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Palynological and Stratigraphical Evidences on the Age of the Outcropped Khabour Formation near Chalki Nasara Village, Kurdistan Region, Northern Iraq

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Abstract

The siliciclastic predominate sequence of the Khabour Quartzite-Shale Formation crops out in Kurdistan Region within a narrow strip which runs semi-parallel to Iraq/Turkey border line, within the Imbricated and Thrusted Ora Zone, in front of the Bitlis Suture Zone which resulted from the collision of the Arabian and Anatolian plate. The studied samples from Chalki Nasara section appeared to be deposited within shallow marine environment and considered as a part of the Tectono- megasequence Ap.2.

The identified seventy nine palynomorphs within the prepared palynological slides were all acritarchs with no observation of other known Lower Paleozoic palynomorphs like chitinozoa, scolecodonts, and graptolites. The identified acritarch species are among those which well documented in Cambrian and Ordovician periods such as Acanthodiacrodium angustum, Dactylofusa squama, Cristallinium cambriense, Saharidia fragilis, Acanthodiacrodium ubuii, Polygonium gracile, Acanthodiacrodium achrasii, Gonisphaeridium tener, Actinotodissus formosus, Polygonium pungens, Actinotodissus spinutisus, Cymatiogalea membranispina, Polygonium symbolum, Actinotodissus crassus. Accordingly and depending on the three distinguished acritarch assemblage palynozones and the stratigraphic position, the age of the lower unit of Khabour Formation in the studied area determined as Late Cambrian-Tremadocian.

The dark brown and black colors of the identified palynomorphs within the formation indicated to thermally post mature condition of the organic matters. On the other hand, kerogen type I appeared to be the dominated quality of the existed organic matters and that based on the ratio between the different organic matter components.

Introduction

Khabour Qartzite - Shale Formation is the oldest formally described and recorded formation within the Iraqi geological column. The type section of the formation locates about 2 km west of Kaista Village which descends to the stream immediately to the north of Chalki Nasara Village in Iraqi Kurdistan in which the formation described for the first time by Wetzel in 1950 in an unpublished report. (Bellen et al, 1959).

The formation has been recorded in only few drilled wells by the Iraqi oil companies. The subsurface penetrated sections from the formation locate in wells drilled in the Western Iraqi Desert which as an area suffered from uplifting and non-depositional condition since the Caledonian orogeny and continued through long periods of time along the geological history of the region. Accordingly, the wide period unconformity surfaces in the area lead the old formations like Khabour be laid in relatively shallow depths (less than 4000m) and within the reach of the drilling operations.

The Cambrian rocks in Iraq have not been reported in outcrop, nor they have been penetrated by any borehole. However, the correlation of deep seismic sections of western Iraq (i.e. Khlesia and Rutbah-Ga'ara Uplift areas) with similar sections and deep wells in Syria and Jordan, lead AI-Haba et al. (1994) to postulate the occurrence of Cambrian rocks, at least in the subsurface of the Western Desert of Iraq. The Cambrian and

Lower Ordovician sequences in the Western and Southwestern Deserts of Iraq probably resemble similar rocks in Jordan and Saudi Arabia. These consist of alluvial and marginal marine clastics: Saq Sandstone Formation of Saudi Arabia, (Powers et al., 1966: Al- Laboun, 1986: McGillivray and Husseini, 1992) and the Ram Group of Jordan (Beydoun, 1991). In order to investigate and prove the presence of the Cambrian aged sequences in Kurdistan section from Northern Imbricate –Thrust zone about 40 km NE of Zakho city and 1 km North of Begufa collection town; the Chalky Nasara-Khabour valley section was selected. In this work a special attention paid to investigate the stratigraphic position of Khabour Formation and also to a precise age determination of its oldest outcropped part. The studied section runs along Khabour valley, on the left banks and integrated with the road cut side from Chalky Nasara village until Iraq/Turkey border (Fig.1).

Previous studies

The pioneer study by McCarthy (1955) includes the drawing of the first geological map for the studied area and nominated whole Phanerzoic successions which exposed North of Zakho city (Kurdistan series maps, K.1).

Bellen et al. (1959, based on the nominated and well described type section of this formation by Wetzel (1950), mentioned that, Khabour quartzite north of Chalky Nasara is about 800 m thick without remarkable lower boundary.

Seilacher (1963) recorded the first *Cruziana* trace fossils within Khabour Formation from Kurdistan and Iraq. Sadiq (1977) concluded out that Early Paleozoic deposits was accumulated in a deep trough divided into two main facies, the first is the Arabian Facies on the west comprising clatics; and the second is the Iranian facies on the east comprising clastics and carbonates. Ma'ala et al. (1990) drew detailed geological map of the studied area and considered the age of Khabour Formation to be Ordovician. Baban (1996), Majidee (1999), Al-Ameri and Baban (2000, 2002), Al-Hadidy (2007), and Al-Ameri (2010) studied the age, palynofcies, maturation, petrography, and petroleum system of the Paleozoic succession based on well data from Western Iraqi Desert. Stevanovitic et al. (2003) in their new drawn geological map of Iraq indicating two major faults in the studied area that trends almost NE -SW and NW –SE which transect the major thrusted Paleozoic sheets. Göncüoğlu et al, (2012) studied the Paleozoic sequence in Hakkari (SE-Turkey) close to the studied area. Baban (1996) stated that the lower part of this formation extends to the Lower most Ordovician (Tremadocian) and that depending on observing some index acritarchs of this age. Karim (2006) made a comparison between the Ordovician Khabour Formation and the Maastrichtian Tanjero Formation. Al-Bassam (1010) studied the petrology, mineralogy and chemical composition of the Khabour Formation in two sections exposed in Ora and Khabour localities, N Iraq. He mentioned that petrographically, quartz arenite and phyllarenite are the main textural varieties of the sandstone with mica and silt-size quartz dominating the shale of the formation, whereas mineralogically the sandstones are mature to submature and texturally mature. Omer (2012) studied the sedimentology and geochemistry of Khabour Formation in Northern Iraq from two outcrop sections at Chalky Nasara, near Kaista village and near Ora village. By combining lithofacies and ichnofacies, Omer (2012) recognized eight facies associations from the type locality and he subdivided them to twenty three facies. Abd-Alwahab (2014) revealed that the general geodynamic framework of the Paleozoic basin in Iraq is its setting as intraplate basin, which exhibits extensional driving forces.

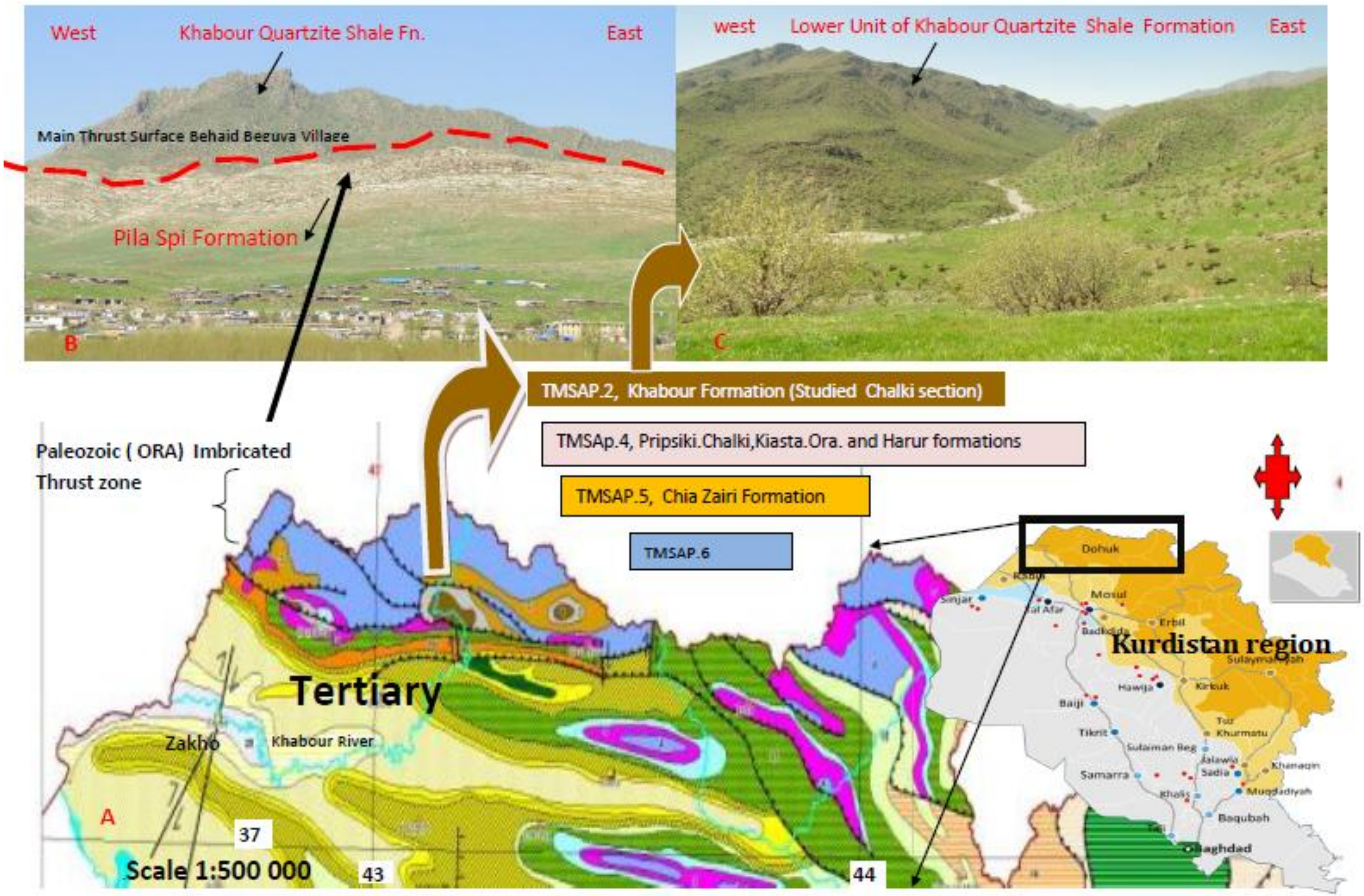


Figure 1: Location and Geology of the studied section. A-Geological map of Studied area after Stevanovitic et al 2003, B- Khabour Quartzite Shale Formation thrusted Over Pila spi (Main thrust sheet). C- Lower Most Part of Khabour Fn., Oldest exposed studied unit.

Materials and Methodology

Extensive field work in the type section was carried out in not easily reached site due to some geopolitical conditions, taking in consideration the structural geological complexity and the thrusted sheets geometry using maps drawn by Ma'ala et al (1990) and Setvanovitic et al. (2003).The oldest exposed in base of the Khabour deep valley, about 500m north of Chalky Nasara village along the deepest valley incised nowadays, towards the border line between Iraq and Turkey where the whole Paleozoic stratigraphic succession exposed with about 4000m thickness. Thirty one samples were collected for palynological studies (mainly age determination) from the lower part of the exposed Khabour Formation for finding out the age of the oldest exposed rocks in Kurdistan and Iraq. Palynological slides have been prepared for the selected samples using HCl and HF acids to remove the carbonate and silicate materials respectively from the samples. Recovering the sedimentary organic materials done using nylon mesh of 10μm size, whereas examination of the slides done using transmitted light microscopy.

Geological Setting

The Early Paleozoic out crops in Kurdistan region have been recorded from a narrow strip runs semi-parallel to Iraq /Turkey Border extending between Hizul Su river from west to Amedi city in the east, extending for more than 50km in length and 20 km width. From tectonic subdivision the studied area is located within Ora imbricated zone and in front of Biltis suture zone, between Arabian Plate and Anatolian (Turkish) plate (Fig.1A). The Paleozoic and Mesozoic successions are generally thrusted over the Cenozoic successions in Kurdistan including the studied area in which Khabour Formation (Ordovician) thrusted over the Pila Spi Formation(Late Eocene) (Figs.1B&C). In Khanut-Qasruk Valley the Khabour Quartzite-Shale Formation thrusted over the Upper Cretaceous Aqra-Shiranish and Paleocene Kolosh formations (Ma'ala et al, 1990).They also indicated that three transversal faults cut across the main thrust faults and show mineralization of Barite, Pb-Zn ore deposits. According to Jassim and Goff (2006) no Precambrian and Cambrian rocks exposed in Iraq and the incomplete whole Paleozoic thickness is about 4000m, and almost interrupted by Silurian and Late Carboniferous hiatuses reflecting the influence of the Caledonian and Hercynian tectonic activities respectively.

The sedimentary cover was deposited during late Precambrian to mid-Permian intra-cratonic phase,(TMSAP.1 -TMSAP.5) (Sharland et al., 2004; Jassim and Goff, 2006; Aqrawi et al., 2010). The siliciclatics predominated facies are deposited in shallow marine depositional environments with extensional, slightly subsided paleotetheys margin (McGillivray and Husseini, 1992; Numan, 1997).Three major tectonic activities influenced the sequence and plaeogeography of the TMSAP.1 which are the Cibbarain, Najid, and Hujaz tectonic activities, where the influence and control the paleoconfigurations of the basin ,sedimentary cover and basement of the Arabian plate, accordingly Horsts and Graben are the most dominant structural features (Sharland et al., 2001 ;Ziegler, 2001). The Mega sequences AP1 to AP3 are dominated by siliciclastics, and contain evidence of two glaciations: one global glaciations during the Late Precambrian and a polar glaciations in the Late Ordovician (Suteliffe et al., 2000).

The studied succession almost deposited within the upper part of the TMSAP.2 (Early Cambrian to Late Ordovician, 520-445Ma) within Paleozoic stratigraphic framework, characterized by extension, intracratonic basins and mild uplift. The oldest exposed rocks are clastics dominate sequence of the Khabour Quartzite Formation, which is exposed in several deep valleys cutting across the imbricated zone (Geli Sinat and Khabour valley), but without clear lower boundary, and occasionally transected by igneous intrusions. The upper unconformable contact with Pirispiki red bed emphasized by the disappearance of the Silurian deposits related to Akkas Formation, as well as the turnover from marine to non marine continental red clastic facies, with mud cracks feature (Figs.2A&B) associated by the Chalki Volcanic intrusions, and disappearance of *Cruziana* rich clastics (Figs.2C&D).The oldest formation on Turkish territory (close to the studied section) is the Giri Quartzite Formation which is homotaxial and almost certainly correlative with the Khabour Quartzite- Shale Formation in Iraq (Bellen et al ,1959). The Pirispiki Formation represents continental (alluvial fan) environments, whilst the Chalki Formation may represent rift-associated extrusive.

Stratigraphy

The Paleozoic sequence of Iraq could be characterized by a partial lack of representatives of Middle Paleozoic periods (Silurian and partially Devonian) (Powers et al., 1966; Stöcklin, 1968). On the other hand, the Paleozoic formations of Iraq, unlike those in Saudi Arabia, are prevalently of marine character, with equilibrium between clastic and carbonate sediments. In this sense a close similarity seems to exist between Iraq on one side and Iran and Turkey on the other. The Paleozoic sedimentary sequences in Iraq and Kurdistan region fall into four tectonic-mega sequences (TMSAP.2, TMSAP.3, TMSAP.4 and TMSAP.5) (Table-1, & Fig.3).They are exposed on the surface in kurdistan while in Iraqi Western Desert only the upper most part of the Paleozoic exposed at the surface representing by Ga'ara Formation. Till nowadays no recodes of Silurian age units from Kurdistan outcrops have been recorded and almost point to major gap in the Kurdistan Paleozoic successions associated by Caledonian volcanism. The lithostratigraphic formations, in the studied Khabour Valley (Iraqi Kurdistan), from oldest to youngest formations can be arranged as Khabour Quartzite- Shale, Prispiki, Chalki, Kiasta, Ora, Harur, and Chai Zairi Formation. Whereas in western Iraq (Western Desert , Akkas wells 1,2, and Khlaisia wells,1,2) the successions are characterized by thicker Khabour quartzite (about 1250m) and presence of thick black shale and sandstones (about 860m) related to TMSAP.3 representing the Silurian Akkas Formation (Table.1) (Ditmar, et al., 1971, Al-Samarrai, et al., 1994, Baban,1996; Al-Hadidy, 2007).

Figure 2: A, Lithostratigraphic road section, Khabour Formation unconformably overlained Prispiki Formation; B, Mudcracks near the lithostratigraphic contact between Khabour and Prispiki formatios; C&D, Traces of giant *Cruziana* within Khabour Formation.

The Lower Paleozoic in Kurdistan region is characterized by siliciclastic sequence which is predominated by olive green to brownish gray shale in the lower parts and change upwards to micaceous, cross laminated, and extensively bioturbated sandstone at the upper parts.

Table-1: Paleozoic stratigraphic framework for Kurdistan outcropped section and Iraqi Western Desert (subsurface).

	Kurdistan Outcropped Section		***TMSAP***	***Iraqi Western Desert Subsurface Section***	
	Formation	***Age***		***Formation***	***Age***
Paleozoic	Chia Zairi	Permian	**5**	Chia Zairi	Permian
	Harur	L. Carboniferous	**5**	Harur	L. Carboniferous
	Ora shale	E. Carboniferous	**4**	Ora shale	E. Carboniferous
	Kiasta	Late Devonian	**4**	Kiasta	Late Devonian
	Chalki	M. Devonian	**4**	GAP	M. Devonian
	Prispiki	M. Devonian	**4**	Gap	M. Devonian
	GAP	Silurian	**3**	Akkas	Silurian
	Khabour Quartzite-Shale	Ordovician	**2**	Khabour Quartzite-Shale	Ordovician
	Infracambrian	**?**	**1**	**?**	**?**

The only surely ascertained formation belonging to this TMSAP.2 is the Khabour Quartzite - Shale Formation. Bellen et al. (1959) included the Piri Spiki Red Beds and the Chalki Volcanic in the Ordovician sedimentary cycle. Seilacher (1963) proved that the Piri Spiki and Chalki formations belong to the Devonian - Lower Carboniferous cycle and were deposited after the Caledonian uplift. Ghienne et al. (2010) mentioned that in southern Turkey (Taurus chain) and Southeastern Turkey (border folds of Arabian Plate), nearly complete Cambrian to Ordovician successions are preserved. They also identified four major sedimentary sequences (namely, Intra-cratonic platform regime, Stable margin platform, Tectonic instability and differentiation of Sag basin, and terminated by Glacio-marine deposits by the Late Ordovician).

Khabour Quartzite-Shale Formation

This formation was first defined by Wetzel (1950), in the Northern Imbricated-Thrust Zone, Kurdistan region (Figs.2A&3). No essential changes were introduced neither in the determination nor in the lithological characteristics of the formation by later workers. The exposed portion of the formation is purely clastic, composed of thin bedded, fine grained sandstones, quartzite greywacke and, silty micaceous, shales (details exist in Bellen et al. 1959, and Seilacher, 1963).The formation in the outcrops area, according to Seilacher (1963), is of intertidal mudflats environment at the base of the sequence gradually changing upwards to relatively deeper, turbidities - affected deeper facies. The direction of currents being north - northeast, changing towards the east and at end almost to the south. The thickness of the Khabour Quartzite - Shale Formation in northern Iraq reaches to about 800m, whereas in Khalisia-1 well it reaches about 1250m without reaching its bottom (Ditmar et al., 1971). The bottom of the formation is not exposed in Iraqi Kurdistan but its real thickness reaches to about 2000m just north of the studied area within Turkey at which the formation underlain by Badenan Formation (Göncüoğlu and Kozlu, 2000). Based on detail investigation by Seilacher (1963), the Cambrian is not presented in the studied Iraqi portion of Khabour Formation, therefore, the known parts of the formation should be attributed to the Ordovician only.

The Khabour Formation was deposited in an alluvial continental to shallow marine environment which prevailed over the entire eastern part of the Arabian Plate (Seilacher, 1963). According to the study of Al-Bassam (2010) the formation seems to be deposited in marine environment extending from shallow intertidal to deep outer shelf, under variable conditions of sea-level fluctuation, subsidence rate, and detritus supply. Omer (2012) concluded that the lower part of the Khabour Formation is of typical pro-delta and the upper part of the formation represents upper, middle and lower shore-face deposits.

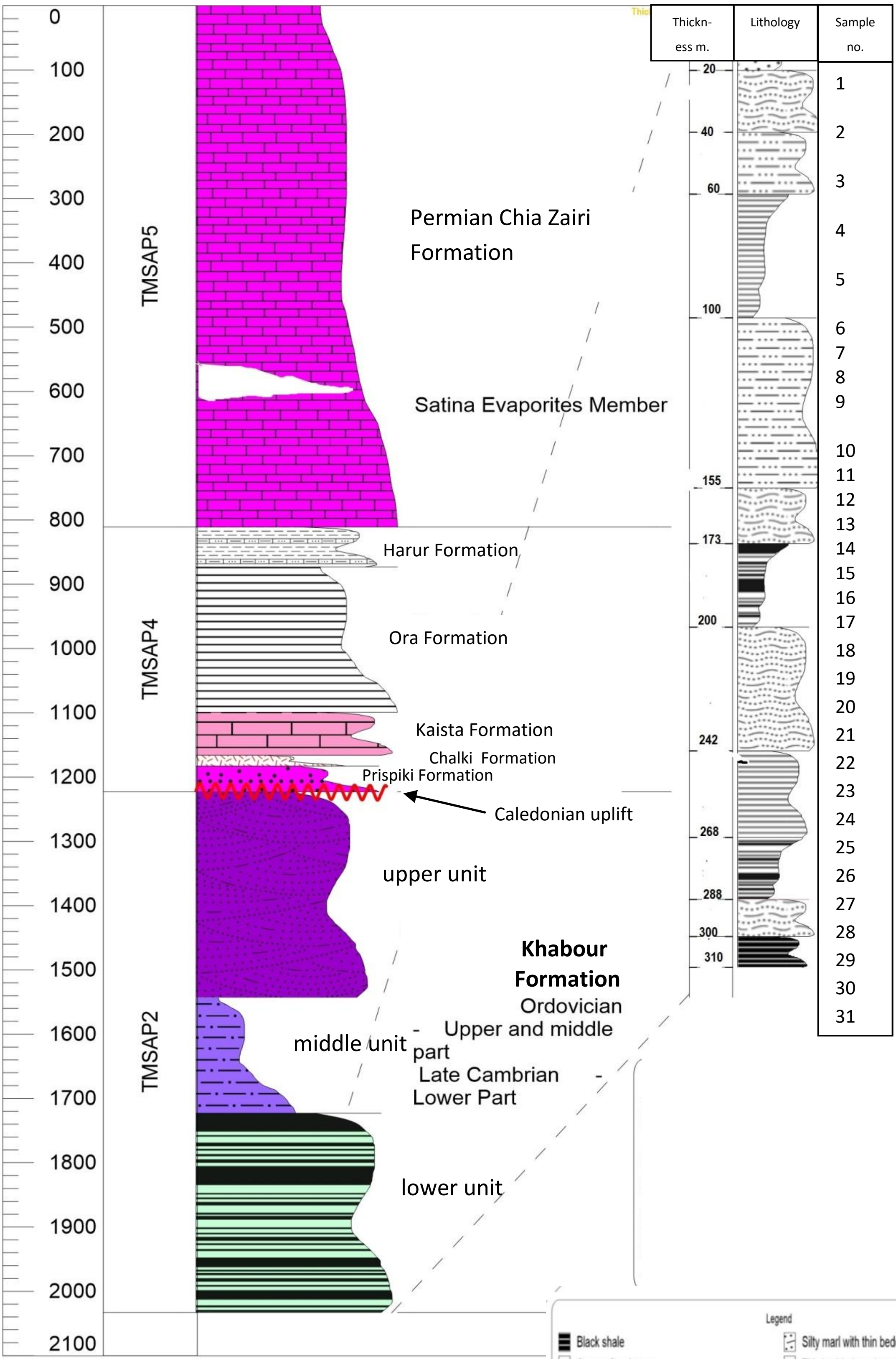
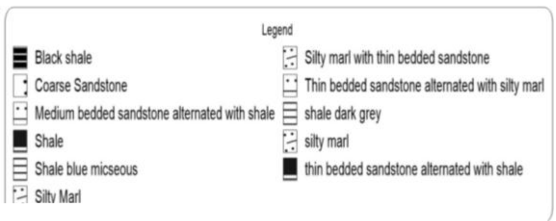


Figure 3: Stratigraphic column of the studied area with the Paleozoic tectonic mega sequences and positions of the studied samples within the lower unit of Khabour Formation.



Legend for the lower unit of Khabour Formation

Göncüoğlu et al. (2012) described the stratigraphic hiatuses, unconformity and irregular distributions of Caradocian -Ashgillain deposits north of the studied area (in southern Turkey) as due to Glacio-Eustatic sea level changes.

Abd- Alwahab (2014) mentioned that the Late Ashgillian event of the Arabian plate had impact on the Clastic deposits of uppermost part of the Khabour Formation and the Late Silurian-Early to Middle Devonian is not proven to be in western desert. The formation in the outcrop area is of inter-tidal mudflats environment at the base of the sequence gradually changing upwards to relatively deeper, turbidities and shows allowing upwards sequences overlain by hiatuses, unconformities surface which might be a reflection of glacio-eustatic sea level changes (Göncüoğlu and Kozlu, 2000).

During the field work and based on the lithological changes of Khabour Quartzite -Shale Foramtion, the formation has been categorized into three major subunits, lower shale dominated unit, middle clastic and shale dominated unit, and the upper sandstone unit (Fig.3), with occasionally igneous bodies like sills and dykes cutting across the lower and middle units. The lower unit (about 311m thick) consists mainly of thick black and grayish brown color dominated shale and marl alternated with thin bedded silty marl and olive green siltstone. The middle part (about 265m thick) characterizes by thin bedded ,fine grained sandstone, quartzite and silty micaeous shale, olive –green to brown in color. The upper unit (about 254m thick) characterizes by very thick to massive, cross bedded sandstone rich in *Cruziana* and Planolites bioturbations. Almost combined by decreasing of shale and marl ratio . Giant and very large *Cruziana* in Kurdistan (and possibly Middle East) can be observed in this unit(Figs.2C&D). It's important to mention that Omer (2012) also subdivided Khabour Formation in Kurdistan to three units namely A,B&C (from lower to upper part respectively) based on field investigations, stratigraphic analysis and vertical variations in lithology combined with petrographic data. Neither thickness of the units nor the dominant lithology of units of both Omer(2012)'s study and this study are the same.

The Kaista, Ora Shale and Harur Limestone formations have been assigned to Late Devonian- Early Carboniferous (Tournaisian) age and related to TMSAP.4 almost overlies the Khabour Formation. Field evidences gathered during the investigation of NIMCO (Hamza and Isaac, 1971) proved the correctness of Seilacher (1963)'s findings and proved that the Pirispiki Red Beds are followed gradationally by the lower parts of the Kaista Formation. Thus the Pirispiki Red Beds, together with the Chalki Volcanics are included in this report among the formations of the Devonian-Lower Carboniferous cycle. In this work mud cracks facies was detected at the boundary with Pirispiki Formation (Fig.2B). which emphasized the Silurian and Early Devonian gap.

Age of Khabour Qartzite - Shale Formation

Bellen et al. (1959) considered the age of Khabour Formation as Cambro-Ordovician throughout, on the evidence of presence of *Cruziana* tracks throughout the type section. The upper part interpreted by them as Ordovician (Liandeilo? at top) and they expected the lower part be of Cambrian age but they didn't prove that. Baban (1996) and Al-Ameri and Baban (2000) studied Khabour Formation in the wells of Akkas-1 and Khleisia-1 in Western Iraqi Desert. Different palynozones have been identified by them and the age of the studied part of the formation considered to be Ordovician (the base of the formation didn't reach by drilling in the studied wells). The studied lowermost part of the formation considered to be of Tremadocian age by Baban (1996) and that depending on a number of identified acritarch species such as *Celtibrium dedalinum, Eomicrhystidium bargourni*, *Heliosphaeridium? lyense*, *Multiplicisphaeridium multiradiale*, *Polygonium symbolum*, *Solisphaeridium flexipilosum, Vulcanisphaera fermosa,* and *Vulcanisphaera gorge* in addition to few chitinozoa species namely *Conochitina primitive*, *Conochitina lepida*, *Conochitina redouanei* and *Armorochitina? niliensis*.

Omer (2012) determined the age of Khabour Formation in the type locality depending on trace fossils (*Cruziana, goldfussi,* and *Furcifera* ichnofacies) as Lower Tremadocian - Arenigian (as oldest exposed rock unit in Iraq).

In this study an attempt has been done to determine the age of the lower part of the out cropped section from Khabour Formation (the lower unit) to find out the age of the oldest exposed sedimentary rocks in Kurdistan and Iraq.

Thirty one samples representing about 311m from the lower part of the outcropped section of Khabour Formation along the road at the north-east of Chalki Nasara village have been collected for determining the age of the oldest part of the formation. The examined samples showed obvious variations in palynomorph richness including barren samples. As Khabour Formation composes mainly of shale, micaceous shale, siltstones, and marl, therefore variations in the palynofacies were expected to be seen with different preservation conditions for the palynomorphs.

Seventy nine species of acritarchs belonging to thirty two genera were identified in this study with no observation of any chitinozoa, scolecodonts, or graptolites. Some of the identified acritarch species were recorded in different areas around the world with long period of occurrence from Cambrian to Ordovician, whereas other identified species mostly used by different authors as indexes to limited period of time within the Upper Cambrian to Lower Ordovician (Tremadocian). Figure 4 shows the range of appearance for the identified acritarch species in this study and plates 1 to7 show their figures. Depending on the range of occurrence for the identified acritarchs, three assemblage palynozones were distinguished along the studied lower unit of Khabour Formation as follows:

Palynozone I

This palynozone represents the lower most outcropped part of the formation (the lowest 40m) which suggested to be of Late Cambrian age. Most of the identified acritarchs in this zone have been recorded by different authors in different areas within the Cambrian beds. Among the identified species in this palynozone are *Granomarginata squamacea, Solisphaeridium lucidum*, *Fimbriaglomerella membranacea, Skiagia orbiculare, Vulcanisphaera spinulifera, Cymatiogalae bellicosa*, *Polygonium martinae*, *Leiofusa stoumonensis, Skiagia ciliosa, Impluviculusvil losiusculus, Acanthodiacrodium cf. timofeevi*, and *Multiplicisphaeridium parvum* which all mostly known as Cambrian acritarchs. Additional acritarch species in this palynozonezone are *Gonisphaeridium tener, Actinotodissus formosus, Stelliferdium cortinulum, Poikilofusa squama, Polygonium pungens, Actinotodissus ubuii, Eliasum llaniscum, Vulcanisphaera africana,* and *Goniosphaeridium uncinatum*, which have been recorded within the Cambrian to Tremadocian age sediments.

Granomarginata squamacea has a worldwide distribution from the Lower to the Middle Cambrian (Rubinstein et al., 2003), whereas Moczydlowska suggested its
stratigraphic range to be extended to lower Upper Cambrian. Jachowicz-zdanowska (2011) also reported *Granomarginata squamacea* and *Vulcanisphaera spinulifera* within the Cambrian sediments in Ukraine. Palacios et al, (2011) recorded *Fimbriaglomerella membranacea* as a Cambrian species in Canada, whereas Palacios et al, (2012) reported *Granomarginata squamacea* and *Multiplicisphaeridium parvum* in Cambrian of Bourinot belt, Cape Breton Island, Nova Scotia. Vergel et al, (2013) mentioned *Solisphaeridium lucidum* as a late Cambrian species in Bolivia, whereas Vanguestaine and Léonard (2005) recorded *Polygonium martinae* in Cambrian of France. *Cymatiogalae bellicosa* is one of the species which reported by Zylinska et al, (2006) as a Cambrian species in Poland. *Fimbriaglomerella membranacea* and *Skiagia ciliosa* recorded by Bryhni et al.(1981) from the Cambrian of Norway.

Palynozone II:

This palynozone occurs within the middle outcropped section of Khabour with about 90m thickness(from sample no.17 to sample no.26). The assemblage of this palynozone includes those acritarch species which mostly known as Cambro-Ordovician species with disappearance of *Granomarginata squamacea*, *Fimbriaglomerella membranacea, Skiagia orbiculare, Vulcanisphaera spinulifera, Cymatiogalae bellicosa,* and *Polygonium martinae*.

Formation	Khabour (Lower Unit)																														
Age	Tremadocian																U. Late Cambrian - L. Early Tremadocian										Late Camb.				
Palynozones	III																II										I				
Acritarchs / Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Acanthodiacrodium crinitum		●		●					●																						
Acanthodiacrodium simplex		●	●					●	●																						
Michrystridium shinetonese		●		●				●	●																						
Actinotodissus crassus		●							●	●																					
Acanthodiacrodium spinum		●							●	●																					
Actinotodissus spinutisus		●				●			●	●																					
Buedingiisphaeridium tremadocum		●		●		●		●		●																					
Baltisphaeridium giganteum		●				●		●	●	●	●		●																		
Stelliferidium furcatum		●				●		●	●		●		●		●					●		●									
Leifusa simples		●						●		●	●				●		●			●		●	●								
Actinotodissus formosus		●							●								●			●							●		●		●
Acanthodiacrodium angustum			●			●		●	●																						
Caldariola glabra var. glabra			●	●				●	●																						
Impluviculus araneus			●			●		●	●	●																					
Acanthodiacrodium echinatum				●					●																						
Vulcanisphaera tuberata				●					●	●																					
Dactylofusa squama				●					●	●																					
Baltisphaeridium lasium				●		●			●	●																					
Acanthodiacrodium sinuosum				●		●		●		●	●																				
Dasydiacrodium sp.				●				●	●		●		●		●		●														
Polygonium gracile				●					●		●				●		●			●		●	●				●				●
Cristallinium cambriense						●			●																						
Baltisphaeridium akrochordum						●		●	●	●																					
Polygonium delicatum						●		●		●	●		●		●							●									
Baltisphaeridium verutum						●		●	●		●		●		●							●	●								
Polygonium symbolum								●	●																						
Arbusculidinium mamillosum								●	●																						
Izohoria sp.									●	●																					
Acanthodiacrodium achrasii									●						●		●			●		●					●				●
Saharidia fragilis																	●														
Acanthodiacrodium vavrdovae																	●														
Solisphaeridium sp.																	●														
Stelliferidium sp.																	●														
Impluviculus sp.																	●														
Polygonium dentatum																	●						●								
Eliasum laniscum																	●					●									●
Gonisphaeridium tener																	●			●							●				●
Vulcanisphaera africana																	●			●		●			●				●		●
Goniosphaeridium uncinatum																	●			●		●	●			●	●		●		●
Acanthodiacrodium baculatum																				●											
Tectitheca prima																				●											
Stelliferidium striatulum																				●											
Adara alea																				●											

Figure 4: Range of occurrence for the identified acritarchs with the distinguished palynozones in the lower unit of Khabour Formation.

Formation	Khabour (Lower Unit)																														
Age	Tremadocian																U. Late Cambrian - L. Early Tremadocian										Late Camb.				
Palynozones	III																II										I				
Acritarchs / Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Vulcanisphaera britanica																				●											
Timofeevia phosphoritica																				●											
Liosphaeridea sp.																				●											
Solisphaeridium akrochordum																				●											
Cymatiogalea velifera																				●		●									
Baltisphaeridium dasos																				●		●				●					
Solisphaeridium chines																				●					●	●	●				
Cymatiogalea membranispina																				●					●	●	●				
Polygonium pungens																				●		●					●				●
Actinotodissus ubuii																				●		●					●		●		●
Coryphidium elegans																				●		●	●		●		●		●		●
Athabascaella penika																						●									
Vulcanisphaera cirrita																						●									
Coryphidium australe																						●									
Tectitheca decorata																						●									
Micrhystridium filiferum																						●									
Acanthodiacrodium complanatum																						●									
Stelliferidium steligerum																						●									
Acanthodiacrodium cf. timofeevi																						●					●				
Multiplicisphaeridium parvum																						●					●				
Goniosphaeridium splendens																						●									
Poikilofusa squama																						●					●				
Leiofusa stoumonensis																						●					●				
Skiagia sp.																						●					●				
Skiagia ciliosa																						●			●						●
Impluviculusvil losiusculus																						●			●			●	●		●
Stelliferdium cortinulum																						●	●		●		●	●	●		●
Stelliferidium gautieri																											●				●
Solisphaeridium lucidum																											●				●
Polygonium martinae																											●				●
Fimbriaglomerella membranacea																											●				●
Granomarginata squamacea																											●	●			●
Vulcanisphaera spinulifera																											●	●			●
Skiagia orbiculare																											●	●	●		●
Cymatiogalae bellicosa																											●	●	●		●
Goniosphaeridium dentatum																															●

Continued...

The most important species in this zone are *Saharidia fragilis, Polygonium dentatum, Eliasum llaniscum, Vulcanisphaera africana, Goniosphaeridium uncinatum, Gonisphaeridium tener, Actinotodissus formosus, Actinotodissus ubuii, Acanthodiacrodium baculatum, Tectitheca prima, Stelliferidium striatulum, Adara alea, Vulcanisphaera britannica, Timofeevia phosphoritica, Solisphaeridium akrochordum, Cymatiogalea velifera, Cymatiogalea membranispina, Solisphaeridium chines, Vulcanisphaera cirrita,* *Tectitheca decorata, Micrhystridium filiferum, Acanthodiacrodium complanatum, Stelliferidium steligerum*, and *Goniosphaeridium splendens.*

According to Vecoli (1996, 1999) and Rubinstein et al.(2003), *Vulcanisphaera africana, Saharidia fragilis, Cymatiogalea velifera, Polygonium dentatum,* and *Actinotodissus ubuii* are common species in the Cambrian-Ordovician transition of Gondwana and related terranes. Ghavidel-syooki and Vecoli (2008) recorded *Vulcanisphaera cirrita, Saharidia fragilis,* and *Cymatiogalea membranispina* in Late Cambrian/Tremadocian sediments in Iran. Vergel et al.(2013) mentioned *Vulcanisphaera africana, Saharidia fragilis, Cymatiogalea velifera, Polygonium dentatum, Eliasum llaniscum, Timofeevia phosphoritica,* and *Solisphaeridium akrochordum* with the Cambro-Ordovician sediments of Southern Bolivia (western margin of Gondwana).

Solisphaeridium akrochordum, Solisphaeridium chines, Eliasum llaniscum, Impluviculusvil losiusculus, and *Polygonium pungens* all recorded by Moczydłowska and Stockfors (2004) in Russia within the uppermost Cambrian - lowermost Ordovician sediments. Rasul (1976) also recorded for the first time *Vulcanisphaera critta, Vulcanisphaera pila, Vulcanisphaera imparilis,* and *Vulcanisphaera britannica* in Tremadocian of England.

Accordingly this palynozone is suggested to be of upper Late Cambrian/ lower Early Tremadocian age.

Palynozone III

This palynozone represented by the upper 181m from the studied Khabour Formation from sample no.2 to sample no.16(sample no.1 was barren). The identified acritarchs in this palynozone are mostly belong to the Tremadocian as recorded in different areas around the world.

Distinguishable acritarch species which appeared only in this zone include *Acanthodiacrodium angustum, Michrystridium shinetonese, Polygonium symbolum, Caldariola glabra var. glabra, Cristallinium cambriense, Acanthodiacrodium crinitum, Arbusculidinium mamillosum, Acanthodiacrodium echinatum, Acanthodiacrodium simplex, Baltisphaeridium lasium, Vulcanisphaera tuberata, Acanthodiacrodium spinum, Impluviculus araneus, Baltisphaeridium akrochordum, Actinotodissus crassus, Dactylofusa squama, Actinotodissus spinutisus, Buedingiisphaeridium tremadocum, Acanthodiacrodium sinuosum, Baltisphaeridium giganteum,* and *Polygonium delicatum* . The zone also included acritarch species extended from the previous two older palynozones (I and II).

Rasul (1979) recorded the following species in Tremadoc Series of the Shineton Shales, Wrekin, and Shropshire in England*:*

*Acanthodiacrodium sinuosum, Baltisphaeridium lasium , Buedingiisphaeridium tremadocum, Acanthodiacrodium spinum***,** *Baltisphaeridium lasium***,** *Polygonium delicatum***,** *Acanthodiacrodium crinitum***,** and *Baltisphaeridium giganteum***.**

Acanthodiacrodium angustum recorded as a Tremadocian species by Deunff and Massa(1975) in Libya, Welsch (1986) in Norway, Fombella (1986, 1987) in Spain, Ghavidel-syooki (2000) and Mehrjerdi (2001) in Iran, Moczydłowska and Stockfors (2004) in Russia, and Vanguestaine (2008) in Belgium.

Michrystridium shinetonese and *Dactylofusa squama* recorded within the Tremadocian sediments by Ghavidel-syooki (2000) in Iran. *Caldariola glabra var. glabra* also recorded by de la Puente and Rubinstein (2009) as a Tremadocian species in northwestern Argentina and by Nowak et. (2015) in Morocco. Martin(1992) mentioned *Buedingiisphaeridium tremadocum* as a Tremadocian species in Wilcox Pass, Alberta (Canada), whereas Olaru (2005) mentioned *Acanthodiacrodium angustum, Dactylofusa squama, and Buedingiisphaeridium tremadocum* as characteristic Tremadocian acritarchs in Romania. Di Millia et al. (1993) also *considered Acanthodiacrodium angustum, Dactylofusa squama,* and *Vulcanisphaera tuberata* as species belonging mainly to Tremadocian.

Polygonium delicatum considered as a lower Ordovician index by Sargeant and Stancliffe (1994) during their reassessment for the species belonging to *Polygonium* Vavrdova emend Sargeant and Stancliffe 1994.

PLATE - 1

All of the figures are from sample no.9 with magnification x600.

1. *Acanthodiacrodium angustum* (Downie, 1958) Combaz, 1967
2. *Michrystridium shinetonese* Downie,1958
3. *Polygonium symbolum* Rasul, 1979
4. *Caldariola glabra var. glabra* (Martin) Molyneux & Rushton, 1988
5. *Cristallinium cambriense* (Slavikova) Vanguestaine, 1978
6. *Acanthodiacrodium crinitum* Rasul,1979
7. *Arbusculidinium mamillosum* Welsch, 1986
8. *Acanthodiacrodium echinatum* (Timofeev,1959) Deflandre & Deflandre-Rigaurd, 1962
9. *Acanthodiacrodium simplex* Combaz, 1967
10. *Baltisphaeridium lasium* Rasul, 1979
11. *Vulcanisphaera tuberata* (Downie 1958) Eisenack et al., 1973
12. *Impluviculus araneus* Vecoli & Playford, 1997
13. *Acanthodiacrodium spinum* Rasul, 1979
14. *Izohoria* sp.

PLATE - 2

1. *Baltisphaeridium akrochordum* Rasul,1979, sample no. 9 , x600
2. *Actinotodissus crassus* (Loeblich & Tappan) Vecoli, 1999, sample no. 9 , x600
3. *Actinotodissus spinutisus* (Timofeev, 1959) Moczydlowska & Stockfors, 2004, sample no. 9 , x600
4. *Dactylofusa squama* (Denuff,1961) Combaz, Lange &Pansart, 1967, sample no. 9 , x600
5. *Baltisphaeridium giganteum* Rasul, 1979, sample no. 9 , x600
6. *Dasydiacrodium* sp. , sample no. 9 , x600
7. *Baltisphaeridium verutum* Vecoli, 1996, sample no. 9 , x600
8. *Gonisphaeridium tener* (Timofeev) Elouad - Debbaj, 1988, sample no. 22 , x600
9. *Acanthodiacrodium achrasii* (Martin, 1973) Martin in Martin & Dean, 1988, sample no. 17 , x600
10. *Polygonium gracile* Vavrdova, 1966 , sample no. 31 , x600

PLATE - 3

1. *Buedingiisphaeridium tremadocum* Rasul, 1979 , sample no. 10 , x600
2. *Acanthodiacrodium sinuosum* Rasul,1979, sample no. 10 , x600
3. *Polygonium delicatum* Rasul, 1979, sample no. 10 , x600
4. *Leifusa simples* (Combaz, 1967) Martin, 1975, sample no. 20 , x400
5. *Saharidia fragilis* (Downie 1958) Combaz, 1967, sample no. 17 , x600
6. *Acanthodiacrodium vavrdovae* Cramer & Diez, 1977, sample no. 17 , x600
7. *Solisphaeridium* sp. , sample no. 17 , x600
8. *Stelliferidium* sp. , sample no. 17 , x600
9. *Impluviculus* sp. , sample no. 20 , x600
10. *Adara alea* Martin, in Martin & Dean, 1981, sample no. 20 , x600
11. *Polygonium dentatum* Timofeev, 1959, sample no. 23 , x600

PLATE - 1

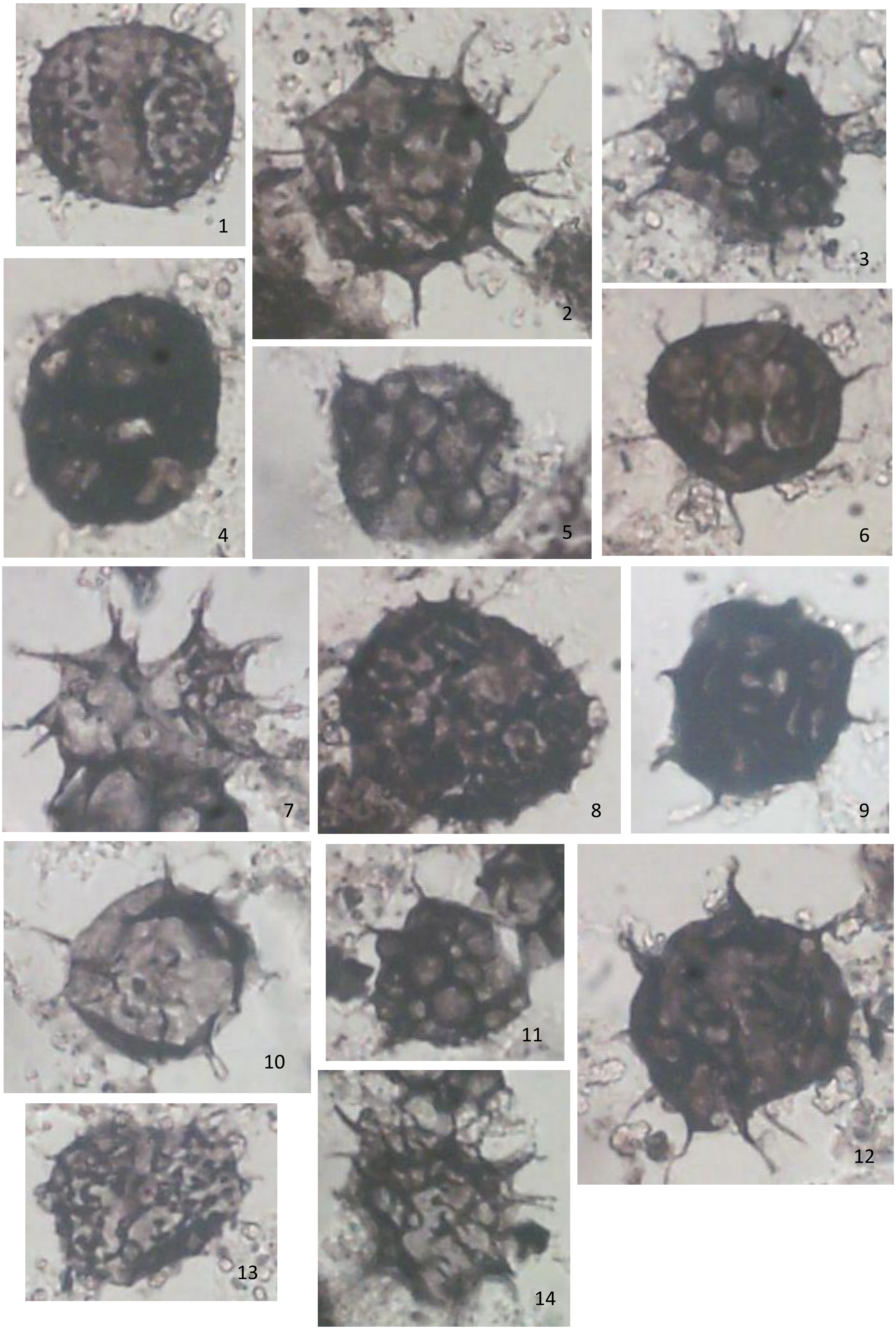


PLATE - 2

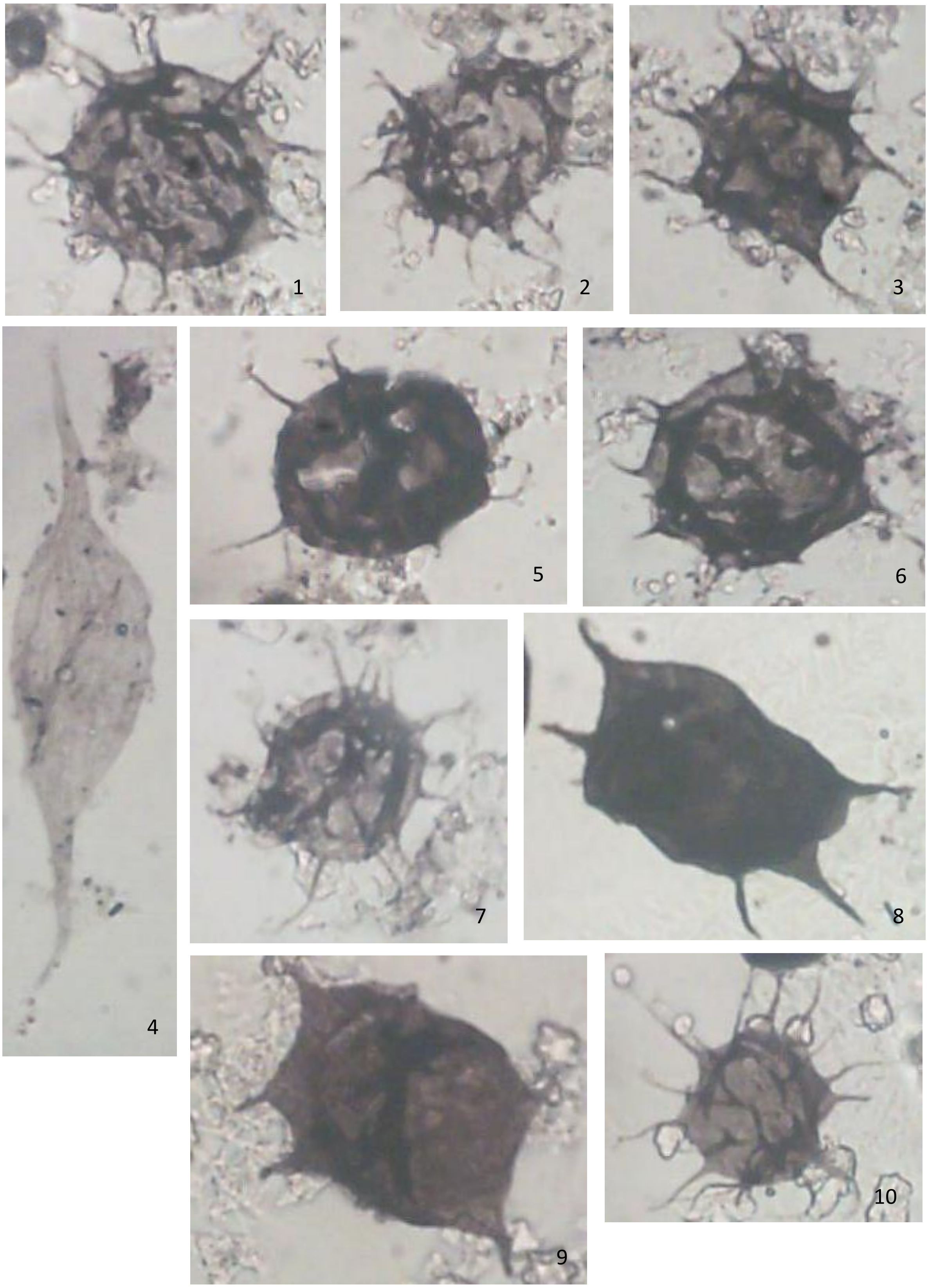


PLATE - 3

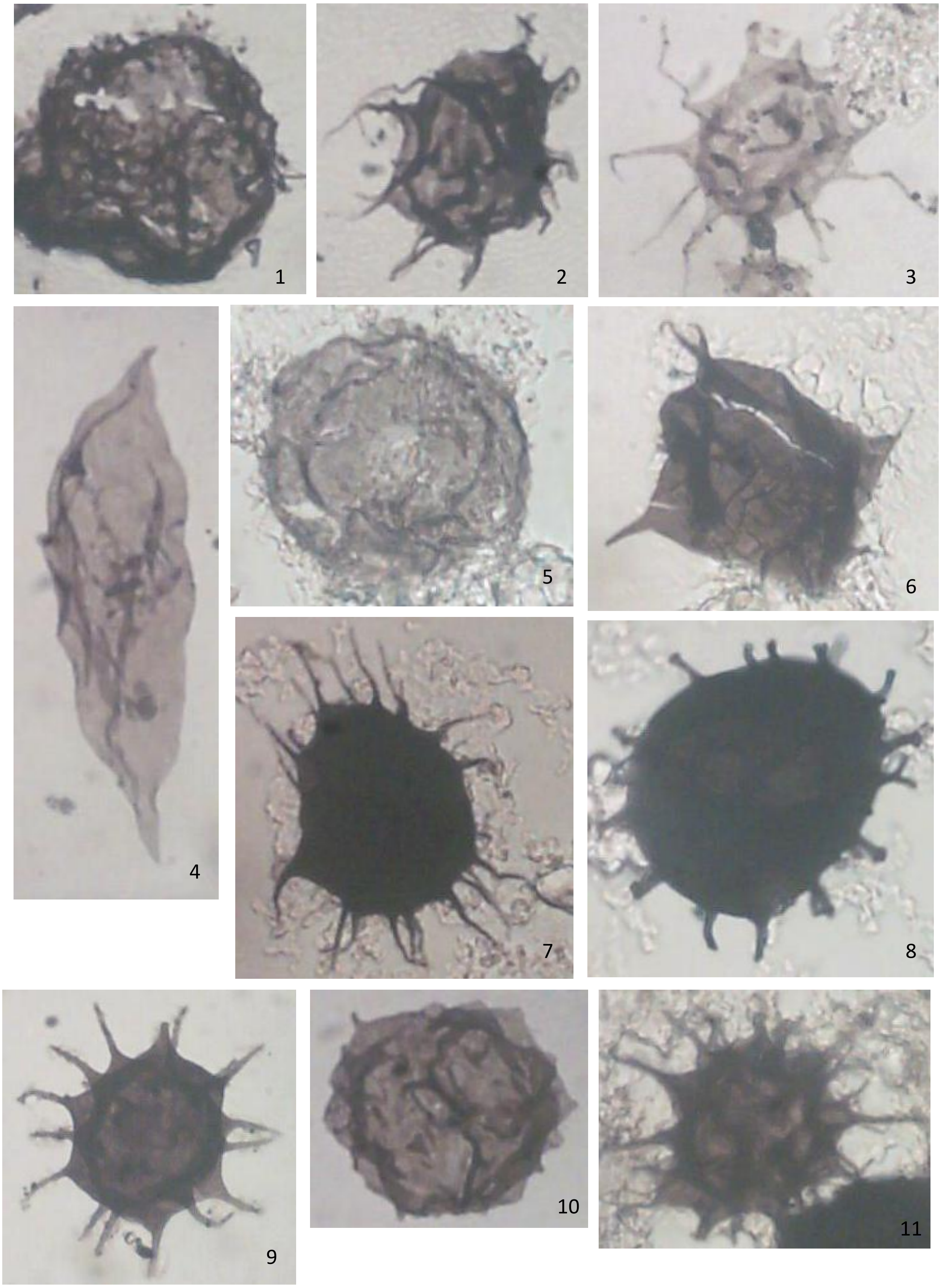


PLATE - 4

1. *Eliasum llaniscum* Fombella, 1977 , sample no. 17 , x600
2. *Vulcanisphaera britanica* Rasul, 1979, sample no. 20 , x600
3. *Goniosphaeridium uncinatum* (Downie) Kjellstrom,1971, sample no. 27 , x600
4. *Acanthodiacrodium baculatum* Vecoli, 1996, sample no. 20 , x600
5. *Timofeevia phosphoritica* Vanguestaine, 1978, sample no. 20 , x600
6. *Liosphaeridea* sp. , sample no. 20 , x600
7. *Leiofusa stoumonensis* Vanguestaine, 1973, sample no. 22 , x400
8. *Skiagia* sp. , sample no. 22 , x600
9. *Solisphaeridium akrochordum* (Rasul 1979) Moczydłowska & Stockfors, 2004, sample no. 20 , x600
10. *Solisphaeridium chines* Moczydłowska & Stockfors, 2004, sample no. 20 , x600
11. *Cymatiogalea membranispina* Deunff, 1961, sample no. 20 , x600
12. *Tectitheca prima* Rasul, 1979 , sample no. 20 , x600

PLATE - 5

1. *Stelliferidium striatulum* (Vavrdova, 1970) Deunff, Gorka & Rauscher, 1974 , sample no. 20 , x600
2. *Stelliferidium furcatum* (Deunff) Deunff, Gorka & Rauscher, 1974 , sample no. 20, x600
3. *Cymatiogalea velifera* (Downie, 1958) Martin, 1968, sample no. 20 , x600
4. *Actinotodissus ubuii* (Martin,1969) Fensomee t al., 1990, sample no. 22, x600
5. *Polygonium pungens* (Timofeev 1959 ex Martin 1969) Albani, 1989, sample no. 22 , x600
6. *Baltisphaeridium dasos* Colbath, 1979 , sample no. 20 , x600
7. *Coryphidium elegans* Cramer, AIlam, Kanes & Diez,1974 , sample no. 20 , x600
8. *Athabascaella penika* Martin & Yin Lei-Ming,1988 , sample no. 22 , x600
9. *Vulcanisphaera africana* Deunff, 1961, sample no. 31 , x600
10. *Vulcanisphaera* cirrita Rasul, 1979 , sample no. 22 , x600
11. *Poikilofusa squama* (Deunff, 1961) Martin, 1973, sample no. 22 , x400
12. *Coryphidium australe* Cramer & Diez, 1976. , sample no. 22, x600

PLATE - 6

1. *Micrhystridium filiferum* Rasul, 1979 , sample no. 22 , x600
2. *Acanthodiacrodium complanatum* (Deunff, 1961) Cocchio, 1982, sample no. 22, x600
3. *Skiagia ciliosa* (Volkova, 1969) Downie, 1982 , sample no. 22, x600
4. *Acanthodiacrodium* cf. *timofeevi* Golub et Volkova, , sample no. 22 , x600
5. *Multiplicisphaeridium parvum* (Hagenfeldt) Moczydłowska, 1998, sample no. 22, x600
6. *Stelliferidium steligerum* (Górka, 19617) emend. Deunff *et al.*, 1974, sample no. 22, x600
7. *Goniosphaeridium splendens* (Paris & Deunff) Turner, 1984 , sample no. 27, x600
8. *Impluviculusvil losiusculus* Volkova, 1990, sample no. 22, x600
9. *Stelliferidium cornitulum* (Deunff) Deuff, Górka, &Rauscher, 1974, sample no. 22, x600
10. *Actinotodissus formosus* (Gorka, 1967) Moczydłowska & Stockfors, 2004, sample no. 27, x600
11. *Goniosphaeridium dentatum* (Timofeev) Cocchio, 1982, sample no. 31 , x600
12. *Tectitheca decorata* Rasul, 1979 , sample no. 22, x600

PLATE - 4

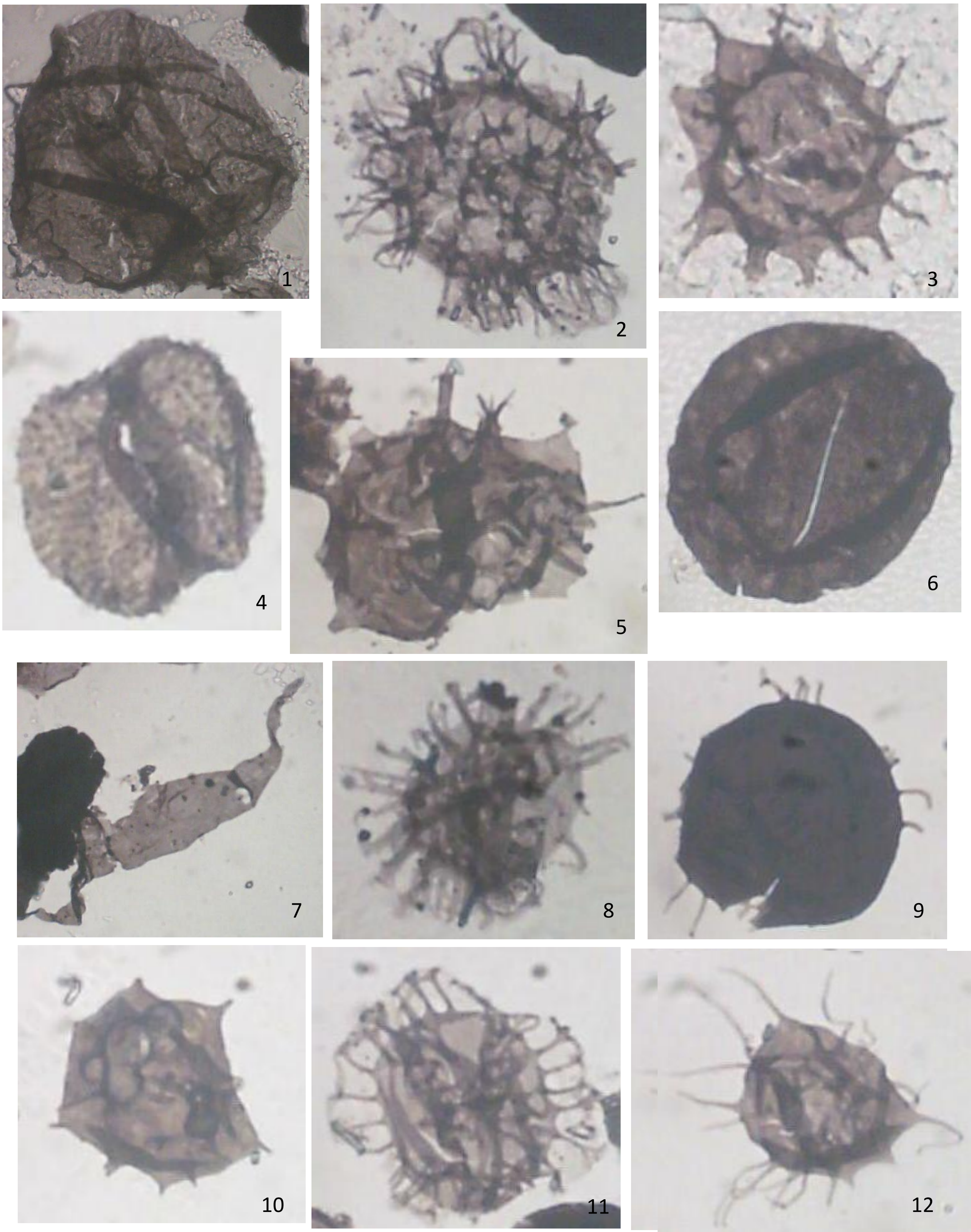


PLATE - 5

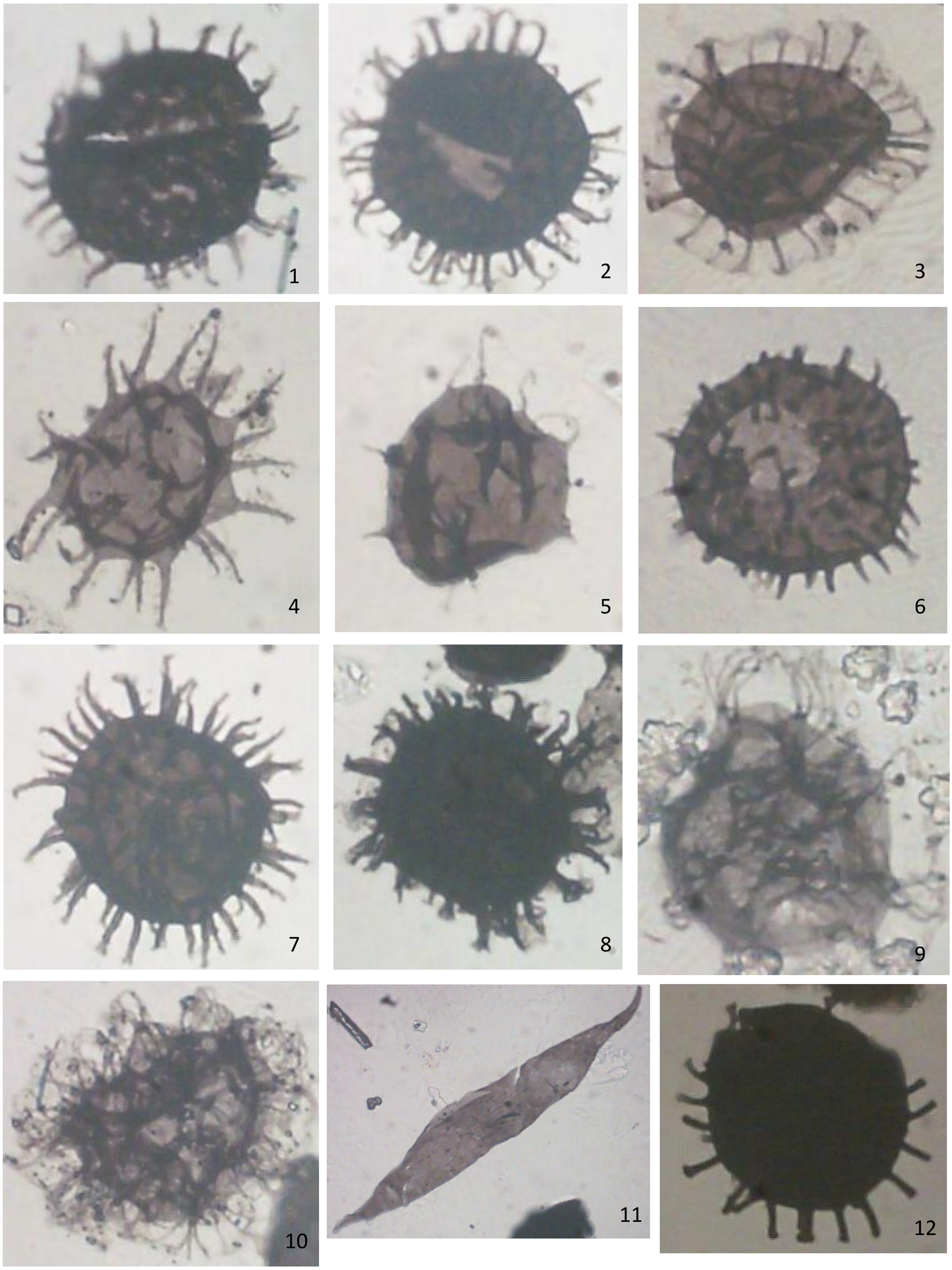


PLATE - 6

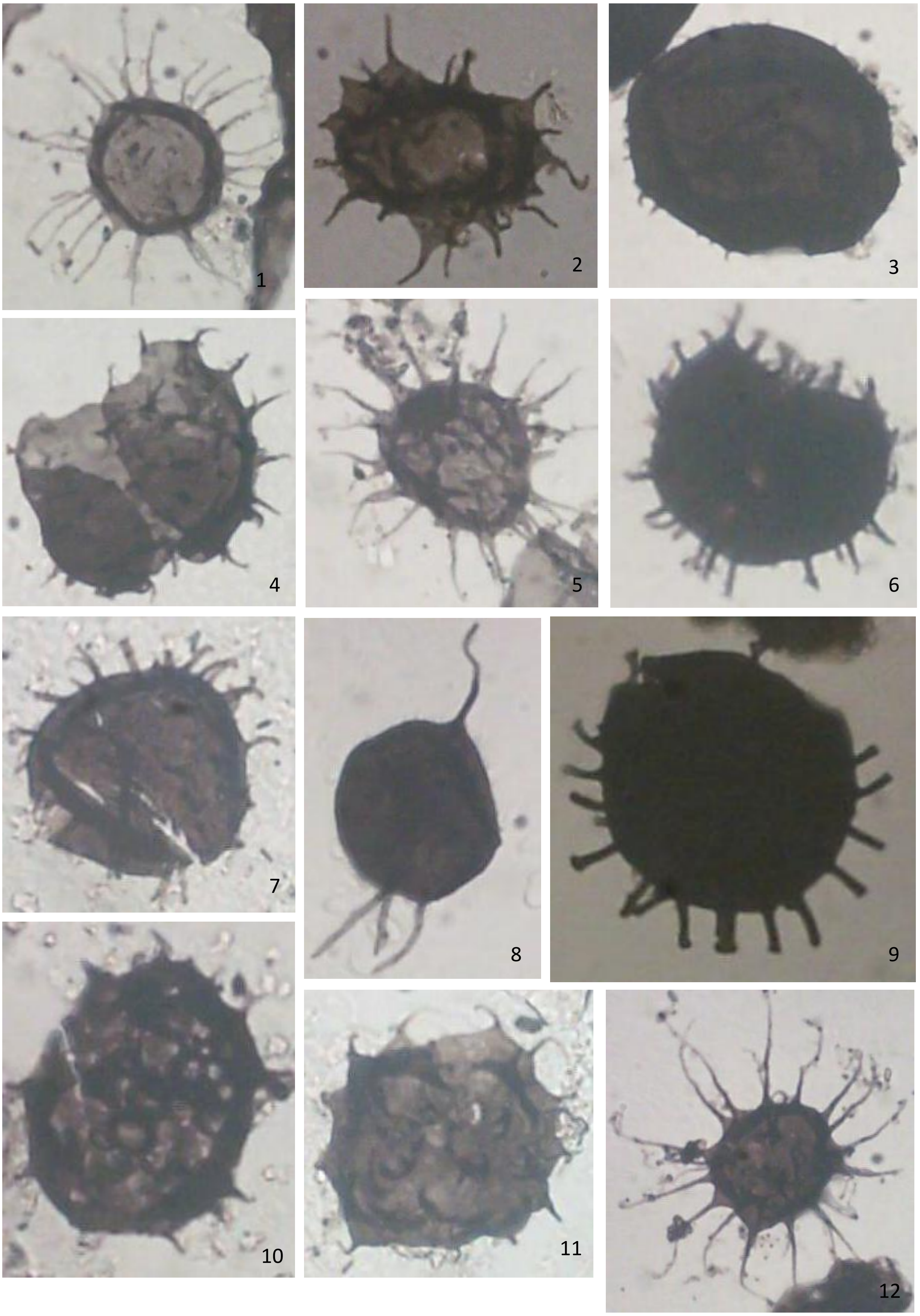
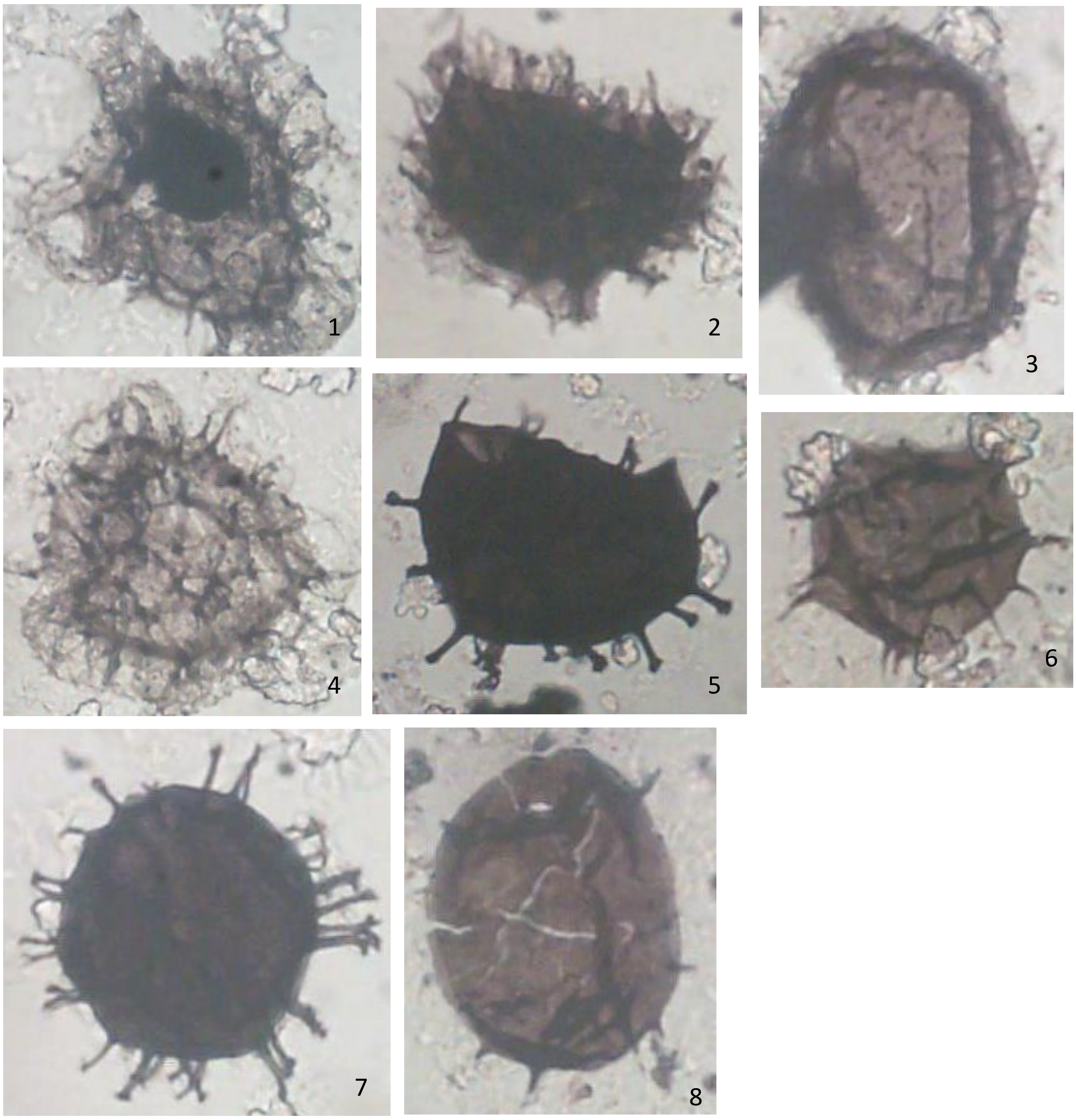


PLATE - 7

All of the figures are from sample no.31 with magnification x600.

1. *Granomarginata squamacea* Volkova, 1968
2. *Fimbriaglomerella membranacea* Kiryanov, 1974
3. *Skiagia orbiculare* (Volkova) Downie, 1982
4. *Vulcanisphaera spinulifera* (Volkova, 1990) Parsons & Anderson, 2000
5. *Cymatiogalea bellicosa* Deunff, 1961
6. *Polygonium martinae* Moczydłowska and Crimes 1995
7. *Stelliferidium gautieri* (Matin, 1972) Elouad-Debbaj, 1988
8. *Solisphaeridium lucidum* (Deunff, 1959) Turner, 1985



Maturation of the organic matters

Examination of the organic matters using transmitted light microscopy allows easily detecting the possible maturation state of the studied samples. The technique of Thermal Alteration Index (TAI) proposed by Staplin (1969) is one of the effective, easy, quick, and cheapest method for determining the maturity of source rocks. Following the color change of the palynomorphs (or other organic matter components) from light colors (immature) to orange or light brown colors(mature) and finally dark brown and black (post-mature) caused by the effect of thermal alteration can aid in determining the potentiality of the source rocks from maturity point of view.

According to Al-Haba et al. (1994) in Al-Juboury and AL-Hadidy (2009) the Khabour shales are highly mature, marine, organic-rich rocks with total organic carbon (TOC) content values of 0.9–5% by weight in Khleisia-1 and Akkas-1. They suggested that these could have generated, in part, the hydrocarbon that was encountered in the Akkas field and Khleisia-1. Baban (1996) and Al-Ameri and Baban (2002) distinguished the immature, mature, and post-mature parts of Akkas and Khabour formations in Western Iraqi Desert depending on the color change of three wide range of occurrence acritarchs (*Dixallophasis denticulata*, *Baltisphaeridium constrictum* and *Orthosphaeridium ternatu*s). They concluded that some levels of Khabour Formation in Akkas locality generated condensate, wet gas and dry gas but their analyzed samples generally didn't show adequate TOC content to consider all parts of Khabour Formation as potential source rock.

Aqrawi (1998) based on data from Al-Haba et al (1994) plotted the burial history and thermal maturation of Khabour Formation in the well of Akkas-1 and he concluded that Khabour started generating gas since Late Devonian.

In this study, and although the studied section from Khabour Formation is cropped out since millions of years but still the organic matters showed an advance thermally mature condition. The color of the palynomorphs as appears in the figures within the plates 1 to 7 are generally dark brown (TAI=3.8) or black (TAI=4.0) indicating to a post-mature source rock type. No TOC determination done for the studied samples and therefore no evaluation can be done for the existed quantity of organic matters within the studied samples. On the other hand, being Khabour Formation of Cambrian-Ordovician age means no type III or IV kerogen is generally expected to be exist in the samples (pre-plant appearance period). Accordingly, and as most of the identified organic matters are belong originally to Algae (acritarchs), therefore mainly type I (oil prone) or may be type II kerogen (oil and gas prone) are mostly expected to be the quality of the organic matters within Khabour Formation.

Conclusions

As a result of the field investigations and palynological study carried out on the outcropped section of Khabour Formation near Chlaki Nasara village and surrounded area in Iraqi Kurdistan; the following conclusions can be summarized:

- The recorded gaps within the Paleozoic succession in the Western Iraqi Desert don't represent the same formations in comparison with the outcropped Paleozoic sections in Kurdistan. The gap in Western Desert includes Prispiki and Chalki formations (Middle Devonian), whereas the gap in Kurdistan includes Akkas Formation (Silurian). Early Devonian sediments are missed in both areas.
- The nature of the contact between Khabour Formation and Prispiki Formation (existence of fossilized mud cracks) supports the idea of missing Silurian in the studied area.
- Khabour Formation can be subdivided to three lithostratigraphic units depending on variations in their lithology (lower Shale dominated unit, middle shale and sandstone unit, and upper sandstone dominated unit).
- The age of the lower unit from Khabour Formation is Late Cambrian-Tremadocian as appeared from the identified acritarch species and distinguished assemblage palynozones. No gaps recognized between Cambrian and Tremadocian.

- Paris et al. (1999) and(2004) mentioned that the marine organic walled chitinozoas started appearing in the early Ordovician (Tremadocian) and disappeared in the latest Devonian (latest Famennian). Accordingly, non observation of chitinozoans in the studied samples may be due to the old age of the studied section and non-well flourishing of chitinozoas yet. The same reason may be true with Scolecodonts and graptolites also (in addition to environmental reasons).
- The identified acritarch assemblages refer to be the studied area within the Gondwana realm from plaeoceangraphic point of view.
- The dark color of the palynomorphs and other organic matter components indicates that the lower part of Khabour Formation in the studied area is thermally within the postmature state . Accordingly, the formation may generated hydrocarbons from its mainly type I kerogen during certain period of time within its burial history.

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