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GEOGRAPHICAL DISTRIBUTION AND FORMATION FACTORS OF KARST CAVES IN SOUTHWESTERN UZBEKISTAN

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Abstract. Karst caves are among the most distinctive geomorphological features of Southwestern Uzbekistan and reflect the combined influence of lithology, tectonics, relief, climate and groundwater circulation. This paper summarizes the geographical distribution and major formation factors of karst caves in the western Zarafshan Range, the Chakylkalon and Karatepa massifs, the Zirabulak–Ziyovuddin low mountains, the Yakkabag and Boysuntau ranges, and the Kugitang Mountains. The study is based on a synthesis of geological-geographical descriptions and previously published speleological observations contained in the source material. The analysis shows that the most favorable conditions for cave development occur where soluble carbonate or evaporite rocks are intensely fractured, uplifted above local erosion bases, and intersected by active groundwater circulation. Paleozoic and Upper Jurassic limestones host many of the region's important caves, while gypsum karst is especially well developed in parts of Boysuntau and Kugitang. The distribution of caves is further controlled by plateau surfaces, canyon incision, seasonal snowmelt and precipitation, as well as the alternation of uplifted anticlines and subsiding synclines. Well-known examples include the deep Kiev Cave near the Takhtakaracha Pass, the Omonkutan, Amir Temur, Kaptarkhona, Teshiktash, Hashimoyoq and Kapkutan cave systems. The findings underline the need for integrated geographical and speleological studies and for careful protection of fragile karst environments.

Keywords: karst, caves, speleology, limestone, gypsum, tectonics, groundwater, relief, Southwestern Uzbekistan, Zarafshan Range, Boysuntau, Kugitang

1. Introduction

Caves have played an important role in human history as shelters, cultural spaces and sources of archaeological and paleontological evidence. At the same time, caves are complex natural systems that preserve information on geological development, groundwater circulation, climate and landscape evolution. Their scientific significance therefore extends across geography, geomorphology, geology, hydrology, archaeology, biology and environmental management.

Central Asia, including Uzbekistan, is one of the regions where karst caves are widespread. The source material reports that more than 1,800 caves have been identified in Central Asia, of which nearly 1,000 are located within Uzbekistan. The active development of regional speleological research, particularly since the 1960s, has greatly expanded knowledge of cave systems and their spatial patterns.

Karst caves develop mainly in water-soluble rocks such as limestone, dolomite and gypsum. Their formation is driven by the infiltration and circulation of chemically active water through fractures and bedding planes. Over time, dissolution enlarges these pathways into shafts, galleries and cave chambers. Secondary mineral forms such as stalactites, stalagmites, flowstones, curtains and cave pearls may develop where dissolved minerals precipitate from percolating water.

Southwestern Uzbekistan is particularly favorable for karst development because soluble rocks of different geological ages are combined with active tectonic structures, dissected mountain relief, seasonal precipitation and groundwater flow. The purpose of this paper is to systematize the geographical distribution of the principal karst cave areas described in the source material and to identify the main natural factors controlling their formation and spatial differentiation.

2. Materials and Methods

The paper is based on the synthesis of the user-provided source material on karst caves of Southwestern Uzbekistan. The material includes descriptive data on cave locations, lithology,

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geological age, depth or length where available, and the main geomorphological, tectonic, climatic and hydrological controls on karst formation.

A comparative geographical approach was used to group the cave areas by mountain system and dominant karst-forming conditions. Particular attention was given to the western Zarafshan Range, the Chakylkalon and Karatepa massifs, the Zirabulak–Ziyovuddin low mountains, the Yakkabag Mountains, Boysuntau and the Kugitang Range. The analysis also distinguishes carbonate karst from evaporite (gypsum and salt-related) karst and interprets the role of relief and groundwater circulation in cave development.

No new field measurements or laboratory analyses are introduced in this paper. Quantitative values are reported only where they are explicitly present in the source material. Original source-reference numbering has been retained conceptually; full bibliographic details should be aligned with the bibliography of the underlying manuscript before conference submission.

3. Results and Discussion

3.1. Major areas of karst cave distribution

The western part of the Zarafshan Range is one of the most important karst regions described in the source material. In the Chakylkalon Mountains, Devonian and Silurian limestones are intensely karstified. The Kyrktau Plateau is characterized by numerous sinkholes, depressions, strongly and weakly weathered karren, and chains of sinkholes along the folded northern slope. Near the Takhtakaracha Pass, the deep Kiev Cave reaches a reported depth of 1,082 m, demonstrating the capacity of fractured carbonate rocks and substantial relief energy to generate very deep underground systems.

Karst landforms are also widespread in the Bulbulzarsoy and Maydansoy areas, where large sinkholes and degraded karren occur in Silurian limestone. Snow accumulation within sinkholes contributes meltwater that enlarges cavity walls. One of these sinkholes formed the Komsomolskiy underground shaft, reported to be 81 m deep. Omonkutan Cave is located nearby.

In the southern foothills of the Karatepa Massif, large caves such as Kattaopa and Yettikiz are present, while other caves occur on the southern slopes of the Zarafshan Range. Amir Temur Cave is particularly distinctive because it is interpreted as having formed through dissolution of limestone embedded among granitic bodies. The cave system contains stalactites, curtain-like forms, ribbed dissolution features and aragonite flower-like formations.

Karst is also developed in the low Zirabulak–Ziyovuddin Mountains, where caves, karren and karst springs occur in limestone. In the Yakkabag Mountains, both limestone and gypsum caves are reported together with karren, sinkholes and depressions. In the Shurobsoy basin and surrounding areas, karst is mainly associated with Upper Jurassic rocks; limestones are relatively weakly karstified, whereas gypsum is strongly affected by dissolution.

Boysuntau is another major karst region. Teshiktash Cave, located near Machay village in Upper Jurassic limestone, is notable for its archaeological importance. In the western Boysuntau sector, particularly around Mingchuqur and Kohisurkh, exposed gypsum karst, juniper forests, numerous sinkholes and complex depressions are widespread. Near Kokbulok village, chains of depressions connect underground and surface flow, and the Kaptarkhona Cave, with a reported length of more than 1 km, is among the largest caves in Uzbekistan.

The Kugitang Range is distinguished by open caves, canyon incision through Upper Jurassic limestone, and karren on steep slopes. Gypsum karst is especially intense. In the northern part of the range, the Khojarustam residual relief contains gypsum karst shafts reaching about 35 m in depth, while some shafts exceed 60 m. In the south, the Karluk cave group, Hashimoyoq and Kapkutan are of particular interest. Hashimoyoq has a main passage of nearly 2 km and includes numerous halls and shafts, whereas the combined passages and chambers of Kapkutan are reported to total about 3 km.

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Table 1. Selected karst cave areas of Southwestern Uzbekistan described in the source material

Area / cave	Dominant lithology / age	Reported characteristic	Main geographical significance
Chakylkalon–Kyrktau Plateau	Devonian–Silurian limestone	Dense sinkholes, karren and shafts	One of the most intensely karstified parts of the western Zarafshan Range
Kiev Cave	Carbonate rocks near Takhtakaracha	Depth about 1,082 m	Example of very deep vertical karst development
Komsomolskiy shaft	Silurian limestone	Depth about 81 m	Sinkhole-to-shaft development influenced by snowmelt
Amir Temur Cave	Limestone within granitic setting	Stalactites, curtains, aragonite forms	Distinctive lithological and speleothem assemblage
Kaptarkhona Cave	Gypsum-karst area, Boysuntau	Length >1 km	One of the larger cave systems reported for Uzbekistan
Hashimoyoq Cave	Upper Jurassic limestone with gypsum speleothems	Main passage nearly 2 km	Large multi-chamber cave in southern Kugitang
Kapkutan Cave	Upper Jurassic limestone	Total passages about 3 km	Important extensive cave system in Kugitang

3.2. Lithological control on karst development

The distribution of karst caves is fundamentally controlled by the occurrence of soluble rocks. Carbonate karst-forming rocks include limestone, dolomite, marble and marl, while evaporite karst is associated mainly with gypsum, anhydrite and salts. The source material notes that soluble rocks occupy a substantial portion of Central Asia and are widely represented in Uzbekistan.

Paleozoic carbonate rocks are especially important for cave formation. According to the source material, approximately 41.2% of the known caves of Central Asia occur in Carboniferous limestones. Their importance is attributed both to their wide distribution and to the high proportion of soluble chemical components. These rocks commonly contain numerous fractures and are favorable for the development of caves, sinkholes, ponors and other karst landforms.

Upper Jurassic carbonate rocks are also highly favorable for karst development, particularly in the southwestern branches of the Hissar system and in Boysuntau and Kugitang. Their porosity and tectonic fracturing enhance water infiltration. Evaporite karst behaves differently: gypsum and salt-bearing formations dissolve much faster than carbonate rocks. This rapid dissolution can generate caves and shafts quickly, but it can also lead to rapid collapse and destruction of karst forms. The source material refers to this high-rate development as 'tachykarst'.

3.3. Tectonic controls

Tectonic uplift and fracturing are among the most important prerequisites for cave development. The mere presence of soluble rocks is insufficient. Caves are more likely to form where these rocks have been uplifted relative to adjacent areas and fractured by tectonic movements. Fractures create

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pathways for infiltration and guide groundwater circulation, while uplift increases hydraulic gradients and relief energy.

The source material emphasizes that neotectonic movements have affected Central Asia since the late Paleogene. Alternating uplifted anticlines and subsiding synclines create favorable hydraulic conditions: recharge occurs in elevated zones, while groundwater moves toward lower structural areas, enlarging fractures along the way. This process helps explain the concentration of major karst systems in mountain belts rather than in low-relief plains.

Deep 'blind' cavities may also occur below the surface. In the southwestern Hissar region, drilling for oil and gas reportedly encountered underground voids at depths of approximately 2,000–2,200 m. Such cavities are inferred from sudden drilling-fluid losses or abrupt drops of drilling equipment, demonstrating that karstification can extend far below exposed surface systems.

3.4. Role of relief, climate and groundwater

Relief strongly influences both recharge and discharge conditions. Flat or gently inclined summit surfaces favor the infiltration of precipitation and snowmelt into fractured soluble rocks. If these surfaces are bordered by deeply incised valleys or canyons, a strong hydraulic gradient is created toward valley sides, where cave entrances commonly occur.

An important regional observation is that many long caves occur along the slopes of small streams rather than major rivers. The source material explains this by the greater stability of groundwater flow directions in small valleys. Large rivers can rapidly deepen their channels and shift local base levels, which may cause underground drainage routes to change more frequently and favor shorter, vertically stacked caves instead of long continuous systems.

Climate is also significant. Although much of Central Asia is arid or semi-arid, mountain areas may receive much greater precipitation, especially on western and northwestern slopes. The source material gives values of about 1,000–1,500 mm of annual precipitation for some mountain sectors, which is sufficient to maintain active dissolution. In arid lowlands, precipitation is lower, but much of it occurs during cool seasons when evaporation is reduced, allowing a larger share of water to infiltrate.

Snow is another major source of recharge. Snow can accumulate in shaded depressions and sinkholes to considerable thickness and melt gradually during the warm season. This sustained supply of cold water promotes dissolution within fractures and helps maintain karst groundwater circulation. Groundwater itself is the principal agent of cave enlargement: it dissolves rock, transports dissolved material and often re-emerges as karst springs at lower elevations.

3.5. Environmental and scientific significance

Karst caves are not only geological forms; they are fragile environmental systems. They may preserve archaeological remains, paleontological materials, mineral deposits, unique cave ecosystems and groundwater resources. Some caves are also associated with mineral or thermal waters and may have recreational, educational or medical significance.

At the same time, karst systems are highly sensitive to disturbance. Quarrying, mining, groundwater extraction, uncontrolled tourism and pollution can alter cave hydrology and damage underground habitats. Because water can move rapidly through fractures and conduits, contaminants may spread through karst aquifers with limited natural filtration. For this reason, cave protection should be integrated with management of the surrounding recharge zones and surface land use.

The geographical diversity of Southwestern Uzbekistan makes the region particularly valuable for comparative karst research. Carbonate and gypsum karst coexist across mountain systems of different geological ages, relief forms and climatic settings. This diversity offers opportunities to investigate cave genesis, landscape evolution and groundwater dynamics within a single broad region.

4. Conclusion

The karst caves of Southwestern Uzbekistan show a clear relationship between geological structure and geographical environment. The most important cave regions are concentrated in the

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western Zarafshan Range, Chakylkalon and Karatepa, Zirabulak–Ziyovuddin, Yakkabag, Boysuntau and Kugitang. Their development is primarily controlled by the presence of soluble carbonate and evaporite rocks, but cave formation becomes especially intensive where these rocks are uplifted, strongly fractured and connected to active groundwater circulation. Relief, canyon incision, seasonal precipitation, snowmelt and groundwater gradients further determine the direction and scale of underground drainage. Paleozoic and Upper Jurassic limestones host many major cave systems, whereas gypsum karst is particularly important in Boysuntau and Kugitang. The regional examples discussed in this paper confirm that karst distribution cannot be explained by a single factor; it is the result of the interaction of lithology, tectonics, geomorphology, climate and hydrology. Future work should combine detailed cave mapping, GIS-based spatial analysis, hydrochemical monitoring and conservation assessment in order to better understand and protect these fragile underground landscapes.

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