

Study and Analysis Heishan Petroglyphs by Digital Preservation in Jiayuguan City

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Abstract

This article aims to study Heishan Petroglyphs. (1) Classification and characteristics, cultural significance, and historical value. (2) Digital protection methods. (3) Source development and use for teaching, research, and creativity. The research samples are six rock painting sites located in the Heishan area of Jiayuguan, Gansu Province, China, classified based on their content. We analyzed the data using descriptive statistics and content analysis, which involved literature analysis, field surveys, high-definition photo collection, and interviews with rock art researchers, managers, and other professionals. The results are as follows: 1. Petroglyphs are divided into six categories including human figures, animals, dance (rituals), hunting, religion, fonts, and plants. They depict the local people's daily life, spiritual beliefs, and ecological environment at different periods. The rock paintings hold significant cultural and historical value, reflecting ancient narratives, artistic expressions, and the relationship between humans and nature. However, they also face challenges such as natural erosion, human destruction, and insufficient protection. 2. Conducting field surveys and collecting photographs to establish a petroglyph photo library. 3. Designed and developed the Petroglyphs Digital Resource Library, integrating field-collected data and other digital materials related, facilitating access and utilization for researchers, educators, and cultural institutions, and aiding in the study, protection, and dissemination of Heishan Petroglyphs. This study emphasizes the importance of combining traditional methods with modern technology in cultural heritage preservation, providing an effective example for the digital preservation of similar artifacts.

Keywords: Heishan Petroglyphs, Digitization, Resource Base, Conservation Research, Jiayuguan City

Introduction

The study of Heishan Petroglyphs is of significant importance for understanding the history and cultural evolution of ancient civilizations in Northwest China. This research builds upon the work of Yang & Zhang (2001) on the artistic and anthropological value of petroglyphs and further expands its cultural analytical perspective by incorporating digital preservation strategies. Although their study provided valuable insights into the symbolic and historical significance of petroglyphs, it also highlighted the urgent need for more adaptive and effective preservation methods in the face of ongoing degradation caused by environmental and human factors.

Currently, the daily management and protection of the Heishan Petroglyphs face numerous challenges, including a large protection area, a complex geological environment, and limited

protection methods. The lack of systematic digital records and monitoring tools exacerbates these issues. While some regions in China, such as the Huashan Petroglyphs in Guangxi, have begun exploring the use of virtual reality and digital platforms for cultural heritage preservation (Nie, 2023), these methods have not yet been applied to the Heishan Petroglyphs. This gap emphasizes the urgent need for a systematic digital preservation study of the Heishan Petroglyphs.

In response to this need, this study focuses on six petroglyph sites in the Heishan area of Jiayuguan, Gansu Province (Sidaoguxing Gully, Hongliu Gully, Shiguan Gorge, Mozigou Gully, Jiaohao Gully, and Jiaohe Gully). This research integrates traditional archaeological fieldwork with digital humanities through a combination of literature analysis, field surveys, high-definition image collection, and expert interviews. Inspired by the successful virtual reality project at Huashan and using Smith & Akagawa's (2009) ideas on "cultural openness" and "public participation," this study aims to not only carefully record the Heishan Petroglyphs but also to raise public awareness and encourage people to get involved in protecting and studying this cultural heritage.

This study was conducted from the end of 2023 to the end of 2024. This study carried out systematic literature analysis, field surveys, image collection, and technological development, establishing a digital resource database for Heishan Petroglyphs. This database provides a new perspective for interpreting the historical narratives contained within the petroglyphs. The research outcomes are expected to promote academic research, optimize cultural heritage management, and support educational innovation through digital tools. Ultimately, this study aims to enrich the theory and practice of cultural heritage preservation and offer a replicable model for integrating traditional cultural research with digital technologies.

Research Objectives

1. To study the characteristics, classification, and cultural connotations of Heishan Petroglyphs, the content has been studied, and a classification system for Heishan Petroglyph images has been established.
2. To study the preservation of Heishan Petroglyphs using digital means, images of Heishan Petroglyphs were collected, and a photo database of Heishan Petroglyphs was established.
3. To study the better study and develop the resources of Heishan Petroglyphs, a teaching resource base has been established for teaching, research, and creation.

Literature Review

1. Core Conceptual Definitions

1.1 Heishan Petroglyphs.

Petroglyphs represent a form of rock-carved culture, wherein prehistoric and early historical human societies inscribed images and symbols onto rock surfaces to document their lives and beliefs. These carvings serve as a repository of rich social memory and historical information. In the Heishan region of Jiayuguan, Gansu Province, the petroglyphs are predominantly found on exposed rock outcrops. Since their initial discovery in 1972, it has been confirmed that they were produced using techniques such as grinding, chiseling, and line engraving (Chu et al., 1990), and they constitute an important cultural legacy of the ancient nomadic peoples of North-west China (Team, 1972).

1.2 Digital Preservation.

Digital preservation refers to the systematic use of digital technologies to document, record, and disseminate cultural heritage. Based on computer, multimedia, intelligence, and information dissemination technologies, it is an approach that ensures the vitality of cultural heritage through features such as mobility, fragmentation, socialization, and interactivity (Xu, 2020). UNESCO has identified information-based methods as one of the recording and protection strategies for cultural heritage and advocates their adoption as a key means for safeguarding intangible cultural heritage (Deng, 2015). The rapid development of digital information technology has also provided an excellent opportunity for the protection, utilization, and transmission of cultural heritage (Zou, 2022).

2. Theoretical

This study is primarily supported by the theories of semiotics and visual narratology, with additional guidance from digital humanities theory to underpin its digital preservation research. Semiotics was initiated by Saussure and further developed by Peirce and Barthes, among others. It provides a fundamental tool for interpreting the symbolic meanings embedded in petroglyph imagery. Heishan Petroglyphs are not only a reproduction of ancient life but also a symbolic expression of socio-cultural and belief systems (Barthes, 1972; Chandler, 2004). In this research, the petroglyphs are regarded as a form of cultural language, and their visual structure and emblematic elements are analyzed in depth.

Visual Narratology originates from the field of visual culture studies, examining how images communicate stories, construct historical narratives, and form collective memories. Research by Mitchell (1995) and by Veltman (1996) demonstrates that images do more than merely transmit information; they play a crucial role in building historical identities and cultural memory. This study further explores how the petroglyphs sequence visual elements to reflect the survival modes and worldviews of early humans and reveal their underlying narrative structures.

In addition, the integration of digital humanities theory supports the digital preservation and dissemination of cultural heritage. Gold (2012) emphasizes the importance of digital technologies in the protection and spread of cultural assets. The design and construction of the digital resource library for Heishan Petroglyphs is a practical manifestation of this concept, facilitating the preservation, sharing, and further research of cultural materials.

3. Related Research

The northern petroglyph system in China is mainly distributed across regions such as Inner Mongolia, Xinjiang, Ningxia, Gansu, and Qinghai. These petroglyphs predominantly depict animals and nomadic life in a realistic style (Chen, 2002). Their extensive distribution and large quantity are unparalleled by other petroglyph systems (Gong & Zhang, 2006). Since the discovery of Heishan Petroglyphs in 1972, preliminary assessments have dated the carvings from the Warring States period to the Ming Dynasty. Scholars generally categorize them into three stages—early (emergence), middle (maturity), and late (continuation)—with their content closely tied to the social structure and ecological environment of the time (Yang & Zhang, 2001). In recent years, natural weathering and human-related influences have led to various levels of deterioration of these carvings (Yang, 2023).

Despite the significant cultural value of the Heishan Petroglyphs, research on their digital preservation remains in its infancy. In contrast, the virtual reality protection of the Huashan Petroglyphs in Guangxi has already demonstrated the potential of digital technologies for cultural

heritage conservation (Nie, 2023). However, Heishan Petroglyphs lack a dedicated digital resource library and do not benefit from a systematic, comprehensive protection mechanism. Some scholars have predicted that the digitalization of cultural heritage will become the core direction for its preservation in the coming decades (Cao, 2023) and is now internationally recognized as the mainstream preservation paradigm (Deng, 2015). In addition, researchers have identified key processes in the digital preservation of petroglyphs, including image data acquisition (Zhao, 2016), resource database construction and maintenance (Gao, 2020), as well as the detailed collection and digital conversion of materials (Jin, 2017). Nevertheless, there is yet to be an established, authoritative national-level petroglyph database system in China, a situation that is particularly urgent given the vast amount of petroglyph resources in the country (Zhu, 2019).

In summary, while the Heishan Petroglyphs possess significant historical, artistic, and anthropological value, existing research has primarily focused on the interpretation of their content and cultural functions. In contrast, systematic preservation—especially through digital means—has been notably insufficient. Therefore, this study will adopt the digital preservation of Heishan Petroglyphs as its entry point and, through methods such as image acquisition, semiotic analysis, and content classification, will construct a comprehensive digital resource library. This will serve as the basis for future comparative studies, cultural dissemination, and establishing digital standards for petroglyphs.

Conceptual Framework

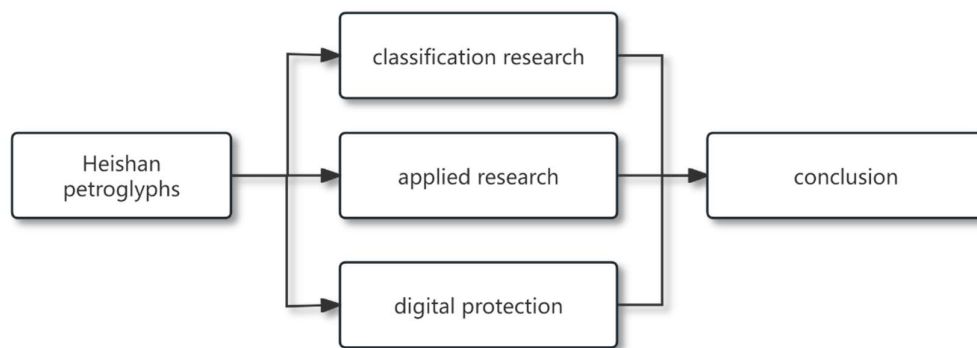


Figure 1 Research conceptual framework.

Research Methodology

This study adopts a clearly sequenced, goal-oriented approach to achieve the research objectives of comprehensively documenting the Heishan Petroglyphs, analyzing their cultural and historical significance, and constructing a digital resource library. It ensures that each research objective has a specific corresponding step.

Literature Analysis

To establish the theoretical foundation and research background, books, dissertations, academic reports, and news articles related to the Heishan Petroglyphs were systematically collected, organized, and analyzed. This step helps to understand the cultural, historical, and economic

backgrounds of the petroglyphs and also points out gaps in current conservation and digital research, giving a strong foundation for future studies.

Field Survey and Image Data Collection

To accurately record the physical characteristics and spatial distribution of the petroglyphs, detailed field surveys and high-definition image acquisition were conducted at six petroglyph sites in the Heishan region. This phase is designed to achieve the goal of comprehensive image data collection and provides key data support for subsequent data classification and resource library construction.

Open-Ended Interviews

To further elucidate the cultural and social significance of the Heishan Petroglyphs and to gather suggestions and research information on digital conservation, open-ended interviews were conducted with petroglyph administrators, experts, researchers, and local residents. The interviews focused on three main themes including the interpretation of petroglyph content, their impact on the local economy and culture, and the prospects and recommendations for digital conservation. This step provides the basis and practical advice for developing effective conservation strategies and designing the digital resource library.

Results

The study of the characteristics, classification, and cultural connotations of Heishan Petroglyphs, the content has been studied, and a classification system for Heishan Petroglyph images has been established.

After field surveys, information collection, visits and interviews, fully listening to the analyses of petroglyphs by relevant experts and staff of Heishan Petroglyphs, combing with the overall combing on the basis of a full study of the existing literature, classifying the petroglyphs of Heishan Petroglyphs of Jiayuguan Mountain based on the commonality of the petroglyphs in different locations, and classifying the petroglyphs according to their contents into six categories of figures, animals, rituals (dances), hunts, religions, writings, and plants, the research was carried out. Data records were made on the petroglyphs in terms of their contents, production techniques, locations, and colors.

Table 1 Jiayuguan Heishan Petroglyphs classification list.







NO	Sample image	Name	Type	Method	Colour	Position
1		ninny	animals	engraving	light green	Jiaohaogou

Table 1 (Cont.)

NO	Sample image	Name	Type	Method	Colour	Position
2		hunting map	Hunting	engraving	ash-colored	Sidaoguxin ggou
3		Dance, sacrificial offerings	Dance, sacrificial offerings	pester	ocher (pigment)	Sidaoguxin ggou
4		stupa (Buddhist shrine)	stupa (Buddhist shrine)	engraving	ash-colored	Shiguan Gorge
5		Tibetan language	text-based	engraving	ash-colored	Hongliu Gully
6		plant species	plant species	engraving	ash-colored	Shiguan Gorge

Animals are the most numerous motifs in the Heishan Petroglyphs, mainly appearing in the Shiguan Gorge and the Sidaoguxing Gullies. Indicates that there was frequent human and animal activity in both places at that time, and most of the rendering techniques are chiselled and engraved. The animal images in the Heishan Petroglyphs appear in the form of single or group images, with rich styles and diversified contents, and the number of animals in the largest one reaches 83, which demonstrates the close connection between the ancient nomads and the natural world and conveys the people's understanding of survival, religion, beliefs, and the social structure in different periods. It reflects a natural observation and record of the state of life and the environment at that time; the painting method, modeling, and composition are very artistic and natural in their sense of form and beauty. Cows and sheep in Heishan Petroglyphs animals accounted for the largest proportion of the longest time in Heishan, indicating that they existed in the Heishan area and had the closest

relationship with human beings. Tapirs, pythons, and moose are all subtropical animals that have long since become extinct. Birds, deer, and tigers are said to have been worshipped by ancient humans.

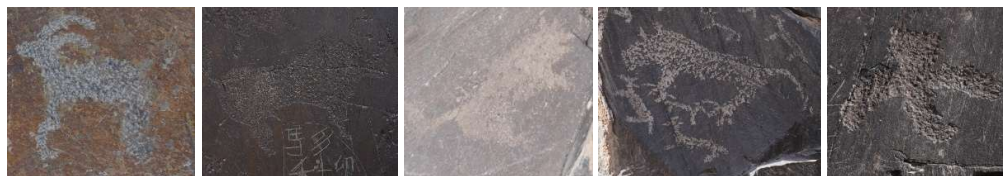


Figure 2 Animal images from Heishan Petroglyphs.

Source: Zhao (2024a)

The main content of the hunting pictures is people and animals forming a hunting scene, mostly appearing in the Sidaoguxing Gully. Heishan Petroglyphs hunting picture enough to reflect the hunting tools, scale and different hunting methods. Hunting is divided into categories such as driven game hunting, standing hunting with bow and arrow, and hunting from horseback; the most frequent hunting tool was the bow and arrow, reflecting the gradual improvement of productivity at that time. It also reflects the main way that people in ancient times relied on to survive, demonstrating hunting techniques and reflecting the interaction between humans and nature. The petroglyphs also reflect domesticated dogs and eagles as hunting helpers, and researchers have classified the number of participants in the Heishan petroglyphs into different ways, such as single hunting, two-person hunting, and roundup hunting, and hunting commanders can be seen in several petroglyphs. (Yang, & Zhang, 2001).



Figure 3 Hunting images in Heishan Petroglyphs.

Source: Zhao (2024b)

Heishan Petroglyphs figure more; the content is presented mainly in the dance and rituals on two expressions including the earliest human dance is in the primitive activities such as rituals, celebrating the harvest and other activities. The Heishan Petroglyphs of the dance are mainly in the four stock grooves. Heishan Petroglyphs dance image content on a grand scale, a variety of forms, showing a part of the primitive society of human life, contains a deep historical and cultural significance. The origin of dance can be traced back to the earliest labor activities of mankind, and the art of dance developed along with the progress of labor. According to the spikes worn by the dancers in the Heishan Petroglyphs, one can judge the status and gender of the characters in the activities, such as the dress code, which may be symbolic of the sexes, e.g., a long gown may be symbolic of the women's dress code, and a short gown was worn by the men when they hunted.



Figure 4 Dance (ritual) images in Heishan Petroglyphs.

Source: Zhao (2024c)

Religious Heishan Petroglyphs are relatively concentrated, with the main contents of halls, pagodas, Buddha statues, etc., reflecting the religious culture of Heishan at that time, and the pagoda figure in the petroglyphs has long been regarded as a Buddhist relic, and even some scholars explicitly pointed out that it is a lama tower (Zhang, 1994) , which belongs to the Late Heishan period according to the investigation. The religious images in the Heishan Petroglyphs reflect the cultural exchanges between the East and the West along the early Silk Road.



Figure 5 Religious images in Heishan Petroglyphs.

Source: Zhao (2024d)

Heishan Petroglyphs are mainly in Tibetan and Chinese characters and are known as rock carvings. The content of the first is the middle and late Tang Dynasty appearing in Tibetan or Tubo, mostly accompanied by pagodas and other patterns; the Tibetan text on the wall of the Shiguan Gorge scholars have determined that it should be the Yuan Dynasty Tibetan; the second is the Chinese characters of the Ming, Qing Dynasty and the Republic of China, which mainly appear in modern times.



Figure 6 Text in Heishan Petroglyphs.

Source: Zhao (2024e)

The plants in the petroglyphs of the Heishan s are mainly ferns, confirming the claim that Gansu belonged to the subtropical climate 1,000 years ago, and these contents are the objective reflections of the ancestors on the local plants, and part of the plants have already died out with

the history, but there are also some plants and the existing existence of a certain correlation, such as poppies can still be seen now, and the scrolling grasses are often found under the beams and columns in modern times as the decorative patterns.

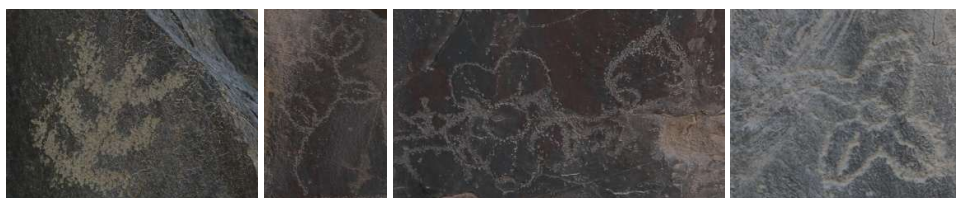


Figure 7 Plants images in Heishan Petroglyphs.

Source: Zhao (2024f)

The continuation of Heishan Petroglyphs from prehistory to modern times fully proves the continuity of long-term population activities in the Heishan area, and the human beings in different periods recorded the unique phenomena of the society at that time in the way of petroglyphs. Through the study of petroglyphs, it is possible to have a more comprehensive understanding of the historical development of the Jiayuguan Pass area and cultural inheritance, and to strengthen the protection and utilization of Heishan Petroglyphs is of great significance for the development of the Jiayuguan cultural cause and cultural industry. It is important for the development of Jiayuguan's cultural cause and cultural industry. Early petroglyphs in the four stock-shaped gorges of Heishan are the cultural relics of the ancestors in the late Paleolithic to mid-Neolithic period, with animals predominating; middle-period Petroglyphs in Hongliu Gully and Shiguan Gorge are the works of ethnic minorities in the period from the Warring States period to the time of the Qin and Han dynasties, and they belong to the cultural relics of nomadic herdsmen in the period from the Warring States period to the Qin and the establishment of the four counties of the Hexi County in the Western Han dynasty; and the Buddhist petroglyphs in the late period Petroglyphs in Hongliu Gully and Shiguan Gorge of Heishan are the religious relics of the TuFan tribe after the middle period of the Tang Dynasty, which mainly reflect religious culture (Yang, & Zhang, 2001). Heishan Petroglyphs not only record the production and life of the ancestors in Heishan but also reflect the geographic evolution of different eras and the characteristics of ethnicity and religion. The judgment of the Petroglyphs' era has had a positive effect on the local area, including the protection of cultural heritage, promotion of academic research, development of cultural tourism, economic and social development, cultivation of talents, and digital preservation, which together promote the sustainable development of the local culture and economy.

The Heishan petroglyphs have a significant positive impact on the local economy and culture in terms of tourism and cultural and creative products and effectively complement the Dunhuang culture and the Great Wall culture in the same region; the unique Petroglyphs content of Heishan Petroglyphs has also become the source of cultural and creative products in Jiayuguan. The visual design works with the regional characteristics of Jiayuguan Heishan Petroglyphs through art forms can promote the protection and development of the resources of Jiayuguan Heishan Petroglyphs and enhance the popularity and influence of Heishan Petroglyphs (Feng, 2021). Based on

the premise of cultural relics protection, the cultural and creative products of Heishan Petroglyphs made by specific technical means have positive significance to the promotion of Heishan culture. In recent years, Jiayuguan has gradually strengthened the protection and utilization of its cultural heritage, focusing on the high-quality development of the integration of local culture and tourism, promoting the development of the cultural tourism market and the local economy, while also having a positive effect on the application of the Heishan petroglyphs in the cultural tourism market.

The study of the preservation of Heishan Petroglyphs using digital means, images of Heishan Petroglyphs were collected, and a photo database of Heishan Petroglyphs was established.

The protection of Heishan Petroglyphs is difficult in practice due to natural and technical constraints. Building a digital resource library can effectively protect and preserve existing resources while also helping to popularize the important value of petroglyph resources among the general public and get more people involved in their protection. Due to the particularities of intangible cultural heritage, such as its living nature, high degree of personalization, inheritance, and variability, the resource database is both a carrier of knowledge and a medium of communication. The interviewed experts, managers of petroglyph protection units and researchers all said that the establishment of a digital resource database is currently an effective means of Heishan Petroglyphs and provides a research basis for the future digital protection of the Heishan Petroglyphs. We conducted five field surveys and collected image information on Heishan, taking pictures and videos of six petroglyph sites. During the collection process, we found that Heishan has a complex terrain, and there are problems such as insufficient manpower, difficulties in transporting equipment, and difficulties in collecting images. In addition, there is no signal in the mountainous area, which poses considerable difficulties for digital protection. Field investigations in the Jiayuguan Heishan area began in March 2024, and the collection of image information has now been completed, effectively ensuring the accuracy, validity, and rationality of the information. The Heishan petroglyph digital teaching resource library has been established, laying a solid foundation for the construction of the petroglyph image database and providing basic research conditions for later research.

The study of the better study and develop the resources of Heishan Petroglyphs, a teaching resource base has been established for teaching, research, and creation.

Research Objective 3. The purpose of creating and improving data repositories is mainly to apply them, and in order for databases to have the value of applying this value, it is necessary to give database utilizers a fuller range of functions (Gao, 2020). We have systematically designed the Heishan Resource Base, upholding the concept of sharing, co-construction, and continuous maintenance, serving researchers, teachers, students, and social enthusiasts, and dividing it into several first-level columns according to the required content, such as international exchange, resource construction, documentation, network resources, policies and regulations, cultural and creative products, etc., and in terms of resource construction, it is divided into a total of eight types of digital resources.

There is no uniform standard for the construction of the Petroglyphs resource base, and there is no standard specification for digitization, so it is difficult to have an accurate basis for specification. In the process of researching Heishan Petroglyphs, the authors classified the petroglyphs according to their contents and formulated the coding form of the resource library. The Heishan

Petroglyphs exhibit specificity and the English nomenclature incorporates heishan, a symbol for unique geographical features. During the coding process, HS serves as the initial letter, and to emphasize its regional nature and set it apart from the geographical features of Heishan in other locations, J, the initial letter of Jiayuguan Pass, precedes it. Consequently, the digital resource library of Heishan Petroglyphs takes the name JHS, and for various types, it's referred to as JHS+resource types.

Table 2 Coding table for Heishan Petroglyphs data.

NO	CATEGORISATION	ENCODINGS	TYPICAL EXAMPLE
1	Photo Images	JHS-P	JHS -P-a-s-001202404-p
2	Shooting Video	JHS-D	JHS -D-a-s-001202404-p
3	Web links	JHS-I	JHS-I-001202404
4	Animation for film and Television	JHS-V	JHS-V-001202404
5	Documentation	JHS-T	JHS-T-001202404
6	Creative industries	JHS-C	JHS-C-001202404
7	Policies and regulations	JHS-Z	JHS-Z-001202404
8	Other information	JHS-O	JHS-O001202404P

Since its completion, the Heishan Teaching Resource Library has demonstrated outstanding application value and significance in teaching practice and cultural and creative design. Through the combination of teaching and practice, especially in the exploration of the integration of cultural heritage and creative design, the Resource Bank has provided strong support for the modern inheritance of Heishan Petroglyphs and, at the same time, providing students with a unique platform for learning and practice. In practical activities, relying on local universities and museums, the creative teaching content of Heishan Petroglyphs has been integrated into curriculum teaching and educational activities, and good results have been achieved. It can be seen that the resource bank of Heishan Petroglyphs will play a significant role in cultural inheritance and protection, scientific research and education, tourism, and cultural dissemination, as well as management and maintenance, which will not only provide valuable information for academic researchers but also provide the public with the opportunity to learn about the ancient culture and history.

Conclusion and Discussion

Conclusion

This study looked closely at the Heishan Petroglyphs by combining reading existing research, visiting the site, talking to people, and using digital tools, focusing on three main areas including sorting them into categories, gathering images, and finding ways to use the resources. The research achieved the following three objectives including (1) It analyzed the content characteristics of the petroglyphs and proposed a content-based classification framework; (2) it collected a large number of digitized images and established a Heishan Petroglyphs image database; and (3) it built a resource platform for teaching, research, and creative practices.

The findings indicate that the Heishan Petroglyphs possess significant historical, artistic, and spiritual value and serve as important legacies by recording early human interactions with nature, society, and belief systems. This not only enriches our understanding of regional cultural diversity but also reveals historical traces of human migration and cultural interactions in the Hexi Corridor, underscoring their importance to the economic and cultural development in the context of the Ancient Silk Road.

The establishment of the Heishan Petroglyphs Digital Repository provides a viable digital solution to current preservation challenges. It reduces research costs and enhances accessibility, fosters interdisciplinary collaboration, and enables long-term preservation. The “cultural cognition—heritage protection—digital dissemination” integrated mechanism proposed in this study offers a reference model for the digital conservation of rock art and other cultural heritage in different regions.

In summary, this study advances the theoretical understanding of the Heishan Petroglyphs and provides practical strategies for cultural heritage preservation, laying a solid foundation for the future integration of traditional heritage with modern technology.

Discussion

This study classified the Heishan Petroglyphs based on their thematic imagery and chiseling techniques. The classification results reveal the diversity of petroglyph content, including historical records, spiritual beliefs, and reflections of early social structures. Before the advent of written language, people were limited by the tools available, and carving on stone became a primary means of recording daily life and expressing ideas. This practice reflects early humans’ fundamental understanding of nature, society, and religion. These findings align with Whitley’s (2001) theory that prehistoric rock art served symbolic and communicative functions.

During the research process, detailed field investigations were conducted at six petroglyph sites, and a Heishan Petroglyph Image Database was established. This image-based documentation preserves valuable visual materials and lays a solid foundation for future research. The collection of original photographs ensures the accuracy and validity of information, aligning with Wang’s (2015) emphasis on data reliability. The construction of the digital resource repository in this study follows current digital heritage preservation strategies and reflects the application of digital humanities in the documentation and management of cultural heritage.

The study also developed a teaching resource repository to facilitate educational applications, interdisciplinary teaching, and artistic practice. The way petroglyph data is organized and processed digitally has greatly improved how easily the public can access the Heishan Petroglyphs, following the idea of “cultural openness” promoted by Smith & Akagawa (2009), which focuses on education and getting the public involved.

From the perspectives of iconography and semiotics, the imagery of the Heishan Petroglyphs depicts aspects of material life and conveys symbolic meanings related to ritual, belief, and social structure. These elements collectively reflect the early human conceptualization of the world and reinforce the significance of the Heishan region as a cultural crossroads. The petroglyphs provide vivid evidence of regional cultural diversity.

At the same time, the study reveals that the current state of preservation of the Heishan Petroglyphs remains weak. Present efforts rely primarily on traditional methods such as patrolling and fencing, while ongoing threats from natural erosion, weathering, and human damage persist. This highlights

the urgent need to adopt systematic and scientific digital preservation technologies. The establishment of a digital resource repository offers a forward-looking solution, closely aligning with the protective approaches advocated in the UNESCO (2003) “*Charter on the Preservation of Digital Heritage*”.

New knowledge from the study

This study, through field investigations and research data, categorizes the Heishan Petroglyphs based on their content and conducts an in-depth analysis from three main perspectives including history, culture, and art. It establishes a foundation for further research on Heishan Petroglyphs. The study also examines and summarizes aspects such as petroglyph content, the construction of an image database, and digital preservation strategies. Additionally, it develops and establishes a digital resource database for Heishan Petroglyphs, reducing research costs and providing practical value for future studies.

This study explores pathways for the digital preservation of petroglyphs. The Digital Resource Library not only enhances the protection of the Heishan Petroglyphs but also promotes cultural openness and accessibility through co-construction and sharing. The integration of petroglyph resources enhances the dissemination and promotion of petroglyphs as an art form. This initiative advances the integrated development and utilization of cultural resources, laying a research foundation for future studies on petroglyphs. It holds practical application value and provides practical guidance for the preservation of petroglyphs in other regions.

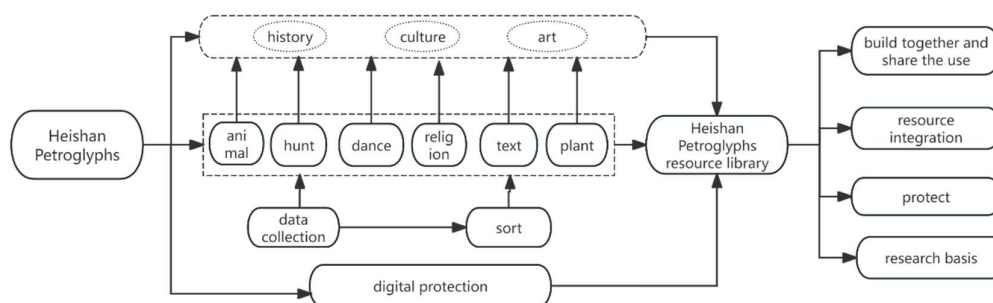


Figure 8 Framework of new knowledge from the study.

Suggestions

The Digital Repository of the Heishan Petroglyphs provides an excellent research resource and foundation for scholars and artists. In addition to deepening academic research, efforts should be made to enhance the creation and dissemination of digital art related to the Heishan Petroglyphs and to expand its application in education and museum exhibitions, thereby further increasing public cultural awareness.

Future research should combine ideas from archaeology, anthropology, and art history and fully use advanced technologies like artificial intelligence and virtual reality to gather and preserve digital data, encourage public involvement, and create a rich digital resource library. Such an approach

will provide solid support for in-depth study and practical exploration and ultimately promote continuous advancements in cultural heritage preservation theory and practice.

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