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KARST FAILURES IN THE NORTHERN CASPIAN

Annotation. *There are small scattered karst areas in the Northern Caspian. They are associated with the outcrops of ancient Late Paleozoic rocks, usually represented by strongly dislocated Lower Permian gypsum in the cores of salt domes. In the article, the author gives a brief overview of karst sinkholes located within the boundaries of these karst areas, based on the analysis of various researchers' work and his own field data. These areas are mainly affected by suffosion-karst and gravity-karst faults. The author not only describes the failures themselves, but also indicates the causes of the failures. The oldest karst sinkhole, which has been monitored for many years, is about 100 years old. Karst sinkholes pose a danger when developing karst areas, so their economic and tourist-recreational development without taking into account the impact of karst is unacceptable.*

Key words: *sulphate karst; karst landscape; karst terrain; karst failure; karst rocks; buried karst; Northern Pre-Caspian; Lake Baskunchak; Lake Inder; Besshoky Highlands.*

Introduction

In the Northern Caspian Sea, within the boundaries of the Pre-Caspian Lowlands, there are many areas that rise above the surrounding plain areas, representing the bottom of an ancient sea. They are elevated to varying degrees by salt-dome tectonics. They are elevated to varying degrees by salt-dome tectonics. The tops of several salt diapirs have brought ancient sedimentary rocks of Paleozoic and Mesozoic age to the day surface. The uplifted rocks are actively exposed to a variety of exogenous processes. Human activity has also substantially changed the topography of these areas. These areas are therefore characterised by a turbulent, dynamic landscape.

Some karst uplifts are surrounded by small karst areas, i.e. areas with karst processes and karst terrain, which are necessary conditions for karst formation. These areas are associated with the outcrop of ancient Late Paleozoic rocks, represented mainly by Lower Permian gypsum (P1kg), in the cores of salt domes, and on Mount Chapchachi by ancient salt rocks of the same age. These areas include the areas adjacent to the lakes Elton, Baskunchak, Inder, Chelkar, as well as the salt-dome uplands: the Chapchachi and Minor Bogdo (Jamantau) mountains, the Hudaibergen hill, and the Bish-Choho (Besshokhi) uplands. These karst areas are unevenly distributed across the Northern Caspian Sea region.

These fragmented karst areas have been studied to varying degrees by various scientists and research organisations. From the 18th century onwards, the salt-dome uplands of the Northern Caspian Region were investigated by I.I. Lepekhin, I.G. Gmelin, P.S. Pallas, M. Tauscher, I.F. Erdmann, I.B. Auerbach, G.P. Fedchenko, I.G. Glushkov, A.A. Bobiatinsky, I.V. Mushketov, F.N. Chernyshev, many other famous scientists[1]. However, the most comprehensive and systematic study of these areas (including karst) began only in the 1930s-40s, in connection with the discovery and exploration of borate deposits around Lake Inder, and the development of the salt industry and the exploration of gypsum deposits on the Baskunchak.Karst processes and phenomena in these areas have been studied by G.R. Aleshchenko, Y.V. Arkhidyakonsky, A.V. Belonovich, N.A. Gvozdetsky, A.A. Gedeonov, S.S. Korobov, E.I. Nurmambetov, S.I. Parfyonov, I.K. Polenov, A.V. Sotnikov, Z.V. Yatskevich, and others [1].

Modern karst processes on the territory of the Northern Caspian Sea have been taking place for about 40,000 years, after the end of the early Khvalyn transgression of the Caspian Sea. Gypsum karst rocks, as a rule, are overlain by loose Khvalynsky deposits, so that karst in these areas refers to the type of covered and sodded, but not uncommonly there are small areas of bare sulphate karst [2].

The sinkholes in the vicinity of the Baskunchak and Inder lakes, as well as on the Bish-choho (Besshokhi) hills are mentioned in the works of many researchers.

However, all descriptions of "falls", "dips", "sinkholes" and "sinkholes" were made in passing, in passing, without proper descriptions of shapes and sizes, while generally describing the topography of the area. Often these terms refer to any karst sinkholes, without regard to their origin. The karst sinkholes and their causes in the territory of the Northern Caspian Region have not been specifically investigated by any researchers. However, the biggest threat to the economic development of karst areas is posed by failure processes.

Since 1986, the Astrakhan section of the Russian Geographical Society's Astrakhan Branch has been studying karst and caves in the Northern Caspian Region [1]. Among other things, a lot of attention during speleological expeditions is paid to the long-term monitoring of karst sinkholes, as well as to identifying and surveying new sinkholes that are being formed.

Materials and methods of research

The methodological basis of the research was the published works of domestic and foreign authors in the field of research of karst processes development, including karst formation, as well as the author's own research. The methods used in the article were: literary source analysis, historical, deduction, statistical, field research, etc.

Research results

Among the various karst landforms, the most dangerous and fortunately least common are karst sinkholes. The danger of sinkholes is that they occur suddenly, their location and time of formation are very difficult to predict without detailed costly large-scale geological investigations by means of drilling and geophysical surveys.

The intensity of karst formation for all karst areas of the Northern Caspian Sea region is different. The most active karst sinkholes are formed in the vicinity of Lake Baskunchak, less so on the Bish-choho (Besshoky) highlands and on the northern shore of Lake Inder [3]. In the karst areas of the Lesser Bogdo Mountain, Khudaibergen Rise, Chapchachi Mountain, the surroundings of the Chelkar and Elton lakes, no failure was observed [3].

Faulty sinkholes (or sinkholes) occur in two types: suffosion-faulty (or suffosion-karstic) and corrosion-faulty (or corrosion-gravity). In the first case, the formation of the sinkholes is due to the collapse of the vault of a cavity formed in loose sediment, due to the overlying sediment washing into the underlying cavities located within the karst rock. In the second case, the sinkhole is formed by the collapse of the karst cavity vault in the bedrock.

Suffosion failures with karst provocation are present in the vicinity of lakes Baskunchak and Inder. In the Pribaskunchak district, such sinkholes are characteristic of the Sharovskaya gully, the bed of the Gorkaya River and other areas with a large thickness of loose deposits on top of karstic gypsum rocks[4]. A typical ground dip discovered in May 2001 is an example. It was probably formed in 2000 and is located on the southern exposure slope of Sharovskaya gully (Fig. 1). The maximum depth of the failure is up to 4.0 m. The diameter of the throat is about 3.0 m. At a depth of approximately 2.0 m, the failure expands meridionally to 5.0 m in length. The extension boundary falls on a change in the composition of the host sediments. Dense light loamy sandy loam is replaced by looser lumpy dark brown loam with the inclusion of Hvalynian shells. Below the neck at the bottom there is a rockfall cone about 0.5 m high. The karst gypsum is not exposed in the walls of the sinkhole, but lies lower and is exposed at the bottom of the gully.

In the same gully, a corrosion and gravity failure can also be observed, formed around 1993-1994, in gypsum rocks due to the collapse of the stone vault of a small karst chamber (Figure 2). The underground cavity is approximately 6.0 m in diameter and 2.5-3.0 m high. The entrance throat, located on the periphery of the cavity vault, is about 2.5 m in diameter. The cavity was discovered in May 1995 during expeditionary works by members of the section of speleology and karstology of the Astrakhan Branch of the Russian Geographical Society.

Figure 1 - Suffosion and karst failure in Sharovskaya gully (photo by I.V. Golovachev)

Figure 2 - Corrosion and gravity failure in Sharovskaya gully (Photo by A.S. Sergeev)

As a rule, the sinkholes are only inspected after they have been formed and opened due to the collapse of the roof. However, in the autumn of 2011, north of the Sharovskaya gully, during expeditionary work, Astrakhan speleologists discovered a 0.25 m diameter hole on the ground surface, behind which a bottle-shaped extension up to 4.0 m in diameter was visible (Fig. 3). The neck of the pit was enlarged with a shovel to a diameter of 0.9 m and then the inner part of the pit was examined (Fig. 4).The maximum depth of the pit was 2.1 m. The vertical walls of the trench inside were composed of interbedded brown clay 15-20 cm thick and yellow thin sandy interlayers up to 5 cm thick (Fig. 5). No karst rocks were exposed. Thus, it was possible to inspect the underground suffosion-karst cavity that had formed before the natural collapse of the roof, to measure it and to make a topographical survey (Fig. 6).

Figure 3 - Hole in the ground (Photo by A.S. Sergeev)

Figure 4 - Enlarged neck (photo by I.V. Golovachev).

Figure 5 - View inside the gap
(Photo by A.S. Sergeev)

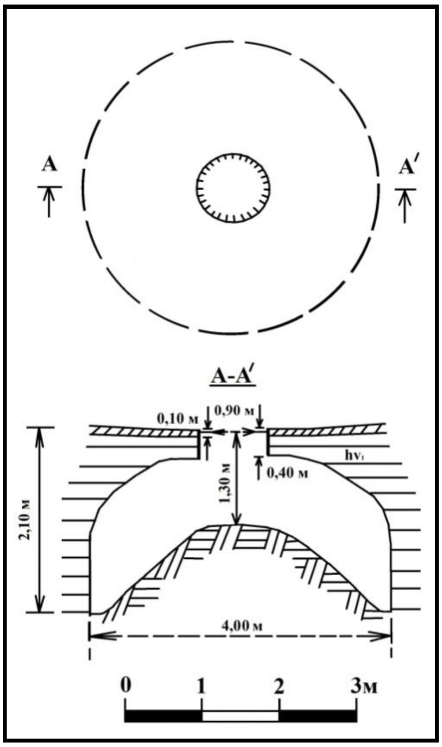

Figure 6 - Plan and Cut of the Fault
(Survey: I.V. Golovachev, A.S. Boyko)

The largest cup-shaped failure occurred on 26.09.1989 in the immediate vicinity of the grader between Sredniy and Nizhniy Baskunchak. The failure was surveyed on 28.09.1989 by the members of a special expert commission set up by the decision of "Astrakhan TISIZIZ" [5. P. 139]. According to the inspection report, the size of the latitudinally elongated neck of the failure was 15.0 m x 18.5 m, at a depth of about 20.0 m. The entire visible section of the failure was composed of loose non-karst sediments represented by horizontally bedded loams and underlying fine-grained compact sands (Fig. 7).

AnhydrideGeological cross-section of the gap

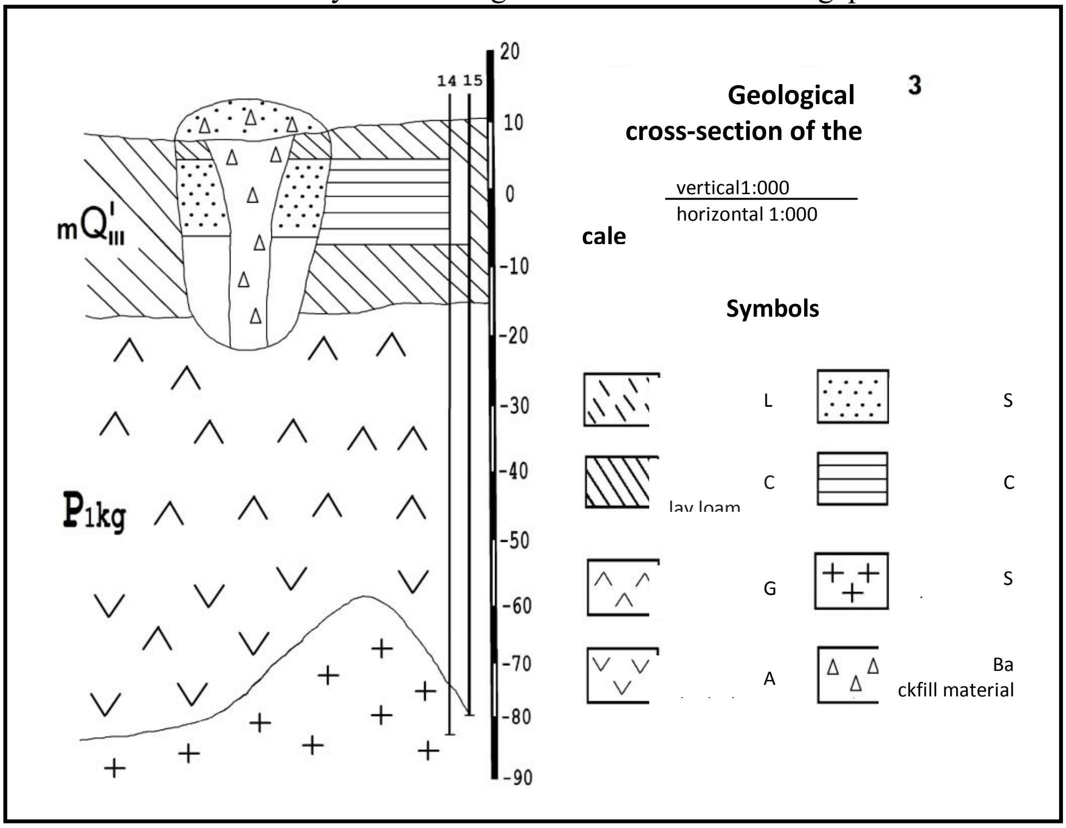

Figure 7 - Geological section of the 1989 sinkhole [5. P. 139]

Gypsum karst is located in the area of the sinkhole at a depth of about 23 m from the surface. According to eyewitnesses: the failure occurred instantly, accompanied by a rumble and upward ejection of loose loamy soil, the noise of flowing water could be heard from the depth of the sinkhole, the bottom of the sinkhole was not visible from the edge, there was also no exposure of karst gypsum in the walls of the sinkhole. The sinkhole was caused by the collapse of the karst drainage canal, which was covered by a thick layer of unconsolidated ancient Caspian sediments. Unfortunately, the failure was hastily backfilled and therefore not adequately investigated. A total of 2,600 m3 of loam and gypsum blocks from the gypsum quarry were required to backfill the failure. The fill in the area of the pit had been sinking for several more years.

In March 1992, in the immediate vicinity of this failure, but to the south of the grader, another vaulted failure silently formed. Its oval neck measured 4.0 m x 3.0 m. It was approximately 10.0 m deep. In the middle and lower part of the failure, the bottle-shaped walls of soil expanded up to 15.0-20.0 m. No karst rocks were exposed in the walls of the pit. The pit was also backfilled with gypsum blocks from the waste dumps of the gypsum quarry located near the village of Sredny Baskunchak. By 1994, the collapse had widened to 10.0 metres.

In 1994, a large suffosion-karst trough with a diameter and depth of about 10 m was formed next to the 1992 failure. No karst rocks were exposed. The walls of the pit were mostly formed by loams. The bottom of the pit was covered with collapsed loose earth material.

In October 1994, during the expedition work, a fresh karst sinkhole was discovered one hundred meters to the northeast of Gorkoe Lake, northeast of the bowl of Lake Baskunchak (Fig. 8). The sinkhole had a latitudinal direction and dimensions of 6.0 by 4.0 m. The depth of the failure was about 3,5-4,0 m. There was water at a depth of 0.6-0.7 m from the top edge of the trough with foam floating on the surface. Along the perimeter of the trench, parallel to the edge, cracks of subsidence had already formed. Loose laminated loamy and sandy loam layers were exposed in the walls of the cavity.

Figure 8 - Failure at Gorky Lake in 1994. (Photo by I.V. Golovachev)

Figure 9 - Failure at Gorky Lake in 2012. (Photo by I.V. Golovachev)

Between 1994 and 2012 (i.e. over 13 years!), the ditch has widened and shallowed. The edge of the pit has flattened and flattened out (Figure 9). Its depth has become less than one metre.

Old suffusion-karst sinkholes can often be observed on the slopes of numerous karst-erosion gullies (surface runoff troughs) located on the western shore of Lake Baskunchak. The sinkholes formed in sandy loam and sandy sediments are less stable and collapse much faster, flatten out, sod and gradually become bowl-shaped suffosion-karst sinkholes. If loams and clays prevail, such sinkholes retain their vertical sides and steepness of slopes much longer.

Karst sinkholes are also formed in populated areas. So, for example, on 10.08.2007 at 21.00 in Nizhnij Baskunchak village, Gorkogo street, 14, a suffosion-karst cavity was formed on the household plot (pic.10).

Figure 10 - Failure in the village of Nizhny Baskunchak (Photo by O.M. Vyazmin)

The last large karst sinkhole was formed in 2008 in the northern karst field in the vicinity of the Koshara Turgai shepherd's field (Figure 11).

Figure 11 - Karst sinkhole in the Turgai koshar (photo by E.A. Lisitsa)

The sinkhole was discovered in time. It was found and examined by members of the karst caving section of the Astrakhan branch of the RGS on 03.10.2014 during the expedition work on the northern gypsum field. The time of formation of the pit was reported by a shepherd from the point "Koshara Turgai".

The sink-hole at the time of the survey was slightly oval in shape, extending in a meridional direction. Its size was about 15.5 x 17.5 m, with a depth of up to 6.0 m. The trench is embedded in horizontally bedded loose sandy-loam sediments. The walls of the pit are vertical, the bottom is flat and dry. Karst rocks are not exposed. The failure occurred suddenly and without prior ground subsidence. At the time of examination, cracks were formed along the perimeter of the failure at the distance of 0.4-1.0 m from the edge of the failure throat. The failure remained unfilled and its development can be monitored in the future.

Subsequently, the sinkholes become conical and protruding due to the collapse of the walls (Fig. 12). They are characterised by regular rounded shapes without erosion incisions and are generally symmetrical.

Figure 12 - An old pit near the Turgai sheep barn (Photo by M.A. Sokolov)

There are also karst sinkholes in the vicinity of Lake Inder. One of the sinkholes examined by Astrakhan speleologists (Fig. 13) is located on the side of an old asphalt road [6, p. 55]. Its opening is most likely due to the vibration of soils caused by the frequent movement of heavy quarry equipment along the road. The failure is of the corrosion-soil (or corrosion-gravity) type.

Figure 13 - Karst sinkhole
(Photo by I.V. Golovachev)

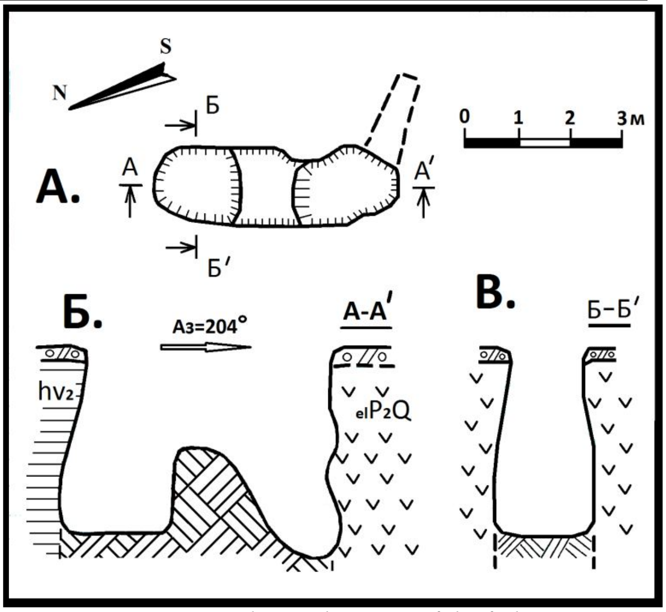

Figure 14 - Plan and section of the failure
(Photograph: I.V. Golovachev)

The dimensions of the pit are 4.5m long, 1.5m wide and 3.5m deep (fig.). Gypsum (black, bituminous, fine- and medium-grained) with traces of karst treatment is exposed in the walls of the pit. Under one of the walls, there is a karst subhorizontal pipe-like sinkhole, a channel 1.5 m long and 0.5-0.6 m in diameter. The bottom of the sinkhole is covered by dealluvial deposits mixed with loose filler material - light yellow-brown sandy loam of uniform colour and composition, of marine genesis.

Judgi ng by the appearance of the sinkhole and the nature of the deposits, the process of opening (restoration) of the ancient buried karst is taking place here.

In May 2017, speleologists from Astrakhan discovered a rather fresh suffosion-karst sinkhole (Fig. 15) [6, p. 56].

Figure 15 - Fresh failure
(Photo by M.A. Kuznetsova)

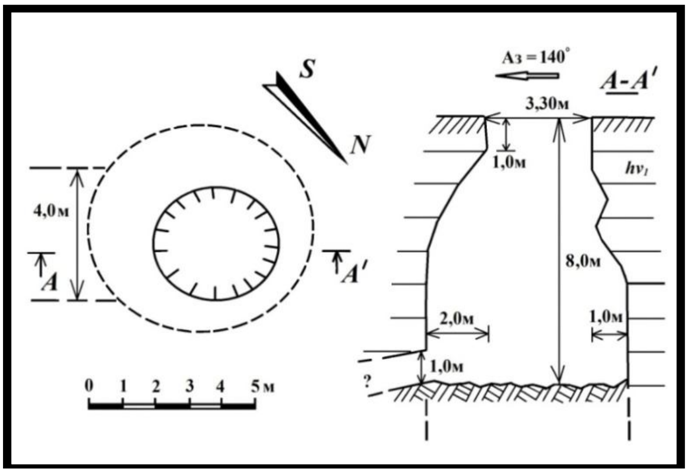

Figure 16 - Plan and section of the failure
(Photograph: I.V. Golovachev)

Judging by its appearance, this failure is no more than 2-3 years old. The ditch is bottle-shaped and has the following dimensions: length 3.6 m, width 3.3 m, depth 8.0 m (Figure 16). The thickness of the overhanging overhang is about 1.0 m. The neck of the failure is oval in shape and slightly extended sub-medially. The edge of the neck of the ditch is sharp. There are subsidence cracks around its perimeter, indicating a gradual widening of the neck. Horizontal Khvalynian deposits are exposed in the walls of the pit, represented by silty and fine-grained sand in the upper part and yellow loam in the lower part of the section. No karst rocks are exposed in the walls of the failure. A wide (up to 4.0m) but low (up to 1.0m) channel runs beneath the base of the south-east wall.

There are also large karstic gaps on the Bish-choho (Besshokhi) Upland. In 1854, the famous Russian geologist Ivan Bogdanovich Auerbach, commissioned by the Imperial Russian Geographical Society, surveyed this upland [7]. He mentions in his work "gypsum cavities, which are found here in even greater numbers than on the Bolshoi Bogdo..." [7, 67]. [For about 100 years there has been a large sinkhole of karstic origin on the upland, which was described in detail in 1934 by the Saratov zoologist Yu.M.Rall [8].This researcher even made sketches and measurements of the sinkhole (Fig.17, 18) According to Yu.M.Rall, this sinkhole was formed in the mid-20th years of the last century.

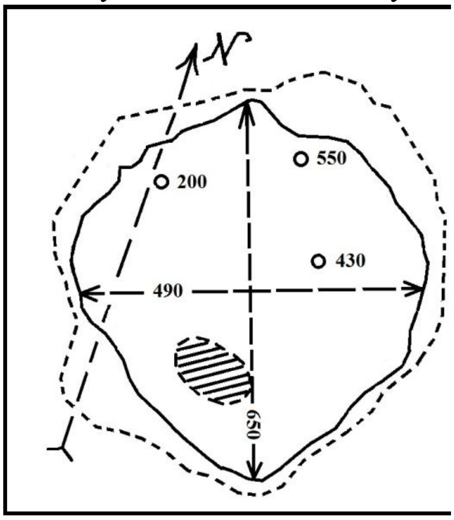

Figure 17 - Plan of the mouth of the main karst. The solid line is the inlet mouth, the dashed line is the water-surface line at a depth of 685 cm from the surface [8].

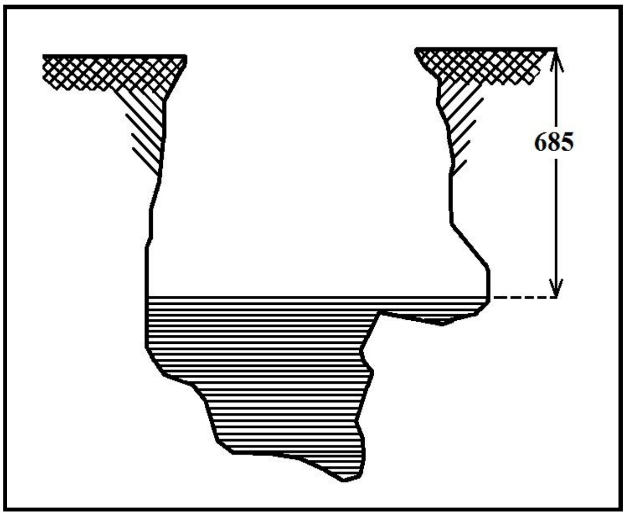

Figure 18 - Section of the main karst with water [8].

This karst sinkhole was first encountered by Astrakhan speleologists in 1987. It was surveyed in more detail in 1997-1999, 2009 and 2019 [1, 9]. In the course of these expeditionary works observations of changes in morphometry and morphology of the failure were made (Fig.19, 20, 22) and water samples were taken for chemical analysis [9].

As a result of the study of this sinkhole, the dynamics of changes in the size of the sinkhole was revealed. In 1934, the size of the throat of the sinkhole was 4.90 m × 6.50 m, and 85 years later in 2019, it had already reached 10.0 m × 11.0 m. Thus, the neck has almost doubled in size! It is also interesting that over such a long period, the walls of the cavity have not aligned, but have remained vertical (Fig. 21).

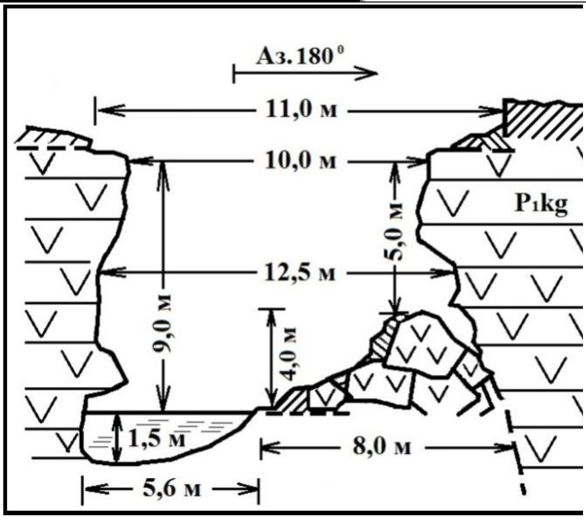

Figure 19 - A cross-section of the Az. 180º (Survey: I.V. Golovachev, E.A. Lisitsa)

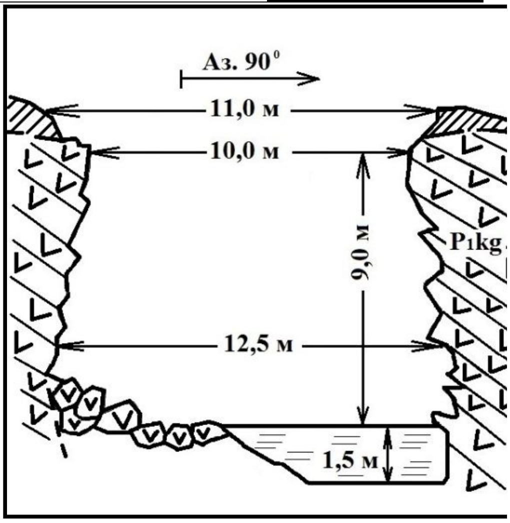

Figure 20 - A cross-section of the failure at Az. 90º (Photo: I.V. Golovachev, E.A. Lisitsa)

Figure 21 - Faulty well (Photo by A.A. Shaposhnikov)

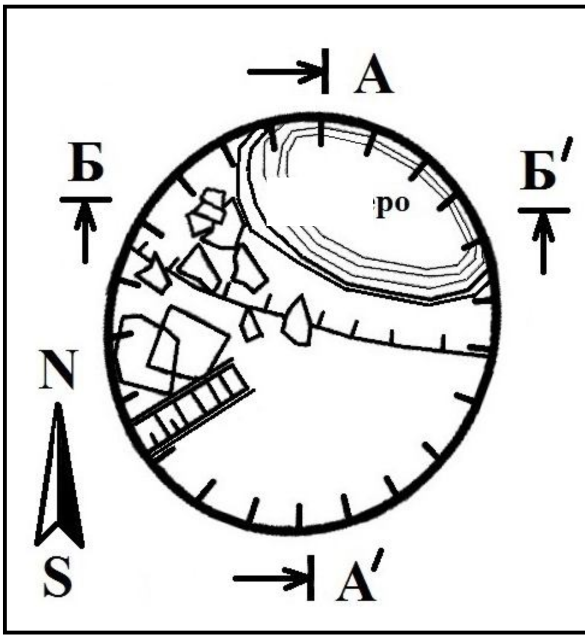

Figure 22 - Plan of the sinkhole neck (Photo: I.V. Golovachev, E.A. Lisitsa)

The depth of the location of the water mirror in the ditch from the surface at the time of its formation in 1924-25 is unknown, but according to witnesses, "water was barely visible in its depth, but then the neighbouring barkhan was almost entirely transferred here by winds and the water level rose" [8, p. 59]. In 1934, the depth of the water table from the surface was 6.85 m. At the same time, the water occupied the entire bottom of the sinkhole! By the spring of 2019, the water level was 9.0 m below the surface (i.e. 2.15 m lowered), and the water occupied only one third of the bottom area.

The highest water depth in the sinkhole in the spring of 1934 was 5.50 m. However, in the spring of 2019, the water depth was no deeper than 1.0 m. In other words, the water depth has decreased by more than 5 times in 85 years! This is most likely due to the tamponisation of the underlying water channels and cracks by loose sandy-clay material entering the sinkhole, the burial of the sinkhole by collapsing clastic gypsum material and siltation of sediments on the lake bed.

Based on the research and analysis of the available data, the further evolution of this sinkhole can be surmised. The lake at the bottom of the sinkhole will be gradually covered by a layer of gravitational and aeolian deposits. The sinkhole will continue to expand due to the collapse of the surrounding gypsum rocks. But this is a long-term process and for the next 80-100 years it will still look like a sinkhole until it evolves into a large sinkhole of sinkhole genesis.

Various natural and anthropogenic factors have an impact on the development of karst formation [10. P.143]. The natural factors influencing the development of karst relief include abnormally high volumes of precipitation, intensive melting of thick snow cover, activation of salt-dome tectonics processes, underground floods. Anthropogenic factors are represented by overgrazing, vibration of soils, artificial lowering of ground (karst) water level, tamponization of drainage channels, etc.

Conclusion

Karst processes pose a certain risk when developing karst areas, due to the formation of all kinds of subsidence on the ground surface and collapses underground. Information and warning signs must be installed in the areas of the highest risk of landslides. Due to the danger of karst development and manifestation, economic and tourist and recreational development of such areas in the future without taking into account the impact of karst is unacceptable.

On the basis of the above it is necessary to conclude about the necessity of further systematic, full-scale research of karst forms and processes, as well as long-term geodynamic monitoring in the areas exposed to the development of karst, including the processes of karst formation.

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Головачев И.В.

КАРСТОВЫЕ ПРОВАЛЫ В СЕВЕРНОМ ПРИКАСПИИ

Аннотация. На территории Северного Прикаспия имеются небольшие по площади разрозненные карстовые районы. Они связаны с выходом на дневную поверхность древних позднепалеозойских пород, представленных, как правило, сильно дислоцированными нижнепермскими гипсами в ядрах соляных куполов. В статье на основе анализа работ различных исследователей и собственных полевых данных, автор даёт краткий обзор карстовых провалов имеющихся в границах этих карстовых районов. Встречаются на данных территориях в основном суффозионно-карстовые и гравитационно-карстовые провалы. Автор приводит не только характеристику самих провалов, но и указывает причины вызывающие провалообразование. Наиболее старый карстовый провал, за которым ведётся многолетнее наблюдение, имеет возраст около 100 лет. Карстовые провалы представляют опасность при освоении закарстованных территорий, поэтому их хозяйственное и туристско-рекреационное освоение без учёта воздействия карста недопустимо.

Ключевые слова: сульфатный карст; карстовый ландшафт; карстовый рельеф; карстовый провал; карстующиеся породы; погребённый карст; Северный Прикаспий; озеро Баскунчак; озеро Индер; возвышенность Бесшокы.

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СОЛТҮСТІК КАСПИЙДЕГІ КАРСТ ОЙЫСТАРЫ

Аңдатпа. Солтүстік Каспий маңы аумағында ауданы бойынша шағын бытыраңқы карст аудандары бар. Олар ежелгі кеш палеозой жыныстарының күндізгі бетіне енуімен байланысты, олар, әдетте, тұз күмбездерінің ядроларында жоғары орналасқан төменгі германдық гипстермен ұсынылған. Мақалада әртүрлі зерттеушілердің жұмыстарын және өзінің далалық деректерін талдау негізінде автор осы карст аймақтарының шекараларында орналасқан карст сәтсіздіктеріне қысқаша шолу жасайды.Бұл аумақтарда негізінен суффозиондық-карсттық және гравитациялық-карсттық шөгінділер кездеседі. Автор сәтсіздіктердің сипаттамасын ғана емес, сонымен қатар сәтсіздікке әкелетін себептерді де көрсетеді. Көпжылдық бақылау жүргізілетін ең көне карсттық сәтсіздіктің жасы шамамен 100 жыл. Карст шұңқырлары карст аумақтарын игеру кезінде қауіпті, сондықтан олардың карст әсерін ескерместен экономикалық және туристік-рекреациялық дамуына жол берілмейді.

Кілт сөздер: сульфатты карст; карст ландшафты; карст рельефі; карст ойысы;карст жыныстары; жерленген карст; Солтүстік Каспий; Баскунчак көлі; Индер көлі; Бесшоқы тауы.