/low magnitude events like surface dissolution and low frequency/high magnitude events like the breaking away of large surfaces.

\textsuperscript{337} Winkler, “Decay of Stone Monuments & Buildings: The Role of Acid Rain”; Winkler, \textit{Stone in Architecture}.
Weathering is not continuous but rather episodic and characterized by periods of quiescence interspersed with episodes of rapid change. Physical weathering depends on the strength of the stone and the magnitude of the stresses. Over a long period of time there is a progressive reduction in strength due to, for example, chemical alteration of fatigue failure and stresses that increase over time such as salts and cycling. Decay, therefore, often progresses in a step fashion and measuring surface loss during periods of inactivity can lead to an underestimation of long-term decay rates. Weathering is concentrated not only temporally but also spatially across the stone.

In order to understand the deterioration mechanisms affecting stone, a broad range of factors including stone formation, construction technique, macro- and micro-climate, and human impact must be studied. The impact of these factors depends on the time of day and season of the year as well as on large scale climatic phenomena and human activities.  

Conservators and scientists have employed numerous methods for measuring the deterioration of stone in situ. In addition to describing decay and understanding the extent and severity of deterioration, the importance of establishing weathering rates is increasingly recognized by conservation professionals. "Being able to identify weathering forms and the nature and rate of their development over time within specific environmental conditions could be of great use in trying to develop strategies for the prevention of such forms."\(^{340}\) Discussions have been widespread within the field of architectural conservation regarding the need to gauge the current condition of an object or monument, compared to its original or previous condition, in order to inform conservation or intervention decisions.

Past researchers have attempted to establish rates of weathering for different types of rocks. Recently, attempts at predictive modeling and risk management have added an additional layer to the studies of weathering rates. Research into measuring rates of deterioration is increasingly being directed toward predicting future behavior under different conditions in order to aid policy and conservation decisions. Although much research has been undertaken into determining recession rates of rocks, site-specific climatic and environmental contexts and variable rock morphologies pose serious difficulties in establishing uniform rates. Depending on the case in question, established

weathering rates are often not applicable. The literature on weathering rates for stone varies from efforts to determine universal weathering rates, to specific case studies that address only particular sites and monuments with no attempt to apply the findings to other scenarios. Various methods for measuring stone weathering have been employed in the past, and researchers continue to develop new approaches, including, in more recent years, computer-aided methodologies.

As discussed in the previous chapter, stone decay is a complex phenomenon, and is often the result of several degradation mechanisms acting simultaneously. The conditions of the Gateway of the Sun will be analyzed in detail in Chapter 7. In addition to a description of the conditions and the decay mechanisms involved, however, a quantitative measurement of decay will be an invaluable tool in ultimately making an analytic assessment of the material and deciding upon appropriate conservation interventions. The methods used to measure stone decay in situ will be explored in this chapter. Although most of these techniques will not be applied in this study, the hope is that future research might benefit from this overview and that one or more of these methods might be utilized for future study of the Gateway of the Sun.

A wide range of literature exists on the subject of measuring stone decay in situ, emerging from fields such as archaeology or object conservation, in addition to architectural conservation. This chapter focuses not simply on methods of measuring the extent of deterioration; but rather on those techniques that are either already utilized for determining rates of decay, or could feasibly be applied to this purpose. Additionally, the techniques summarized in this section are organized by those methods that measure surface decay and those that measure subsurface deterioration. Understanding the status
of surface and subsurface deterioration is critical to the comprehension of the total
damage to the monument and to predictions of future damage (and thus decisions
regarding conservation interventions).

6.1 Surface Techniques

Surface recession occurs when weathered material is lost from a rock. A rate of
recession can be established if one can determine where the original surface lay. Stone
recession rates provide evidence of average weathering rates of different rock types in a
variety of environmental settings.\textsuperscript{341}

6.1.1 Profilometry

Deteriorated stone tends to produce uneven surfaces from the differential
weathering of various minerals and inclusion. Surface roughness can be assessed either
qualitatively or visually.\textsuperscript{342} Profilometry is a qualitative technique used to measure
surface irregularities.\textsuperscript{343} Stylus profilometry is a technique in which a metal needle or
stylus moves across the stone surface and a transducer obtains values by receiving
electrical signals from the position of the stylus. Powerful stylus profilometers used in
laboratory research can be expensive; however, there are field models which, although
are less expensive, may not be as effective in measuring extremely rough stones. In one
experiment, stylus profilometry was one of three techniques used to measure the effects

\textsuperscript{341} Livingston and Baer, “Stone Damage Rates Measured at Historic Buildings and Monuments”.
\textsuperscript{342} Pope, et al., “Geomorphology’s Role in the Study of Weathering of Cultural Stone”, 211-225.
of abrasive cleaning on various stones. Some of the drawbacks of the stylus profilometry technique for measuring the surfaces of stone include replica preparation, the limited vertical range, and the inability to measure highly irregular surfaces such as caused by tooling. The researchers concluded that tactile, and, to a lesser extent, visual examination, were the most effective methods to evaluate roughness on a range of stone surfaces, if compared against a set of standards.

Profilometry can also be administered using a laser, where a series of lines at 45 degree angles are superimposed onto the surface. Relief measurements are detected based on triangulation and any surface irregularities become immediately evident. Laser surface profilometry (LSP) is a non-destructive method for determining the surface topography of materials. Although increasingly expensive and time consuming, laser profilometry systems more accurately read 3D relief than other types of profilometry. The majority of the research regarding laser profilometry is related to determining the micro-topography of painted surfaces rather than the surface relief of stone monuments in situ.

6.1.2 Microerosion Meter

The microerosion meter is a micrometer device that measures the surface height at a number of predetermined points, relative to datum points set into the stone.

Microerosion meter measurements (MEM) of stone surface relief can be obtained with a

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345 Important to note is that roughness is not necessarily a measure of surface recession, as “surfaces of weathered stones are found to maintain constant roughness as grains are dislodged, although they may recede significantly. Charola, “Measuring Surface Roughness on Stone: Back to Basics”, 78.
relatively straightforward tool known as a needle-point depth micrometer. Relief readings are taken relative to a set of predetermined reference points in the stone. This technique has been well utilized at St. Paul’s Cathedral in London to measure the surface height of the balustrade over the span of a 20 year period.\(^{349}\) The microerosion meter yielded results reliable to two decimal places, although measurements were made to 0.0001 mm. The simple technique is effective in situ, but the reliability of data can be compromised by errors in calibrations, temperature fluctuations, deposition, unreliable datum points, and erratic erosion.

6.1.3 Photogrammetry

Photogrammetry is often used in the field of stone conservation and provides accurate surface relief data at a much lower cost than laser scanning. Photogrammetry is a technique used to detect surface loss and is sensitive to the point of 0.1 mm.\(^{350}\) Photogrammetry takes precise measurements from stereo-photographs, which are overlapping photographs taken from slightly different vantage points from metric cameras in order to eliminate distortion effects.\(^{351}\) When viewed in stereo, the photographic pairs allow one to observe surface relief. Actual depth or height measurements may be calculated by comparing grid points of the photogrammetric images on a computer or with tools such as an Abrams Heightfinder which is accurate to 0.02mm.\(^{352}\)

Using a plaster cast from 1862, photogrammetry was used in 1990 to determine the surface recession rate of certain areas of Trajan’s Column.\textsuperscript{353} Photogrammetry techniques have also been used to assess rates of deterioration for the marble of the Merchants Exchange Building in Philadelphia.\textsuperscript{354} Close-range stereoscopic photographs were taken in 1987 and 1991 at several locations and these locations are re-photographed at five or ten-year increments. At each location, 3D profiles were collected, plotted, and analyzed and then archived for future comparison. The data from the exterior weathered marble was compared to erosion at an interior location and the degradation rates were determined. Using close-range stereoscopic pairs, they were able to evaluate long term erosion rates by overlaying profiles. This technique offers a valid approach to the measurement of surface degradation and erosion especially for long-term rates of change.\textsuperscript{355}

\section*{6.1.4 Three-Dimensional Laser Scanning}

Three-dimensional laser scanning is increasingly employed in the field of architectural conservation. In one study, the erosion rates of adobe structures were determined by producing a set of 3D models from Cartesian coordinates obtained first from using photogrammetry. These models, produced in AutoCAD, can subsequently be overlayed with one another and the deterioration compared. Assuming that erosion is

\begin{footnotesize}
\textsuperscript{353} Conti, “A Method for the Evaluation of Material Loss from Bas-Reliefs Due to Air Pollution”, 12-26.
\textsuperscript{355} The one limiting factor in this study was the poor resolution in the 1987 sets of photographs that made precise short-term erosion rates nearly impossible to measure. Coe, et al., “Measuring Stone Decay with Close Range Photogrammetry”, 924.
\end{footnotesize}
occurring at a sufficient pace, 3D models can be produced at set intervals and the quantity and percentage of erosion can be calculated using computer software.\textsuperscript{356}

\textit{6.1.5 Laser Interferometry}

Laser interferometry is another method of monitoring surface loss on stone, to at least 0.5 \( \mu \)m. Variations of this technique are the electronic speckle pattern interferometry and video holography.\textsuperscript{357} Significant developments in the use of laser interferometry to detect surface erosion have been developed since the 1970s. The advanced technology uses TV holographic interferometers with fibre-optic illumination based on the random interference of scattered waves from illuminate surfaces.\textsuperscript{358} The result is known as the speckle effect, and the method is referred to as electronic speckle pattern interferometry (ESPI). Much of the literature on the technique is in regard to its application to painted surfaces, specifically frescos because of the portability of the technology. However, the technique is increasingly being used to detect masonry surface topography and to monitor the loss of stone monuments.

Paoletti et al. has used laser interferometry to measure surface erosion depths in marble monuments.\textsuperscript{359} The method has the ability to detect the smallest deformations at 0.5 microns and has also been successful in monitoring the effectiveness of conservation projects.\textsuperscript{356, \textsuperscript{357, \textsuperscript{358, \textsuperscript{359}}}

\textsuperscript{358} Paoletti and Schirripa, “The Potential of Portable TV Holography for Examining Frescos In Situ”, 127-132.
\textsuperscript{359} Paoletti, et al., “Electronic Speckle Pattern Interferometry for Marble Erosion Measurements”.
treatments over time. Precise evaluation of damage can be achieved by comparing the roughness and the depth of the stone’s surface with its initial conditions.

Optical techniques, such as the holographic and optical contouring methods, have long been used for determining deterioration rates. Schirripa Spagnolo et al. propose a new optical technique able to obtain the surface topography of stone based on fibre optical projection interferometer and the Fourier transform analysis. The system is simple and inexpensive, gives quantitative results, and is suitable for work in situ. The technique is capable of measuring surface profiles of diffusely reflecting objects and is based on the principle of Fourier transform method of phase measurement and the deformed grating image produced by a fibre optic interferometer. Data interpretation is relatively easy by fast Fourier transform. Disadvantages of this technique are that the method can be applied to only relatively flat objects with adequate reflectivity. Also, only a small area of the object can be investigated at once in order to obtain sufficient high depth resolution. Additionally, running the software, as well as reading the results may require a trained specialist.

6.1.6 Monument Mapping and Damage Functions

Precise damage diagnosis is critical for understanding the causes, processes and characteristics of stone damage and for sustainable monument preservation. Fitzner et al. describes a monument mapping method for mapping the decay of stones in situ in

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order to qualitatively and quantitatively assess the weathering state. Monument mapping for in situ investigation focuses on the “mesoscale,” defined as cm to m detail of visible deterioration phenomena and weathering forms. Weathering forms are based on defined schemes, which are then related to damage categories. A detailed classification scheme begins with the main groups of weathering forms. The types of damage are generally identified as loss of stone material, detachment, discoloration, deposits, fissures, and deformation. The types of damage are then more precisely defined by the type of loss of material, the type of deposit, and the type of detachment. All weathering forms are registered systematically according to type, intensity, combinations, and distribution. Additionally, the level of intensity must be ascribed to each weathering form. Damage categories are most useful for correlations with weathering forms, which provides a comprehensive approach to the condition assessment of stone and a basis of evaluation for intervention. Damage indices are then used to quantify and rate the damage categories.\(^\text{366}\) The weathering forms are subsequently illustrated on top of maps of weathering forms. The weathering form maps can be superimposed to show combinations and intensities of damage as well as quantitatively evaluated, allowing for the calculation of average weathering rates.\(^\text{367}\)

Damage functions describe the acceleration in the rate of damage associated with a change in pollution level.\(^\text{368}\) A number of studies devoted to the identification of damage functions attempt to describe the rate of deterioration of a given stone when


exposed to a given atmosphere. These mathematical functions describe the rate of surface loss as a function of the concentration of gaseous pollutants (mostly sulphur dioxide) and of the pH of rain.\textsuperscript{369} Although potentially useful for quantifying stone surface loss due to atmospheric mechanisms, damage functions do not take into consideration other important mechanisms of deterioration such as human influences and the history of construction and use over time. Torraca further argues that our present knowledge is insufficient to correctly or adequately set up mathematical damage functions, although it may be possible to formulate equations which are valid for one set of standard microclimatic conditions and for a standard rock type of a defined chemical and mineralogical composition.\textsuperscript{370}

The damage function itself only predicts the rate of damage. The accumulated damage, however, must be related to a significant point of erosion that is pre-determined by the conservator. This critical level is based on human visual perception, or may be determined by computer simulation. Damage functions, however, need to be more fully developed. Much of the research has focused on the rate of pollution deposition, which is not very useful for architectural conservation. Nondestructive methods for measuring deposition and recession rates, as well as the type of damage need more investigation. Finally, a systematic terminology for damage functions, types and causes of decay needs to be established.\textsuperscript{371}

Livingston argues that a three dimensional geometry is necessary to investigate the deterioration of sculpted stone on real structures, rather than the simple planar

\textsuperscript{369} Bugini, et al., “Rate of Formation of Black Crusts on Marble: A Case Study”, 112.
\textsuperscript{370} Torraca, “Air Pollution and the Conservation of Building Materials”, 384.
geometry of test specimens. Computational geometry approximates curved surfaces by a
set of tangent planes, each defined by a position vector and local unit normal vector. The
tangent planes are drawn as a triangular finite element mesh on the surface. The surface
recession produced by erosion is measured as the displacement of the position vector. A
damage function can define relating surface recession to environmental stress. The
typical planar one dimensional measurement depicts surface recession as uniform.
However, of concern to architectural conservators is loss at corners, edges, sculptural
details, inscriptions and 3D set of coordinates are required to measure this. Moreover, the
rate of erosion is not uniform over a surface and varies from point to point. A constitutive
law, or damage function, can define relating surface recession to environmental stress.
However, the exact form of this law has not been determined. Failure to apply the finite
element methodology to actual measurements on stone will result in errors in
determination of the surface recession as function of position, in turn causing errors in the
inference of the spatial variability of environmental stresses around real structures.  
This approach, however, requires the establishment of constitutive laws that have not been
developed.

6.1.7 Comparative Photography

Comparing historic and contemporary photographs is a qualitative method to
assess material deterioration rates. This method has been employed in a number of case
studies. Matero compared historical records and photographs matched with modern views
to conduct a comparative analysis of the general decay types and mechanisms over time

of Perry’s Memorial.\textsuperscript{374} This case demonstrated that although comparative photography is not a quantitative method, this technique is a valuable non-destructive approach that can inform the deterioration history of the object and assess a general, observational, rate of decay. This method has also been utilized at Angkor Wat.\textsuperscript{375} A comparison of old photographs from the literature and current photographs visually demonstrated a rapid increase in surface loss. This method was also used by Löfvendahl et al., in a study of the weathering of Scandinavian rune monuments.\textsuperscript{376} Employing documentation from the 17\textsuperscript{th} century in the form of drawings and descriptions, along with 19\textsuperscript{th} century photographs, the researchers marked the damages noted in each document on a recent black and white photograph. Using different colors to quantify the damage progression between the times of documentation, the researchers were able to produce a semi-quantified assessment of the damage through time.\textsuperscript{377}

\subsection*{6.1.8 Isotope Decay Rates}

A relatively new technique uses the decay rates of isotopes of Berillium, Aluminum and Chlorine. Isotope decay rates gives data on the long term decay rates of naturally occurring material with time spans of greater than 1000 years.\textsuperscript{378} Massey examined the decay rates of geological materials in order to determine the order of magnitude estimates for the maxima and minima. These values were determined by

\textsuperscript{374} Matero, “A Diagnostic Study and Treatment Evaluation for the Cleaning of Perry’s Victory and International Peace Memorial”, 40-42.
\textsuperscript{375} Leisen and von Plehwe-Leisen, “Conservation of the Bas Reliefs at Angkor Wat Temple in Cambodia: Research, Practice, Training”, 739.
\textsuperscript{377} Löfvendahl, et al., “Weathering of Runestones in a Millennia Perspective”, 121.
studying the long-term erosion from cosmogenic isotope measurements in comparison to short-term exposure trials. Massey developed time scales for significant decay (identified as greater than 10mm) for weak, medium and strong materials: 10, 50-100 and 100-1000 years, respectively. Within this estimate, the author acknowledged that enormous ranges will occur due to the gross variability of factors affecting erosion.

6.1.9 Measurement of Weathering Rinds

Rocks, particularly siliceous rocks, may exhibit an outer weathered zone during the initial stages of weathering. The outer zone is known as a weathering rind. As weathering continues the thickness of the weathering rind increases and thus can be used as an indicator of the amount of deterioration that has occurred. According to Winkler, weathering of silicate materials cannot be measured in terms of surface reduction, but rather should be based on the width of the weathered rims and rinds.379 The iron of gray to bluish-gray sandstones, granites, andesites, and basalts is chiefly derived from black micas, hornblende, and some other minerals. The thickness of the brown weathered rim depends on the length of exposure to a given amount of annual precipitation, the permeability of the stone, and the degree of iron bond in the crystal lattice.

Oguchi and Matsukura measured the development of weathering rinds on andesite gravel using the Vickers hardness number.380 The thickness of the outermost brown rind layer depended on time, whereas the thickness of the entire weathering rind is controlled by the porosity of the rock in addition to time. The authors found that rocks with higher

379 Winkler, Stone in Architecture, 88.
porosity have thicker weathering rinds than they do outer brown layers. The researchers Sak et al. studied the weathering rind thickness on basaltic clasts along the Pacific coast of Costa Rica. The authors evaluated the rate of weathering rind development using a diffusion-limited model that predicted a parabolic rate law for weathering rind thickness as a function of time.

6.1.10 Chemical Denudation (Run-off)

Chemical denudation measures the amount of solutes dissolved from the surface in rainfall runoff. The run-off from stone surfaces has been used to provide a good measure of the erosion rate of the stone object. In one case, this method was used for marble and the excess calcium concentration was measured as run-off. If the surface area is known, the amount of calcium run-off can be converted to a universal metric of surface recession, using appropriate marble density values. This method was also tested to determine the different affects of air pollution and seasonal changes on sandstone monuments in India.

Cooper et al. argues that this method offers a vast improvement on previous methods, such as photographic records, surface recession from lead plugs, and the portable reflex microscope. Using a micro-catchment unit, the controlled measurement of decay rate under different conditions is possible. The micro-catchment unit exposes standard samples of a test stone on a concrete plinth, which is insulated to insure

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384 Sherwood, and Dolske, “Acid Deposition Impacts on Marble Monuments at Gettysburg”, 251.  
temperature stability. The stone is fitted with a PVC edging to collect run-off. An outlet is provided for the run-off water to be collected by a collection bottle. The water is then analyzed in the laboratory. By comparing the decay rate against test standards, a prediction of future losses is possible. The researchers used the micro-catchment technique for measuring stone decay rates of both freshly quarried stone and old weathered Portland limestone. The authors were able to calculate both atmospheric deposition and surface erosion using this method. The disadvantages of this technique are that decay rates for weathered stone are extremely variable and the causes of the surface loss are specific to the situation.387

6.1.11 Other Methods

Many other methods exist for measuring surface loss. The use of inscriptions or dated engravings from, for example, tombstones, has been a popular approach.388 Several researchers have used tombstones to record the depth of inscription and the reduction rate of the original stone surface, mostly using caliper measurements.389 Physical analysis of tombstone deterioration consists of quantifying the change in physical dimension in order to estimate the rate of surface recession. Inscription depth would seem to be the most characteristic measure of damage but actual measurement is complex. The initial affects of weathering reduces the sharpness of the profile of the characters rather than producing any overall surface recession.

388 For example Livingston and Baer argue that tombstones offer a large sample, are widely distributed, possess simple geometries, and are usually dated. Livingston and Baer, “The Use of Tombstones in the Investigation of the Deterioration of Stone Monuments”, 859-867.
389 Winkler, Stone in Architecture, 196.
Another method typically used is the Lead Plug Index (LPI) which involves inserting lead plugs into the structure and measuring the surrounding decay as the lead deteriorates at a much slower rate than the stone. Measurements using this method were employed at Saint Paul’s Cathedral in London.390

Weathering may alter the hardness of a stone; therefore measurements of the rock’s hardness may be used as a tool for the amount of weathering.391 Scientists have employed different types of hardness tests to assess weathering rates.392 For example, the Schmidt hammer was originally developed for testing concrete, but has been utilized for testing stones.393

Because of the slow rate of surface recession and typical roughness on a stone surface, statistically significant surface recession may take many years. Therefore, mass loss is another way to measure material loss over time. Given the surface area of an object, an average mass loss per unit surface can be calculated, but this assumes a uniform loss over the whole surface.394 Surface recession is the most relevant for architectural conservators, but finding appropriate reference points for this measurement is difficult.395 Computer simulations can possibly be used to estimate the amount of volume lost. With a very fine resolution three-dimensional model, layers of volume elements would be added until the object’s original shape is restored. This approach is only semi-quantitative because the construction of the model and the estimation of the object’s original shape is

based on human subjectiveness.\textsuperscript{396} Other possible measures of damage are surface roughness, increased porosity, discoloration, and cracking.\textsuperscript{397}

\textbf{6.2 Subsurface Techniques}

\textit{6.2.1 Integrated Computerized Analysis for Weathering}

The Integrated Computerized Analysis for Weathering (ICAW) is a non-destructive technique that can determine the state of conservation of stone material exposed to weathering and to evaluate the rate of weathering over time.\textsuperscript{398} The technique, which can be used in situ, involves analyzing decayed areas using pictorial images in order to determine the actual area of the deterioration. The geometric section of the same areas is analyzed in order to establish the thickness and nature of the deteriorated layers. The first part of the method utilizes a computer that converts the image into a digital image and measures the reflections of light from the different colors, producing a weathering map.\textsuperscript{399} The second part of the process measures deterioration below the surface using ultrasonic pulses that cross the decay layers, producing a distance-time diagram. The thickness relates to the severity of decay, and the time reflects the weathering rate.\textsuperscript{400} This technique was applied to assess the deterioration of prehistoric rock art in caves in Altamira Spain.

\textsuperscript{400} Zezza, “Non-Destructive Technique for the Assessment of the Deterioration Processes of Prehistoric Rock Art in Karstic Caves: The Paleolithic paintings of Altamira (Spain)”, 379.
6.2.2 Geographical Information System

Another method that is increasingly being utilized for measuring deterioration is a Geographical Information System (GIS). A relatively simple classification system of weathering forms based largely on visual criteria, historic, and contemporary images, in addition to surveys, can be combined with a spatial reference for an integrated GIS. By analyzing these images through time, the development of decay can be monitored and quantified, and future decay may be predicted.\textsuperscript{401}

6.2.3 Ultrasonic Tomography

The use of ultrasonics is an important approach for the detection of cracks, voids, and other foreign inclusions in stone. The transmission of ultrasonic waves in stone is dependent upon many factors and the interpretation of the data is less than straightforward.\textsuperscript{402} A significant amount of literature has been recently published on the use of ultrasonic tomography in building stone conservation. A variety of ultrasonic methods are available, but in general the technique involves using the velocity of sound as a measurement for consistency within the rock fabric. The waves are transmitted from a fixed transmission point on one side of the stone and a receiver on the opposite side of the stone measures the velocity based on the distance. Ultrasonic tomography can be used in a specific location to detect cracks, crevices, pores, joints, added mortar, and steel reinforcement.\textsuperscript{403}

Several laboratory case studies have utilized ultrasonic tomography and are yielding interesting results. For example, the weathering behavior of carrara marble was determined from the ultrasonic velocity distribution based on the orientation of calcite crystals in the marble.\textsuperscript{404} Ultrasonic tomography was utilized on a marble column at the Marmorpalais in Germany in which data from the synthetic tomogram model was used in conjunction with a detailed visual mapping of the conditions.\textsuperscript{405} Another example involves the use of ultrasonic tomography in situ to assist in developing a conservation treatment for several limestone blocks in Egypt, dating to 1900-1400 BCE. In this case the technology was also used to determine the distribution of the consolidant treatment.\textsuperscript{406} An ultrasonic netting and tomographic procedure were used to study the internal deterioration of cross-sections of stone sculpture in the Qianling Mausoleum. With this data, ultrasonic velocity can also produce a distribution diagram and using reflective ultrasonic method, an evaluation of fissures and fractures extending into the interior can be conducted.\textsuperscript{407}

As ultrasonic tomography is used more frequently in the conservation field, the need for accurate data interpretation by a skilled profession is becoming clear. More research in this area is needed to establish standards and higher quality results.

\textsuperscript{405} Siegesmund, Siegfried et al., “Deterioration Characteristics of Columns from the Marmorpalais Potsdam (Germany) by Ultrasonic-Yomography”, 145-153 (vol. 2).
6.2.4 Ground Probing Radar

Similar to ultrasonic tomography, ground probing radar (GPR) also utilizes electromagnetic waves; GPR, however, uses radar as opposed to sonic waves. Much of the research on ground probing radar comes from the field of archaeology, but the technique is being increasingly applied to buildings. GPR can provide vital information on the internal structures of historic buildings and is considered more practical and usable than some of the other non-destructive methods for the examination of subsurface conditions. By measuring the intensity of reflections, the system provides three dimensional data of the subsurface stratigraphy including voids, cracks, layers, and tie locations. In their 1996 review of nondestructive test methods, Nappi and Cote suggest that the best results for subsurface examination combine two or more test methods such as sonic tests and radar.

6.2.5 X-Ray Tomography

A recent development, X-Ray computed microtomography has been used to detect subsurface conditions in stone conservation. The resulting scans can display a variety of important information including petrophysical properties, internal structure, and pore size distribution. The X-Ray tomography can provide three dimensional data with a resolution of up to 12 μm and has been used to determine natural weathering patterns of building masonry as well as the effectiveness of certain treatments.

410 Cnudde and Jacobs, “Preliminary Results of the Use of X-Ray Computed Microtomography as a New Technique in Stone Conservation and Restoration”, XX.
6.3 Conclusion

The establishment of weathering rates, as opposed to measurements of weathering, is a difficult process. Microscale weathering agents have a large effect on the rate of decay and in fluctuations of weathering rates. Some researchers assume a linear weathering rate and some propose stepped or episodic rates. Researchers further disagree whether weathering rates increase over time as deterioration accelerates, decrease, or stabilize. Additionally, average weathering rates can conceal the variability in decay processes over time. Deterioration is likely an episodic process that reacts to a multitude of intrinsic and extrinsic factors and agents, working simultaneously.

The techniques summarized in this chapter are an overview of available approaches to the study of weathering rates and the measurement of stone deterioration. This thesis employs photographic comparisons for the qualitative evaluation of the deterioration of the Gateway of the Sun. The other techniques discussed will hopefully be useful in any future studies of the Gateway.
An enormous volume of literature has been published on the material properties and decay mechanisms of sedimentary rocks such as limestone and sandstone, as well as marble. Volcanic rocks, however, have had comparatively little attention or in-depth study, even though, as Grissom\(^{411}\) (who has written the most thorough review on the literature on volcanic rocks) points out, some of the world’s most inspiring monuments are made of volcanic stone. The deterioration of volcanic rocks has been largely ignored in the conservation literature, as has the in-depth study of their material properties. According to Grissom, in 1990 at the time of her writing, only 8% of papers presented at stone weathering and conservation symposiums referred to igneous rocks, and the number discussing volcanic rocks were even fewer. The lack of attention to igneous and volcanic rocks can be attributed to a Euro-centric focus of the study of stone decay, as most researchers work in either Europe or North America where buildings are primarily constructed from limestone, sandstone, granite, or marble. The most significant volcanic-rock monuments, on the other hand, lie elsewhere, including Central and South America, Southeast Asia, and Anatolia.

This chapter will proceed to focus on the formation, properties, uses, and weathering behavior of andesite and related volcanic rocks.

\(^{411}\) Grissom, "The Deterioration and Treatment of Volcanic Stone: A Review of the Literature".
7.1 Volcanism and Formation of Andesite and Other Volcanic Rocks

Igneous rocks derive from molten magma material. Volcanic rocks specifically refer to those rocks that have solidified from magma and rose to the earth’s surface; as opposed to rocks that formed from magma and remained inside the earth’s crust. This later category is known as plutonic rocks, and includes granites. Plutonic rocks form slowly inside the earth’s crust, resulting in coarse grained stones; while volcanic rocks are formed rapidly, resulting in fine grains. The large crystals that are often apparent in volcanic rocks are caused by periods of slower cooling that occurred before eruption, and are called “phenocrysts.” Most volcanic rocks, including rhyolite, andesite, and basalt, are formed from flows of lava. Pyroclastic rocks, such as tuff, are formed from fragmented material and drops of lava that are propelled through air or water and are subsequently consolidated. Most volcanic rocks contain one or more of silicate materials, including feldspars, olivines, pyroxenes, amphiboles, quartz, and micas. Volcanic rocks can be further sub-divided into acid rocks, such as rhyolite; intermediate rocks, such as andesite; and basic rocks, such as basalt. These terms do not refer to the pH level, but to the amount of silica present. Acid rocks contain the most silica basic rocks the least. In general, acid rocks display a lighter color than basic rocks.

Volcanism can be classified according to its plate tectonic setting. Volcanism at oceanic ridges is dominantly submarine and basaltic, and their products form the oceanic crust. Destructive plate boundaries form island arcs and active continental margins, where the volcanic products range from basalt through andesite and dacite to rhyolite in composition. Island arcs, active continental margins, and collision zones have been

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412 The information in this section is from Grissom, “The Deterioration and Treatment of Volcanic Stone: A Review of the Literature”.

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abundant throughout much of geological time. Presently, most of these features are located around the Pacific. The eastern Pacific has no island arcs, but has volcanism on an active continental margin extending from the western USA, through Mexico and Central America, to the western edge of South America. Volcanism also occurs in the Mediterranean Aeolian and Aegean region, as well as a very active collision zone that extends from the Alps through Turkey and Iran into the Himalayas. The rocks produced are intrusive, including granite and diorite; and extrusive, including andesite and basalt. These rocks are all ubiquitous components of what are called “orogenic” belts.\footnote{Thorpe, "Introduction".}

Orogenic volcanic rocks from basalt to andesite tend to have less than 60% SiO$_2$ in composition, however there are marked regional differences.\footnote{Baker, "Evolution and Classification of Orogenic Volcanic Rocks".}

Andesites are usually distinguished from other members of the calc-alkaline association based on silica percentage; although the percents vary somewhat, andesites usually have a 55-63% silica content. Scientists have attempted to distinguish calc-alkaline rocks from island arcs from those of continental margins. This latter group has been referred to as the “Andean” type; however there is considerable diversity of andesites even within the Andes. Most Andean andesites are higher in K and related elements Rb, Sr, Ba, Zr, Th, and U.\footnote{Baker, “Evolution and Classification of Orogenic Volcanic Rocks".}

Important regional variations in andesite occurs, not just globally, but locally even within the Andes. No one single type of Andean volcanic rock exists. Active andesite volcanism occurs in three areas of the South American Andes: a northern zone in Columbia and Ecuador; a central zone largely in southern Peru and northern Chile; and a
southern zone in southern Chile. Each zone has a well defined tectonic setting and range of volcanic products. Geographically, we are most concerned with the central zone (16 – 28 °S), which is characterized by andesite-dacite lavas and dacite-rhyolite ignimbrites. Alkaline volcanic rocks occur at scattered localities to the east of the active volcanic chain. The central zone lies on top of a thicker continental crust and the rocks are more silicic and have higher K, Rb, Sr, and Ba than the lavas from the other zones. The central zone rocks result from fractional crystallization of andesite magma during relatively slow up rise through the continental crust.416

7.2 Andesites

The term ‘andesite’ was originally given in 1836 to a particular rock found in the Andes, a type of lava that contained plagioclase and hornblende. Used to distinguish andesites from basalts, this definition was based on the presence of hornblende in andesite and olivine in basalt. The term andesite has been applied at different times to various volcanic rocks. If the definition of andesite is based on the composition of plagioclase, this category will include an assortment of lavas that may differ significantly from each other. Current uses restrict the term andesite to intermediate rocks of cal alkaline affinity, i.e. silica-oversaturated rocks with relatively high Al₂O₃ (15-19%) and moderate total alkalis. Andesite is an intermediate rock with generally 52-66% silica, containing more silica than basalt and less silica than rhyolite. Andesites are composed mainly of intermediate plagioclase (half calcic and half sodic) and normally some glass. In some cases small amounts of one or two additional minerals are present, such as

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biotite, hornblende, pyroxene, and quartz. Andesite rocks are generally dark gray, green, or red.\textsuperscript{417}

The central Andes lie in one of the world’s most extensive and diverse volcanic zones. Lavas from the central zone are more acidic in composition, largely falling within the range of 56-66\% SiO\textsubscript{2}. Basalts are almost entirely absent and the most common lavas are pyroxene andesites (occasionally olivine, hornblende-biotite bearing andesites), generally with over 60\% SiO\textsubscript{2}; and dacites with over 63\% SiO\textsubscript{2}. Lavas from the central zone are more silica rich and show less Fe enrichment; they also tend to have higher concentrations of K, Rb, Sr, and Ba than rocks from the northern or southern zones.\textsuperscript{418}

\textbf{7.3 Properties of Igneous Rocks}

Igneous rocks are formed of variable percentages of feldspars, quartz, amphiboles, pyroxenes, micas and other accessory minerals, which make them, as a group, quite diversified. This variety can be compared to limestones, which are composed almost exclusively of carbonate and some impurities (quartz, clay minerals), sandstones which are composed of quartz plus accessory minerals (feldspars, micas), and marbles which are virtually pure carbonate. For igneous rocks, the biggest distinguishing factor is the presence of secondary minerals, sometimes of clay, such as kaolinite, montmorillonite, chlorite, etc, which are responsible for their weathering. The importance of secondary minerals in igneous rocks can be compared to sedimentary rocks (limestones, sandstones) for which their primary mineral is more significant. Another important difference between igneous and other rock classifications is the pore space.

\textsuperscript{417} Thorpe, et al., "The Andes".
\textsuperscript{418} Thorpe, et al., "The Andes".

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Sedimentary rocks contain from their origin a particular porosity, which varies from zero to above 40%. Non-volcanic igneous rocks are not porous at the origination; rather porosity develops after their formation and does not reach more than 5% in sound rocks. Igneous rocks can additionally be characterized by the large variety of mineral phases, as sedimentary rocks contain only one or two phases.419

7.4 Weathering of Igneous Rocks

Weathering is one of the main factors that results in the alteration of rocks; therefore, mechanical behavior of the weathered rocks and classification of weathering grades are important factors in conservation treatments. Weathering can be categorized into two main processes: physical weathering and chemical weathering. Physical weathering involves mechanical disintegration of the rock particles and is mostly associated with temperature and freeze/thaw cycles. Chemical weathering can be defined as the decomposition and the chemical alteration of the primary rock minerals, resulting in the formation of secondary minerals. Theoretically well defined, in reality, field conditions vary greatly and depending upon climatic conditions, interact in very different ways. Climate, properties of the rock, groundwater conditions, topography, biological activity, vegetation, and time, are all interacting factors.420

The main factors affecting weathering are the quality of the stone and the structure of the monuments.421 In most igneous rocks, the interstices of joints, fractures, fissures, etc. all affect the degree and depth of weathering. Climate and biological

419 Delgado Rodrigues, "Some Problems Raised by the Study of the Weathering of Igneous Rocks".
420 Celal and Kapuz, "Rock Mechanics Characteristics of Ankara Andesites in Relation to Their Degree of Weathering".
421 Anom, "Conservation of Stone Monuments in Indonesia".
conditions are the external weathering factors. Different kinds of rocks respond
differently to the effects of air pollution and acid rain.422 Carbonate rocks, including all
limestones and crystalline marbles, are composed of the mineral calcite which is
moderately soluble in water. Carbonate rocks are the type of stone most affected by air
pollution and acid rain. Silica rocks includes sandstones that are composed of sand grains
which are made mostly of quartz and are held together largely with secondary silica
cement. The solubility of silica is a function of the degree of crystallinity, the
temperature, and the pH of the solvent. While calcite dissolves best in cold and carbon-
dioxide rich acidic waters, silica dissolves best in high temperatures with alkaline range
waters (high pH). Silicate rocks, including andesites and basalts, are composed of mostly
silicate minerals, with SiO₂ built into the crystal lattices. These rocks are very resistant to
weathering and are not normally affected by significant acid rain-induced deterioration.

Silicate minerals possess tight crystal lattices. Leaching or solubilization can free
the attached ions (Ca, Na, K, Mg, and Fe) and fill the voids with water. As chemical
weathering continues, clay and quartz grains form an insoluble residue which forms as
surface soiling. These exposed ions hydrate rapidly upon exposure to moisture and
hydrogen ions tend to penetrate the mineral surfaces, readily breaking down the silicate
structure. Much attention should be paid to the weathering of feldspars which comprise
nearly two-thirds of all minerals present in igneous rocks. Dense igneous rocks tend to
weather from the surface inward and slowly develop weathering rinds.423 The degree of
kaolinization of igneous rocks strongly determines their strength and durability. The rate

422 Winkler, "Decay of Stone Monuments & Buildings: The Role of Acid Rain".
423 Winkler, Stone in Architecture, 211-213.
of silicate weathering therefore, is difficult to evaluate due to the large number of factors influencing the process.\textsuperscript{424}

\section*{7.5 Weathering of Volcanic Rocks}

Water is, almost always, the dominant agent of deterioration. Volcanic rocks are formed at high temperatures and are not chemically stable at ambient temperatures in the presence of water. Water will, over time, solubilize metal ions, especially calcium, magnesium, sodium, and potassium. Zeolites, clay minerals, and other hydrous materials are then formed from residual material. Water also transports soluble salts, causes damage by freeze/thaw cycling, and supports biological growth. Rates of weathering will increase with temperature and precipitation, therefore, volcanic rock in tropical environments is at increased risk. Many of the same general rules apply as to other stone weathering. Porous rocks, like tuff, have large surface areas and tend to hold water, thus will deteriorate faster than denser rocks like basalt. Also, the glassy portions of rocks weather at a faster rate than the crystalline portions because of the greater instability of the glass. Volcanic rocks, however, undergo slower weathering due to water, than carbonate rocks. Volcanic rocks, additionally, are less susceptible to decay caused by air pollution, as opposed to calcareous rocks that are immensely affected by sulphur dioxide.\textsuperscript{425} In a 1991 article, however, some evidence was found regarding the affects of air pollution on the deterioration of andesite stone.\textsuperscript{426}

\textsuperscript{424} Winkler, \textit{Stone in Architecture}, 213.

\textsuperscript{425} Grissom, "The Deterioration and Treatment of Volcanic Stone: A Review of the Literature".

\textsuperscript{426} Martinez and Martinez, "Characterization of Stone from the Metropolitan Cathedral and from the Facade of the National Museum at Tepotzotlan, Mexico".
Basic rocks, like basalt, will deteriorate at a faster rate than acid rocks, like rhyolite. Andesite falls somewhere in the middle. The faster deterioration rate of basalt is possibly due to the presence of large amounts of ferromagnesian minerals. The degree of crystallinity in volcanic rocks is a determinant factor in the deterioration process, as rocks with greater crystalline components will weather slower than those with more glassy components.\textsuperscript{427} Andesite and basalt have been much less researched than tuff, which presents the largest problems in terms of conservation of volcanic rock monuments, perhaps because andesite and basalt are more durable than tuff. Biological growth is a critical conservation issue that disfigures volcanic stonework, and in particular, crustaceous lichens cause great damage. Air pollution and stone cleaning, which are of primary concern for calcareous stones and sandstones, are not as critical with volcanic stones.\textsuperscript{428}

\textbf{7.6 Treatments for Volcanic Rocks}

Consolidation has been the topic most often discussed, but usually in reference to tuff stone. All of the consolidants that have been tested, however, are expensive and none had been applied to date (1990) on a large scale. For tuffs, the application of water repellents is usually favored, and the treatment of biological growth has become an important issue with volcanic rocks in tropical climates. Cleaning of soiling or surface deposition is not as much of an issue with volcanic rocks as it is with other rock types.\textsuperscript{429}

\textsuperscript{427} Helmi, "Study of the Deterioration of Volcanic Rocks from Egypt".
\textsuperscript{428} Grissom, "The Deterioration and Treatment of Volcanic Stone: A Review of the Literature".
\textsuperscript{429} Grissom, "The Deterioration and Treatment of Volcanic Stone: A Review of the Literature". 
7.7 Uses of Volcanic Rock

The uses of volcanic rock extend to both buildings and sculptures. Volcanic rocks are easily carved and, when used, have often been employed on a large-scale. This, however, has created problems for their conservation, especially when looking at cost. At Borobudur in Indonesia, for example, there are over 33,000 relief blocks and almost 500 sculptures constructed from andesite stone. Many sites, in addition, have been carved from rocks in situ rather than cut stone blocks.430

7.8 Examples of Andesite Monuments Around the World

The Buddhist monument, Borobudur, was erected in central Java around AD 800.431 While the rock is generally referred to as an andesite, it is actually, in composition, lies in the middle between andesite and basalt. This site has been intensively studied. A major restoration of the site was begun in 1973 and completed in 1983, and which had an entire issue of Studies in Conservation devoted to it in 1973 (volume 18). Studies and documentation of the site done prior to treatment showed, when compared to photographs taken in 1910, loss of detail of the carvings. Located in a tropical climate with heavy rainfalls, biological deterioration, especially crustaceous lichens, are considered a critical concern for this site. Additionally, salts from old cements have caused damage through deposition and efflorescence. Treatments involved using Hyamine 3500 to prevent regrowth of algae and lichens and a 1% solution of Hyvar X-L was applied to remove and prevent moss growth. Paper poultices or the Mora

430 Grissom, "The Deterioration and Treatment of Volcanic Stone: A Review of the Literature".
431 This section largely summarized from Grissom, "The Deterioration and Treatment of Volcanic Stone: A Review of the Literature".

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mixture, known as AB 57 were to was the stones and remove the salts, while lichens were removed with a mixture of AB 57 and clay.

Red and green porphyritic andesites are found in the classical and Egyptian regions. Notable uses of red andesite are the sculptures of the Tetrarchs on the exterior of the Basilica of San Marco in Venice and the early Christian sarcophagi of Constantine’s daughter Constantina and his mother, St. Elena, now located in the Vatican Museum. The stone is considered rather durable. Green porphyritic andesite has phenocrysts of labradorite in a dark green matrix and is quarried in the Peloponnesus of Greece. It is also called *serpentine* in Italian. It is used in Venice and is considered one of the most resistant to weathering and air pollution, and in most cases, it is still perfectly preserved.

Andesite was used in Mexico for the colossal Olmec heads at San Lorenzo, La Venta, Laguna de los Cerros, and Trez Zapotes. The andesite used for these sculptures likely originates from a single quarry, but the source has not been identified. Since being exposed from excavation 50 years ago, the stones are rounded and have lost detail. In Central America, the Mayan city of Copan in present day Honduras was constructed between AD 400 and 800 and built of greenish andesite. The stone used for the sculptures is softer and has large feldspar inclusions than the stone used for the pyramids and walls. Heavy rainfall is dissolving the rock, is transporting damaging salts, and is supporting an abundant amount of biological growth. Of particular concern is the deterioration of the carved hieroglyphic staircase. Treatments have included the removal of biological material in 1977 with diluted Clorox, followed by sodium perborate. This treatment was repeated two more times and it has been advised to re-spray with Clorox every 4 to 8 years. Consolidant testing using ethyl silicates started in 1985.
Andesite was also employed at Aztec sites and most of these sculptures are in good condition because they were covered or have been moved inside after excavation.

And, last, andesite has been used at South American Inca and pre-Inca sites, such as Tiwanaku, where the andesite was employed for a number of carved sculptures and monuments.

7.9 Case Study: San Francisco Monastery

All of the façade rocks on the San Francisco Monastery are constructed from andesite stone, varying in color from light to dark grey. The rock was probably quarried from nearby; therefore the conservators took samples from four different nearby quarries for comparison. All of the façade and quarry samples were characterized as andesites with silica content from 56 – 60%. The primary mechanism of decay observed on the facades is the crystallization of soluble salts in the porous system of the stones, a process that generates sufficient energy to overcome the compressive strengths of the stone. Different forms were observed on the façade: efflorescence, fissures, flakes, granular disintegration and detachment of large pieces of stone. The air pollutants, together with moisture, in the form of both rainwater and capillary rise, contribute to the crystallization of salts within the pore network. This process is further accelerated by wind action. Together, alveolar corrosion has appeared, marked by large cavities and the detachment of small or larger flakes from the stone surface.

Another typical decay pattern in areas that are exposed to rainwater is the dissolution of pyroxene crystals, which results in the accumulation of iron and

432 This case study from Moropoulou, et al., "San Francisco Monastery, Quito, Equador: Characterisation of Building Materials, Damage Assessment and Conservation Considerations".
magnesium oxides along the crystal boundaries and proceed to crack. In places that are protected from rainwater, the crystallization and detachment processes are much slower and the surface is covered with a dark skin. Laboratory examination showed that the crust contains P, S, K, Fe, Ti, and Ca and lower concentrations of Si and Al. The outer part of the crust is more porous and consists mainly of gypsum, which is widely known to be associated with sulphur dioxide pollution. The inner part of the crust, consisting of gypsum and calcium phosphate, is similar to other examples found on granite surfaces. The presence of phosphorous is very common, in the form of orange-brown patinas, on limestones, granites, and basalts that are exposed either in rural or urban environments.

The cleaning of silicate stone is considerably more difficult than cleaning carbonate stones. Little research exists on treating weathered andesite surfaces, therefore the conservators compared the andesite to granite, which is also an igneous rock with very low porosity. The conservators tested chemical cleaning with an acid cleaner and abrasive cleaning, yet even gentle methods resulted in loss on granite surfaces. Laser cleaning was considered but possible chromatic changes on andesites had to be tested. The conservators also advocated a water repellent after cleaning since any unprotected surface would then be exposed to weathering mechanisms and the decay processes accelerated. Polysiloxane was recommended, which has been proven affective and less harmful on granite.
7.10 Weathering of Andesite Stone at the site of Tiwanaku

Dr. Bergt, a German scientist, examined the stone at the site of Tiwanaku in 1894 and classified four different types of igneous rocks including andesite. Arthur Posnansky conducted tests on the sculpture in 1945 and found that the rocks contained plagioclase, pyroxene, and biotite. The volcanic rocks were further classified as intrusive and extrusive rocks and identified as granites, dacites, andesites, and basalts using samples taken from a variety of the sculptures, gateways, and artifacts. Max Mille and Carlos Ponce Sangines examined the andesite at the site of Tiwanaku in 1968. The authors divided the andesite found in the area into three main groups based on the presence of plagioclase (a feldspar), anfiboles (a silicate mineral), and pyroxenes (dark green and black iron and magnesium silicate). They further concluded that the andesite at the site of Tiwanaku did not originate from the nearby quarries of Comanche or Viscachani.

Environmental monitoring was conducted at Tiwanaku in 1990 by The Getty Conservation Institute and the Bolivian National Institute of Archaeology in relationship to the deterioration of the stone monuments and architecture at the site. The scientists contend that the aggressive environment at Tiwanaku greatly affects the deterioration and stability of its stone architecture and monuments, constructed of both sandstone and andesite. The andesite monuments, including the Gateway of the Sun and the Ponce Monolith, exhibit vertical cracks and extensive surface degradation. After monitoring the environmental impact on large stone blocks of both andesite and sandstone over a period of 22 months, the authors concluded that three main environmental factors contribute to

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433 Mille and Ponce Sangines, Las Andesitas de Tiwanaku.
434 This section is taken from Maekawa, et al., "Environmental Monitoring at Tiwanaku", 885-891.
the decay of the stone monuments at the sites: wind, water, and temperature. In combination, these factors are incredibly detrimental.

Located on a windy plateau, the wind at Tiwanaku is almost always present. Variable in direction, the wind has caused overall erosion of the carved details rather than a decisive loss on one particular side. Abrasive course sand particles are not swept into the air, but stay close to the ground, causing increased wind erosion on the monuments near the ground level. The wind also causes an increase in water evaporation at the surfaces of the stones.

The annual precipitation rate at Tiwanaku averages only about 500mm per year, therefore driven rain is not a major cause of deterioration on the andesite structures. However, the rain accumulates as ponds and puddles which create localized groundwater sources that transport soluble salts present in the soils and stones. The salts are transported to the surfaces of the stones where they crystallize, causing severe loss material and details to the stone carvings.

Large temperature changes between day and night at Tiwanaku are translated into temperature changes within the stones. This is a critical factor for the andesite monuments due to the combination of the low air temperature, intensity of solar radiation, and the orientation of the sun. Large daily variations in relative humidity, as discussed in the current environmental context section in Chapter 3, results in frequent wet-dry cycling on the surface of the exposed monuments at the site. The climate at Tiwanaku greatly affects the temperatures of the exposed stone. Sky-facing surfaces of andesite and sandstone were almost identical in temperature to Tiwanaku’s climate. The large amount of radiation heating during the daytime and radiation heat loss during the
nights cause a large daily temperature change in the stone. A 24-hr analysis of stone temperature revealed that in the morning, the stones were about 2-5°C below that ground surface temperature. When warmed by the sun, the temperature of the stones rose more quickly than the ground surface, reaching a temperature of 6-7°C higher than the ground temperature. Over time, these thermal stresses add significantly to the deterioration of the stones.

The combination of the temperature changes with the moisture in the air is perhaps the most significant source of damage. There are many nights in which the surface temperature of the stone is lower than the dew point temperature, resulting in condensation on the stone surfaces and within the tiny crevices of the monuments. When the stone’s temperature drops to zero, as often happens in the winter and occasionally during the summer as well, the moisture freezes. These frost conditions cause very damaging freeze/thaw cycles. The temperature differentials as the sun rapidly heats the surface of a cold stone and the freeze/thaw cycles are strong stone-splitting factors, and may be the cause of the through-and-through vertical cracks in both the Gateway of the Sun and the Ponce Monolith. At the very least, they are powerful degradation mechanisms.

7.11 Conclusion

At the site of Tiwanaku, an extremely useful environmental monitoring exercise has been completed; however, the study was conducted in 1990, now fifteen years ago. Additionally, environmental factors are just one part, albeit a critical one, in determining the weathering rates of the andesite monuments at the site. Cultural issues, excavation
history, the construction and use of the monument, as well as the impact of visitors must be examined as well. A thorough analysis of the conditions and decay mechanisms of the Gateway of the Sun will be conducted in the next chapter.

Much more conservation research needs to be conducted into the material properties and weathering behaviors of volcanic rocks aside from tuffs. Volcanic rocks are used to construct a number of highly significant monumental sites in Southeast Asia and Central and South America, many of which, including the site of Tiwanaku, are undergoing severe deterioration. To assume that andesites, as well as other volcanic rocks, are simply less resistant to weathering is to risk losing this cultural heritage.
Chapter 8: Current Conditions, Decay, and Analysis of Deterioration Mechanisms

Archaeological sites present a complex set of decay mechanisms that change through time. An enormous variety of natural and cultural processes continually transform archaeological sites and their material remains. This chapter provides a description of the current visible conditions on the Gateway of the Sun, a qualitative evaluation of the deterioration patterns based on comparative photographs, and explanations for the causes of decay.

8.1 Description of Current Conditions

Based on current photographs of the Gateway of the Sun from 2004 and 2005, as well as information from the 2004 condition assessment produced by conservation architect Gionata Rizzi, a description of the current conditions is presented. Without an on-site condition assessment, or non-destructive testing or sampling of the stone for material analysis, this description of the current conditions is qualitative and based mainly on visual observation from present-day photographs. Nevertheless, types and patterns of deterioration can be identified and recommendations submitted for further study.

The main conditions observed on the Gateway of the Sun, as apparent from present-day photographs, include: a major fracture; delamination; surface erosion; spalling; microflora; major loss; pitting; other (such as repair); and possibly microcracking. (Appendix A: Illustrated Conditions Glossary)
8.1.1 Major Fracture

The major fracture, or shear crack, the most visible condition of the Gateway of the Sun, has been evident since the 1830s and 1840s, the time of the earliest available visual documentation.\(^{435}\) (Appendix B: Additional Historical Photographs) The fracture has split the monolithic stone into two large fragments. A complete break, the fragments have since been re-erected and abutted together. The fracture is located on the upper portion of the monument, above the northwest corner of the doorway. (Fig. 8.1)

8.1.2 Delamination

The delamination occurring on the Gateway of the Sun is severe. Located around the stepped niches and moldings and above the doorway, the delamination is mainly centered on the upper portion of the Gateway and in particular on the west façade. Delamination is occurring around the shallow protrusions, but not on the carvings on the east façade. (Fig. 8.2)

8.1.3 Surface Erosion

The surface erosion is the phase before delamination and is visible on the Gateway of the Sun in areas where delamination is also occurring, mainly on the west façade around the carved niches, doorway, and step moldings. Localized surface erosion

\(^{435}\) Hand drawings by D’Orbigny, *Voyage dans l’Amerique meridionale*, 1835-1847.
resulting in the reduction of surface details such as edges, is occurring on the monument and in particular on the carved bas-relief on the east façade. (Fig. 8.3)

8.1.4 Spalling

Dimensional loss in the form of spalling is the result of external pressures or impacts. Spalling is discrete dimensional fragments that have split or broken off the object. Fitzner defines these as outbursts due to direct anthropogenic influence, for example war, damage, or vandalism. Spalling is observed on the west façade of the stone, around the niches, and doorway. Spalling is also seen on the north and south façades, also in relation to the carved niches. (Fig. 8.4) Additionally, there is some evidence of small, localized spalls in the shape of bullet holes.

8.1.5 Microflora

Biogrowth or microflora is clearly visible on the Gateway of the Sun, concentrated on the top and on the upper portions along the doorway and step moldings, as well as in other crevices below the niches (Fig. 8.5). The biogrowth appears to be a combination of dark green or black algae and green-white-orange lichens. The algae, in appearance, looks like a dark gray or black surface staining or water staining on the vertical surfaces of the gray stone. (Fig. 8.6) The lichens are flourishing, covering large expanses of the surface. The biogrowth is transpiring in easily wetted areas (the top) and

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possibly in areas that are undergoing higher water absorption due to an increase of
surface area resulting from deterioration of the stone.

8.1.6 Major Loss

Major loss has occurred on the carved bas-relief engravings on the east façade.
The north side of the bas-relief has experienced major loss when compared to the south
segment. (Fig. 8.7) Overall loss of surface legibility is evident throughout the carved and
incised relief on the Gateway, as well as on the recessed surrounds of the carved niches
on the west façade. Apparent in the present-day photographs is a loss of detail of the
edges of the figures and geometric shapes when compared with the 1894 photographs.

8.1.7 Pitting

A form of surface erosion, pitting has occurred in certain localized areas around
the monument and can be seen on the face of the central staff god. (Fig. 8.8) Pitting is
localized and exhibits a unique form.

8.1.8 Other

There are certain areas of the Gateway of the Sun that have undergone repairs.
Two holes at the base of the legs of the monument have been filled in with cement,
perhaps for stability. (Fig. 8.9)
8.1.9 Microcracking

Although microcracking is not visible on the available current condition photographs, the condition was noted by conservation architect Gionata Rizza in his 2004 field report on the conditions of the monuments at the site of Tiwanaku. Microcracking is present on some of the other andesite monuments at the site, such as the Ponce Monolith. (Fig. 8.10)

8.2 Evaluation of Decay over Time

By employing photographic comparisons between historical photographs from 1894 with present-day photographs from 2004 and 2005, decay over time can be qualitatively evaluated. A set of photographs of the Gateway of the Sun (in addition to many others of the monuments and site) were taken by archaeologist Max Uhle in 1894. Archaeologist Alexei Vranich matched these photographs in 2004 and 2005, producing a series of photographic pairs that capture the same subject and similar angle, 110 years apart. Although only qualitative, a careful visual comparison of the photographs of the Gateway of the Sun reveals much about the monument’s rate and patterns of damage, as well as the excavation history.

Table 8.2 lists the eight photo pairs used for the comparison. A variety of full views and details, the photographs illustrate the major conditions described in section 8.1, Current Conditions. These conditions are noted where found and any additional conditions or changes in the state of the Gateway are also documented, such as change in display or extent of excavation/exposure. The majority of the listed conditions are visible in each photo pair. The main differences between the 1894 and 2005 photographs are the
extent of the conditions. For example, surface erosion and microflora can be seen on
many of the historic images; yet in the 2005 images these conditions have progressed and
have become much more extensive.

8.2.1 Comparison of Photographic Pairs

The first photo pair (Figs. 8.11 and 8.12) of the full west, or rear façade, shows an
increased presence of microflora as well as increased surface erosion. Additionally, the
Gateway has been fully excavated, re-erected, and set in a cement footing. Sections of
loss at the base have been filled in with cement. Extensive delamination is obvious on
both photographs. The burial line is apparent on the 1894 photograph, indicating that at
some point previous to the date of this photograph, the Gateway of the Sun was
excavated and the base exposed.439

Photo pair 2, (Figs. 8.13 and 8.14) a detail of the carved lower frieze on the east
façade shows significantly increased surface erosion and the growth of microflora.

Photo pair 3, (Figs. 8.15 and 8.16) another detail of the lower relief, displays a
definite progression of surface erosion and microflora, as well as possibly microcracking.

Photo pair 4, (Figs. 8.17 and 8.18) a detail of a figure from the upper relief on the
east façade, exhibits significant increases in the degree of surface erosion and the
presence of microflora.

Photo pair 5, (Figs. 8.19 and 8.20) another detail of the upper frieze, displays a
substantial increase in surface erosion since the earlier photograph, to the point where the
figure is almost unrecognizable due to the rounding of the edges and loss of detail. This

439 The burial line can be seen more clearly on a 1903 photograph by the Sintich Brothers (Appendix B:
Additional Historical Photographs).
erosion is possibly occurring in the locations where, in the 1894 photograph, microflora appears present. The amount of microflora has also increased.

Pair 6, (Figs 8.21 and 8.22) depicting the central staff figure on the carved east façade also shows an extreme loss of detail and increase in surface erosion since 1894. The amount of microflora has also intensified.

Photo pair 7, (Figs 8.23 and 8.24) a side view of the Gateway, or the north façade, clearly shows the change in use and display is clearly evident. The segments were excavated in place and the lower third of the Gateway exposed. In the 1894 photograph, the right section is supported by a pile of rocks at the base of the monument. In the current 2004 photograph, the base of the south leg of the monument shows that the hole was repaired with cement.

Last, photo pair 8, (Figs 8.25 and 8.26) a sectional view of the upper left portion of the carved east façade, clearly shows a proliferation of microflora, increased surface erosion, and loss of detail. The major loss is apparent in both the 1894 and 2005 photographs, and appears to have worsened.

The majority of the conditions affecting the Gateway in the present day can be seen on the historical photographs as well. Delamination, microflora, spalling, pitting, major loss, and surface erosion can be discerned in the photographs, past and present. The crucial element is the extent and progression of these conditions. In some of the detail photographs, the apparent loss of surface detail has been incredibly severe over the last 100-plus years. The carved elements, in particular on the east façade, are in danger of being lost.
*Conditions Code for Table 8.2*

1. Major Fracture (MF)
2. Microflora (F)
3. Surface Erosion (SE)
4. Spalling (SP)
5. Major Loss (ML)
7. Pitting (P)
8. Delamination (DL)
9. Other Changes (O)
10. Microcracks (MC)
## Table 8.2: Historical and Contemporary Photographic Comparisons

<table>
<thead>
<tr>
<th>Photo Pair</th>
<th>Date of Photograph</th>
<th>Face or section</th>
<th>Conditions Noted*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>1894</td>
<td>West or rear facade, full view</td>
<td>DL, F, MF, ML, SP</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>West or rear facade, full view</td>
<td>DL, significantly increased MF, F, SE, ML, SP, O (fully excavated, re-erected, placed in cement; missing base pieces replaced with cement for stabilization)</td>
</tr>
<tr>
<td>Set 2</td>
<td>1894</td>
<td>East façade, carved detail 1 (from lower frieze below central figure)</td>
<td>ML, SE</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>East façade, carved detail 1 (from lower frieze below central figure)</td>
<td>ML, significantly increased SE, possibly MF</td>
</tr>
<tr>
<td>Set 3</td>
<td>1894</td>
<td>East façade, carved detail 2 (from lower frieze below central figure)</td>
<td>SE, ML, MF, possibly MC</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>East façade, carved detail 2 (from lower frieze below central figure)</td>
<td>significantly SE, ML, increased MF, possibly MC</td>
</tr>
<tr>
<td>Set 4</td>
<td>1894</td>
<td>East façade, carved detail 3 (from upper frieze on side of central figure)</td>
<td>MF, ML, SE</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>East façade, carved detail 3 (from upper frieze on side of central figure)</td>
<td>increased MF, ML, significantly increased SE</td>
</tr>
<tr>
<td>Set 5</td>
<td>1894</td>
<td>East façade, carved detail 4 (from upper frieze on side of central figure)</td>
<td>ML, MF, SE,</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>East façade, carved detail 4 (from upper frieze on side of central figure)</td>
<td>extreme SE and loss of detail (especially in areas where there was MF?), increased MF, ML</td>
</tr>
<tr>
<td>Set 6</td>
<td>1894</td>
<td>East façade, carved detail 5, central figure</td>
<td>P, SE, MF, DL</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>East façade, carved detail 5, central figure</td>
<td>significantly increased SE and loss of detail, P, increased MF, DL</td>
</tr>
<tr>
<td>Set 7</td>
<td>1894</td>
<td>North façade, looking South, full view</td>
<td>MF, DL, OL, SP, O (can see clearly the right section is propped up by piles of rocks)</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>North façade, looking South, full view</td>
<td>MF, F, DL, OL, SP, O (the base is exposed and set in cement)</td>
</tr>
<tr>
<td>Set 8</td>
<td>1894</td>
<td>East façade, carved frieze, left side detail</td>
<td>DL, ML, MF, SE</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>East façade, carved frieze, left side detail</td>
<td>DL, ML, increased MF, increased SE and loss of detail</td>
</tr>
</tbody>
</table>
8.3 Analyses of Deterioration Mechanisms

Conditions of a monument or site are the result of the accumulation of many different and disparate factors. On archaeological sites, these agents include: original design, materials, and construction techniques; changes in use; human and natural alterations and weathering; micro-and macro-environments and climate; disuse or abandonment; destruction and burial; excavation; stabilization, display, and maintenance.\textsuperscript{440} According to Matero, these determinants shape the life cycle of any structure, monument, or site and are accumulated evidence for the interpretation of condition.\textsuperscript{441}

As discussed in Chapter 5, the deterioration of stone is related to many interrelated factors. The material properties and weathering of andesite is discussed in Chapter 7. The Gateway of the Sun is estimated to have been carved in A.D. 200-400 and has endured a variety of uses, locations and presentations (constructed, tooled, exposed, partially buried, excavated, re-erected, set in concrete, etc.). The Gateway has not been located in a museum, or otherwise climate controlled or access-controlled environment. Therefore, all decay mechanisms must be examined. Of course, some factors are more likely than others, and this section will proceed to identify and describe those causes.

An analysis of the deterioration mechanisms of the Gateway of the Sun will be presented utilizing two reports on the conditions of the andesite monuments at the site of Tiwanaku, information about the Gateway’s excavation and conservation history, climate data, and knowledge of stone decay mechanisms in general and those mechanisms that

\textsuperscript{440} Matero, “Managing Change: The Role of Documentation and Condition Survey at Mesa Verde National Park”, 41.
\textsuperscript{441} Matero, “Managing Change: The Role of Documentation and Condition Survey at Mesa Verde National Park”, 42.
affect andesite and volcanic rocks in particular. One report, produced by the Getty
Conservation Institute and the Bolivian National Institute of Archaeology, based on the
results of an environmental monitoring program at the site of Tiwanaku in 1990, is
discussed in Chapter 7 and will be revisited here. The other report, an unpublished
condition survey of some of the stone monuments and structures at the site of Tiwanaku,
was authored by conservation architect Gionata Rizzi in 2004. Some of these findings
have already been mentioned in Chapters 3 and 4. These reports will be combined with
the previous discussions regarding stone decay and the weathering of andesite to develop
an understanding of the complex deterioration mechanisms affecting the Gateway of the
Sun.

The deterioration mechanisms of the Gateway of the Sun have been categorized
into three main groups of factors: environmental; material; and history of use. These
categories, useful for describing the mechanisms of decay, are intrinsically interrelated.
The stone’s material and history of use affect its response to the environment, and vice-
versa. Table 8.3 shows the matrix of the major conditions.

8.3.1 Environmental

The micro and macro environmental conditions in the Lake Titicaca Basin and
surrounding the site of Tiwanaku greatly impact the weathering of the Gateway of the
Sun. Thermal cycles, freeze-thaw cycles, wind, and moisture availability all affect the
rate of deterioration.

Location of mechanical breakdown occurs in areas where temperature and
moisture cycling is more intense and frequent; where stonework has been previously
weakened from chemical alteration, such as beneath case-hardening; where stonework is inherently weak along bedding planes, grain boundaries, or pores; at certain depths related to frequent wetting depths and outward mineral and salt migration; and in areas that form convergent directions such as corners, edges, and protuberances which are particularly subject to increased temperature and moisture gradients.442

*Delamination*

The location of the severe delamination is around the step moldings and particularly above the doorway. These are areas that are likely undergoing water saturation. The areas of delamination are in locations of shallow protrusions and step moldings where rainwater is collecting and seeping into the stone. Water is not the cause of the delamination, but is exacerbating the problem through freeze-thaw action from water absorption at uniform depth. Alternatively, soluble minerals are being transported to the surface in the wettest areas causing case hardening (a densification) of the surface in areas where more wet-dry cycles are occurring, such as on the corners and edges. Case hardening results from the dissolution and transport of soluble minerals from the presence of water. The delamination is transpiring on the carved elements and the protruding elements around the corners and niches and not on the vertical surfaces. This, therefore, indicates a direct relationship to water. The delamination is uniform, signifying that the damage is most likely being caused by freeze-thaw action, from water absorption at a uniform depth. Possibly, freeze-thaw is acting simultaneously with case-hardening.

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**Microflora**

The microflora is occurring in the same areas as the delamination, further indicating a water problem. Microflora, in the form of algae and lichens, are a contributing problem, but are not the cause of the damage. The microflora can increase the surface area available to water absorption due to the carvings in the affected area of the stone. Lichens may increase water absorption by enlarging existing fissures and creating new ones. Additionally, they might cause microcracks from the pressure resulting from the expansion and contraction of the thallus. Climate, moisture availability, and the material properties of the stone all affect the monument’s ability to support these life forms.

Lichens are usually associated with fungi and algae, and although most commonly found on limestones, have been known to attack basalts and granites as well. Basic igneous rocks (as opposed to acid granites) with low silica content are very susceptible algae, fungi, lichens, and mosses. Silicolous lichens in silicate rocks, like andesite, live either within the rock or on the surfaces, either encrusting the stone surface, often in patches, or as leaf-like lobes.\(^\text{443}\) The lichens are most likely selectively attacking the minerals in the andesite.

The algae and lichens, occurring in the same areas as the delamination, are further evidence that the damage is water instigated. The microflora are contributing and perhaps accelerating the deterioration, but the growth is not the underlying cause.

Salts and Flaking

Flaking is not readily visible on the photographs, but flaking from the presence of salts is possible. The source of the salts could be standing ground water, which is a problem at the site of Tiwanaku. No efflorescence line is visible on the Gateway, but in the recent photographs, a line and change in color is evident approximately a third of the way up the monument. This line could be the burial line or it could be evidence of capillary rise. Although salt damage is not readily visible in the form of efflorescence, the occurrence of subflorescence is possible. According to Maekawa, accumulated rain water in the form of ponds or large puddles create localized groundwater sources. (Fig. 8.27) Soluble salts present in the groundwater from the soil migrate into the stones, travel near the surfaces, and crystallize, resulting in severe loss of material at the stone surface. Due to lack of visual evidence of salt efflorescence and the durability of andesite to salt damage, this mechanism is difficult to discern, although the presence of salts is likely.

Moisture Availability

The moisture is mostly from rainwater, which, although not heavy at the site of Tiwanaku, does fall in short intense bursts. Additionally, the high relative humidity will prevent the water from evaporating, keeping the monument wet. The temperature in the air reaches the freezing point on many nights of the year and any moisture in the monument will freeze. The winds at the site will also contribute to an increased water evaporation rate at stone surfaces, contributing to rapid wet-dry cycles. Further, wind may increase the amount of water absorption in the monument by driving water into the

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monument and the air lift displaces the moisture along the surface. Wind gusts at the site of Tiwanaku will cause a fluctuating pressure between the interior and exterior of the monument, which may force water in the layer running over the surface into the cavities and pores of the structure.  

*Major Fracture*

According to Maekawa et al., the pressure from thermal cycling would be sufficient to fracture the stone. As mentioned in the earlier discussion on andesite weathering at the site of Tiwanaku, the combination of the temperature changes with the moisture in the air is perhaps the most significant source of damage to the stones at the site of Tiwanaku. During many nights of the year, the surface temperature of the stone is lower than the dew point temperature, resulting in condensation on the stone surfaces and within the tiny crevices of the monuments. When the stone’s temperature drops to zero, as often happens in the winter and occasionally during the summer as well, the moisture freezes. These frost conditions cause very damaging freeze/thaw cycles. The temperature differentials as the sun rapidly heats the surface of a cold stone and the freeze/thaw cycles are strong stone-splitting factors, and may be the cause of the through-and-through vertical cracks in both the Gateway of the Sun and the Ponce Monolith.  

*Microcracking*

Microcracking is usually caused by thermal cycling which is, according to the GCI monitoring study, occurring at a high rate on all of the stone at the site of Tiwanaku,  

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but is particularly affecting the andesite. However, there is little, if any, microcracking on the Gateway of the Sun according to the photographs and the 2004 report by Gionata Rizzi. Extensive microcracking, however, is readily apparent on the Ponce Monolith, another andesite monument at the site. If thermal cycling is causing the microcracking, this phenomenon should be occurring on all of the andesite at the site. One possible explanation is water saturation from extensive tooling, as the microcracking on the Ponce Monolith appears to be occurring around the deepest carved crevices and niches. Another cause of microcracking can be from stress from differential settlement or a change in load. The presence and extent of microflora in the form of lichens can also cause microcracking from the expansion and contraction of lichen thallae.

Although microcracking is not specifically mentioned, Maekawa et al., discusses the continual thermal cycling that occurs at the surfaces of all of the stones at the site of Tiwanaku, a factor that affects the andesite more intensely.\textsuperscript{447} High thermal gradients are generated in the andesite because of the low air temperature, high intensity of solar radiation, and the orientation of the sun. Long-term stresses caused by this daily thermal cycling are significant contributors to andesite deterioration and the combination of the thermal gradients with freeze-thaw cycles are powerful stone-splitting mechanisms.

\textit{Surface Erosion}

In addition to freeze-thaw and case hardening, wind is another possible mechanism of some surface erosion.\textsuperscript{448} According to the environmental monitoring program conducted by the Getty Conservation Institute, the wind at the site of Tiwanaku

\textsuperscript{447} Maekawa, et al., "Environmental Monitoring at Tiwanaku", 885-891.
\textsuperscript{448} Maekawa, et al., "Environmental Monitoring at Tiwanaku", 885-891.
is almost always present, gusty, and variable. Although westerly winds predominate, the presence of varied-directional winds “…results in a general erosion of detail on Tiwanaku artifacts rather than a decided loss of features on any one face or edge of a stone or carving.”

The surface erosion occurring on Gateway of the Sun is causing an alarming loss of detail of the engraved reliefs. The figures and carvings are becoming increasingly rounded and are losing depth and legibility. Generalized flaking can often be attributed to salts and their ensuing effects, as discussed in Chapter 5, the overview of stone decay. The migration of salts, acquired from the soil if the Gateway was laying in the ground or partially buried, or transported from current localized groundwater sources, can cause flaking and disaggregation. Additionally, thermal cycling may have begun when the monument was re-erected. As discussed above, case hardening of the soluble minerals is likely occurring in areas undergoing water saturation and wet-dry cycling. Further, flaking can transpire in areas where there are mineral inclusions undergoing freeze-thaw cycling. All of these mechanisms are related to mineralogical inclusions, chemical composition, location, and micro-and macro climate.

Pitting

Pitting can be caused by a number of factors. The constant and gusty wind at Tiwanaku could result in abrasion and material loss from propelled sands and small pebbles. Salt crystallization may also cause the appearance of pitting, as well as possibly

attack from lichens. Additionally, naturally-occurring mineral inclusions inherent in the rock make-up may deteriorate at a faster rate than the surrounding stone, resulting in mineral loss in these areas and possibly causing a pitting effect.

8.3.2 Material

The material properties of andesite are responsible for the monument’s reaction to the environmental conditions and the construction methods used to create the Gateway of the Sun. The Gateway is constructed of andesite, a rather durable stone. According to Maekawa et al, the andesite at the site of Tiwanaku responds more intensely to thermal gradients and daily thermal cycling than the sandstone at the site. The finely grained volcanic rock and high silica content also make andesite more susceptible to freeze-thaw action. Otherwise, andesite is less susceptible to salt damage and the effects of air pollution than other rocks. The delamination that is occurring is not due to the material as andesite is not a bedded stone.

8.3.3 History of Use

The history of use of the Gateway of the Sun includes the initial design and construction and the tooling and carving that created the monument. At various time after its construction, the Gateway has been abandoned, intentional damaged, relocated, partial buried, excavated and exposed, reset, and possibly undergone conservation treatments.

In a 1903 photograph of the Gateway (Fig. 8.28), the burial line of the Gateway is evident. The staining approximately a quarter of the way up from the bottom indicates the

Gateway was previously buried more deeply. The earlier 1894 photograph (Fig. 8.11) does not show the burial line as clearly. This suggests that between 1894 and 1903 the Gateway was further excavated or at least the base was cleared of fill and stone rubble. Also apparent in the early photographs are the areas of loss at the bases of each of the legs. These losses may have been the locations of attachments or pins from the Gateway’s original location and when the Gateway was moved, the attachments broke off, leaving the holes. A likely scenario is that the Gateway was moved from its original location and from its original base, breaking the bottom attachment pins. At some time before 1830s and 1840s, the time of the first visual documentation, the Gateway was propped up and, using fill and rocks, was supported in this position for some years. By 1903, some of the fill and rubble was cleared from the base and in the 1950s the Gateway was further exposed, fitted back together, and set in a concrete base. Additionally, two of the areas of loss at the base of the legs were repaired with cement for stability. (Fig. 8.29) Since the 1950s, the Gateway of the Sun has been set in concrete. The monument is not sufficiently embedded in the concrete for the monument to be stable; therefore, an internal anchor was likely inserted before setting the Gateway.

**Major Fracture**

The major fracture is located at the weakest point of the Gateway of the Sun. Any large single piece of carved stone will be weakened by the load and the size of the rock and the stress will be centered at the thinnest part. The Gateway fractured at the thinnest and weakest area of the carved stone, above the doorway at the vertical cross. Any thermal movement would trigger a torque-like movement of the Gateway and resulting
stress could cause a major shear crack. The fracture likely occurred after the Gateway was moved from its original location, either before or during re-erection. The Gateway was likely still been in one piece when it was moved to its present location. After moving, the Gateway fractured and the south section slipped. Therefore, the holes at the bottom of the legs likely occurred when the Gateway was in its original location as the monument was removed from its base, and the fracture occurred in the second location, although the crack could have begun before.

Stress from differential settlement could also result in a major fracture. An object will fracture when the stress acting on it is raised to sufficiently high levels. This level depends on the type of rock, its porosity, its previous history, the types of stresses applied, degree of saturation and pressure of the pore fluid, and the rate at which the load is applied. Also, larger samples of rock have been shown to be weaker than smaller ones.\textsuperscript{451}

The historical records indicate that the Spanish intentionally damaged many of the monuments and sculptures at the site of Tiwanaku after they arrived in the mid 1500s. No direct evidence exists that the Spanish damaged the Gateway of the Sun in particular; however, the Gateway’s prominence and elaborate carvings would have made the monument an attractive target if the Spanish were destroying examples of a pagan civilization. Additionally, systematic destruction occurred at the site of Tiwanaku around the time of its abandonment about A.D. 1000. Possibly, the Gateway was moved or damaged at this time.

\textsuperscript{451} Walsh, “Deformation and Fracture of Rock”, 99-105.
Major Loss

Wall exposure and lithology can result in different types of decay on exposed and sheltered surfaces. The major loss evident on the upper south-east façade of the Gateway of the Sun is most likely caused by the monument’s history of use and abandonment. The probable scenario is that the Gateway, once fractured, became partially buried (or at least face down in the earth) and partially exposed to the atmosphere. The south side of the bas-relief is significantly more eroded than the north side. The north segment was protected from atmospheric weathering and the south segment was possibly left exposed, either lying in the ground, or remaining standing upright. However, interesting to note is that the south portion of the south piece is more weathered than the north-most side of the segment. For an unknown reason, the rightmost side of this south section was protected from the weathering agents that were attacking the leftmost side.

Spalling

The areas of stone loss or spall on the Gateway are likely caused by human activities. The Spanish intentionally destroyed many of the sculptures and monuments at the site of Tiwanaku and are perhaps the cause of the localized losses. Also, researchers have found evidence of systematic destruction at the site around the time of its abandonment in approximately A.D. 1000. Alternatively, the losses could have occurred at any point before the earliest visual records. According to the records of Max Uhle’s visit to the site in 1910, he was shocked by the use of the monuments for target practice by the Bolivian army. Uhle makes specific reference to the most important stone on the
site being utilized for target practice, but it is unknown if he was referring directly to the Gateway of the Sun.

8.4 Conclusion

The current conditions of the Gateway of the Sun are caused by a multitude of interrelated factors. The intrinsic stone properties of the andesite, including pore structure, size and permeability and the presence and type of mineral inclusions, interact with a large variety of extrinsic factors. This interaction results in the types and patterns of deterioration. Temperature, relative humidity, and moisture act simultaneously to cause damaging freeze-thaw cycles and thermal movement. The history of construction, tooling, use, abandonment, and excavation directly impact the deterioration of the Gateway.
<table>
<thead>
<tr>
<th>Current Condition</th>
<th>Possible Causes</th>
</tr>
</thead>
</table>
| Fracture (Shear cracking)         | - Intentional destruction  
- Differential settlement  
- Thermal movement  
- Heating-cooling cycles  
- Freeze-thaw cycles  
- Related to size of stone, porosity, construction technique, tooling, and chemical & physical composition |
| Microflora in the form of algae and lichens | - Climate, moisture  
- Material properties of the stone  |
| Surface erosion in the form of flaking and/or disaggregation | - Salts  
- Thermal cycling began when re-erected  
- Case-hardening from soluble minerals  
- Related to mineralogical inclusions, chemical composition, climate, perhaps cement base  
- Wind  |
| Spalling                           | - Intentional destruction  
- Movement from original base and setting (breakage of pins)  
- Target practice  |
| Major loss                         | - History of use, abandonment, excavation  
- Salts  
- Case-hardening  |
| Delamination                       | - Freeze-thaw  
- Case-hardening  
- Construction and tooling  |
| Pitting                            | - Wind abrasion  
- Salt crystallization  
- Lichen attack  
- Heavy use and tooling  |
| Microcracking                      | - Thermal cycles  
- Stress cracking from differential settlement  
- Microflora |
Chapter 9: Recommendations and Conclusions

While it takes time to form an attachment to place, the quality and intensity of experience matters more than simple duration.
- Yi-Fu Tuan, Space and Place

Part one of the present study has examined the historical, archaeological, and conservation history, as well as the current context of the Gateway of the Sun and the archaeological site of Tiwanaku. Part two entailed an examination of comparative historical and present-day photographs. This comparison, in addition to site records and documentation, has shown that the Gateway of the Sun is undergoing surface erosion, delamination, and is the host for potentially damaging microflora. Although the monument is not currently in critical condition, a loss of detail and engraved carvings has occurred in the past one hundred years. The surface erosion, the increase in potentially damaging microflora in the form of algae and lichens, and the extensive delamination, indicate that some conservation intervention measures should be considered. Additionally, and equally troubling, is the current presentation of the Gateway. Surrounded by barbed-wire and set in cement, the present display of the Gateway of the Sun is detrimental to its interpretation and to the legibility of the site as a whole.
9.1 Conservation Recommendations

9.1.1 Condition Assessment

The first action that must be taken is a thorough, on site condition assessment of the Gateway of the Sun. Current conditions should be recorded in AutoCAD software. The previous conditions as seen in the historical photographs should also be recorded in CAD in a similar fashion. This information should then be integrated into a GIS (Geographical Information System) in order to further analyze the decay mechanisms and to serve as a future monitoring system. A GIS database can function as a database and record-keeper of any future conditions or changes.

Along with the implementation of a CAD and GIS monitoring program to track and record conditions, a yearly on site monitoring system needs to be implemented. Any changes in material need to be carefully observed, including continued loss of surface detail, an increase in microflora, delamination, and any appearance of microcracking.

9.1.2 Quantitative Measurement of Decay

A quantitative rate of decay should be established using the previous documentation and photographs with current observations. Additional documentation methods such as photogrammetry and micron-level laser scanning could be used to determine a quantitative rate of decay. A micron-level laser scan of the Gateway’s facades would allow for a trained professional to lay the historic and contemporary photographs over the laser scan surface and measure the changes in surface loss over time. Photogrammetry would also enable a more precise measure of the depth of engravings. The amount of decay could be inferred from the amount of recorded loss.
Further, a rubber mold may be taken of the Gateway as a future reference if at any time a
decision is made to construct a replica, as well as be used for measuring surface loss.

9.1.3 Material Intervention

If deterioration continues, other conservation interventions should be explored. Consolidation, after appropriate testing, is one possible option. However, andesite as a rock type has been inadequately tested on site and in the laboratory. Before any material intervention is taken, thorough testing of samples of the andesite from the site of Tiwanaku should be completed using a variety of material analysis techniques to determine salt damage, porosity, permeability, durability and strength, and mineral composition. Additionally, any treatments must be fully tested before application.

As part of the on-site investigation, non-destructive testing methods should be investigated and employed, including X-Ray analysis and Ground Penetrating Radar. These methods may be able to impart important information regarding the depth of stone deterioration as well as the type of decay. Material analysis would be ideal, however, due to the importance of the Gateway, sampling from the stone might not be allowed by the Bolivian government. However, samples from other andesite blocks from the sites could be taken for testing to determine the mineralogical composition of the rock and the extent and types of salts present in the stone.

If chemical conservation interventions are desired, in-situ testing of treatments should first be observed on other andesite rocks exposed at Tiwanaku. After initial testing, a small portion of the Gateway might then be tested with the chosen treatment.
One intervention that should be considered is the removal of the microflora with a tested biocide.

### 9.1.4 Preventive Conservation Measures

Certain preventive conservation measures should be implemented. Sheltering during the rainy season is one possible option for minimizing the Gateway’s access to water. Although the amount of precipitation in the form of rain that actually falls at the site of Tiwanaku is minimal, water-induced damage caused by freeze-thaw and case-hardening is rampant. Major delamination has occurred at areas that receive the most falling rain. Additionally, pooling and standing water, and issues of erosion at the site should be addressed.

Thermal cycling and freeze-thaw cycling are a major problem. The ambient temperature and relative humidity greatly affect the moisture content and temperature of the stone. The temperature of the stone significantly rises and falls during the day due to the high levels of atmospheric relative humidity, resulting in internal stress of the stone and the potential for cracking. This, unfortunately, can only be addressed in a climate-controlled environment such as a museum. Freeze-thaw cycling is also difficult to address. Keeping the stone dry is important. Sheltering during the rainy season is one option. The high relative humidity, however, is another source of moisture. With proper testing, consolidation of the fissures, cracks, and pits, should be investigated as a method for eliminating access points for moisture. Testing of different consolidants should occur on site, first with other blocks of andesite, and then on small areas of the Gateway. Water-repellents can cause more harm than benefit, and those coatings, although they
should be investigated, are not recommended. Wrapping the stone in an insulating material during the colder months, at least at night, is another option to consider; however, the daily maintenance required for this approach might eliminate this method as viable or sustainable in the long-term.

At this point a replica is not needed; nor is it necessary or desirable to relocate the Gateway of the Sun inside the site museum. The stone is relatively stable and removing the monument to the museum would completely sever the connection between the Gateway and the site. If, however, the Gateway continues to deteriorate, moving the Gateway to the museum and designing a replica for the site might be considered, although other measures should be considered first.

9.1.5 Conservation and Management Plan for the Site

Finally, a complete conservation plan for the site of Tiwanaku needs to be developed. The Gateway of the Sun is only one monument at this site and any conservation program that does not include the entire site will be deficient. The information gathered here on the Gateway and the recommendations may be utilized for looking at the rest of the site and at the very least, should be used for all of the andesite sculptures and monuments.

9.2 Presentation Recommendations

In addition to considering the material conditions of the Gateway, the presentation of the monument must also be evaluated. The current presentation of the Gateway of the
Sun separates the monument from the rest of the site. By surrounding the Gateway with a barbed-wire fence and placing the monument in a concrete “stage,” the context that imparts meaning and understanding is removed. The first recommendation is to remove the barbed-wire fencing and explore other design options for the protection of the monument. Experimenting with natural material found at or near the site, a less obtrusive barrier could be designed that does not separate the Gateway from the site, or the visitor from the Gateway. A more natural looking barrier would be less visibly intrusive and could blend more completely with the overall setting. A temporary barrier and/or increased security during the solstice festivals may be implemented.

As part of the presentation, the cement footing should be removed. If the cement can be removed without damaging the stone, other measures for its stability should be investigated. The cement, in addition to increasing risks of salt damage and stress cracking, is unattractive and contributes to the separation of the Gateway from its setting. The method of attachment between the Gateway of the Sun and the cement base is, however, unknown. The Gateway is not embedded deeply enough for stability, therefore, an attachment mechanism was likely inserted. Removing the Gateway from the cement base will require care and investigation into the nature of the attachment as to insure no further damage.

Currently located in the northwest corner of the reconstructed Kalasasaya Platform, the monument was re-erected by Ponce Sangines in the 1950s in the same location where, according to the visual records, the Gateway had been standing for hundreds of years. Questions have arisen regarding the authenticity of this placement. However, researchers do not know where the Gateway was originally located. One theory
poses that the monument was originally part of the Pumapunku Complex. Another theory, based on the Gateway’s astronomical significance, is that the monument was originally located along the main axis of the Kalasasaya Platform. Advocating a recommendation about the original location of the Gateway is certainly inappropriate in this study. However, if and when any conclusion is reached by the archaeologists concerning the Gateway’s original placement at the site, any physical re-location should be carefully considered. The Gateway is currently stable; however, the monument should not be moved more than necessary. The nature of the attachment of the Gateway to its current cement base is unknown, but an internal connection was likely installed. Moving the Gateway could cause additional damage. Therefore, a consensus needs to first be reached among scholars of the site of Tiwanaku, DINAR, the Aymara, and conservators regarding the Gateway’s proper location and the safest method of movement.

As mentioned above, a replica of the Gateway or moving the monument inside to the museum is not needed or desired. The presentation of the Gateway and the interpretation of the monument would be further sacrificed. Already legibility and understanding of the significance of the Gateway and of the entire site is severely compromised. Relocating the monument into the museum would only add to the problems of presentation and comprehension.

An important aspect of the site of Tiwanaku is the interplay between the art, sculpture, architecture, and view sheds. Another option under consideration is the installment of a permanent or temporary shelter during the rainy months. Due to the importance of the view sheds and landscape to the overall experience of the site, even a temporary shelter would disrupt the monumentality and magnificence of the site of
Tiwanaku. The experience of the connections between all of the elements needs to be enhanced, not further destroyed. In Bender’s discussion of the presentation of the monuments at Stonehenge, “the stones today are viewed by the visitor in isolation. The landscape is simply the backdrop to the photograph. But to understand the stones in the past or present, they have to be returned to the landscape.”

This exemplifies the inherent problem at the site of Tiwanaku, and at many archaeological sites. The preservation of the material fabric of the Gateway of the Sun is at odds with the preservation of the site experience. The goal, therefore, is to balance the two needs. A temporary shelter only during the rainy months might be acceptable except that the view sheds and the relationship between the landscape and the monuments is the crux of the meaning of this site. Therefore, material interventions might offer a better solution. With adequate testing and analysis, material interventions on the stone monument could offer protective measures against increased deterioration. If, however, material interventions are undertaken and the Gateway of the Sun is still undergoing deterioration, other options will have to be considered. Either a shelter must be installed during the rainy season or the original monument will have to be moved inside and perhaps replaced with a replica.

9.3 Conclusions

Archaeological sites are formed, and transformed, over vast expanses of time, from countless forces. Thus, understanding the agents that have shaped the site of Tiwanaku in the past, and which forces continue to do so, is an integral part of assessing

the current conditions of the Gateway of the Sun and in making recommendations
regarding its conservation and presentation.

The site of Tiwanaku is a complex site with difficult conservation and
presentation issues. The site is further complicated by the current political situation. The
struggle over indigenous rights and competing claims over the site of Tiwanaku make the
management, preservation, and conservation of the site, or any piece of the site, a
difficult endeavor. Any recommendations must take into consideration the competing
needs, desires, and assertions of the Aymara people, the Bolivian government, tourists
and visitors, as well as archaeologists, conservators, and UNESCO.

The site of Tiwanaku and its monuments are at great risk. Lack of previous
conservation efforts, inconsistent and short-sighted management decisions, irresponsible
excavations and reconstructions, and lack of cooperation between invested parties, has
resulted in a site that has been called “disappointing.” For one of the most important
archaeological sites in South America, this current state of affairs is unacceptable.
Although a management plan for the entire site of Tiwanaku is outside the purviews of
this thesis, any conservation program developed for a particular monument or structure
cannot be divorced from the needs of the entire site.

A balance is required between the protection of the material of the Gateway of
the Sun and the other monuments at the site and the conservation of the meaning of the
Gateway and the site. The recommendations presented here are an attempt to contribute
to the discussion concerning the preservation of the site of Tiwanaku. This thesis is not a
complete or thorough study, but an opportunity to present some of the most pressing
issues of the site through a detailed evaluation of the Gateway of the Sun. One of the
most important monuments in Bolivia, the Gateway of the Sun is emblematic of the site of Tiwanaku and symbolic to the Aymara people and the nation of Bolivia. Addressing the conservation and presentation issues of the Gateway of the Sun can serve as a model for the site and the implementation of some of the recommendations presented here will significantly contribute to the long-term preservation of the site of Tiwanaku.


Arnold, A. and Zehnder, K. “Salt Weathering on Monuments.” In La Conservazione dei Monumenti nei Bacino del Mediterraneo: Influenza dell’Ambiente Costiero e dello Spray

168


Benitez, Leonard R. “A Unique Lunisolar Observatory and Calendar in Pre Columbian Bolivia.” In press.


Celal, and Kapuz, A. "Rock Mechanics Characteristics of Ankara Andesites in Relation to Their Degree of Weathering." In Proceedings of the 7th International Congress on


French, P. “In Situ Conservation of Archaeological Sites in Turkey.” In Science, Technology, and European Cultural Heritage. Proceedings of the European Symposium,


International Committee for the Conservation of Mosaics. Mosaics Make a Site: the conservation in situ of mosaics on archaeological sites: VIth conference of the
International Committee for the Conservation of Mosaics, Nicosia, Cyprus, 24-28 October 1996.


Romao, P. “Understanding Lichens colonisation on granitic substrata.” In Conservation et restauration des biens culturels : pierre, pollution atmosphérique, peinture murale,


Thompson, Jane, et al. “La Protezione e la Valorizzazione de uno sito a rischio.” Forma urbis: itinerary nascosti de Roma antica. 2005


Viceministerio de Desarrollo de Las Culturas, Bolivia.  


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Location Maps of Bolivia and the site of Tiwanaku
Courtesy of Alexei Vranich
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Spanish-era church in the modern-day town of Tiahuanaco; the church was constructed using stones from the site of Tiwanaku. Courtesy of Frank Matero, 2005
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Local Aymara at the Winter Solstice Festival
Courtesy of Alexei Vranich
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Courtesy of http://brasil.indymedia.org/images (Google Images)
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Courtesy of Gionata Rizzi, 2004
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Courtesy of Frank Matero, 2005.
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Courtesy of Gionata Rizzi, 2004
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Courtesy of Alexei Vranich
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Courtesy of Google Images and created by Lauren Hall, 2006
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Courtesy of Alexei Vranich

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Courtesy of Gionata Rizzi, 2004
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Courtesy of Gionata Rizzi, 2004

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Courtesy of Amila Ferron
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Courtesy www.philcat.it/ufonum_images (Google Images)

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Drawing by Leonce Angrand, 1848; from the Bibliotheque National, Paris, Vh 240 Res 4° (16), courtesy of Georgia de Havenon
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Courtesy of Gionata Rizzi, 2004
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Courtesy of Gionata Rizzi, 2004
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Courtesy of Gionata Rizzi, 2004
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Courtesy of Kari Zobler
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Courtesy of Kari Zobler
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Courtesy of Kari Zobler
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Courtesy of Kari Zobler
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Courtesy of Gionata Rizzi, 2004
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Microflora is rampant all over the upper portions of the Gateway and is located in the same areas as the delamination
Courtesy of Gionata Rizzi, 2004
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Courtesy of Gionata Rizzi, 2004
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Major Loss has occurred on the carve upper frieze on the east façade
Courtesy of Alexei Vranich, 2005
Localize pitting has occurred on the face of the central staff god figure on the east façade of the carved frieze on the Gateway. The pitting, a form of surface erosion, has occurred on the parts of the figure that extend farthest out and are most subject to water absorption and damage.

Courtesy of Alexei Vranich, 2005
Figure 8.9
Areas at the base of the legs of the Gateway have been repaired with cement, likely for stability
Courtesy of Gionata Rizzi, 2004
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Ponce Monolith, constructed of andesite stone; Microcracking is visible on the monument, particularly on the lower carved portion where extensive tooling occurred
Courtesy of Gionata Rizzi, 2004
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Photo comparison 1: west façade looking east; the delamination and fracture are readily apparent; the southwest section is propped up with fill and rocks; Courtesy of Max Uhle, 1894

Figure 8.12
Photo comparison 1: west façade looking east; the Gateway has been much further exposed, fit together, and set in cement; Courtesy of Alexei Vranich, 2005
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Photo comparison 2: west façade looking east; detail of the carved frieze
Courtesy of Max Uhle, 1894

Figure 8.14
Photo comparison 2: west façade looking east; detail of the carved frieze; loss of detail and rounding of the carvings is readily visible
Courtesy of Alexei Vranich, 2005
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Photo comparison 3: west façade looking east; detail of the carved frieze
Courtesy of Max Uhle, 1894

Figure 8.16
Photo comparison 3: west façade looking east; detail of the carved frieze; loss of detail and rounding of the carvings is readily visible
Courtesy of Alexei Vranich, 2005
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Photo comparison 4: west façade looking east; detail of the carved frieze
Courtesy of Max Uhle, 1894

Figure 8.18
Photo comparison 4: west façade looking east; detail of the carved frieze; loss of detail and rounding of the carvings is readily visible; Courtesy of Alexei Vranich, 2005

Figure 8.19
Photo comparison 5: west façade looking east; detail of the carved frieze
Courtesy of Max Uhle, 1894

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Courtesy of Max Uhle, 1894 and Alexei Vranich 2005
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Photo comparison 8: upper southeast section of the east façade, facing west
Courtesy of Max Uhle, 1894

Figure 8.26
Photo comparison 8: upper southeast section of the east façade, facing west; major loss has occurred in this area, particularly towards the edge of the monument
Courtesy of Alexei Vranich, 2005
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View of the site of the site of Tiwanaku with standing water
Courtesy of Gionata Rizzi, 2004

Figure 8.28
The burial line can be seen along the lower third of the base of the Gateway
Courtesy Sintich Brothers, 1903
Figure 8.29
The repaired area at the base of the monument is apparent; these holes were filled with cement likely for stability.
Courtesy of Gionata Rizzi, 2004
Spalling

Other (repair)
Appendix B: Additional Historical Images of the site of Tiwanaku

Figures B.1, B.2, and B.3:
Figures B.4 and B.5:
Photographs from Alfons Stübel and Max Uhle. *Die Ruinenstaette von Tiahunaco*, 1892. Date of photographs is 1877.
Figure B.6:  
Detail photograph of the central figure, from Alfons Stübel and Max Uhle. *Die Ruinenstaette von Tiahunaco*, 1892. Date of photograph is 1877.
Figure B.7:
Photograph by the Sintich Brothers, 1903
**Figure B.8:**

However, Figure B.8 above, taken in 1912, shows that the Gateway is not re-erected.

**Figure B.9:**
The caption reads “The Sun Door erected and placed on foundations in the year 1908.” However, Figure B.8 above, taken in 1912, shows that the Gateway is not re-erected.
Figure 8.10:
**Appendix C: Historical Chronology of the Site of Tiwanaku**

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>4550-1450 B.C.</td>
<td>Arid period, low lake levels</td>
<td>(Kolata and Ortloff 1996)</td>
</tr>
<tr>
<td>1550 B.C.</td>
<td>Agriculture begins in region, lake rising</td>
<td>(Binfor and Kolata 1996)</td>
</tr>
<tr>
<td>1450 B.C.</td>
<td>Tiwanaku climate becomes more moist, sharp rise in lake level begins</td>
<td>(Binford et al 1996; Kolata and Ortloff 1996)</td>
</tr>
<tr>
<td>1300-500 B.C.</td>
<td>Raised field agriculture begins in Lake Titicaca Basin</td>
<td>(Binford et al 1997)</td>
</tr>
<tr>
<td>1200 B.C.</td>
<td>Tiwanaku begins as small settlement</td>
<td>(Isbell and Vranich 2004)</td>
</tr>
<tr>
<td>500 B.C.</td>
<td>population of Tiwanaku begins to overtakes that of neighboring polities</td>
<td>(Stanish 2003)</td>
</tr>
<tr>
<td>800 B.C.- A.D. 200</td>
<td>Earliest building campaign at the site</td>
<td>(Young-Sanchez 2004)</td>
</tr>
<tr>
<td>A.D. 200-400</td>
<td>More elaborate architecture begins to be constructed</td>
<td>(Young-Sanchez 2004)</td>
</tr>
<tr>
<td>A.D. 330</td>
<td>High global climate variability, lake ht. becomes stable,</td>
<td>(Binfor and Kolata 1996)</td>
</tr>
<tr>
<td></td>
<td>Raised field agriculture supports growth</td>
<td></td>
</tr>
<tr>
<td>A.D. 350-500</td>
<td>Lake levels significantly higher than normal</td>
<td>(Kolata and Ortloff 1996)</td>
</tr>
<tr>
<td>A.D. 500-1000</td>
<td>Tiwanaku dominates central Andes</td>
<td>(Isbell and Vranich 2004; Janusek 2005)</td>
</tr>
<tr>
<td>A.D. 610-610</td>
<td>Period of high rainfall</td>
<td>(Kolata and Ortloff 1996)</td>
</tr>
<tr>
<td></td>
<td>Major new construction campaign creating increased monumentalism; expansion of Tiwanaku Empire; establishment of colonies; growth of urban population</td>
<td>(Isbell and Vranich 2004)</td>
</tr>
<tr>
<td>A.D. 700</td>
<td>Decreased precipitation</td>
<td>(Kolata and Ortloff 1996)</td>
</tr>
<tr>
<td>A.D. 760-1040</td>
<td>Population of Tiwanaku disperses</td>
<td>(Erickson 1999; Janusek 2005)</td>
</tr>
<tr>
<td>1000-1200</td>
<td>Shift from raised fields to terraced fields</td>
<td>(Binfor and Kolata 1996)</td>
</tr>
<tr>
<td>1000-1040</td>
<td>400 year drought begins, rise in mean annual temperature of 0.5 C to 1.0 C</td>
<td>(Binford et al 1996, Kolata and Ortloff 1996)</td>
</tr>
<tr>
<td>1100</td>
<td>High global climate variability, Drought, Tiwanaku abandoned, Raised fields abandoned</td>
<td>(Binfor and Kolata 1996)</td>
</tr>
<tr>
<td>12145-1310</td>
<td>Severe drought</td>
<td>(Kolata and Ortloff 1996)</td>
</tr>
<tr>
<td>Date</td>
<td>Event</td>
<td>Source</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>1450</td>
<td>Inca conquest</td>
<td>(Binfor and Kolata 1996)</td>
</tr>
<tr>
<td>1560</td>
<td>Spanish Conquest, terraced fields abandoned</td>
<td>(Binfor and Kolata 1996)</td>
</tr>
<tr>
<td>1600</td>
<td>Small scale subsistence farming takes over</td>
<td>(Kolata and Ortloff 1996)</td>
</tr>
<tr>
<td>August 6, 1825</td>
<td>Independence from Spain</td>
<td>(Osborne 1965)</td>
</tr>
<tr>
<td>December 11, 1825</td>
<td>Earliest cultural heritage preservation legislation adopted</td>
<td>(Torres 2006)</td>
</tr>
<tr>
<td>1860's</td>
<td>Ephraim George Squier visits Tiwanaku</td>
<td>(Kolata 1996)</td>
</tr>
<tr>
<td>1877</td>
<td>Ephraim George Squier publishes his monograph: <em>Peru Incidents of Travel and Explorations in the Land of the Incas.</em></td>
<td>(Kolata 1996)</td>
</tr>
<tr>
<td>1892</td>
<td>Max Uhle publishes <em>The Ruins of Tiwanaco in the Highlands of Ancient Peru.</em></td>
<td>(Young-Sanchez 2004)</td>
</tr>
<tr>
<td>1903</td>
<td>Arthur Posnansky beings excavations at Tiwanaku</td>
<td>(Young-Sanchez 2004)</td>
</tr>
<tr>
<td>1930</td>
<td>remains at Tiwanaku declared National Monuments</td>
<td>(ICOMOS)</td>
</tr>
<tr>
<td>1931</td>
<td>Ephraim George Squier publishes his monograph: <em>Peru Incidents of Travel and Explorations in the Land of the Incas.</em></td>
<td>(ICOMOS)</td>
</tr>
<tr>
<td>1930's</td>
<td>国际 Charter adopted by ICOMOS; the first major international standard for the preservation of built heritage</td>
<td>(ICOMOS)</td>
</tr>
<tr>
<td>July 3, 1932</td>
<td>Bennett Monolith relocated to downtown La Paz amid protests by Aymara</td>
<td>(Arnold and Yapita 2005)</td>
</tr>
<tr>
<td>1940s</td>
<td>Period of political instability in Bolivia</td>
<td>(Osborne 1965)</td>
</tr>
<tr>
<td>1945</td>
<td>Posnansky publishes <em>Tiahuanacu: The Cradle of American Man</em></td>
<td>(Young-Sanchez 2004)</td>
</tr>
<tr>
<td>1950's-1970's</td>
<td>Excavations by INAR including the archaeological work by nationalist Carlos Ponce Sangines</td>
<td>(Kolata 1996)</td>
</tr>
<tr>
<td>April 9, 1952</td>
<td>Revolution of April 9</td>
<td>(Osborne 1965)</td>
</tr>
<tr>
<td>August 2, 1952</td>
<td>All Bolivians are given the right to vote</td>
<td>(Osborne 1965)</td>
</tr>
<tr>
<td>1961</td>
<td>New Bolivian constitution declares the State as protector of the nation's cultural heritage including supervising proper conservation</td>
<td>(Torres 2006)</td>
</tr>
<tr>
<td>1965</td>
<td>Intl Charter for the Conservation and Restoration of Monuments and Sites (Venice Charter) adopted by ICOMOS</td>
<td>(ICOMOS)</td>
</tr>
<tr>
<td>Date</td>
<td>Event</td>
<td>Source</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------------------------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td>Getty Conservation Institute Conservation Workshop at the Site of Tiwanaku</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>City of Potosi first Bolivian site listed as World Heritage Site Charter for the Protection and Management of the Archaeological Heritage adopted by ICOMOS</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>Getty Conservation Institute runs environmental monitoring program at Tiwanaku</td>
<td>(Maekawa et al 1995)</td>
</tr>
<tr>
<td>1990</td>
<td>UPENN and DINAR begin excavations at the Pumapunku</td>
<td>(Vranich 2006)</td>
</tr>
<tr>
<td>1995</td>
<td>Australia's Burra Charter adopted; considered the standard for the management and conservation of cultural heritage sites</td>
<td>(ICOMOS)</td>
</tr>
<tr>
<td>1999</td>
<td>Tiwanaku inscribed on UNESCO's World Heritage List</td>
<td>(UNESCO, World Heritage Centre)</td>
</tr>
<tr>
<td>2000</td>
<td>Local Aymara seize control of the archaeological site of Tiwanaku from the national government Bennett Monolith returned to Tiwanaku, culminating in traditional ceremony and celebration at the site</td>
<td>(Vranich 2003)</td>
</tr>
<tr>
<td>March, 2002</td>
<td>Evo Morales elected president of Bolivia, holds inauguration ceremony at the site of Tiwanaku</td>
<td>(Arnold and Yapita 2005)</td>
</tr>
<tr>
<td>January 21, 2006</td>
<td></td>
<td>(Goodman 2006)</td>
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Appendix D: Visual Timeline of the site of Tiwanaku

Courtesy of Amila Ferron
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