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GEOLOGICAL CHARACTERISTICS OF DESERT AND UPPER DESERT CAVES (NE BLUE DIAMOND HILL, NEVADA, USA)

GEOLOŠKE ZNAČILNOSTI DESERT IN UPPER DESERT CAVE (NE BLUE DIAMOND HILL, NEVADA, USA)

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Stanka Šebela & John W. Hess: Geološke značilnosti Desert in Upper Desert Cave (NE Blue Diamond Hill, Nevada, USA)

Desert Cave (72 m) in Upper Desert Cave (62 m) sta najdaljši znani jami na Blue Diamond Hill in se nahajata znotraj enega od več kanjonov. Jami sta razviti v apnencu iz zgornjega dela spodnjega permija (Kaibab formacija). V najnižjem delu Desert Cave, ki je 12,6 m globoka, jamski rov doseže litološko mejo med Kaibab apnencem in sedimentacijsko brečo (spodnji del Kaibab formacije). Stik breča-apnenec je ena od inicialnih struktur iz freatičnega obdobja razvoja jame, vendar ne pred mezozojskimi narivnimi deformacijami. Površinska razdalja med vhodoma v Desert in Upper Desert Cave je 81 m, jami nista povezani.

Desert Cave se nahaja 2 km zahodno od nariva Bird Spring. Prevladujoče smeri razpok v jami so NW-SE in NE-SW. Smer rova je skoraj vzporedna s smerjo razpok NE-SW. Obstaja jasna povezava med javljanjem podorov v jami in močneje izraženimi razpokami v smeri NW-SE.

Ključne besede: geologija, krasoslovje, Blue Diamond Hill, Desert Cave, Upper Desert Cave, Nevada, ZDA.

Abstract UDC: 551.442(79)

Stanka Šebela & John W. Hess: Geological Characteristics of Desert and Upper Desert Caves (NE Blue Diamond Hill, Nevada, USA)

Desert Cave (72 m) and Upper Desert Cave (62 m) are the longest known caves in Blue Diamond Hill and are situated in one of its canyons. Caves are developed in limestone of latest early Permian age (Kaibab formation). In lowest part of Desert Cave, which is 12,6 m deep, cave passage reaches lithological contact between Kaibab limestone and sedimentary breccia (lower part of Kaibab formation). The contact breccia-limestone is one of initial structures in phreatic period of cave development but not before Mesozoic thrusting tectonics. Surface distance between entrances to Desert and Upper Desert Cave is 81 m, the caves are not connected.

Desert Cave is situated 2 km W from Bird Spring thrust. Prevailing fissure directions in the cave are NW-SE and NE-SW. Passage direction is almost parallel with the NE-SW fissures direction. There is obvious connection in occurrence of breakdown in the cave with strongly expressed fissures in NW-SE direction.

Key words: geology, karstology, Blue Diamond Hill, Desert Cave, Upper Desert Cave, Nevada, USA.

On 9th Symposium on the Geology of the Bahamas (4-8 june, 1998), San Salvador, Bahamas, a short version of this paper was presented on poster session. But because all presentations on the symposium were related to geology of carbonate islands of Central America, we decided to publish the complete paper in this publication.

INTRODUCTION

Field area belongs to northern part of Blue Diamond quadrangle and SE part of La Madre quadrangle, Nevada-Clark Co. (7,5 minute series - topographic) in scale 1:24.000.

Blue Diamond Hill (1.440 m) is situated 10 km W from Las Vegas, Nevada (fig. 1). For research we choose N and NW part of the hill, where some karst caves can be found.

Principal aim of research was to understand structural control on cave development. Detailed structural geologic mapping was done in caves and also on the surface. To understand development and occurance of the caves special attention was dedicated to stratigraphic units.

Most of eastern Nevada is underlain by carbonate rocks, especialy in central and southern part, but karst caves are not as common as expected. Prevailingly they are short caves with breakdown and sediment fillings. There is only one show cave, Lehman Cave in Great Basin National Park with 2,4 km of mapped passages in central part of E Nevada. The largest known cave in Nevada with approximately 3,9 km of passages is Baker Creek Cave system.

In Blue Diamond Hill between several small caves are 3 longer caves: Desert Cave (72 m), Upper Desert Cave (62 m) and Wounded Knee Cave (51 m).

Entrances to Desert Cave and Upper Desert Cave are on the north side of canyon which in flash flood events can be filled with water.

One third of eastern part of Nevada is built from carbonate rocks. Regional movement of ground water may be strongly influenced by the Late Mesozoic-Early Tertiary deformation of the Upper Precambrian and Paleozoic miogeosynclinal rocks, their subsequent erosion and the faulting that took place during the Late Cenozoic orogeny (Mifflin & Hess, 1979).

Analysis of geology indicates that nearly all springs are controlled by impermeable fault contacts or exposure of cavernous systems in limestone due to faulting or erosion. The faults are usually perpendicular to the gradient of ground-water flow (Hughes, 1966).

Mean annual precipitations in Las Vegas valley are 105-250 mm/year and in surrounding mountains 250-500 mm/year, Las Vegas's mean annual temperature is 19°C.

Lower and middle Paleozoic carbonates and the Quaternary-Tertiary valley fill are the principal transmitters of ground water. Subsurface movement of water in the area of Blue Diamond Hill is towards E.

The conceptual model of groundwater flow in southern Nevada is based on flow in fractured carbonate-rock aquifers that have been structurally deformed by compression and more recently extension. These processes have produced a central corridor of thick (several thousand meters or more), laterally continuous Paleozoic carbonate rock in which most groundwater flows in southern Nevada (Thomas, 1996).

GEOLOGY-STRATIGRAPHY

Geological map 1:250.000 (Longwell et al., 1965) shows that NE Blue Diamond Hill is built of Permian rocks (red beds, Coconino formation, Toroweap and Kaibab formation). Above is erosional discordance and than Triassic Chinle and Moenkopi formation (Trcm), and Jurassic Aztec sandstone (Ja).

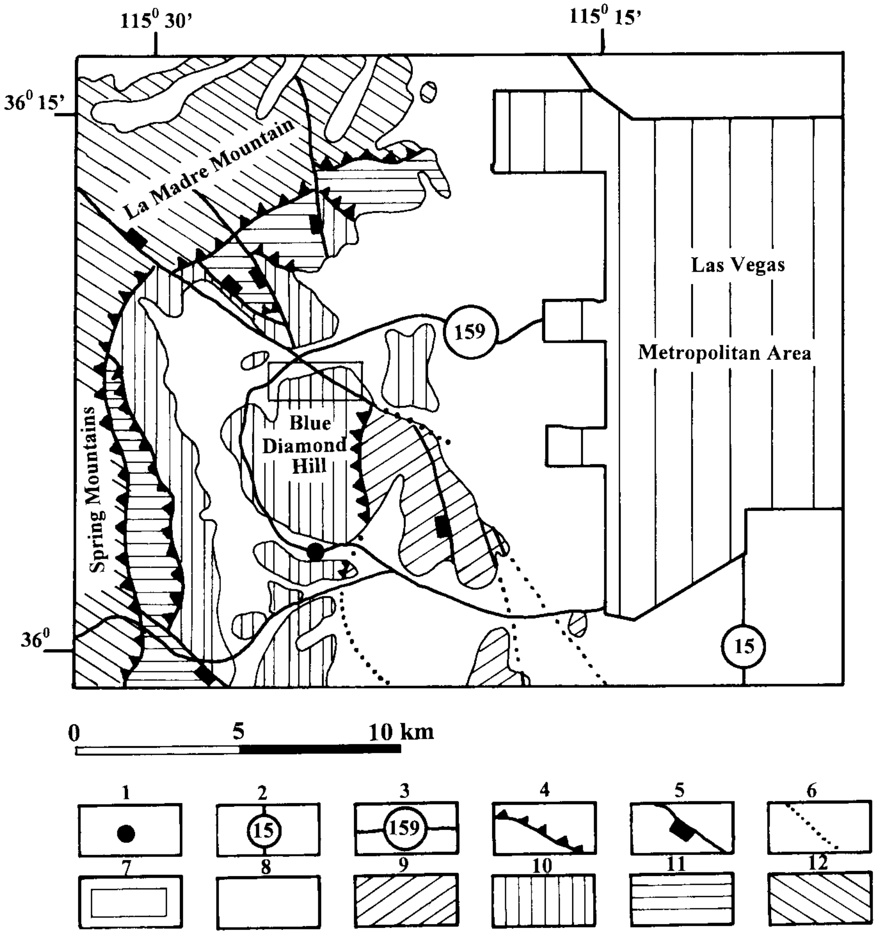


Fig. 1: Generalized geological map of northern Spring mountains, showing location of studied area on Blue Diamond Hill. Modified after Longwell and al. (1965) and Axen (1984).

1-town of Blue Diamond, 2-highway, 3-road with number, 4-thrust, 5-fault with vertical displacement, 6-supposed thrust or fault, 7-studied area, 8-surficial deposits (Quaternary), 9-Autochthonous rocks, 10-Bird Spring thrust plate, 11-Contact-Wilson Cliffs-Red Spring thrust plate, 12-Keystone thrust plate.

Sl. 1: Generalizirana geološka karta severnega dela Spring mountains, z označeno lokacijo raziskovanega terena na Blue Diamond Hill. Prirejeno po Longwell and al. (1965) in Axen (1984).

1-mesto Blue Diamond, 2-avtocesta, 3-cesta in oznaka, 4-nariv, 5-prelom z vertikalnim premikom, 6-domneven nariv ali prelom, 7-raziskovan teren, 8-površinski sedimenti (Kvartar), 9-avtohtone kamnine, 10-nariv Bird Spring, 11-kontakt med narivom Wilson Cliffs in narivom Red Spring, 12-nariv Keystone.

Within Clark County, Nevada, the Coconino Sandstone is crossbedded, but on a much smaller scale than in the thicker section of the Colorado Plateau. In some cliffs this sandstone, whitish to pink, forms a prominent band between the Permian red beds beneath and the Toroweap Formation above. The formation is included with the Permian red beds on the geological map. Lower member of red beds represents pinkish-gray sandstone and upper member reddish sandy shale and fine-grained sandstone (Longwell et al., 1965).

Generally there are 2 thick limestone units associated with weak beds of shale, sandstone and gypsum. This entire sequence of beds was for many years included in a single formation known as the Kaibab Limestone. McKee (1938) recognized that the sequence is logically separated into 2 mappable units, each containing a considerable thickness of sandstone, gypsum and shale in addition to limestone. He proposed that the upper unit be called the Kaibab Formation and the lower the Toroweap Formation (Longwell et al., 1965).

The Toroweap and Kaibab Formations are among the most easily recognizable geologic units in Clark County, Nevada. In each the most prominent member is gray limestone with abundant dark-weathering chert in lenses and thin layers arranged parallel to the bedding (Longwell et al., 1965).

Sandstone and shale, interlayerd with considerable gypsum, form a basal member of the Toroweap Formation as much as 37 m thick. The overlaying limestone is in part distinctly bedded but locally appears massive expect for irregular stripes of chert. The limestone varies in thickness from 60-75 m. Above it is a section about 30 m thick, of weak beds that vary in composition; locally redish shale and sandstone predominate, commonly some gypsum is included and at some localities nearly the entire unit consists of gypsum. On this weak unit the basal beds of the Kaibab Formation lie with some unconformity; commonly they consist of breccia containing fragments of the beds below and in many places they fill shallow valleys, some of which were cut sharply into the beds of the Toroweap before filling began. This deposit grades upward into dark- grey limestone, much of it crystalline, containing abundant chert. This limestone member is about 120 m thick. Above it is a weak zone consisting of reddish shale, gypsum and layers of light- gray limestone and dolomite rich in chert nodules. This upper unit of the Kaibab is known as the Harrisburg Gypsiferous member and ranges in thickness from 45-67 m. It containes quantities of nearly pure gypsum which have been extensively exploited at the Blue Diamond and other quarries near Las Vegas (Longwell et al., 1965).

At many places a considerable part of the Kaibab Formation was removed by erosion prior to deposition of the next younger formation the Moenkopi (Triassic). Locally both the Kaibab and Toroweap rocks were completely eroded in pre-Moenkopi time; at several localities on both sides of the Spring Mountains the basal Moenkopi deposits rest on beds far below the original top of the Permian red beds. Probably this erosion occured during Late Permian time and this time interval is not represented by any deposits in the region. Both the Toroweap and the Kaibab Formations contain fossils of latest Early Permian age (Longwell et al., 1965).

STRUCTURAL GEOLOGY

The structural geology of Red Rock Canyon and surrounding Spring Mountains is complex and includes several periods of Paleozoic deformation, Mesozoic thrust faulting and Cenozoic normal

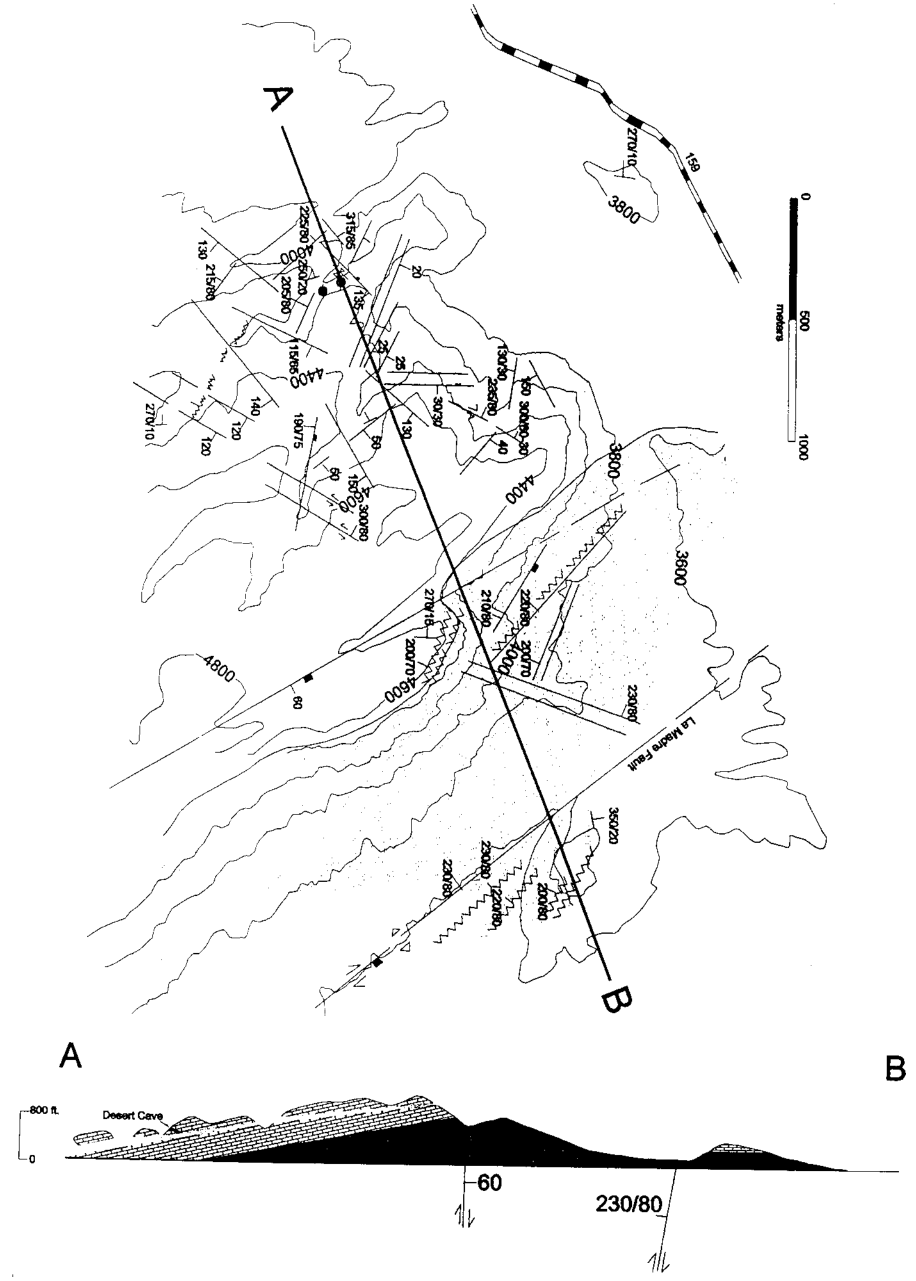


Fig. 2: Geological map of NE Blue Diamond Hill, SW Nevada with cross section A-B.
Sl. 2: Geološka karta NE dela Blue Diamond Hill, SW Nevada s prečnim profilom A-B.

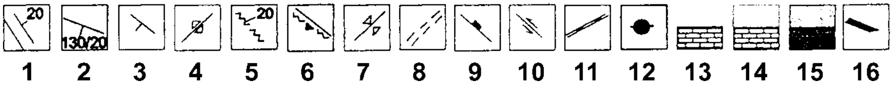
faulting (Axen, 1984).

The major orogenic activity in southern Nevada began in the Cretaceous Period and continuated into Tertiary time. The sequence of structural and related events may be summarized as follows:

1. Initiation of folds and large scale thrust faults, accompanied by some normal, steep-reverse, and strike-slip faulting. Local accumulation of coarse clastic sediments derived from thrust plates and folds.
2. Intrusion of plutonic rocks, initiation of volcanic activity.
3. Dolomitization and other alteration of limestone.
4. Large-scale normal faulting and volcanic activity.
5. Repeated sedimentation within structural basins (Longwell et al., 1965).

The Sevier orogenic belt was form during Cretaceous by: uplift, folding, development of thrust faults from the folds and translation of thrust plates along eroded surfaces. Extending from E California to S Wyoming the orogenic belt thrusts basinal marine carbonates over marginal deltaic deposits, involving a crustal shortening of between 38-68 km (Fleck, 1967). Movement on the thrusts was from west to east.

Armstrong (1963) belives that the displacement took place on a single master thrust. Estimates of the magnitude of the displacement vary from 32-120 km. The only mechanism which could produce a displacement of this magnitude on a single plane is a detachment or decollement. He also



LEGEND for Fig. 2 and 5:
1-principal faults, 2-less important faults and fissures, 3-stike and dip of bedding planes, 4-anticline, 5-small fissures, 6-fault zone with tectonic breccia, 7-syncline, 8-supposed fault or fissure, 9-vertical movement, 10-horizontal movement, 11-road, 12-cave, 13-Kaibab formation (breccia and limestone with shale, gypsum), Permian, 14-Toroweap formation (mostly limestone with sandstone, shale, gypsum), Permian, 15-Red beds and Coconino sandstone, Permian, 16-Desert Cave.

LEGENDA za sl. 2 in 5:
1-glavni prelomi, 2-manj pomembni prelomi in razpoke, 3-smer in vpad plasti, 4-antiklinala, 5-majhne razpoke, 6-prelomna cona s tektonsko brečo, 7-sinklinala, 8-domneven prelom ali razpoka, 9-vertikalni premik, 10-horizontalni premik, 11-cesta, 12-jama, 13-Kaibab formacija (breča in apnenec s skrilavcem, sadra), permij, 14-Toroweap formacija (predvsem apnenec s peščenjakom, skrilavec, sadra), permij, 15-rdeče plasti in Coconino peščenjak, permij, 16-Desert Cave.

suggests continuity of a major overthrust bringing lower Cambrian rocks over upper Paleozoic rocks, from NW Utah to S Nevada as the main thrust of the Sevier belt.

Evidence of a late Cretaceous metamorphic event in E California suggests a possible relation between that metamorphism and the Sevier orogenic belt (Fleck, 1967).

All these features, the major thrust and smaller related structures, have been rotated westward through 90° by right-lateral strike slip movement on the adjacent Las Vegas Valley shear zone (Ebanks, 1965). The displacement is reported to have been in excess of 40 km (Longwell, 1960; Burchfiel, 1965).

In the La Madre Mountain area, Paleozoic miogeosynclinal carbonate rocks have been transported eastward on 2 major thrust faults, the Keystone and Red Spring thrusts (fig. 1), with an estimated minimum cumulative transport of 30 km (Axen, 1984).

Autohtonous or parautochtonous rocks in the area are Permian to Jurassic nonmarine and shallow-marine strata, which are unconformably overlain by Upper Jurassic or Lower Cretaceous Synorogenic conglomerates (Longwell et al., 1965).

Clockwise oroclinal rotation of the entire La Madre Mountain area is inferred to have occurred in late Tertiary time and probably rotated these Mesozoic fold axes from N-S trends to NE-SE trends (Burchfield et al., 1974).

Red Spring thrust is interpreted as the Keystone thrust which was broken and differentially rotated during Neogene oroclinal bedding associated with the Las Vegas shear zone. All of the features of the Red Spring blocks can be explained by one episode of thrust faulting during Sevier deformations, and one episode of oroflexural folding during the Neogene Basin and Range deformation (Matthews, 1988).

Older thrust faults lie east of younger thrust faults. Rocks east of the Bird Spring thrust (fig. 1) form the authochthon of the North American craton. Toward the north the Bird Spring thrust loses displacement. At its northern recognized end, just south of the La Madre fault it only duplicates Permian red beds (Burchfield & Davis, 1971). The Bird Spring thrust (Longwell et al., 1965) may underlie La Madre Mountain at depth.

The Keystone, Contact-Red Spring and Bird Spring thrust plates all lie above channel-confined conglomerate units, a relationship that suggests that these plates moved across erosional surfaces (Burchfield & Davis, 1971).

Blue Diamond Hill is caped by Permian Kaibab and Toroweap limestones with Permian red beds in the slope. At the base of the hill the Permian red beds are repeted by the Bird Spring thrust. The La Madre fault passes between the small hills south of the road 159 (fig. 1) and the higher flat-topped hill farther south (Burchfield & Davis, 1971). The Bird Spring thrust fault looses displacement NE ward and dies out into the eastward vergent folds (Carr, 1992).

The rocks in the western part of the Bird Spring Range dip moderately west. Toward the east they become nearly horizontal. This is interpreted to be the result of a ramp-flat geometry in the Bird Spring thrust. South from highway 15 Bird Spring thrust must have at least 5-6 km of displacement, considerably more than in northern part (Burchfield & Davis, 1971).

Normal faults could have developed:

1.) At the time of movement on the Las Vegas Valley shear zone (Ebanks, 1965)
The major displacement along that zone, is largely post-Oligocene (Fleck, 1967).
2.) During the almost continuous block faulting of later Tertiary time (Ebanks, 1965).

The second major episode began in early Miocene when normal faulting and transcurent shearing or oroflexure deformed the crust and probably extended into the mantle. Lateral translation involved a combination of folding about vertical axes and right-lateral strike-slip faulting (Las Vegas Valley shear zone) (Fleck, 1967).

Axen (1985) belives that the NE Spring Mountains were involved in Tertiary eastward oroflexure related to the movement on the Las Vegas shear zone, and that this movement accounts for the anomalous trends of Mesozoic structures in the La Madre Mountain area.

Fig. 3: Brown flowstone in fissures can be deposited in vertical and horizontal directions, photo by Stanka Šebela.
Sl. 3: Rjava siga v razpokah je lahko odložena v vertikalni ali horizontalni smeri, foto Stanka Šebela.

The most conspicous structures NE from Blue Diamond Hill are N-NW striking, mostly SW dipping steep faults. The largest of these faults have dip separation of 150-300 m. Slip directions are not known. The Permian and Triassic strata had already been deformed by Mesozoic folding and thrust faulting prior being tilted further along steeply dipping faults. Gypsiferous units (Woods Ranch and Seligman Members of the Toroweap Formation) below each of this two competent carbonate rock units acted as zone of detachment, allowing disharmonic strain in the carbonate rocks (Carr, 1992).

Late Tertiary block faulting-isolated terraces of cemented fanglomerate deposits 60 m above recent alluvial fans (Ebanks, 1965).

The dating of the associated calcic soils and calcretes by amount and rate of pedogenic carbonate accumulation is the initial step in designing a regional chronostratigraphy for fan evolution and the faults that displace these soils. One approach to this problem is to date soils and other surface deposits that have been offset by Quaternary faults. Last period of faulting recorded in the Red Rock Canyon alluvial fan, therefore, can be constrained between 120.000 and 80.000 years ago (McDonnell-Canan, 1989).

GEOLOGICAL MAPPING OF NE BLUE DIAMOND HILL

Mapped area covers 7,5 km^2 of NE Blue Diamond Hill. On N side of the hill there are more canyons with lengths of 0,2-2 km (fig. 2).

Fig. 4: Entrance room of Desert Cave, photo by Stanka Šebela.
Sl. 4: Vhodna dvorana Desert Cave, foto Stanka Šebela.

In the mouth of canyon where Desert and Upper Desert Cave are situated, we can observe Toroweap limestone which is covered by red, yellow and light green clays and sandstones. Over them lies breccia and than Kaibab limestone with cherts. Breccia belongs to lower part of Kaibab formation, clays and sandstones are upper part of Toroweap formation. General dip direction of Permian limestone is towards W for 10°, but locally bedding planes can dip towards SW, NW and W.

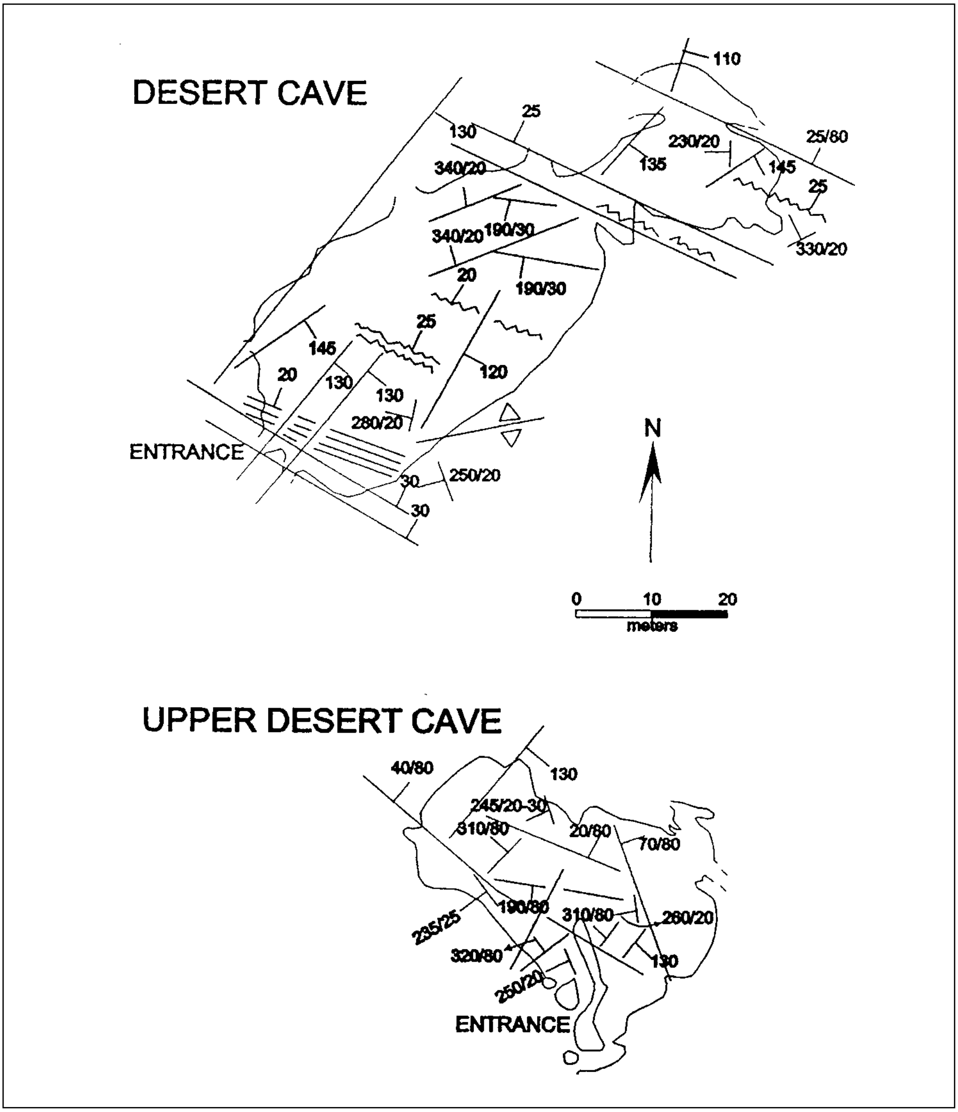


Fig. 5: Geological map of Desert Cave and Upper Desert Cave, Blue Diamond Hill, SW Nevada.
Sl. 5: Geološka karta Desert Cave in Upper Desert Cave, Blue Diamond Hill, SW Nevada.

Limestone bedding planes can be tectonically broken and disrupted, but normaly not for more than 0,09-0,5 m. Smaller phreatical openings not larger than 0,5 m can be found in limestone layers with more clay and gypsum components. Some bedding planes show interbedded movements. There are many examples in the canyon of opened strata filled with calcite. A brown flowstone is deposited inside opened layers. The thickness of this flowstone is from 0,9-15 cm. Also in some of opened fissures we can observe at least 2 generations of brown flowstone, vertical deposition which is older and horizontal deposition which is younger (fig. 3). Also stalagmites in the caves are composed of the same brown calcite.

More redish and white calcite crystals can be find in opened fissures, which are especially developed in NE- SW direction. The thickness of fissures can reach 0,15 m, inside such fissure we can find also tectonic breccia.

Principal tectonic zones are developed in NE-SW direction, the other important direction is NW-SE and almost E-W. Most of tectonic zones are vertical. In some fissures we can determine horizontal and/or vertical movements. Displacements are small, not larger than 1 m.

Fissures in general direction NE-SW are normally filled with calcite. They can occur in zones or singularly. Just West from entrance to Desert Cave we determine fault with horizontal and vertical movement. Vertical movement caused that limestone layers are folded in gentle syncline, which axis is in direction NE-SW. Here we can see opened and moved layers.

In the canyon north from the canyon with Desert Cave there are strongly expressed tectonic zones with dip directions 20° and 190°/45°. These last faults have gentle thrust movement character. They can be genetically related to thrusting period. Fault 190°/45° is cut by fault 300°/80° which has horizontal displacement.

In the northern part of geological map (fig. 2) we find strong fault zone 90°/30° which shows reverse movement. Limestone with chert is obviously moved. It's interesting that the same zone can not be determined in southern edge of canyon.

The bottom of the canyon in some places is developed inside bedding planes. In one part just in one limestone layer which can be opened for 0,2 m. In such openings we can find deposition of brown flowstone. Sometimes flowstone can be broken in same directions as limestone.

Smaller hill (1.170 m) E from Blue Diamond Hill is in upper part build of Permian Kaibab limestone with cherts. At 1.140 m in south and at 1.116 m on SW there is contact between Permian red beds and Permian Kaibab limestone. Contact is normal sedimentological and not thrust contact.

SW edge of hill is developed in steep slope in fissures 200°/80°. Principal tectonic zone is in bottom of the valley and according to Axen (1984) represents La Madre fault and in some parts is also boundary between Permian Kaibab limestone and Permian red beds (fig. 2). La Madre fault south from La Madre Mountains (fig. 1) has characteristics of dextrial horizontal movements and vertical movements with NE block moved down and SW up. NE from Blue Diamond Hill La Madre fault has the same characteristics. The only fact which can be added is that the fault goes through the crest of anticline (fig. 2, cross section A-B). Horizontal dextrial movement of the fault is younger than vertical movement.The fault shows the reverse fault character. SW block of fault is in the bottom of Blue Diamond Hill build of sandstone, the top of hill is built from limestone (fig. 2, cross section A-B).

Second stronger fault on mapped area lies in morphologicaly expressed depression just a little bit NW from top of Blue Diamond Hill. Dip direction of fault is 60°, it is vertical fault, where NE

Fig. 6: Entrance to Upper Desert Cave, photo by Stanka Šebela.
Sl. 6: Vhod v Upper Desert Cave, foto Stanka Šebela.

Fig. 7: The passage is controled by bedding plane, Upper Desert Cave, photo by Ray Keeler.
Sl. 7: Rov poteka po leziki, Upper Desert Cave, foto Ray Keeler.

block fell down and SW rose up for at least 2 m. Between both stronger faults in direction NW-SE we find other directions of fissures and faults as 290°/80° and 190-200°/70°. Fault 220°/80° contains tectonic breccia, near fault 210°/80° we can observe smaller folds in sandstone as anticline and syncline.

Both most expressed NW-SE trending faults were active during Cenozoic normal faulting and La Madre fault was probably active already in Mesozoic thrust faulting.

DESERT CAVE AND UPPER DESERT CAVE

Desert Cave is the longest cave on Blue Diamond Hill. It was discovered in 1970. It lies east of Red Rock Canyon Conservation Area, which is turistically very popular. In last 20 years Desert Cave was exposed to many visitors who almost destroyed the cave (fig. 4).

The entrance to Desert Cave lies at 1.212 m a.s. l. in a strongly expressed tectonic zone with dip direction 30° (fig. 5). The entrance is partly hidden with limestone blocks. The cave is developed E from tectonic zone 135° which formed gentle syncline. The cave is not developed west of that fault.

Just after the entrance the cave enlarges to bigger chamber where fissures in dip direction 130° cut fissures 20° (fig. 5). The cave ceiling is developed along dip of limestone layers 250-280°/20°. Bedding planes form gentle anticline. Before first step down to another chamber the cave ceiling is formed in fissures 340°/20° and 190°/30° (fig. 5). Blocks between these fissures fall down as collapse blocks in shape of prism. Cave ceiling here has the shape of zigzag. On the ceiling we can find horizontaly deposited brown flowstone, which in many parts is eroded. Brown flowstone was deposited after the collapse of prism blocks. It's deposited in different altitudes and can be found also in fissures in the canyons.

After entrance chamber the cave has 3 steps which are developed according to fissures 25°. The cave is 12,6 m deep. In northern edge of the cave we find sedimentary breccia (lower part of Kaibab formation). The breccia-limestone contact (on aproximatlly 1.200 m) shows possible traces of water flow in phreatic conditions. This can be one of initial structures in phreatic period of cave development.

Surface distance between entrances to Desert and Upper Desert Cave is 81 m, the caves are not connected (fig. 5). The entrance to Upper Desert Cave is 14 m higher than entrance to Desert Cave.

Upper Desert Cave is 62 m long and 6,6 m deep. General direction of the cave is NW-SE. The cave has 3 entrances and only 2 are high enough for cavers to enter (fig. 6). The distance in altitude between these two entrances is 4,2 m. The cave is developed in Kaibab limestone. Cave ceiling follows dip of bedding planes.

Principal tectonic fissures are developed in NW-SE and NE-SW directions. Because of these fissures many collapse blocks fell from the ceiling. There are no large displacements, it looks that fissures were opened just enought to cause breakdowns. The cave is so deformed with collapses that original cave passage can not be determined any more. The only proof of phreatic origin can be deducced from the shape of lower entrance to the cave which is developed along bedding planes (fig. 7).

After collapse event the cave was filled with water again. The proof is horizontal deposition of brown flowstone which can be seen on many places as for example on fissure plane 70°/80°. Exposure of that fissure is post breakdown. After deposition of brown flowstone there was period of erosion, because flowstone is today eroded and preserved just in some places.

CONCLUSIONS

Mesozoic thrust faulting and Cenozoic normal faulting deformations are most important tectonic events in southern Nevada. Jurassic to Cretaceous tectonic deformations are related to Sevier orogeny. Cenozoic deformations are primarily extensional and include normal faulting and strike-slip faulting. Thrust faulting deformations and extensional faulting deformations are most important tectonic structures for development of cave passages, which are developed inside bedding planes but in correlation with fissure directions.

When caves in Blue Diamond Hill area were formed the climate in southern Nevada was more humide than is today. After formation of breakdowns in the cave brown flowstone was deposited. Later caves suffered processes of erosion of flowstone, infillings and replacement of the sediments. Surface canyons were formed at least at time of deposition of brown flowstone and can represent older cave passages which ceiling is collapsed and removed.

Principal question shows up when we compare areas of limestone in southern Nevada and number of caves. There is small number of karst caves comparred to the thickness of limestone what means that important factors in karstification are missing. One can be water.

Desert Cave and Upper Desert Cave are developed near thrusting deformations alohton over autochthon or parautochthon. Permian limestones in which caves are developed show results of thrusting and folding deformations, as later faulting and erosion. Cave passages developed after thrusting, in relaxation conditions when limestone bedding planes were opened enought to transport water also using fissures directions caused by Cenozoic faulting.

Desert Cave and Upper Desert Cave show obvious primary development according to thrusting and later collapsing period in fault structures.

Cross section A-B (fig. 2) shows some characteristics. Thickness of Permian Coconino sandstone and Permian red beds in NE part of Blue Diamond Hill is at least 480 m. Bird Spring thrust looses displacement NE of Blue Diamond Hill (Carr, 1992).

Geological mapping of NE part of Blue Diamond Hill added some new interpretations of La Madre fault (Axen, 1984). Vertical displacement in La Madre fault is 540 m (cross section A-B) and vertical displacement on fault 60°/90° (cross section A-B) is 0,5-1 m. Vertical displacements on bigger faults have E part moved down and W part up.

The boundary between Toroweap-Kaibab is represented by red and yellow sandstone and breccia. The thickness of that layer in canyon with Desert Cave can reach 10 m. In northern canyon from the canyon with Desert Cave the thickness of this layer is 2-7 m. Possible explication is that border lithological unit between Toroweap-Kaibab can vary in thickness, in SW canyons of Blue Diamond Hill is thicker than in northern canyons. The cause for that can be in surface errosion in Permian period. That boundary unit is also deformed to gentle anticlines and synclines. It's possible that the lithological unit was used also for thrust deformations.

NE from Blue Diamond Hill but S from road 159 is on S edge of dry stream escarpment which can be caused by younger fault with NW-SE direction. Fanglomerates are 10 m higher than stream valley. It looks that southern part of fault mooved up and northern down. McDonnell-Canan (1989) determined last period of faulting in the Red Rock canyon alluvial fan between 120.000-80.000 years ago.

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GEOLOŠKE ZNAČILNOSTI DESERT IN UPPER DESERT CAVE (NE BLUE DIAMOND HILL, NEVADA, USA)

Povzetek

Geološko-krasoslovne raziskave hriba Blue Diamond Hill (slika 1) in dveh kraških jam Desert Cave in Upper Desert Cave (10 km zahodno od Las Vegasa, Nevada, ZDA) smo opravljali v obdobju od januarja do sredine marca 1997 v okviru štipendije Slovenske Znanstvene Fundacije ter v letu 1998 od marca do konca maja v okviru Fulbrightove štipendije.

Glavni namen raziskav je bil določiti vpliv geoloških strukturnih elementov pri razvoju kraških jam. Zato smo opravili litološko tektonsko kartiranje širšega terena nad jamami, ki je zajelo SV del hriba Blue Diamond Hill ter kartiranje obeh jam.

Nevada je v veliki meri zgrajena iz karbonatnih kamnin, še posebno v osrednjem in južnem delu, toda število kraških jam ni tako veliko, kot bi pričakovali. Predvsem gre za krajše jame, zasute s podori ali jamskimi sedimenti. V celotni Nevadi je le ena turistična jama Lehman Cave v narodnem parku Great Basin (osrednji del vzhodne Nevade), katere rovi merijo 2.400 m. Najdaljša jama v Nevadi je Baker Creek Cave z okrog 3.900 m znanimi rovi.

SV del hriba Blue Diamond Hill je zgrajen iz permijskih kamnin (rdeče plasti, Coconino formacija, Toroweap in Kaibab formacija). Zgornji del hriba Blue Diamond Hill pripada Kaibab formaciji, ki je mlajša kot Toroweap. Obe formaciji sta zgrajeni predvsem iz apnenca s številnimi polami in plastmi roženca. Vmes najdemo več plasti peščenjaka in skrilavca, breče ter sadre. Zgornji del Toroweap formacije predstavlja plast, ki je lahko rumeno-rdeče barve, gre pa za skrilavce, peščenjake, sadro. Navzgor v litološkem stolpcu sledimo bazalne plasti Kaibab formacije (predvsem gre za brečo, ki vsebuje dele starejših kamnin), ki je na Toroweap formacijo odložena diskordantno. Nad brečo sledimo v Kaibab formaciji plastovit, temno-siv, apnenec z roženci, debeline 120 m. Temu sledi rdečkast skrilavec, sadra in plasti svetlo sivega apnenca in dolomita bogatega z roženci. Plasti sadre izkoriščajo v bližnjem rudniku. Toroweap in Kaibab formaciji vsebujeta fosile zgornjega dela spodnjega permija (Longwell et all., 1965).

Strukturna geologija področja Red Rock Canyon in okoliških Spring Mountains zajema več obdobij paleozojskih deformacij, mezozojskega narivanja in kenozojskih normalnih prelomov (Axen, 1984). Sevier orogenski pas je nastal v kredi z dviganjem, gubanjem, razvojem narivov iz gub ter narivanjem po erodiranih površjih. Glavni narivi so bili kasneje zarotirani proti zahodu za 90° z desno-zmičnim prelomom, ki poteka čez dolino Las Vegasa. Horizontalni premik ob prelomu je 40 km (Longwell, 1960; Burchfield, 1965).

Starejši narivi ležijo vzhodno od mlajših. Kamnine vzhodno od Bird Spring nariva (slika 1) tvorijo avtohton severno ameriškega kratona. Proti severu nariv Bird Spring izgubi značilnosti nariva, ob narivnici ni velikega premika, saj večinoma le podvaja permijske rdeče plasti (Burchfield & Davis, 1971). Zato pravilneje govorimo o gubah z vergenco proti vzhodu (Carr, 1992).

Z geološkim kartiranjem površja na NE delu hriba Blue Diamond Hill smo zajeli 7,5 km^2. Kartirali smo permijske rdeče plasti, Toroweap in Kaibab formacijo (slika 2). Generalni vpad plasti je proti zahodu za 10°. Glavne tektonske cone potekajo v smeri NE-SW, ostale tektonske cone so zastopane v smeri NW-SE in smeri skoraj E-W. V nekaterih primerih lahko določimo vertikalne in/ali horizontalne premike, ki niso večji kot 1 m. V nekaterih odprtih prelomnih conah je siga odložena v vertikalni in horizontalni smeri (slika 3). Najpomembnejši prelom je LaMadre prelom, katerega potek je severno od hriba Blue Diamond Hill določil Axen (1984). Na kartiranem ozemlju (slika 2) predstavlja prelom mejo med permijskim Kaibab apnencem in permijskimi rdečimi plastmi. Prelom ima značilnosti desnega zmika, določljiv je tudi vertikalni premik, kjer je NE blok spuščen in SW blok dvignjen. Vertikalni premik je ocenjen na 540 m. LaMadre prelom poteka čez teme antiklinale.

Med močnejšimi prelomi moramo omeniti tudi prelom, ki je skoraj vzporeden LaMadre prelomu in poteka čez morfološko depresijo nekoliko NW of vrha Blue Diamond Hill. Na prelomu lahko določimo vertikalni premik za okrog 2 m, kjer se je NE blok spustil in SW blok dvignil.

Oba pomembnejša preloma v smeri NW-SE sta bila aktivna med kenozojskim obdobjem normalnih prelomov, LaMadre prelom pa je bil verjetno aktiven že v Mesozojskem obdobju narivnih deformacij.

Vhod v Desert Cave se odpira v močneje izraženi tektonski coni s smerjo vpada 30° (slika 5). Jama je razvita vzhodno od tektonske cone 135°, ki je povzročila blago sinklinalo. Strop vhodne dvorane poteka po lezikah 250-280°/20°. Podorni bloki apnenca med razpokami 340°/20° in 190°/30° imajo obliko prizme. Na stropu jame lahko najdemo sledove horizontalno odložene rjave sige, ki je na več mestih erodirana. Rjava siga je bila odložena, ko so bili podori že oblikovani. V severnem delu jame naletimo na sedimentacijsko brečo (spodnji del Kaibab formacije). Kontakt breča-apnenec kaže sledove freatičnega vodnega toka in verjetno predstavlja eno od inicialnih struktur v razvoju jame.

Vhod v Upper Desert Cave je 14 m višje kot Desert Cave, površinska razdalja med jamskima vhodoma je 81 m, jami nista povezani (slika 5). Glavne tektonske cone v jami potekajo v smereh NW-SE in NE-SW. Podorni bloki, ki so se luščili s stropa, so omejeni prav s temi razpokami. Edini dober dokaz za razvoj jame v freatičnih pogojih predstavlja oblika spodnjega vhoda v jamo, ki je razvit vzdolž lezik (slika 7).

Narivne deformacije in ekstenzijske Kenozojske prelomne deformacije so najpomembnejše tektonske strukture pri razvoju jamskih rovov, ki so razviti znotraj lezik, vendar skladno s smermi razpok in prelomov.