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CLASSIFICATION AND GIS-BASED MAPPING OF KARST CAVES IN SOUTHWESTERN UZBEKISTAN

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Abstract. This study systematizes the classification and cartographic representation of karst caves in Southwestern Uzbekistan by integrating morphogenetic, genetic and lithological approaches with GIS and remote-sensing techniques. Karst forms are grouped into low-mountain and mountain classes, with low-, middle- and high-mountain subclasses, while lithological types include limestone, dolomite, marble, chalk, gypsum-anhydrite and salt karst. The paper synthesizes the approaches of M.M. Sweeting, V.N. Dublyansky and V.N. Andreychuk, the cave-origin classification of B.A. Vakhrushev, and the regional karst zoning framework used for Central Asia. The study area belongs to the Hissar–Alay subprovince of the eastern Paleozoic karst province and corresponds largely to the Hissar–Zarafshan karst district. Eight regional karst sectors are distinguished: Ziyovuddin–Zirabulak, Karatepa, Chakylkalon, northeastern Hissar, western Hissar, Boysuntau, Kugitang and Bobotag. GIS technologies and remote-sensing data are used to support cave mapping, spatial database construction and the development of speleotourism maps. The results provide a methodological basis for scientific inventory, regional karst zoning, cave protection and the development of speleotourism in Southwestern Uzbekistan.

Keywords: karst caves, classification, GIS, remote sensing, cave mapping, karst zoning, Hissar–Zarafshan, Southwestern Uzbekistan, speleotourism

1. Introduction

Karst landscapes are spatially complex natural systems whose classification is essential for understanding cave genesis, regional differentiation and the relationship between underground cavities and surface landforms. Because karst affects individual landscape components and entire natural-geographical complexes, karst regions can be treated as specific geographical landform systems and classified according to the degree to which karst processes influence the landscape.

Different classification approaches emphasize different aspects of karst. M.M. Sweeting distinguished five broad geographical types: true karst (holokarst), fluviokarst, glacial-nival karst including permafrost karst, tropical karst, and arid or semi-arid karst. At a more detailed level, morphogenetic characteristics can be integrated with lithology, producing types such as exposed limestone karst, covered gypsum-anhydrite karst, buried chalk karst and other combined forms.

For Southwestern Uzbekistan, classification is especially important because the region includes structurally and lithologically diverse mountain systems where Paleozoic and Mesozoic carbonate rocks, gypsum and other soluble formations occur under arid and semi-arid climatic conditions. The

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aim of this study is to systematize the major classification schemes relevant to the region, establish a regional karst zoning framework, and describe a GIS-based workflow for mapping caves and speleotourism resources.

2. Materials and Methods

The study is based exclusively on the provided source material, which compiles published karst classifications, regional zoning concepts, cave-origin typologies, and methodological descriptions of GIS- and remote-sensing-based cave mapping. No new field measurements are introduced in this paper.

The methodological framework combines four components: (1) morphogenetic classification, (2) lithological classification, (3) genetic classification of underground cavities, and (4) regional karst zoning. The cartographic component follows a staged GIS workflow involving topographic maps, remote-sensing imagery, field observations, geodetic measurements, digital databases and thematic mapping.

The source material indicates the use of topographic maps at scales of 1:10,000, 1:30,000, 1:50,000 and 1:100,000, together with satellite imagery, textual descriptions and tabular data. Digital processing is described using Adobe Photoshop, Microsoft Word and Excel, MapInfo, ArcGIS and GIS Panorama. These tools are treated here as part of the documented methodological workflow rather than as newly performed analyses.

3. Results

3.1. Integrated karst classification

The combined morphogenetic and lithological approach separates karst into low-mountain and mountain classes, with low-, middle- and high-mountain subclasses. The principal lithological types identified in the source material are limestone karst, dolomite karst, karst in marble, chalk karst including chalk-like marl, gypsum-anhydrite karst, and salt karst.

When morphogenetic and lithological criteria are combined, more specific regional types can be recognized, for example exposed limestone karst, covered gypsum-anhydrite karst and buried chalk karst. These types can then be assigned to plain or mountain classes according to their geomorphological setting.

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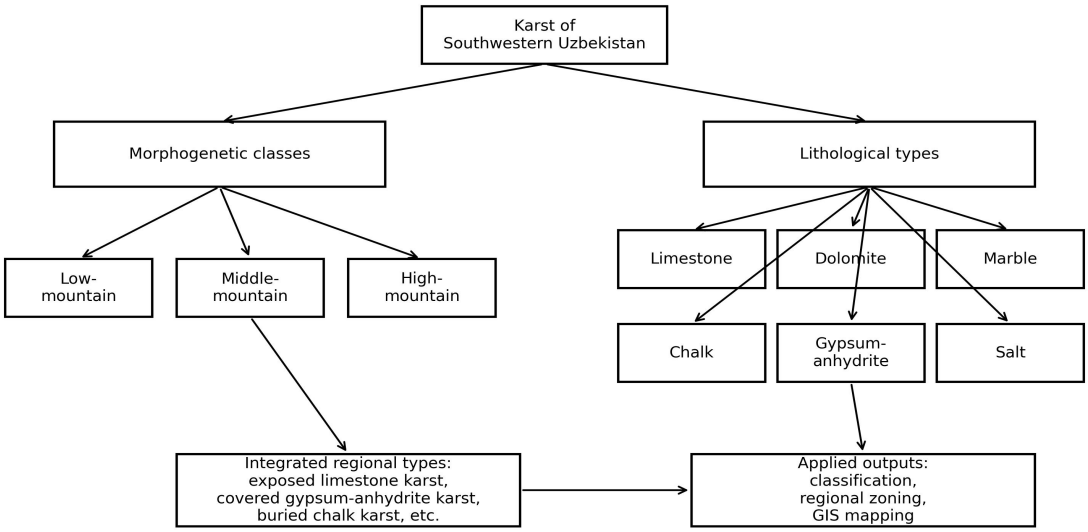


Figure 1. Integrated morphogenetic and lithological classification scheme of karst in Southwestern Uzbekistan.

Table 1. Main lithological karst types identified in the source material

Type	Dominant soluble material	Interpretive significance
Limestone karst	Limestone	The most common carbonate karst type
Dolomite karst	Dolomite	Carbonate karst influenced by dolomitic lithology
Marble karst	Marble	Karst in metamorphosed carbonate rocks
Chalk karst	Chalk and chalk-like marl	Typically associated with softer carbonate units
Gypsum-anhydrite karst	Gypsum and anhydrite	Rapidly developing evaporite karst
Salt karst	Soluble salts	Highly soluble evaporite karst

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3.2. Genetic classification of caves

Genetic classification provides a complementary perspective. According to V.N. Dublyansky and V.N. Andreychuk, underground cavities are hierarchically divided into groups, classes, subclasses, types and subtypes. At the highest level, cavities are separated into natural and artificial groups. Classes are defined by the energy source of cavity-forming processes and include endogenic, exogenic and anthropogenic forms. Subclasses reflect the nature of material movement, whereas the cavity type is determined by the dominant forming process.

The cave-origin classification attributed to B.A. Vakhrushev further distinguishes natural and artificial groups and recognizes endogenic, exogenic and anthropogenic origins with several subordinate categories. This framework is useful because it separates true karst cavities from other underground voids that may look morphologically similar but have different genesis. It also highlights the distinction between monogenetic cavities, produced by a dominant single process, and polygenetic cavities, which reflect the combined or sequential influence of several processes.

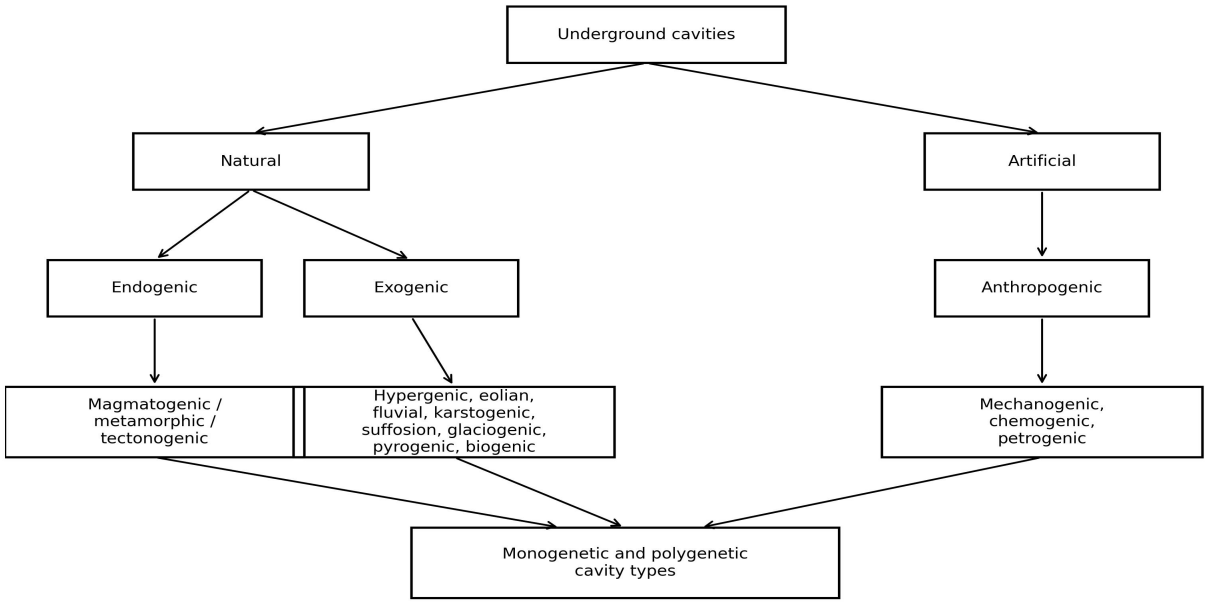


Figure 2. Simplified genetic classification of underground cavities after the schemes cited in the source material.

3.3. Regional karst zoning of Southwestern Uzbekistan

Regional karst zoning in Central Asia uses a hierarchical sequence of taxonomic units: karst country, region, province, subprovince, district and sector. Central Asia is treated as a single large karst country, subdivided into mountainous and plain karst regions. The mountainous region is further

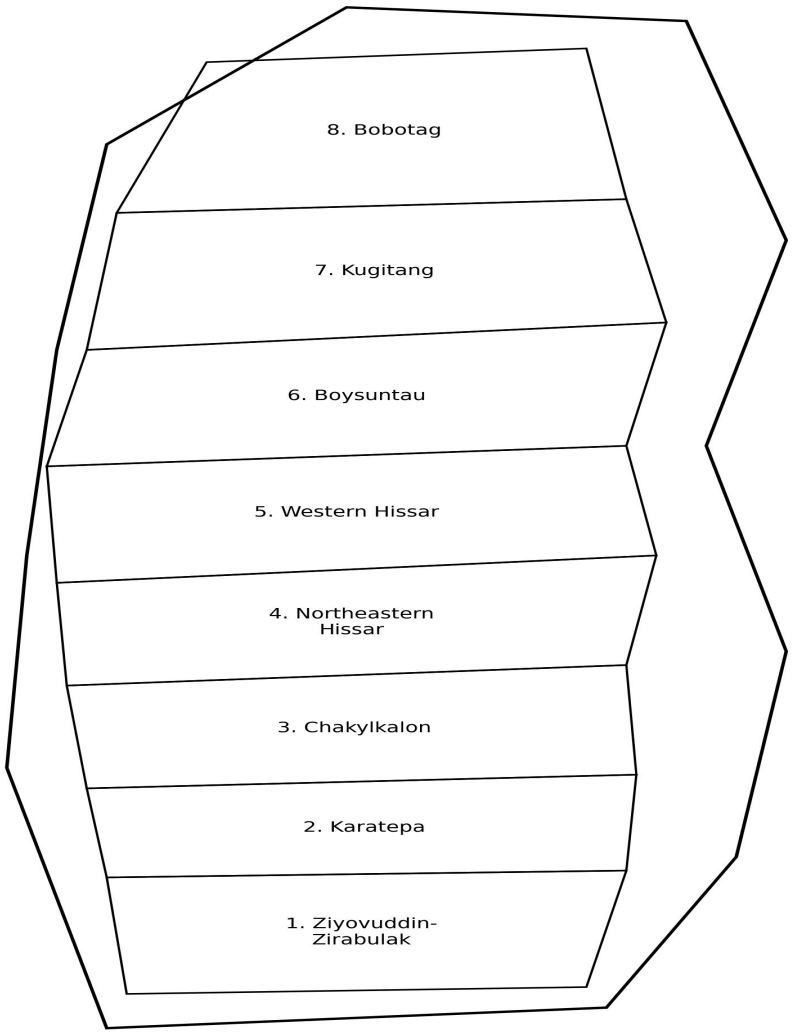
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divided into two large provinces: the eastern Paleozoic folded structures of Central Asia and the southern Alpine folded uplifts. The plain region corresponds to the Turan province.

The study area belongs to the Hissar–Alay subprovince of the eastern Paleozoic province. Within this subprovince, three karst districts are distinguished: Alay–Turkestan, Nuratau and Hissar–Zarafshan. The Hissar–Zarafshan karst district corresponds most closely to Southwestern Uzbekistan.

Eight karst sectors are identified within the study area: Ziyovuddin–Zirabulak, Karatepa, Chakylkalon, northeastern Hissar, western Hissar, Boysuntau, Kugitang and Bobotag. This regionalization provides the spatial framework for systematic cave inventory, comparative analysis and mapping.

Schematic regional zoning map of karst sectors in Southwestern Uzbekistan



Note: schematic representation based on the sector list in the provided source material.

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Figure 3. Schematic regional zoning map of karst sectors in Southwestern Uzbekistan based on the sector list provided by the source text.

Table 2. Karst sectors of the Hissar–Zarafshan district in Southwestern Uzbekistan

No.	Karst sector
1	Ziyovuddin–Zirabulak
2	Karatepa
3	Chakylkalon
4	Northeastern Hissar
5	Western Hissar
6	Boysuntau
7	Kugitang
8	Bobotag

3.4. GIS-based cave and speleotourism mapping

After karst classification and zoning, cartographic representation becomes the next major task. The source material emphasizes that cave mapping should be based on explicit geographical and cartographic principles and should proceed in a defined sequence.

The documented workflow begins with object study and data collection, including geological materials, historical records and existing maps. Field surveys are then used to examine cave morphology, dimensions, location and other attributes. Geodetic measurements are required for accurate positioning and may involve GPS or laser-scanning technologies. The collected data are then analyzed and prepared for GIS-based cartographic production.

Topographic maps at scales of 1:10,000, 1:30,000, 1:50,000 and 1:100,000, as well as remote-sensing images, are digitized and prepared for GIS use. The source material describes preprocessing in Adobe Photoshop, storage of textual information in Microsoft Word, tabular organization in Microsoft Excel, spatial processing in MapInfo and ArcGIS, and interpretation of remote-sensing images using GIS Panorama.

The final stage is the compilation of speleotourism maps based on the developed information database. Such maps should display the geographical position of cave-related objects, legal status, quantitative and qualitative characteristics and evaluation information. They should be legible, visually expressive and designed without unnecessary cartographic overload.

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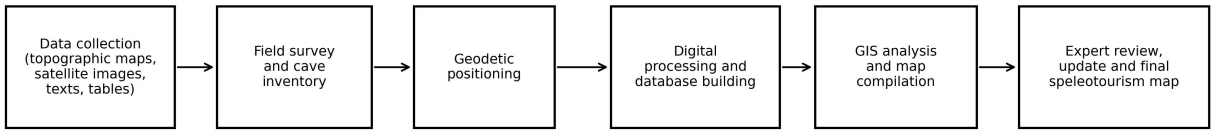


Figure 4. GIS-based workflow for cave and speleotourism mapping reconstructed from the source methodology.

4. Discussion

The integrated classification approach is particularly suitable for Southwestern Uzbekistan because the region contains karst systems that differ simultaneously in lithology, genetic origin, geomorphological position and regional tectonic setting. A purely lithological classification would not adequately explain the spatial organization of caves, while a purely genetic scheme would not capture regional geographical differentiation.

The hierarchical zoning into country, region, province, subprovince, district and sector creates a bridge between general karst theory and regional applied geography. For the Hissar–Zarafshan district, the eight identified sectors provide a practical basis for comparing karst intensity, cave density, lithological controls and speleotourism potential.

The GIS workflow described in the source material is methodologically important because cave inventories are inherently spatial. Integrating topographic maps, satellite imagery, field observations and geodetic coordinates makes it possible to create updateable geodatabases and thematic maps. Such products can support scientific research, tourism planning and cave conservation.

At the same time, the source material does not provide a complete quantitative GIS dataset, coordinate inventory or statistical comparison among the eight sectors. Therefore, the present article should be considered a methodological and regional synthesis rather than a spatial-statistical analysis. Future work would benefit from harmonized cave coordinates, lithological layers, digital elevation models, remote-sensing indices and standardized morphometric measurements.

5. Conclusion

The classification and mapping of karst caves in Southwestern Uzbekistan require an integrated approach combining morphogenetic, lithological, genetic and regional-geographical criteria. The study area belongs to the Hissar–Alay subprovince and is represented mainly by the Hissar–Zarafshan karst district, within which eight karst sectors are distinguished.

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Limestone, dolomite, marble, chalk, gypsum-anhydrite and salt karst form the principal lithological categories, while genetic classifications distinguish natural and artificial cavities and further separate endogenic, exogenic and anthropogenic processes. GIS and remote-sensing methods provide the most practical framework for integrating these classifications with field data and cartographic representation.

The resulting maps and geodatabases can serve as a basis for scientific inventory, karst monitoring, cave conservation and the development of speleotourism. Further research should focus on standardized spatial databases, quantitative comparison of karst sectors and the integration of cave morphometry with lithological, tectonic and geomorphological layers.

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