



Depositional and erosional features of Oligocene paleokarsts in the Kirkuk Group, Kurdistan Region, Northeast Iraq

Kamal Haji Karim¹ · Polla Azad Khanaqa² · Soran Osman Kharajiani³ · Zardasht Ahmad Taha¹ · Mushir Mustafa Baziany¹

Received: 12 June 2019 / Accepted: 3 March 2020 / Published online: 12 March 2020
© Saudi Society for Geosciences 2020

Abstract

Paleokarst features are rarely preserved in geologic history due to terrestrial erosion and later burial diagenetic changes. In rare cases, where karstification was intense it can be preserved by burial in areas where erosion was slow. In Iraq, one of the ages that preserved clear features of the paleokarsts is the Oligocene. During this age, a thick succession of shallow (platform) carbonates were deposited and assigned stratigraphically as Kirkuk Group. During the late Oligocene, the inner shelf of the platform exposed for long time and an unconformity was developed and associated with well-developed epi- and endokarst features. The present study focused on the documentation of the erosional and depositional features of paleokarstification during the latter age for the first time in Iraq and Zagros Orogenic Belt. In the northeast Iraq, many Oligocene paleokarst features are discovered in the medium beds of Anah and Bajwan Formations (as two units of the Kirkuk Group) in the Sulaimani and Erbil Governorates. These features are such as vertical and inclined shafts filled with brown pebbly sandstone, horizontal cavities, large planoconcave cavities filled with conglomerates, solution breccias, underground solution networks, travertine, and palaeosoil. All these features are discussed to prove their attribution to the Oligocene by highlighting many field and petrographic evidences. The documented paleokarst can indicate accurately depositional extent, paleogeography, and paleoshoreline of Oligocene succession in Iraq and part of Western Zagros. Therefore, this study is significant for paleo-mapping of the northwestern margin of the Arabian plate and applicable for paleoenvironment concerns and oil explorations in the studied area.

Keywords Oligocene karstification · Endokarst · Kirkuk Group · Paleosol · Sandstone-filled shaft · Oligocene unconformity · Arabian plate margin

Responsible Editor: Beatriz Badenas

✉ Kamal Haji Karim
karimgeology@yahoo.com; kamal.karim@univsul.edu.iq

Polla Azad Khanaqa
polla.khanaqa@kissr.edu.krd

Soran Osman Kharajiani
Soran.muhammad@univsul.edu.iq

Zardasht Ahmad Taha
zardasht.taha@univsul.edu.iq

Mushir Mustafa Baziany
mushir.qadir@univsul.edu.iq

¹ Department of Geology, University of Sulaimani, Sulaimani City, Kurdistan Region, Iraq

² Kurdistan Institution for Strategic Studies and Scientific Research, Sulaimani City, Kurdistan Region, Iraq

³ Department of Fine Art, University of Sulaimani, Sulaimani City, Kurdistan Region, Iraq

Introduction

According to Dunnington (1958), Bellen et al. (1959), Buday (1980), and Jassim and Goff (2006), the proven and the largest unconformity in Iraq is that of Oligocene. While Alsharhan and Naim (1997) mentioned the development of more restricted conditions during the Oligocene due to sea level fall, culminating in a late Paleogene hiatus, during which all the Oligocene, and late Eocene beds were eroded from over much of the Arabia platform. Alsharhan and Naim (ibid) recorded occurrence of this unconformity almost everywhere and referred to sediment deposition of the latter two ages only in coastal Iran, the northern U.A.E. and parts of northern Iraq.

The unconformity developed on the uplifted land that covers most of northern and northeastern Iraq including High Folded and Thrust Zones (Fig. 1a). This uplifted land was looking over a foreland basin in which Oligocene succession (Kirkuk Group) was depositing in the central Iraq.

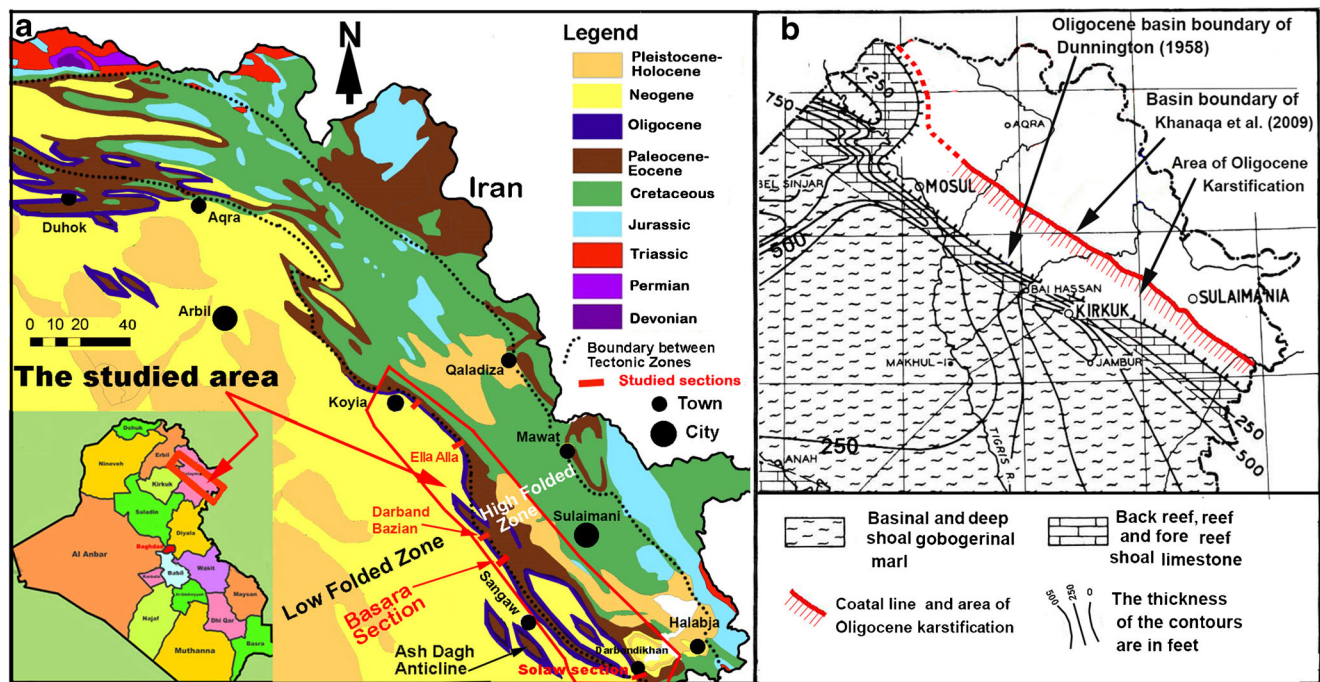


Fig. 1 **a** Geological map (modified from Sissakian 2000) on which the studied area and location of the sampled sections are shown, **b** Isopach-Facies map of the Oligocene (Dunnington 1958) on which the paleokarstification areas and extended basin boundary of Khanaqa et al. (2009) are indicated

Recently, Khanaqa et al. (2009), extended the deposition area of group into a part of the north and northeast of the country which was considered previously as an uplifted area by Dunnington (1958), Buday (1980), and Jassim and Goff (2006) (Fig. 1b). The present study is conducted on this extend area where a clear stratigraphical unconformity developed and below and on this surface excellent Oligocene epi- and endopaleokarst features are observable along the valley sides and road cuts. Ameen (2009) concluded that the unconformity formed as results of non-deposition, weathering, and mass wasting; consequently, its surface was covered by different types of conglomerates which deposited on top of the Pila Spi Formation.

The stratigraphy and paleontology of the Oligocene succession intensively attracted attentions and was studied in detail in Iraq and Iran (as main part of Asmari Formation) due to their hosting of huge quantities of oil in the two countries. Oligocene carbonate successions (Kirkuk Group) are recorded and described in Iraq by aforementioned authors. Dunnington (1958) and Bellen et al. (1959) divided the group into nine formations that are included in three cycles which are shown in the (Fig. 2). The later authors referred to partition of the upper and lower boundaries of the three cycles by breaks and unconformities. Baba Shekh (2006), observed two conglomerate beds and fossiliferous limestones between the Pila Spi and Lower Fars Formations near the boundary between Low and High Folded Zones. He mentioned the

possibility of the presence of Oligocene rocks in the Sangaw area. Kharajiani (2008) focused on the fossiliferous limestones and recognized Baba, Sheikh Alas, Bajwan, Shurau, and Anah formations along both limbs of the Ash Dagh anticline, southeast of Sangaw town, in the studied area.

Karst terrains, both ancient and modern, are erosional landscapes in which large portions of the rock record are removed (Plotnick et al. 2009). As a general characteristics of karstification, Ford and Cullingford (1976) mentioned the occurrence of a fossil paleokarst beneath unconformities where solutional features of land surface covered by later deposits. These latter authors added that the cavities and depressions produced by karstification can act as accommodation space for subsequent sediment accumulation (deposition). In Arabian Gulf, a huge unconformity (Supra-Dammam Unconformity) is recorded by Weijermars (1999) and Al-Fahmi et al. (2014) during which upper Eocene and whole Oligocene sediments were eroded and associated with karstification and peneplanation. In Iraq, Anah and Bajwan formations are the two lagoonal and partially reefal calcitic limestones of middle and late Oligocene ages and their lithologies, in the studied sections, consist of well bedded to massive, gray or milky, occasionally brecciated limestone with milliolids, molluscs, intraclast, and extraclasts allochems. The present study is focused on the depositional and erosional features of Oligocene paleokarsts in the in the latter two formations.

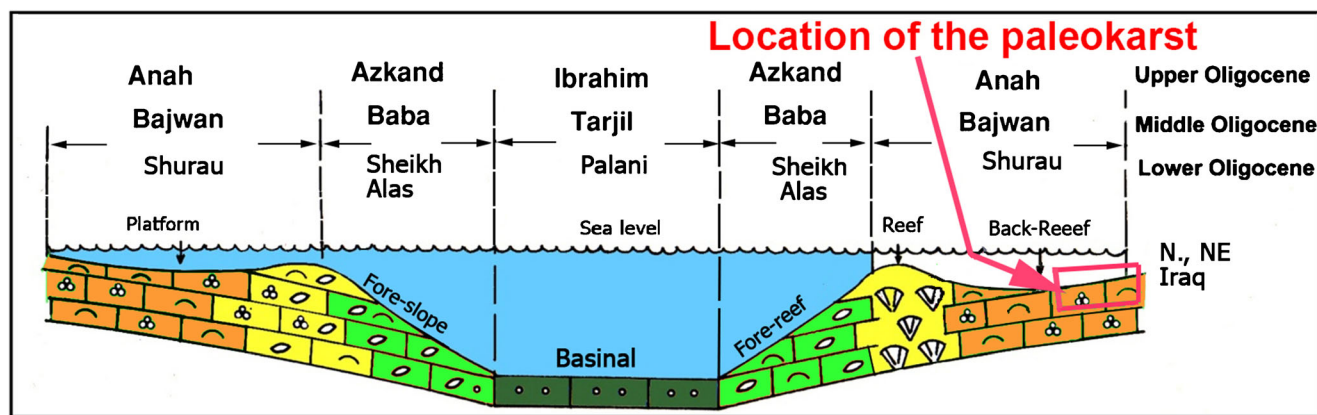


Fig. 2 A sketch of paleogeography and environments of the Oligocene succession (Kirkuk Group) shows the environmental setting of the formations (Al-Hashimi and Amer 1985) on which paleogeographic

and stratigraphic locations of the Oligocene paleokarsts are indicated (by red parallelogram) in the present study

Location and geological setting

The studied area is a part of the boundary between High and Low Folded Zones of Buday (1980), Buday and Jassim (1987) in the Erbil and Sulaimani Governorates (Fig. 1a). At the northeast, it bordered by high amplitude anticlines of the High Folded Zone of Iraqi Zagros and toward southwest they gradually change to low amplitude anticlines of the Low Folded Zone in the area between Kirkuk and Sulaimaniyah Governorates. The studied area extend for about 150 km from north of Koyia town, from northwest, to the east of Darbandikan town at southeast and including Haibat Sultan, Qshlagh (Darbani Bazian), Baranan, and Zimnako mountains (or anticlines). These mountains are about 1200 and 700 m high from mean sea level and from surrounding areas, respectively.

The peaks and upper slopes of the above mountains are shaped by dolomitic limestone of Pila Spi Formation while Kirkuk Group (Oligocene succession) and Lower Fars Formation are exposed, respectively, on the southeastern lower slopes of the above mountains. During Oligocene, the location of these structures was coinciding with coastal areas (inner shelf) of the Oligocene basin which was very close to the source area (area of the present High Folded and Thrust Zones) (Fig. 1a). In the studied area, the Kirkuk Group is underlain and overlain by Pila Spi Formations and Lower Fars Formation unconformably (Fig. 3a).

Methods and materials

From the outcrops of Kirkuk Group four sections were selected and studied during fieldworks, the sections are inspected for their lithologies and fossils identifications (Fig. 1a). The samples and the whole sections were described with $\times 10$ hand lens and under stereomicroscopes then a stratigraphic columns were drawn (Fig. 3a). For the petrographic study, 20 thin sections were prepared and studied under polarizer microscopes

for identifying the lithologic constituents of the Kirkuk Group. Four Samples are taken from Basara Gorge, while the others from Ella all section. Among them, three samples are analyzed by XRF device in the Tasluja Cement Factory for indication of the oxides in the samples of the Ella Alla section and their loss of ignition weighted in the Department of Geology, University of Sulamani. The beds and karstic features attitudes are measured in the deep valley sides where the Oligocene signals of paleokarsts are well expressed either as negative or positive reliefs. In these valleys erosional and depositional features of the karstification were measured, photographed, indicated by GPS, and plotted on maps.

Results: paleokarst depositional and erosional features

Mineralogy of Kirkuk Group and paleokarstification

In the studied area (Fig. 1), the Kirkuk Group consists of stiff gray to milky limestone with abundant red spots and laminae in addition to local occurrence of chert nodules. The thin sections and XRD analyses of the samples revealed calcitic mineralogy of the group. It consists of more than 95% (equivalent to 55% CaO) of either micro or macrocrystalline calcite (Table 1) and thin sections rarely show pockets of silicification and dolomitization. This type mineralogy of the Oligocene rocks in the studied area promotes epi- and endokarstification by solution due to water infiltration.

Oligocene underground limestone breccias and conglomerates

In the studied area, Khanaqa et al. (2009) and Ameen (2009) mentioned several conglomerates inside or at the

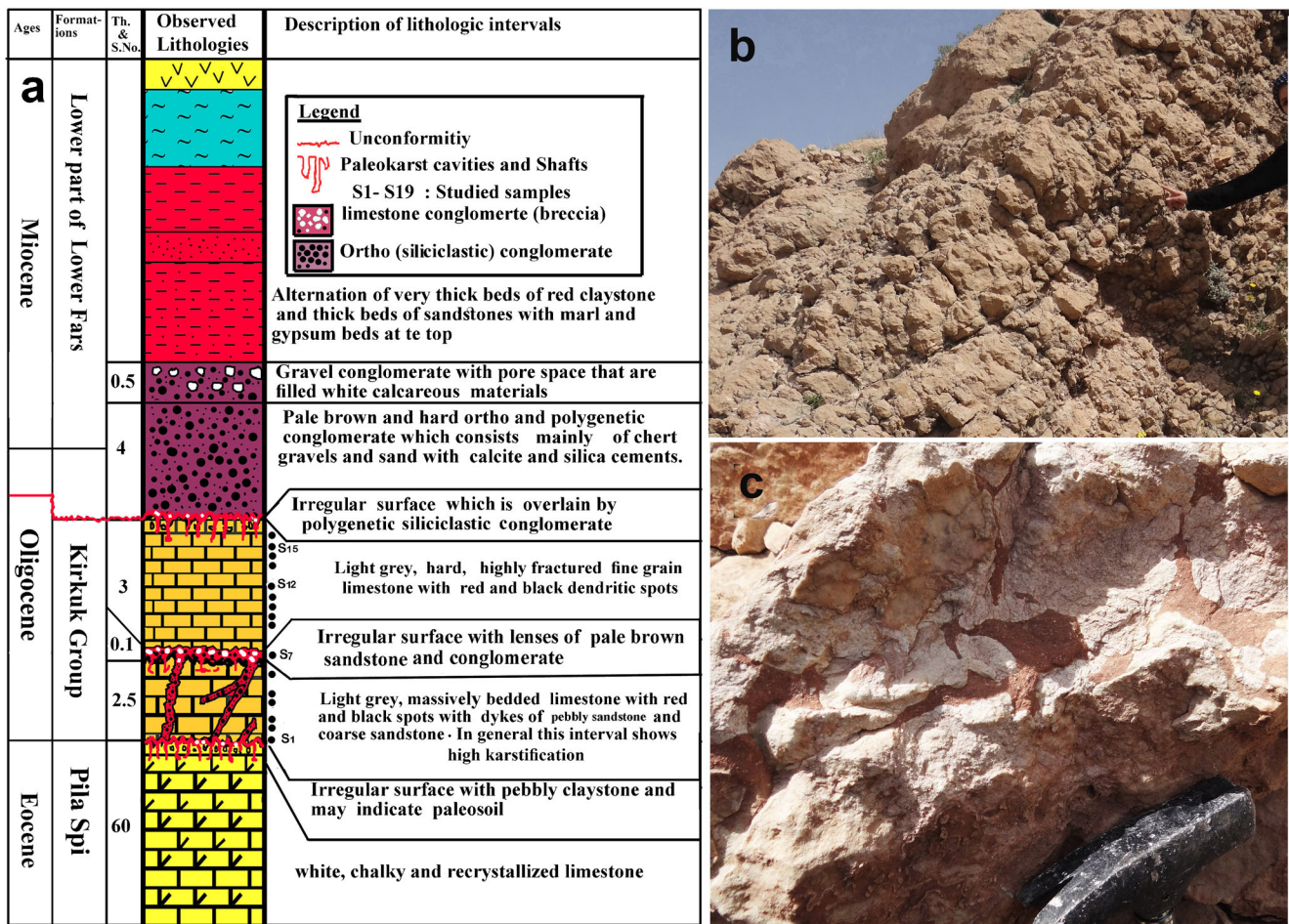


Fig. 3 a Stratigraphic column of the studied area shows the intervals of karstified limestones during Oligocene, b Solution limestone breccias at the top of Oligocene succession at the southwestern limb of Zinnako

anticline (near Bani Bi village), and c in some case the voids (cavities) between the clasts are filled with lithified red sandy soil at 1 km north of the Zhalla Nau village

boundaries of the Kirkuk Group. Our observation revealed that most of these conglomerates (breccias) consist of badly sorted and subangular clasts (gravels) of limestones; their matrixes consist either of sand, mud, or sparry calcite (Fig. 3a). The breccias are widespread in the Oligocene succession in the studied area, in some case the voids between the clasts are filled with lithified red sandy matrix (soil) (Fig. 3b and c). But, in extreme case of karstification, complex networks with very coarse solution breccias are observable along deep valley vertical sides.

In one case, the sizes of the angular blocks are more than 40 cm in diameter and floating in polymictic conglomerates (siliciclastic conglomerates and pebbly sandstones). The siliciclastic conglomerates consist of well sorted and rounded clasts of cherts of different types which fill cavities of karstification and act as a matrix for the limestone blocks (Fig. 4). These siliciclastic sediments are derived from obducted radiolarian bedded cherts of the Qulqula Radiolarian Formation at the end of the Oligocene from remote source areas inside Iran which was about 200 km far from present karst location during of their deposition.

Table 1 Chemical analysis of the three sample of the Ella Alla village section

Sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	LOI	Total
Ella alla 1	0.91	0.12	0.22	54.00	1.08	0.04	0.05	0.01	42.76	99.16
Ella alla 2	0.37	0.02	0.07	54.01	0.23	0.05	0.02	0.03	43.70	98.50
Ella alla 3	0.28	0.07	0.06	55.34	0.20	< 0.08	0.04	–	43.59	99.66
Mean	0.53	0.07	0.119	54.13	0.51	0.06	0.035	0.025	43.35	99.10

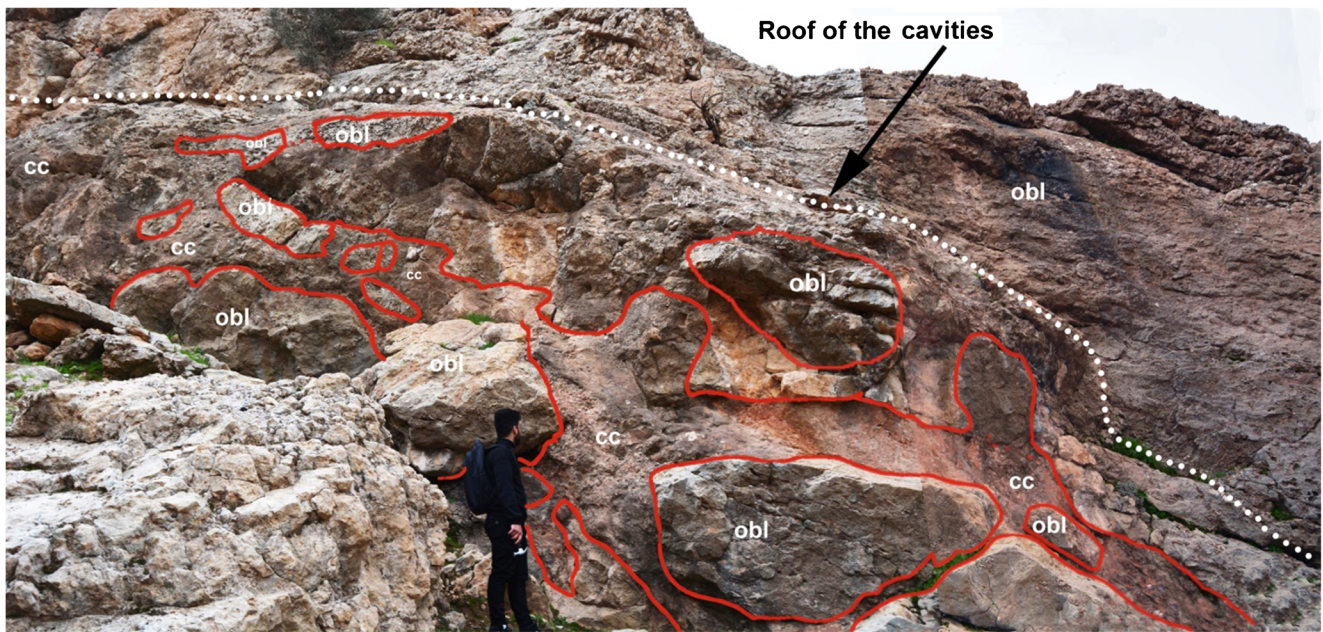


Fig. 4 Vertical wall of Ella Alla valley shows complicated inter-connected networks of solution cavities filled by chert conglomerate (cc) and brecciated limestone blocks (obl). These depositional features are formed by intense subsurface (endo) karstification in Oligocene

Oligocene vertical shafts and horizontal conduits in the Kirkuk Group

The most well expressed paleokarst features are vertical and cylindrical bodies (sandstone-filled shaft) of coherent and stiff

pebbly sandstone that descending from an erosional surface below the Anah Formation and penetrate vertically the fossiliferous limestone of Bajwan Formation (Fig. 3 and 5b). These bodies are consist of siliciclastic pebbly sandstones and have variable diameter ranging between 5 and 40 cm and their

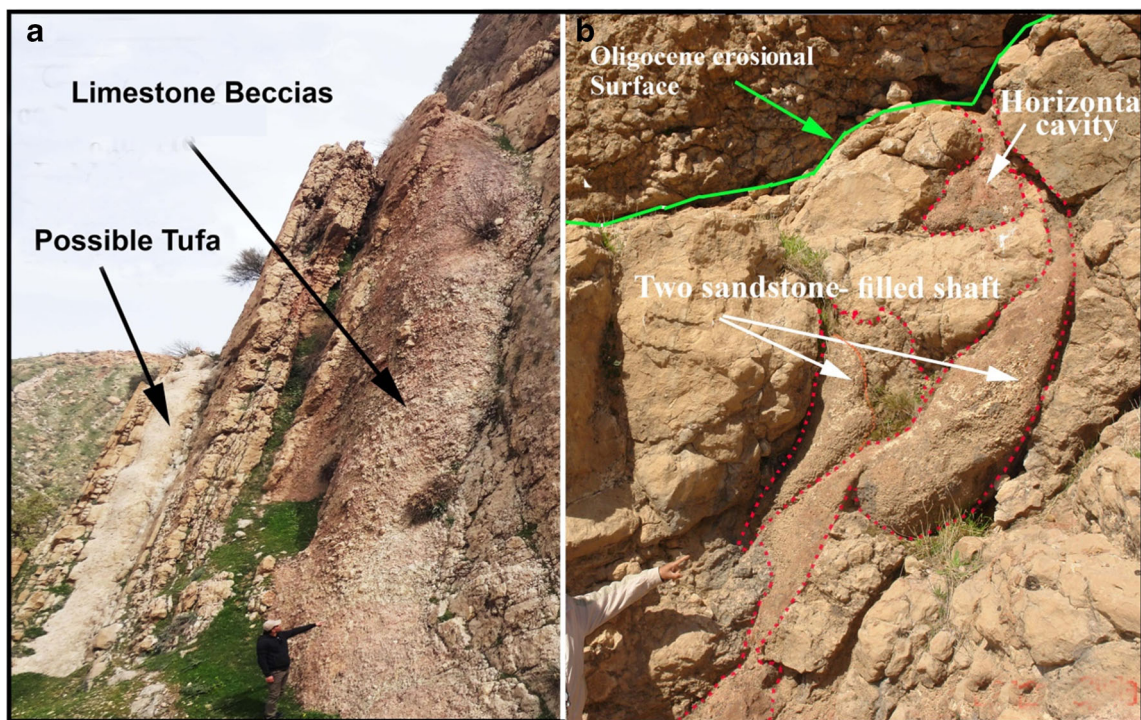


Fig. 5 a Two conglomerate beds at the top of the Kirkuk Group at 2 km north of Solaw village on the southwestern limb of Khushk mountain, at the latitude and longitude 34° 58' 40.26" and 45° 43' 32.38" **b** A vertical sandstone-filled shaft in the Bajwan Formation, near Ella Alla village

lengths reach 3.5 m; moreover, they are slightly inclined in the direction of palaeoslope (toward southwest). At the top, they are discordant to the bedding of the Bajwan Formation while at the base they became concordant (Fig. 6h). These sandstone bodies are originally solution shaft that filled with pebbly siliciclastic sandstone.

In the example above, one of the two shafts is connected (in the photographed section) to the overlying erosional surface, while the other one (in the left) diverted from the section in the lower and upper ends. These depositional sandstone bodies are associated with horizontal cavity fill too (Fig. 5b) and they originally formed as a result of an intense Oligocene endokarstification.

Possible paleo-cave

About 30 m to the southwest of the location of vertical sandstone -filled shaft (dyke), there is an irregular but crudely downward planoconcave body of pale brown conglomerate inside fossiliferous limestone of Bajwan Formation (Fig. 7a). This body is about 1.5 m high and 6 m wide. Most of conglomerate clasts consist of rounded chert gravels (Fig. 7b) with angular larger clasts of limestone which are possibly detached from the host limestone by chemical solution and erosion of flowing water. The cave has flat roof which possibly attributed to the bedding plane control and prevented collapse of the roof.

The large cave is not the only one; since at 200 m to the east of the large cave, there are many small ones that have the shapes of downward planoconvex) and filled with brown coarse sandstone (Fig. 8a). The sediment fill of these small caverns show two phases of the deposition with different grain sizes and colors. The two phases are separated by laminae (crust) of coarse crystalline calcite (Fig. 8b).

Oligocene red discoloration inside the Kirkuk Group

In the studied area there are local areas such as the area around Darbanikhan town and Qirja anticline at the southeast of Sangaw town where Oligocene succession is thick (reaches 30 m) and massively bedded. In these areas, due to deposition in mid-shelf, the karst features are not observable clearly in the succession except occurrence of one bed of limestone conglomerate which may be solution breccia. However, the fossiliferous milky limestone shows common discoloration in the form of successive brown to red parallel laminae and each one contains one or more dark red lines (Fig. 9) which cover, in some case, 50% of surface area of the polished slabs ($30 \times 30 \text{ cm}^2$) cut perpendicular on the bedding plane.

These laminae have thickness of 1–5 cm while their lengths reach several meters and in some case extend along whole outcrops. Due to the massiveness of the Oligocene limestone in this area, the polished slabs of the succession are widely

used for internal and external house decorations inside Sulaimaniyah city and surrounding towns during the last century.

Travertine and tufa

Travertine, as a chemically-precipitated continental limestone is formed around seepages, springs and along streams, and rivers channels, occasionally in lakes and consisting of calcite or aragonite, of low to moderate intercrystalline (Pentecost 2005). Most travertine deposits are active or of Quaternary (especially Holocene) age and few are older. The shortage of pre-Quaternary record is attributed to recognition problem as they deposited commonly as fragmentary erosional remnant (Pedley 2009).

The present study recorded, in nearly all sections, one or two beds of coarsely crystalline limestone (travertine) with a thickness range from 1 cm to 0.5 m in the middle of the outcropped sections (Fig. 10a and b). In many cases, the clear calcite crystals are surrounded or colored with light red or milky coating and the intercrystals spaces show darker color than crystal boundaries. The travertine beds are hard to differentiate from the bounding fine grain limestones due to similarity of weathering color of the both rocks (Fig. 10b and c). The travertine beds are folded and faulted similar to the host rocks of Oligocene; moreover, under petrographic microscope their thin sections reveal bending of the calcite twin laminae in addition to undulatory extinction and sutured crystal contact denoting high stressed condition during burial (Fig. 11). In rare case, detrital calcite crystals, form beds, and laminae of travertines inside Oligocene succession. In thin sections, the grains (detrital crystals) show sorting and roundness due to reworking (Fig. 11).

Additionally, the development of the tufa is not excluded since white lithified paraconglomerate with light weight and chalky matrix are observable in many places (Figs. 5a and 10d). The beds are matrix supported and hosting partially weathered angular clasts of the Oligocene parent rocks floating in snow white matrix in the Solaw section at east of Darbandikhan town and in the Basara Gorge (Fig. 1a). The recorded thickness is 30 cm to a meter which is thicker than the travertine layer. Unfortunately, the characteristic laminae of the travertines are not found in side the tufa which may attributed to after deposition crystallization and compaction during deep burial of Oligocene succession till late Pliocene when it finally exposed by exhumation and tectonic uplift. The same thing is true for tufa in which we expect many changes by diagenesis during burial by which it had lost many properties that can be seen in present day's tufa.

Oligocene paleosols

Oligocene pebbly, sandy or clayey paleosols are common in all the sections especially at the base of succession at the top of

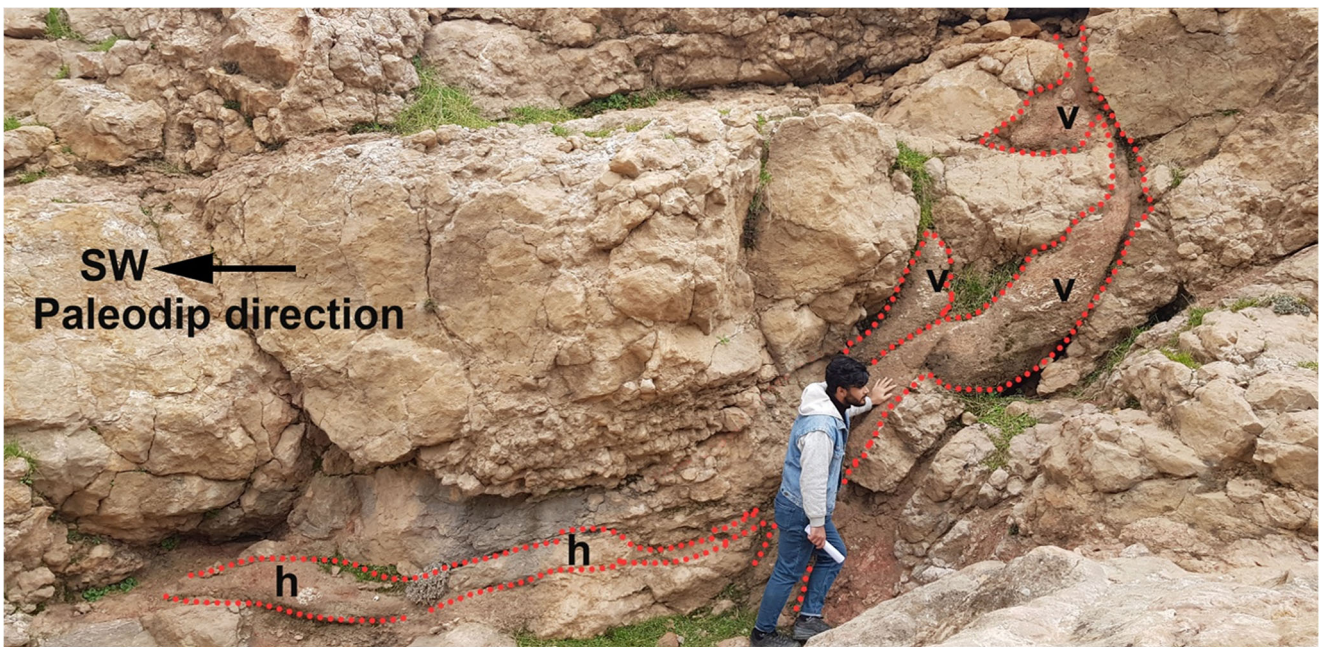


Fig. 6 Wide view of the vertical sandstone bodies (sandstone-filled shaft or dyke) shows their inclinations toward paleodip (slope) and changing direction from discordant (v) to concordant (h) at the base of the Bajwan Formation

Pila Spi Formation but in all levels of the succession they can occur too (Fig. 12). The gradation of palaeosol profiles begins from discoloration at the base (Fig. 9) passed into solution breccias (Fig. 5). Later goes through partial weathering of breccia and then to gravelly soils (Fig. 3c). These soils are seen

as a lithified pebbly red soil with angular partially weathered clasts (Fig. 12), however well-developed lithified paleosol is observable also. Previously Ameen (2009) recorded these paleosols during his study of the Oligocene unconformity in the northeastern Iraq including the studied area.

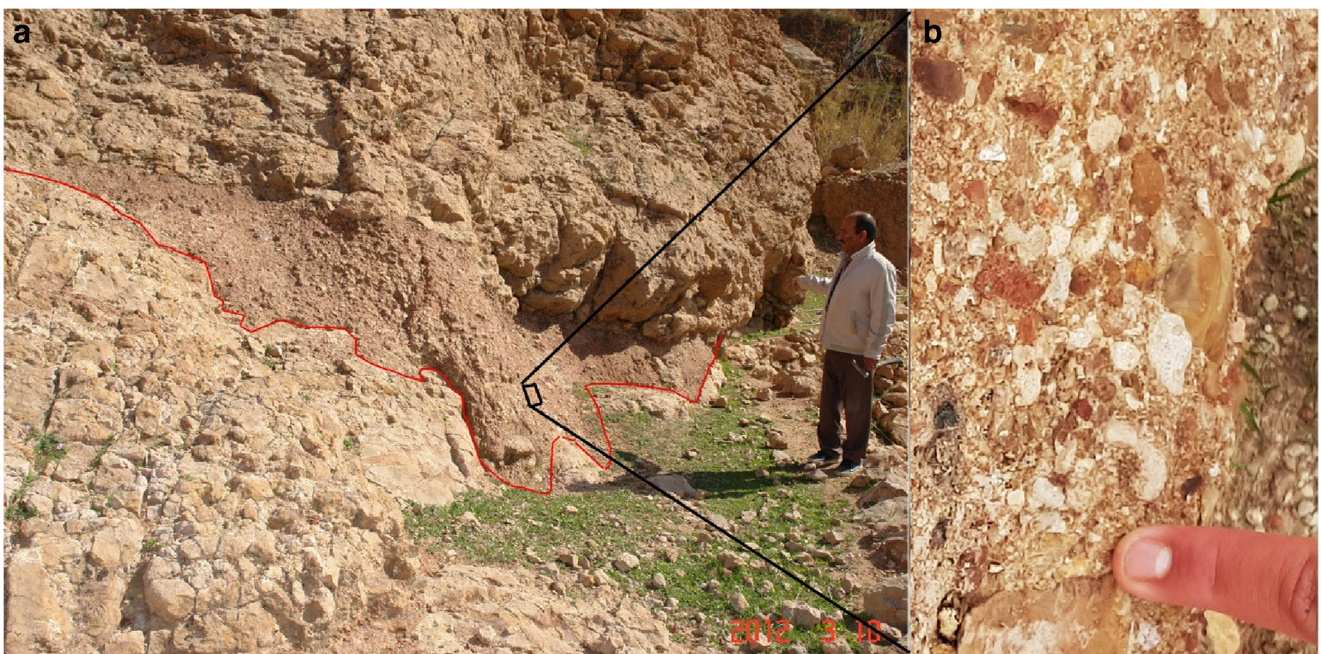


Fig 7 **a** Chert conglomerate inside in a planoconcave cavity (cave) inside the Kirkuk Group near Ella Alla village in the Bajwan Formation, **b** close view of stiff and coherent polymictic conglomerate in the cave, at the latitude and longitude 35° 56' 09.99" and 45° 52' 18.28"

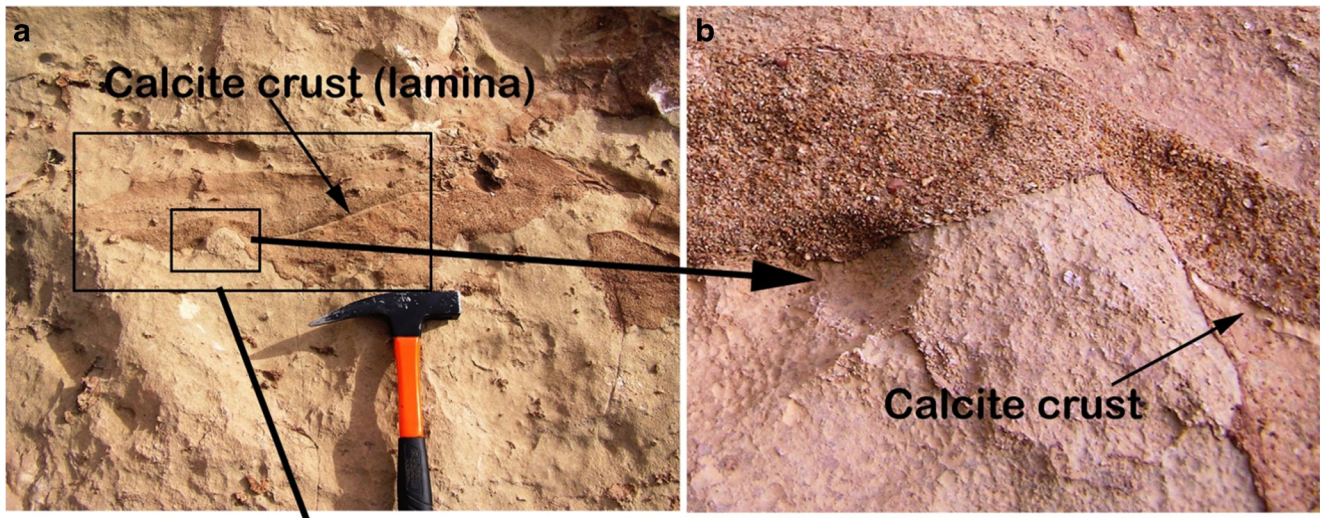


Fig. 8 **a** Exposed vertical section in Ella Alla valley shows small internal sedimentation inside Oligocene solution downward planoconvex cavities, **b** Close view of the cavity fill consists of chert coarse sandstone

Discussion

Interpretation of the karst erosional and depositional features

The buried karst by Bosák et al. (1989) can be applied to the present one which is the first documentation of the process of paleokarstification and its associated unconformity in the Zagros Fold-Thrust belt. The gathered evidences about the Oligocene endokarsts are strong and unique to a level of exclusion being recent karstification. During this age epi- and endokarsts were developed during Late Oligocene when inner self of the carbonate platform uplifted and transformed to terrestrial land temporarily. On this land, weathering and erosion prevailed, for about 10 million years when there was no deposition of Oligocene rocks (Dunnington 1958; Buday 1980). In the studied sections, the interval of the 10 million years of the erosion was interrupted by shorter intervals of

deposition of calcitic limestones. Therefore, there is relatively thin deposition of Oligocene rocks which ranges in thickness from 2 to 30 m in which the present paleokarsts are recorded.

According to Chen et al. (2012), lithology controls the position and extent of underground paleokarst. This type of control, in the studied area, might be an important factor to accelerate the chemical weathering and karstification of the Kirkuk Group limestone during Oligocene. Another factor is massiveness of the Oligocene succession in the studied area which results in more vertical weathering than horizontal one by which chemical solution and erosion penetrated downward in to underground and developing endokarsts features of the present study. The massiveness and vertical weathering prevented mass wasting (more common in a layered succession) and helps preservation of paleokarsts expressions.

The recorded vertical and inclined shafts were water seepage conduits into phreatic zone which started through fissures and later enlarged to underground water cavities draining

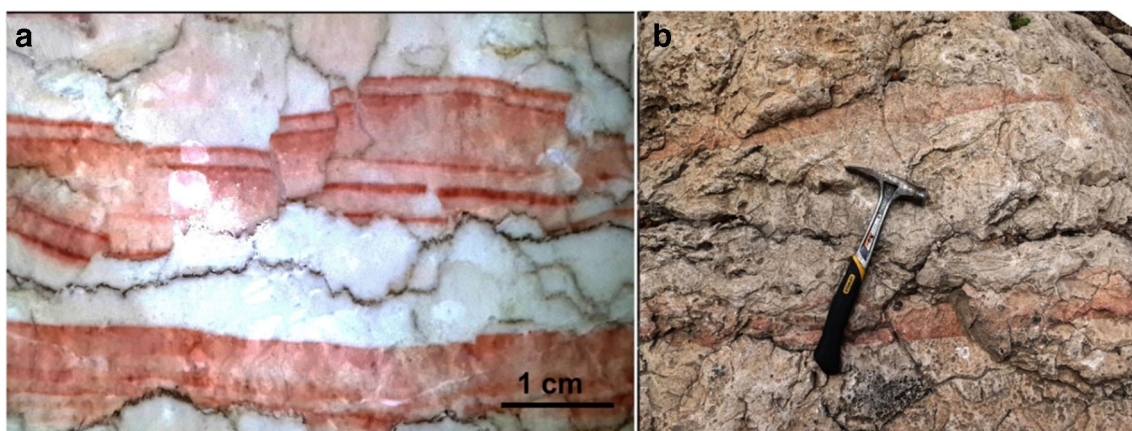


Fig. 9 **a** Discoloration as red laminae in Kirkuk Group which are affected by faulting and stylolitization, directly to the west of Darbandikan town on Baranan mountain. **b** Same laminae in the weathered outcrop on the

Qirja anticline southeast of Sangaw town, 2.5 km northeast of Garawi village at the latitude and longitude $35^{\circ} 17' 25.26''$ and $45^{\circ} 03' 27.68''$

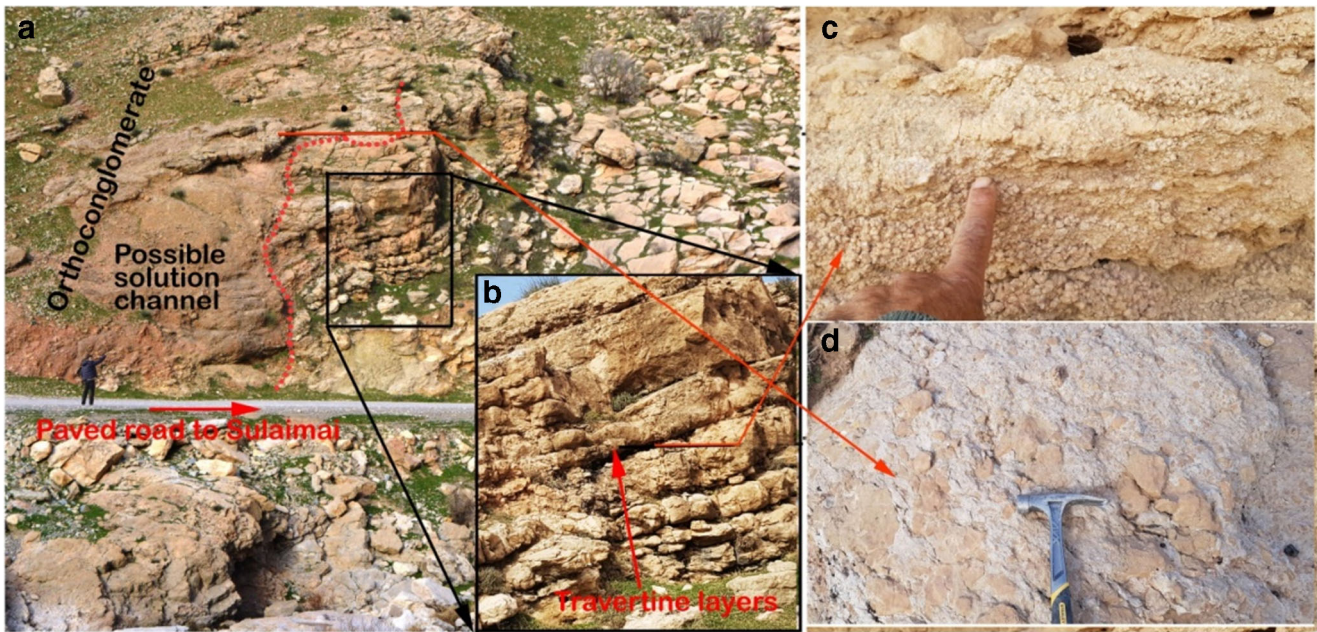


Fig. 10 a Vertical outcrop section of Oligocene succession (inside parallelogram) in Basara Gorge show s possible surface channel filled with othoconglomerate during Oligocene, b Close view of the

succession shows location of two beds of travertine, c A travertine bed shows weathering color, and d Possible pebbly tufa at the top of the succession, at the latitude and longitude 35° 26' 40.53" and 45° 09' 18.81"

surface runoff through subsurface channels networks in the limestone of Kirkuk Group (Figs. 4 and 6). Continuity of this processes developed endokarstification to a depth of several meters below surfaces. At that time, the strata were dipping southwestward and the underground drainage was toward same direction. This is evidenced by the angle between the strata of host rocks and the sandstone-filled shafts that turning away from the vertical and sloping toward the southwest (Fig. 6). The water conduits were possibly existed in complex network of the erosional karstic features which filled with the pale brown to red pebbly chert sandstone. In literature Sando (1987) mentioned that in the Madison Limestone (Mississipian) Wyoming, USA, the shape of paleocaves is controlled by bedding plane.

Timing of the karstification

The evidences of the Oligocene karstification are three; the first is depositional features represented by vertical cylinders of pebbly sandstone and large planoconcave conglomerate bodies in the Oligocene succession (Figs. 5, 7 and 8). These features are interpreted as solution shaft and caves later filled with siliciclastic sediments. These erosional features were developed by enlargement with time by chemical solution and erosion during Oligocene aided by possible humic acids that generated from decaying of organic material on the surface of the unconformity such as tree leaves and grasses. In this connection, Faimon (1983) stressed on rule of these acids on epikarst development.

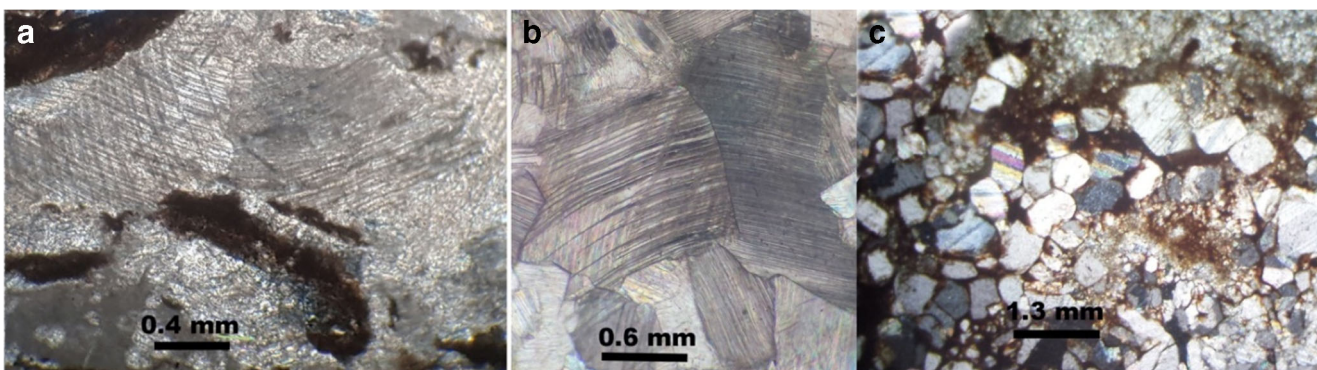


Fig. 11 a, b Bending (deformation) of the calcite twin laminae in a travertine bed in Basara Gorge section, s.no.17, XP light, c) detrital travertine (calcite) in the Basara section shows sorting and roundness, s.no.19, XP light.



Fig. 12 **a** Oligocene pebbly paleosol at the base of the Oligocene succession (on the top Pila Spi Formation) at the north of Koyia town on the northern side of the paved road, **b** Pebbly paleosol at the base of

Kirkuk Group on the southern side of paved road between Erbil city and Dokan town at the latitude and longitude 35° 55' 10.98" and 45° 53' 46.78"

In some cases the underground cavities filled with a mixture of pebbly sandstone (transported from outside) and large angular blocks of limestone (solution breccias) that detached from the cavity roofs of the same host rocks and mixed with guest conglomerates (Fig. 4). In the northern Norway and in the carbonate of middle Carboniferous, Eliassen and Talbot (2005) recorded solution breccias that their clasts are typical of the limestone facies that occur in the unbrecciated parts of the stratigraphic interval and observed that both monomictic and polymictic breccias exist, but a monomictic composition is more common.

The second evidence is presence of discoloration laminae and paleosols which exist, as features, below surface and found along fresh valley sides, cliff, and road cuts which exclude their recent origin. The laminae are faulted and underwent stylolitization (Fig. 9) which indicate post-depositional discoloration and deep burial deformations which are not related to recent processes. According to Wilson (1975) and Kahle (1987) discoloration of rocks in

shade of red and orange is normally attributed to oxidation due to subaerial exposure. It is interpreted that these laminae are the result of karstification due to oxidation by Fe bearing groundwater penetration into the formation after exposure to weathering during Oligocene (Fig. 9). These laminae are discolored at the lower limit of the seasonal groundwater penetration into homogenous semi-impermeable limestone of Kirkuk Group. In the lower limit zone, the maximum precipitation of minerals occur and leads to discoloration. This is similar to soil profile in which material transported from upper layers of soil to lower levels by downward precipitation of water across soil horizons, and accumulation of the material (illuvial deposit) in lower illuviation. The development of both liesengang rings (Vysinka et al. 2011) and the laminae of the present study are similar. The liesengang rings occur in geologic record and the recent times in sedimentary rocks such as limestones and sandstones.

The third evidence is the demonstration of macro and micro deformations (faulting and bending) of the discolored laminae

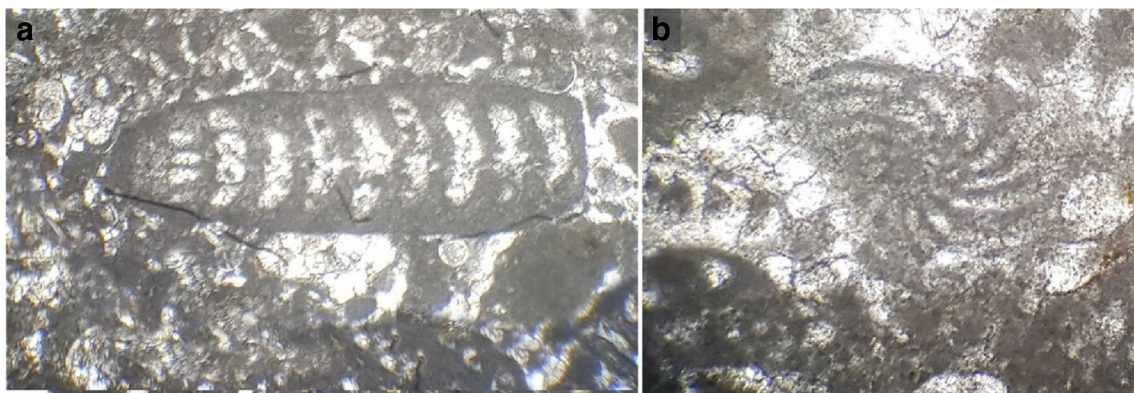


Fig. 13 Index fossils of Oligocene succession in which the paleokarsts evidences are found, **a** *Praerhapydionina delicata*, **c** *Peneroplis evolutus*, S.No.9 Ella Alla section

and trvertine beds which exclude their relation of recent deformations but they deformed during burial and uplift (Figs. 9 and 11). Another evidence is finding of lithified detrital calcite grains as rounded and sorted crystals (Fig. 10c) inside the fossiliferous limestone of Kirkuk Group. These grains indicate deposition of the travertines as products of the karstification during Oligocene later they reworked by rejuvenation of groundwater seepage.

In all studied sections, the endokarst filling materials (sandstones, conglomerates, and solution breccias) are harder than host limestone of Oligocene and they are more expressed, as positive relief, than host rocks (Figs. 6 and 8) which oppose recent sediments or rocks, especially recent siliclastic sediments (similar to present sandstone and conglomerate) cannot lithify stiffer than their hosted rocks. These siliclastic sandstone and conglomerate (similar to present cavities-filling ones) are well known as flat layers in the contact between Oligocene and Miocene successions in northeastern Iraq and they are assigned as pre-Miocene deposits by Buday (1980) and Ameen (2009). Another evidence is existence of the all aforementioned evidences inside hosted rock that contains index fossils of middle and upper Oligocene (Fig. 13).

Palaeoclimatic conditions during paleokarst formation

Although climate of the Oligocene is inferred as humid in Eurasia (Li et al. 2018), in Iran Roozpeykar and Moghaddam (2016) determined warm tropical climate during Oligocene-Miocene Epochs from the fossil content of the Asmari Formation (equivalent of Kirkuk Group). There are strong signals from stratigraphy of the northern Iraq, indicate the prevalence of a semi-arid climate similar to present days Mediterranean climate (with warm dry summers succeeded by wet cool winters). When works of Buday (1980) and Jassim and Goff (2006) are considered, the stratigraphic signals manifested by sandwiching of the Oligocene succession, by Pila Spi Formation (late Eocene) at the base and Lower Fars Formation (Early–Middle Miocene) at the top. The lithologies of these two formations are lagoonal dolomitic limestone and gypsiferous sediments, respectively (Fig. 3a). The lithologies and fossils of these two formations show aridness during both Late Eocene and Miocene in the studied area. Therefore, the semiarid climate is the one that fits the Oligocene especially the Oligocene sea had exposed to a major regression and the land progradation in Middle East by which the terrestrial lands nearly doubled as compared to Eocene as shown by facies maps published by Sadooni and Alsharhan (2019) and Jassim and Goff (2006). Outside the Eurasia, on the North America, Zanazzi et al. (2015) concluded very dry ecosystems during both Eocene and Oligocene.

In addition to the stratigraphic evidence for the semi-arid climate in the studied area, occurrence of the red claystone

(similar more or less to terra rosa soil) and travertine and tuffa are additional evidences (Figs. 3c, 8, 10, and 11). These two latter rocks are discussed by Kosun (2012) in Mediterranean area of Turkey during Quaternary, while Pedley (2009) mentioned areas where travertine and tufa are actively forming and widespread in temperate and warm climates, such as the Mediterranean region. Farhan et al. (2016) suggest that the carbonate sedimentation of Oligocene sequence took place in tropical waters under oligotrophic to slightly mesotrophic conditions.

Conclusions

For the first time Oligocene epi- and endokarsts are documented inside Kirkuk Group from Zagros Fold Thrust belt and many depositional and erosional features are recorded and discussed as evidences of paleokarsts. These evidences are such as sandstones-filled vertical shafts, solution limestone breccias, and complicated interlocking underground networks of solution cavities filled by angular limestone blocks floating in chert conglomerate and coarse sandstones. Other recorded paleokarstic features are conglomerate-filled paleocaves, paleosoils, discoloration laminae, detrital travertine clasts, bedded travertine, and possible tufa. All these features with the well-known Oligocene unconformity were exposed on the near shore area of the Oligocene basin where processes of erosion and deposition were affecting the area. The documented karstification indicates a paleogeography setting of a part of Zagros mountain belt during Oligocene. Additionally, the paleokarstification manifests the limits of terrestrial and marine realm of the northeastern Arabian Plate Margin during Oligocene and has application for oil explorations and paleoenvironment concerns in the Zagros.

References

- Al-Fahmi M, Cooke ML, Cole JC (2014) Modeling of the Dammam outcrop fractures: Case study for fracture development in salt-cored structures. *GeoArabia* 19(1):49–80
- Al-Hashimi H, Amer RM (1985) Tertiary Microfacies of Iraq. Geological survey and mineral investigation, Baghdad, Iraq
- Alsharhan AS, Naim AEM (1997) Sedimentary basins and petroleum geology of the Middle East. Elsevier, Amsterdam 99p
- Ameen BM (2009) Lithological indicators for the Oligocene unconformity, NE Iraq. *Iraqi Bulletin of Geology and Mining* 5(1):25–34
- Baba Shekh SMR (2006) Hydrogeochemistry of some springs in Sangaw- Chamchamal area. Unpub. M. Sc. Thesis, University of Baghdad, 150pp
- Bellen RC, Dunnington HV, Wetzel R, Morton D (1959) *Lexique Stratigraphique, International. Asie, Iraq*, 3c. 10a, 333 p
- Bosák P, Ford DC, Glazek J, Horáček I (1989) Paleokarst: a systematic and regional review. *Academia, Asterdam-Praha*

- Buday T (1980) Regional geology of Iraq. In: Kassab IIM, Jassim SZ (eds) Stratigraphy, vol 1. GEOSURV, Baghdad 445p
- Buday T, Jassim SZ (1987) The regional geology of Iraq. In: Tectonism, magmatism, and metamorphism, vol 2. GEOSURV, Baghdad 352 p
- Chen Q, Zhao Y, Li G, Chu C, Wang B (2012) Features and controlling factors of epigenic karstification of the Ordovician carbonates in Akekule arch, Tarim Basin. *J Earth Sci* 23(4):506–515
- Dunnington HV (1958) Generation, migration, accumulation and dissipation of oil in northern Iraq. In: Weeks LG (ed) *Habitat of oil*. AAPG, Tulsa, pp 1194–1251
- Eliassen A, Talbot MR (2005) Solution-collapse breccias of the Minkinfjellet and Wordiekammen formations, Central Spitsbergen, Svalbard: a large gypsum palaeokarst system. *Sedimentology* 52: 775–794
- Faimon MSJ (1983) Are recent karst processes influenced by soil humic substances? *Environ Sci Technol* 17(1393):156–158
- Farhan HN, Kadem LS, Mohammed QA (2016) Microfacies and depositional environment of Bajawan and Baba Formations in Kirkuk Oil fields north Iraq. *Tikrit J Pure Sci* 21(6):112–125
- Ford TD, Cullingford CHD (1976) *The science of speleology*. Academic, Cambridge
- Jassim SZ, Goff JC (2006) *Geology of Iraq*. Dolin, Prague and Moravian Museum, Berno 341p
- Kahle CF (1987) Surface and subsurface paleokarst, Silurian Lockport, and Peebles Dolomites, Western Ohio. In: James NP, Choquette PW (eds) *Paleokarst*, pp 229–255
- Khanaqa PA, Sissakian VS, Karim KH, Karim SA (2009) Lithostratigraphic study of a late Oligocene-Early Miocene succession, south of Sulaimaniyah, NE-Iraq. *Iraqi Bull Geol Min* 5(2):41–57
- Kharajiani SOA (2008) Sedimentary facies of Oligocene rock units in Ashdagh Mountain-Sangaw district- Kurdistan Region, NE Iraq. M.Sc. thesis, University of Sulaimani, Iraq, p 138
- Kosun E (2012) Facies characteristics and depositional environments of quaternary tufa deposits, Antalya, SW Turkey. *Carbonates Evaporites* 27(3–4):269–289
- Li S, Xing Y, Valdes PJ, Huang Y, Su T, Farnsworth A, Lunt DJ, Tang H, Kennedy AT, Zhou (2018) Oligocene climate signals and forcings in Eurasia revealed by plant macrofossil and modelling results. *Gondwana Res* 61:115–127
- Pedley M (2009) Tufas and travertines of the Mediterranean region: a testing ground for freshwater carbonate concepts and developments. *Sedimentology* 56:221–246
- Pentecost A (2005) *Travertine*. Springer-Verlag, Berlin, Heidelberg 445 p
- Plotnick RE, Kenig F, Scott AC, Glasspool IJ, Eble CF, Lang WJ (2009) Pennsylvanian paleokarst and cave fills from northern Illinois, USA: a window into late carboniferous environments and landscapes. *PALAIOS* 24:627–637
- Roozpeykar A, Moghaddam IM (2016) Benthic foraminifera as biostratigraphical and paleoecological indicators: an example from Oligo-Miocene deposits in the SW of Zagros basin, Iran. *Geosci Front* 7:125–140
- Sadooni FN, Alsharhan AS (2019) Regional stratigraphy, facies distribution, and hydrocarbons potential of the Oligocene strata across the Arabian plate and Western Iran. *Carbonates Evaporites* 34(4):1757–1770
- Sando W (1987) Madison Limestone (Mississippian) Paleocast: A geologic synthesis. In: James NP, Choquette PW (eds) *Paleocast*, pp 256–277
- Sissakian VK (2000) Geological map of Iraq, sheets no.1, scale 1: 1000000, 3rd edn. GEOSURV, Baghdad
- Vysinka M, Mizusawa M, Sakurai K (2011) Growth and Characteristics of Liesegang Rings in Cu–Cr System: Optical and XRF Study, WDS'11 Proceedings of Contributed Papers, Part III, pp147–154
- Weijermars R (1999) Surface geology, lithostratigraphy, and tertiary growth of the Dammam dome, Saudi Arabia: a new field guide. *GeoArabia* 4(2):199–226
- Wilson JL (1975) *Carbonate Facies in geologic history*. Springer-Verlag, Berlin 471p
- Zanazzi A, Judd E, Fletcher A, Bryant H, Kohn MJ (2015) Eocene–Oligocene latitudinal climate gradients in north American inferred from stable isotope ratios in perissodactyl tooth enamel. *Palaeogeogr Palaeoclimatol Palaeoecol* 417:561–568