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Dachstein-type Avroman Formation: An indicator of the Harsin Basin in Iraq

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ABSTRACT

A field survey was carried out in 2012 focusing on the tectonic position and the role of Upper Triassic (Upper Norian–Rhaetian) Avroman Formation outcrops located in the Zalm area of Iraq, close to the Iraq-Iran border. At this location, the Cretaceous chert-bearing strata of the Qulqula Formation are overlain by sheared mafic bodies, which are in turn topped by the cliffs of the megalodontaceae-bearing Upper Triassic Avroman Formation. Similarities in lithology, sequence and tectonics position, suggest that the Triassic section of the Bisotoun Unit from the Kermanshah Zone of Iran can be used as a tectonic analogue of the Avroman Formation. According to our model, both the Avroman and the Bisotoun units formed an intra-oceanic carbonate platform, built-up by a characteristic megalodontaceae-bearing carbonate platform assemblage during the Late Triassic.

The Harsin oceanic basin, which separated the Avroman-Bisotoun Platform from the Arabian Platform, was characterised by deep-marine sedimentation, the remnants of which form the Qulqula Formation in Iraq, and the Radiolaritic Nappe and the Harsin Mélange in the Kermanshah Zone. This tectonic setting is not unique; numerous authors suggest the existence of an oceanic rim basin, separating carbonate platform units (e.g. Oman 'exotics') from the Arabian Platform. The age of the deformation could be Late Cretaceous (Maastrichtian), but using analogues from Iran, a Palaeogene deformation also seems possible.

The Avroman Formation was interpreted to be a Dachstein-type sediment, similar to the well-studied Dachstein Formation of the Northern Calcareous Alps, Austria. Rock units, with similar lithology, or identical depositional environment and macroscopic fauna, were described by numerous authors along the Neo-Tethys suture zone from Austria to Japan, and from several tectonic units along the Panthalassa margin. The implication of this correlation is important for future studies: using well-described type localities of the marine units from the Northern Calcareous Alps as a reference, it is possible to significantly extend the available background knowledge, and to gain better insight into the Triassic regional depositional environment of the Middle East.

INTRODUCTION

The Zagros-Taurus Mountains formed during the Cretaceous to Recent collision between the Arabian and Eurasian plates. In Iraq and Iran, they are comprised of six tectonic zones oriented parallel to the Arabian-Eurasian plate boundary, as follows (Figure 1): (1) the Mesopotamian Foredeep/Arabian Gulf (part of the Arabian Plate), (2) the Zagros Fold-and-Thrust Belt, (3) the Outer Zagros Ophiolitic Belt, (4) the Sanandaj-Sirjan Zone, (5) the Inner Zagros Ophiolitic Belt, and (6) the Urumieh-Dokhtar Magmatic Arc (Stocklin, 1968; Shafaii Moghadam and Stern, 2011). Surface folding and thrusting occurred mainly during the Pliocene phase of orogeny, although evidence exists in the surrounding area for earlier, pre-Miocene, extensional and compressional episodes.

This paper presents new geological information from the Zalm area, Kurdistan Region of northern Iraq, in the NW continuation of the Kermanshah Zone of the Outer Zagros Ophiolitic Belt (Figures 1 and 2). The majority of the investigated sections are dominated by an Upper Triassic platform

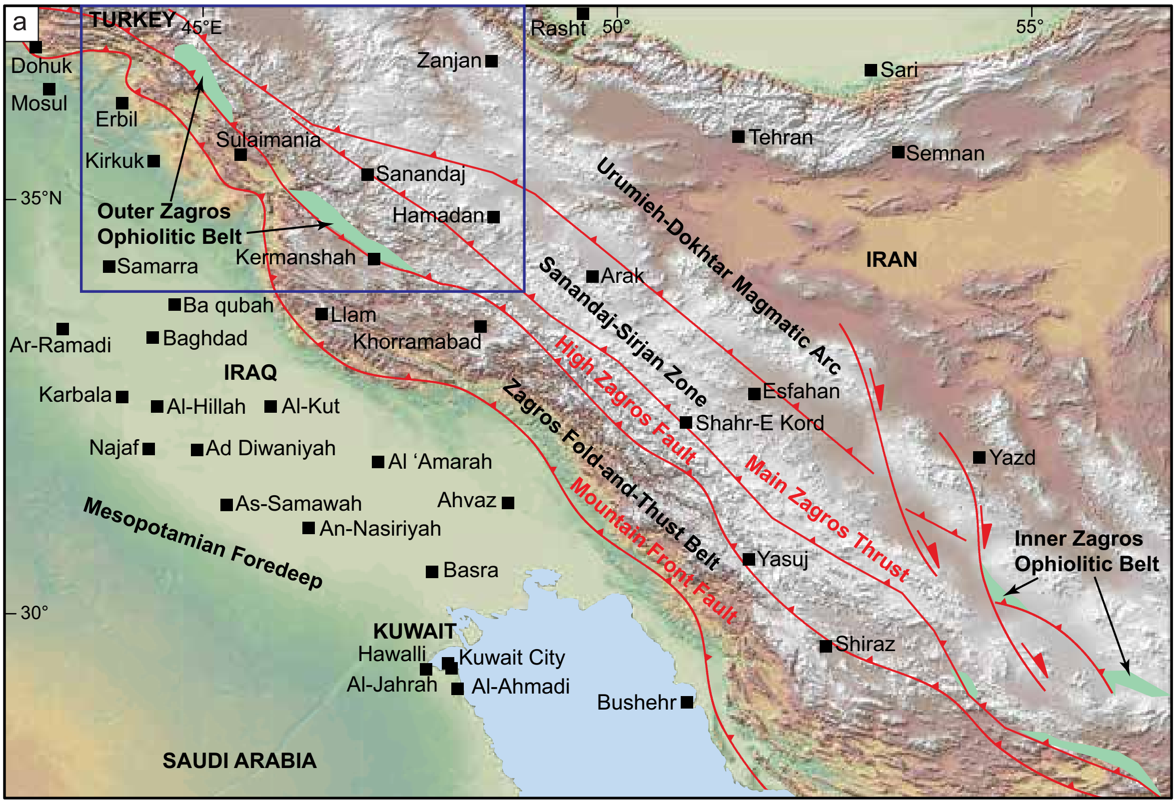


Figure 1: (a) Structural divisions of the Zagros Fold-and-Thrust Belt with the position of the Inner and Outer Zagros Ophiolitic Belt.

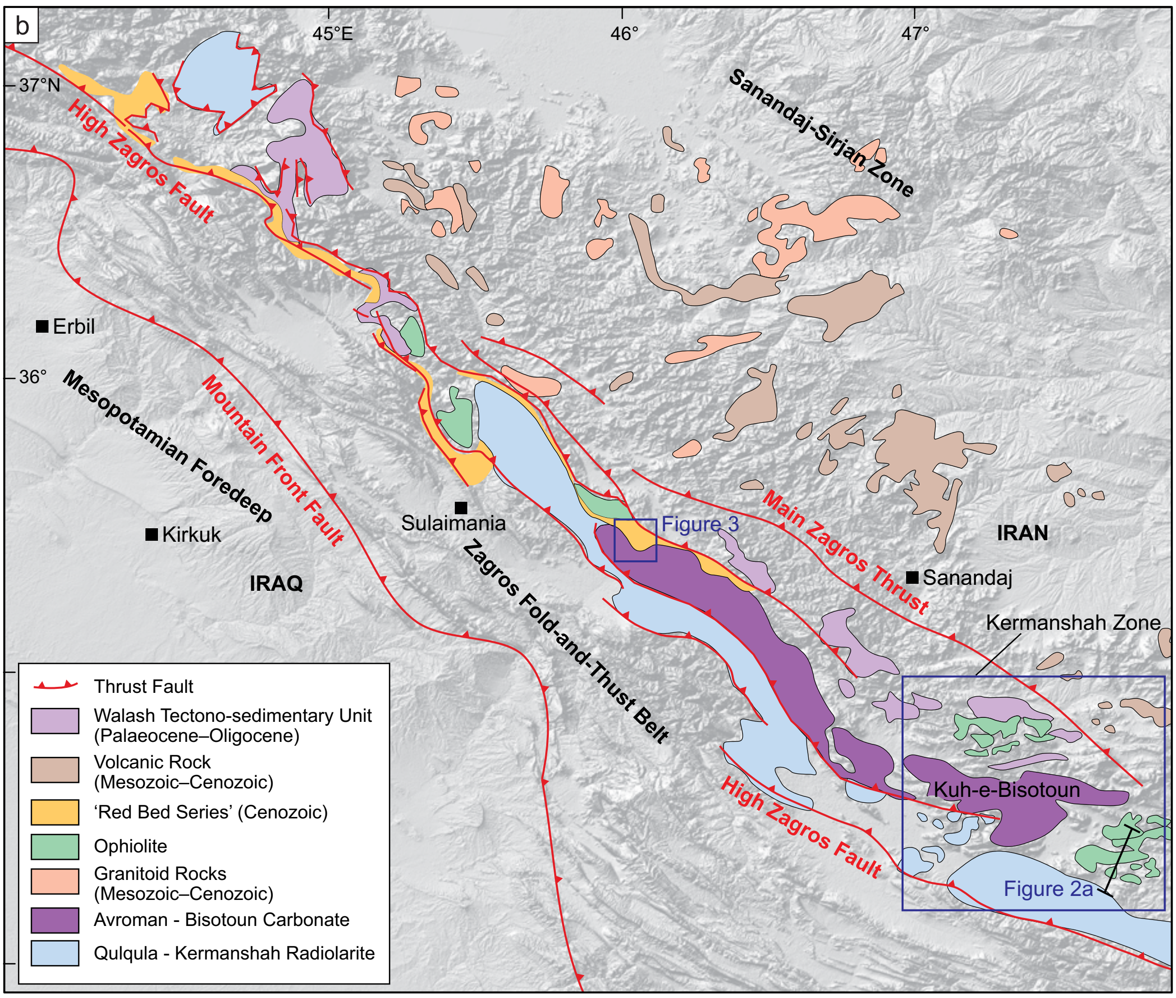
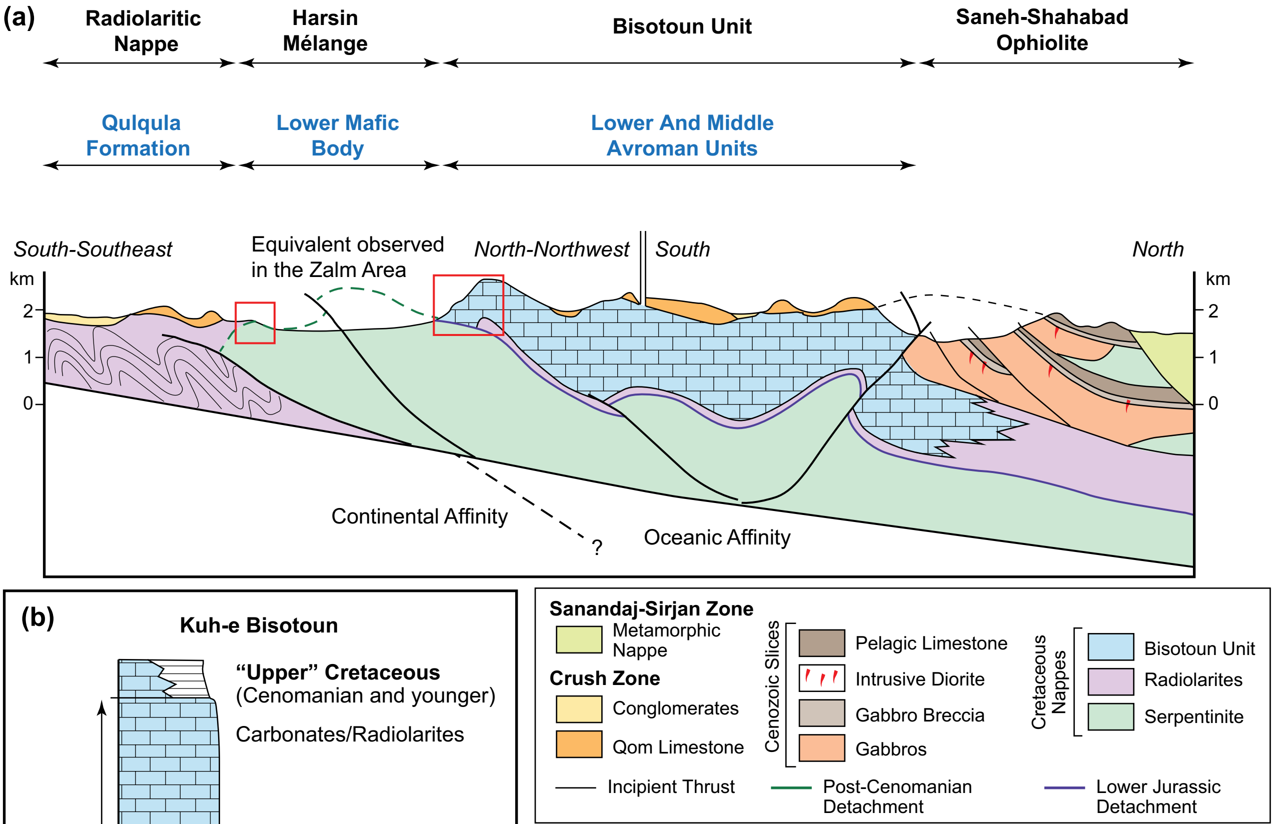


Figure 1: (b) Geological map of the Zagros Suture Zone along the Iraq-Iran border, showing the location and tectonic division of the study area (after Ali, 2012).



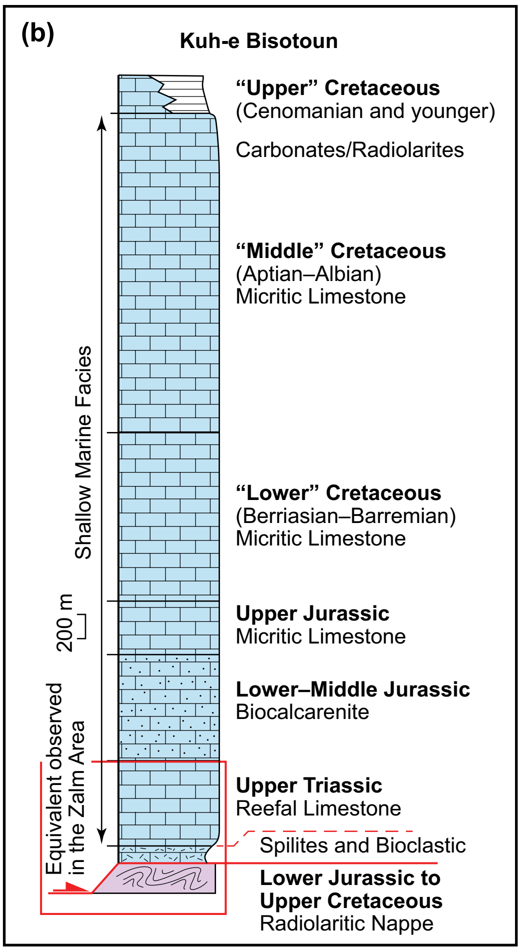


Figure 2: (a) Tentative cross-section of the Kermanshah Zone with rock names (black) after Wrobel-Daveau, et al. (2010). The blue unit names are their equivalent units from Kurdistan Region of Iraq, using the nomenclature of this study. (b) Synthetic stratigraphic log of the Bisotoun Unit in Kuh-e Bisotoun (simplified after Braud, 1978). See Figure 1 for locations.

carbonate named the Avroman Formation. This name was first introduced by Bolton (1958a) and relates to the carbonate sequence described from the Avroman Mountains near Halabja, Kurdistan Region of Iraq, which forms a NW-trending mountain range near the Iraq-Iran border (Sissakian, 2000).

The Avroman Formation comprises 800 m of light-grey, thick-bedded to massive limestone with minor amounts of clastic content. Microfacies indicators, such as bioclasts, ooids, lamination, algae and bioturbation, support an interpretation of a subtidal to peritidal environment (e.g. Bolton, 1958a; Buday, 1980; Karim, 2007). Alkali olivine basalt dykes and trachyte also occur in the formation, most likely related to Tethyan volcanic activity (von Richthofen, 1860; Pisa, 1974; Viel, 1979; Brack and Rieber, 1993). An abundance of megalodontaceae and foraminifera were described from this lithological unit, including for example, *Gemmelarodus seccoi seccoi* and *Triasina hantkeni*, which indicate a Late Norian–Rhaetian age (cf. Jassim and Goff, 2006). A similar lithological unit, the Ubaid Formation, which yielded *Neomegalodon* sp. in Wadi Hauram in southern Iraq, may be coeval to Avroman Formation (Karim and Ctyroky, 1981; Jassim and Goff, 2006; Sissakian and Mohammed, 2007).

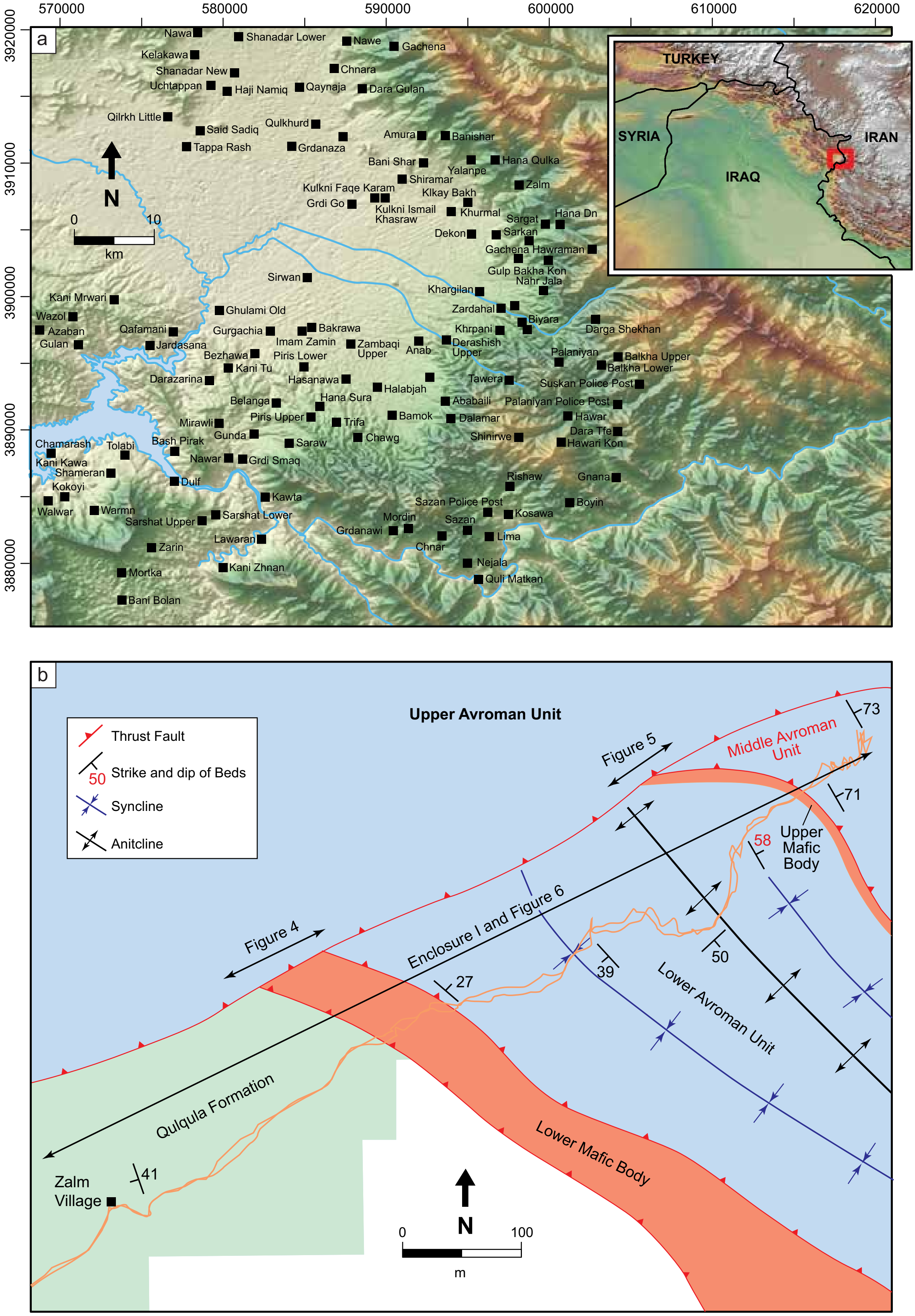


Figure 3: (a) Topographic map of the Halabja area, and (b) geological map of the Zalm Valley.

This paper focuses on the tectonic and stratigraphic role of the Avroman Formation (Figures 1 and 2). Our main goals are to: (1) extend local observations on the structural relationship and deformation history of the investigated units in the Zalm area to a larger scale; (2) confirm their Upper Triassic tectonic position by investigating the correlation of these units to those seen in the Kermanshah Zone of Iran. The Kermanshah Zone seems to be a valid structural analogue of the investigated Zalm section (Wrobel-Daveau et al., 2010; Shafaii Moghadam and Stern, 2011; Figure 2). (3) We correlate the characteristic megalodontaceae-bearing sediments of these units to the Circum-Tethyan realm, especially to the well-studied and described Austrian equivalents.

ZALM VILLAGE SECTION, NORTHEASTERN KURDISTAN, IRAQ

Close to Zalm Village in the Avroman Mountains (Figure 3), a deformed sequence of the Avroman Formation (Figures 4 and 5) crops out. Three Avroman tectonic units (Lower, Middle and Upper Avroman units) were identified. The section is intensely folded, and thrusted onto the younger Mesozoic Qulqula Formation (Karim and Baziany, 2007; Ma'ala, 2008; Al-Qayim et al., 2012; Davies et al., 2014; Ali et al., 2014) along a sheared mafic body (Lower Mafic Body). A second sheared mafic body (Upper Mafic Body) was observed between the Lower and Middle Avroman units.

Figure 4: View and geological interpretation of the Lower Mafic Body and its surroundings. Photo by Agoston Sasvari.

Sedimentological Observations

Qulqula Formation

Samples from the Qulqula Formation (Enclosure Ia–d) have been petrographically evaluated and described as planktonic foraminifera-rich wackestones with 50% lime mud content. Original grains are rare (approximately 5%) but they include planktonic foraminifera, globigerinids, sponge spicules and skeletal debris. The vast majority of grains (particularly the planktonic foraminifera and globigerinids, the dominant grain types) have been recrystallised. Primary calcite microspar has cemented the pore structures within the thin-walled globigerinid foraminifera (ca. 10%). Grains have been replaced by a later phase of calcite microspar (ca. 15%) and non-ferroan calcite (ca. 5%). A large fracture system fans out and splits into several smaller veins. It is cemented by non-ferroan calcite (ca. 10%). There are also a small percentage of stylolites (< 1%).

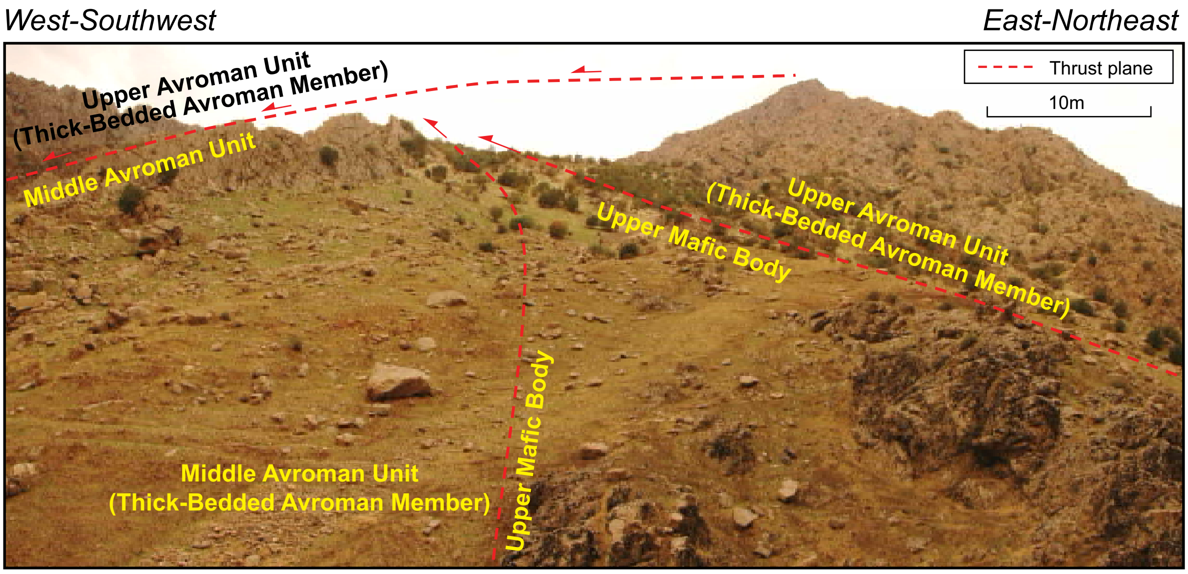


Figure 5: View and geological interpretation of the Upper Mafic Body and its surroundings. Photo by Agoston Sasvari.

Avroman Formation

Based on the field observations (Figures 4 to 6 and Enclosure I) the Avroman Formation is not lithologically uniform from a stratigraphic or sedimentological point of view. It consists of the lower "Thick-Bedded Avroman Member", and the upper "Thin-Bedded Avroman Member". Historically, these members have been mapped and described as a single formation (e.g. Sissakian, 2000; Karim, 2007).

Thick-Bedded Avroman Member

This member consists of megalodontaceae-bearing, white to light-grey, light-yellowish metre-thick beds of limestone (Enclosure Ih, i and k). Complete megalodontaceae and a significant amount of thick shell fragments were found, indicating a subtidal platform or platform edge. With the exception of the macroscopic fossils, neither bioturbation, nor ichnofossils or sedimentary structures were found. The analysed samples (Enclosure I) are texturally wackestones and packstones, and the following textures were identified.

Peloidal wackestone-packstone: limestones containing 20–30% lime mud, the grains (10–40%) are peloids, which also include thin-shelled bivalves and skeletal debris. Sometimes a much lower percentage of original grains (10%) is observed due to a dominance of cements and grain replacements. A large percentage (33.5%) of early primary equant non-ferroan calcite cement and micritised envelopes surround some of the neomorphically recrystallised grains. Small percentage (3–4%) stylolitisation of these samples was observed.

Skeletal packstone: grain-supported, consisting of 20–30% lime mud and a relatively high percentage of neomorphically recrystallised skeletal material. There is a total of 20–30% non-replaced grains with peloids and skeletal debris being the dominant grain types. There are also minor amounts of Dasycladaceae, benthonic foraminifera, echinoids, intraclasts and thin-shelled bivalves. 20% of the grains have been leached and cemented by early drusy non-ferroan calcite cement, and micritic envelopes are also present around some recrystallised bivalves and benthonic foraminifers.

Dolomitic skeletal wackestone: upwards of 44% lime mud and 18% scattered matrix replacive dolomite. Remaining grains represent 12%, including skeletal debris, thin-shelled bivalves and bryozoans, while 17% of grains (including green algae fragments, skeletal material and bivalves) have been cemented or replaced by non-ferroan calcite and microspar, which have also cemented vugs.

Thin-Bedded Avroman Member
This member consists of well-bedded, decimetre-thick beds (ca. 10–20 cm) of light-brown to medium-grey, slightly nodular limestone with small-scale spherical grains, ooids, bioclastic debris of algae and echinoderms, oncoids or probably peloids (Enclosure Ij, l and m). Minor stylolitisation was observed. The spherical clasts are completely recrystallised, well rounded, poorly sorted, and from field observations, calcareous in nature. No macroscopic fossils were observed, and except for the spherical components, the texture is micritic. At one location, a slightly nodular bed surface was observed.

In thin-section view, the Thin-Bedded Avroman Member can be described as an oolitic, mud-lean packstone, which primarily consists of neomorphically recrystallised ooids (and secondary peloid grains), which make up 60% of the rock. They have been cemented by blocky non-ferroan calcite, micritised envelopes formed around a number of grains. The matrix in parts has also been replaced by microspar and there is only 10% lime mud remaining. The remaining original grains equate to just 6% of the whole rock composition, with peloids, intraclasts, gastropods and faecal pellets (Favrina).

Structural Geological Observations

Because of the folding, the steepness of the gorge walls and the loose blocks, the structural elements were not clearly visible in the field. Accordingly a combination of field observations and satellite image interpretations were used to interpret a sequence of structures both as a geological map (Figure 3) and cross section (Figure 6). Three important deformation zones occur in the study area, and are interpreted as detachment planes below and in between the deformed Avroman units (Figures 3 to 6 and Enclosure I).

(1) Sheared mafic rocks, forming the Lower Mafic Body, were observed at the contact of the Qulqula Formation to Lower Avroman Unit (Figure 4, Enclosure Ie–f).

(2) Sheared mafic rocks, forming the Upper Mafic Body, were mapped at the contact of Lower to Middle Avroman units (Figure 5, Enclosure In and o).

(3) The third deformation zone occurs at the contact between the Middle to Upper Avroman units (Figures 3 and 6), and is mainly interpreted from remote field observations and satellite images. Detailed observations were not possible in the area due to the large number of unexploded objects and the proximity of the state border.

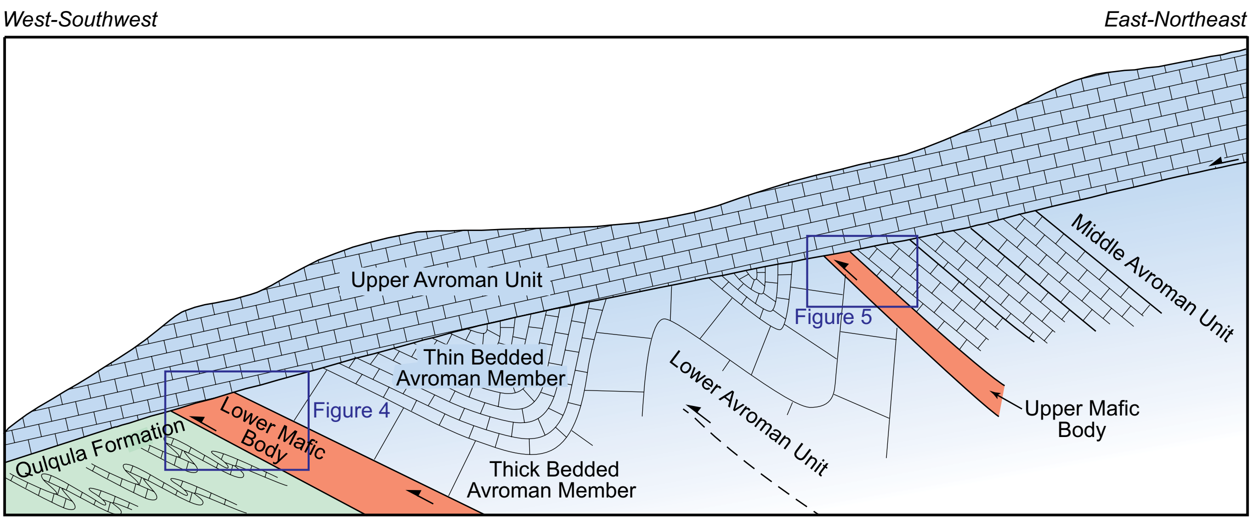


Figure 6: Geological cross section of the Zalm area.

Lower Mafic Body between the Qulqula Formation and Lower Avroman Unit

The first deformation zone was identified immediately above the dark-grey radiolaritic Qulqula Formation (Bolton, 1958b; van Bellen et al., 1959; Figures 3, 4, 6 and Enclosure Ie–g), which forms the lowermost part of the section. The age of this formation is poorly constrained; Karim et al. (2009) assigned a Late Cretaceous (Early Maastrichtian) age. The topmost chert beds are overlain by sheared mafic rocks of the Lower Mafic Body; this contact is close to the NE edge of Zalm. Due to recent road constructions, the contact has become visible, but the relationship of the chert to mafic material is not visible. The Lower Mafic Body (Figure 4) is slightly weathered and subsequent alteration has obscured its internal structures. The estimated thickness of the Lower Mafic Body is approximately 60–80 m.

Thick-bedded, megalodontaceae-bearing limestones of the Lower Avroman Unit overlie the Lower Mafic Body (Figures 3, 4, 6 and Enclosure I). The contact between the mafic body and carbonates is structural and not sedimentological. The lowermost bed of the thrusted Lower Avroman Unit is nearly parallel to the NE-dipping thrust plane. Significant change in the bedding is observed from the Qulqula Formation to the Lower Avroman Unit outcrops: the Qulqula Formation beds are tilted by an average about 45˚ to the SW whereas the Avroman beds dip by about 40˚ to the NE.

SE-vergent thrusting is indicated by the great number of detachment planes, the geometry of shear indicators, the overall geometry of the ophiolitic body, as well as the geometry and bedding of the overlying Lower Avroman Unit limestone (Figure 6).

Upper Mafic Body between the Lower and Middle Avroman Units

The second deformation zone was observed between the Lower and Middle Avroman units, approximately 700 m ENE from Zalm Village (Figures 3, 5, 6 and Enclosure I). Both of these units dip 70–85˚ to the ENE, and are separated by the Upper Mafic Body. The contact between the carbonate and mafic body is partially obscured, but the overall linear geometry of the mafic is clearly visible, both in the landscape and on the satellite imagery.

Loose blocks, most likely sourced from this mafic body, are found in the surroundings of the upper mafic detachment plane, and cubic metre-size, unsorted, polymictic, clast-supported chert breccia blocks are also observed at this location. The clast material is dominated by chert and limestone with subordinate amounts of rectangular mafic clasts. No sedimentological structures (bedding, gradation) were observed.

The position and the geometry of the sheared mafic body, as well as the bedding geometry of both the Lower and Middle Avroman units, can be used to identify SE-vergent thrusting, parallel to the Lower Mafic Body geometry.

Contact between the Middle to Upper Avroman Units: Indication of a Young Overthrust?

The Middle Avroman Unit is tectonically uniform (Figures 3, 6 and Enclosure I), with no visible internal thrust planes and/or sheared mafic bodies. Elevated cliffs with almost horizontal and tectonically undisturbed bedding, tilted slightly to the SW, overlie both the highly folded Lower and Middle Avroman units. According to field observations, this Upper Avroman Unit is composed of the same thick-bedded carbonates as the Lower and Middle Avroman units, and despite the lack of outcrop data, this carbonate unit can be associated with the Avroman Formation. The Upper Avroman Unit is less deformed, and structurally cuts the folds of both Lower and Middle Avroman units.

BASIN-SCALE INTERPRETATION AND DISCUSSION

In the recent tectonic model, which is in agreement with Ali (2012) and Ali et al. (2014), the Kermanshah Zone (Figure 2) was used as a structural and sedimentological analogue of the Zalm section. Palaeo-facies correlation of the investigated units helped reconstruct the palaeo-tectonic position and deformation of the structural units of the study area (Figure 7). The significance of

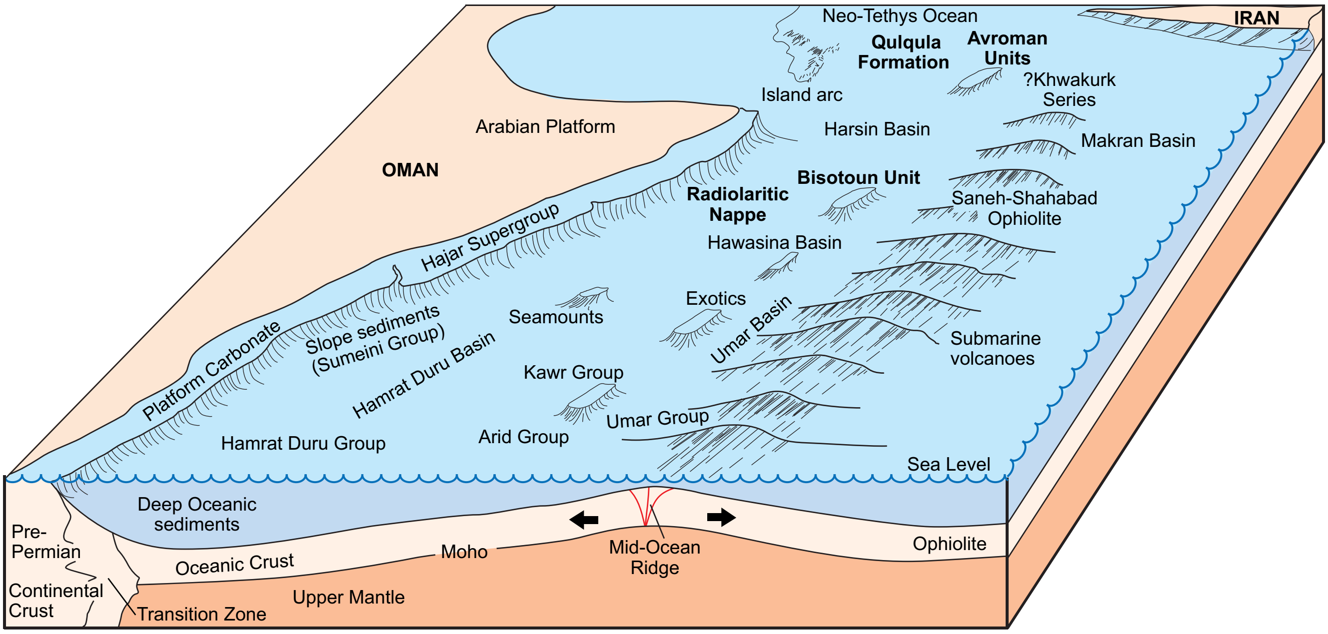


Figure 7 : Original model of Hanna (1995) with the Kermanshah Zone and Zalm area tectono-sedimentary units.

the Kermanshah Zone deformation model is to illustrate the existence of the Triassic Harsin Basin equivalent in Kurdistan, separating the Arabian Platform from the intra-oceanic Bisotoun Unit (e.g. Wrobel-Daveau et al., 2010). The basal part of the Bisotoun Unit is built up by megalodontaceae-bearing platform carbonates (Braud, 1978, 1989), which are similar to the Avroman Formation (see below).

The position, stratigraphic tectonic sequence, as well as tectonic model for the Kermanshah Zone are not unique. A similar model for the Oman 'exotics' (e.g. Béchennec, 1987; Béchennec et al., 1990; Pillevuit et al., 1997) suggests the existence of an oceanic rim basin, separating a carbonate platform unit from the Arabian Platform margin (Figure 7). In this early model, a bipartite nature of the Hawasina branch of the Neo-Tethys Ocean was interpreted. The original model was to assume a chain of platforms in the middle of the Hawasina branch (Oman 'exotics' and Kawr Group, equivalent of the Bisotoun Unit), separating the Hamrat Duru Basin (equivalent of the Harsin Basin) and the Umar Basin.

Tectono-sedimentary Units of the Kermanshah Zone

The Kermanshah Zone in Iran is exposed along the Main Zagros Thrust, and is composed of the following elements (Wrobel-Daveau et al., 2010; Shafaii Moghadam and Stern, 2011; Figures 2, 7 and 8a).

The ***Radiolaritic Nappe*** interpreted to be the substratum of a continental rim basin (Harsin Basin, Ricou et al., 1977; Braud, 1978, 1989), separating the carbonate dominated Bisotoun Unit (see below and Figures 7 and 8a) from the Arabian Platform. According to Gharib (2009), its age is early Pliensbachian to early Turonian. In the Early Jurassic–Cenomanian period, sedimentation remained cherty in the Harsin Basin, and was controlled by carbonate deposition in the Bisotoun Unit. The Qulqula Formation in the Avroman Mountains area of northern Iraq was associated to the 'Kermanshah Radiolarite' by Ali et al. (2014) (Figures 2 and 8).

The ***Harsin Mélange*** composed of serpentinites, radiolarites, lava beds and carbonate blocks. The Harsin Ophiolite, SW of the Bisotoun Unit, is seen as the oceanic crust of a small basin between the Arabian and the Bisotoun Unit (Figures 2, 7 and 8a).

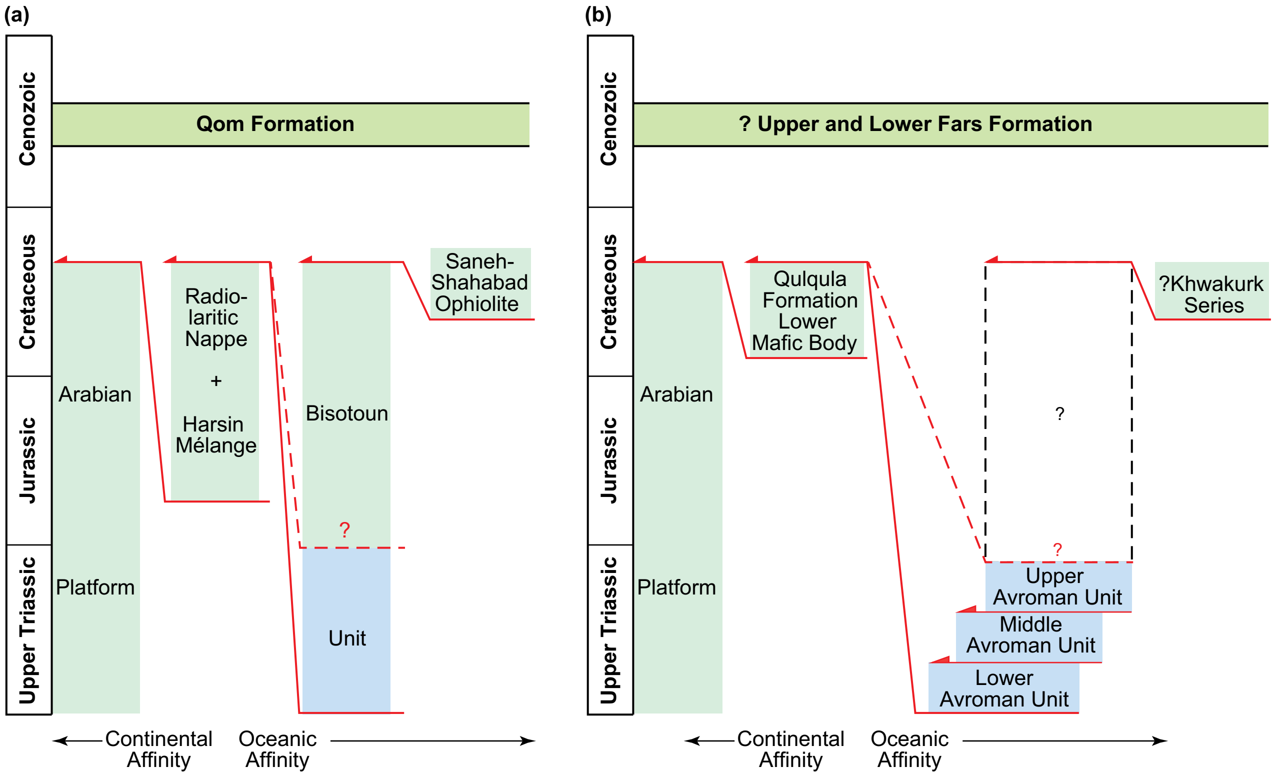


Figure 8: Sequence of deposition and deformation in: (a) Kermanshah Zone, and (b) Zalm area. Red lines indicate thrusting age and vergency; blue units are the equivalents of the Dachstein Formation on the Northern Calcareous Alps. Dashed lines and polygons indicate assumed thrust planes and units.

The ***Bisotoun Unit*** is composed of 1,500–3,000 m-thick Upper Triassic–Cenomanian platform carbonates, with megalodontids in the Triassic section (Braud, 1978, 1989). Ricou et al. (1977) and Braud (1978, 1989) suggested the existence of a radiolaritic trough (Harsin Basin), separating the Bisotoun Unit from Arabia since the Late Triassic (Figure 7). The nature of the original substratum beneath the Bisotoun Unit remains unknown but is assumed to be continental crust (Braud, 1978, 1989). Such a limestone, deposited in a shallow-water environment over more than 100 million years, could be consistent with a continental substratum (Wrobel-Daveau et al., 2010). In their work, Ali et al. (2014) assumed the same tectonic position for the Avroman Mountains in the Zalm area as for the Bisotoun Unit, and interpreted them as the same structural unit (Figures 2 and 8).

The ***Saneh-Shahabad Ophiolite*** has an intra-plate oceanic island arc to island arc chemical signature (e.g. Desmons and Beccaluva, 1983) and has been assigned a Late Cretaceous age (Figures 2, 7 and 8). Ali et al. (2014) associated this ophiolitic body with a mafic unit, tectonically overlying the Avroman Formation in the Avroman Mountains.

The above noted units (called 'Cretaceous Nappes' after Braud, 1978) were emplaced during the first, Campanian obduction in Iran (Braud, 1978; Homke et al., 2009), and Oman (e.g. Boote et al., 1990; Warburton et al., 1990; Breton et al., 2004), and are unconformably overlain by the Oligocene–Miocene Qom Formation (Figure 8a). In a subsequent phase of deformation, both the Cretaceous Nappes and the Qom Formation were folded and thrusted, together with Cenozoic turbidites and pelagic limestones, as a result of the second collision between the Central Iran Block and the Eocene arc (e.g. Leterrier, 1985).

Different models were proposed to explain the origin, evolution and tectonic position of these units. Agard et al. (2005) consider that the Bisotoun Unit is a tectonic window located in the footwall of the Saneh-Shahabad south-verging thrust. In their model, the thrusting of the Bisotoun Unit is a late and out-of-sequence deformation event.

In the model of Wrobel-Daveau et al. (2010), the Bisotoun Unit is the cover of a micro-continental block and not a tectonic window. This unit is thrusted between the Tethyan units (Saneh-Shahabad Ophiolite) and the Harsin Basin (exhumed mantle and its radiolarite filling). According to Wrobel-Daveau et al. (2010), two oceanic domains are proposed for the evolution of the Kermanshah Zone. One domain is the Harsin Basin (continental rim basin) separating the Arabian Platform and the Bisotoun Unit, and a second, the Neo-Tethys Ocean, initially located northeast of the Bisotoun Unit.

Qulqula Formation

In the case of the Qulqula Formation, the large percentage of lime mud, planktonic foraminifera including globigerinids, indicative of a pelagic, relatively deep-marine, sub-wavebase environment. These results are in agreement with the observations of Karim (2007) and Karim et al. (2007). According to Ali (2012) and Ali et al. (2014), the Qulqula Formation is interpreted as the equivalent of the Radiolaritic Nappe of the Kermanshah Zone from both depositional and tectonic points of view. Using this analogue, the Qulqula Formation is a good indicator of the same rim basin as interpreted by Wrobel-Daveau et al. (2010); in the same way, the Qulqula Formation can be interpreted as a tectonically affected remnant of the Harsin Basin.

Lower and Upper Mafic Bodies

Both the Lower and Upper Mafic Bodies are believed to represent a significant tectonic contact below and in between the Avroman units. The available geological information does not allow excluding a more complex tectonic position: an overturned Lower Avroman Unit topped by overturned mafic fragment, or a more complex tectonic window position (Agard et al., 2005). However, according to our structural observations, these scenarios are unlikely. If we use the Kermanshah Zone as a model for the Zalm region, the tectonic significance of the Lower Mafic Body is crucial: this unit could be indicative of a fragment of the oceanic basement either below the Qulqula Formation, and/or the mafic basement of the Lower Avroman Unit, and in this scenario, it may be an equivalent of the Harsin Mélange of the Kermanshah Zone. The Upper Mafic Body can be interpreted as an out-of-sequence, back-thrusted fragment of the Lower Mafic Unit. An alternative interpretation is that the Upper Mafic Body is an exhumed mafic 'basement' of the Avroman Formation.

Avroman Formation

The peloidal wackestone and packstone samples described from the Avroman Formation are part of a back-shoal, subtidal setting. The presence of green algae in samples of this formation may indicate a lagoonal environment. The overall microfacies type indicates shallow, inner-neritic environment with relatively high water energy. The overall diagenetic history for the Avroman Formation shows early leaching and cementation of the grains by an equant calcite spar, with some later grain replacements and finally followed by mechanical and chemical compaction, forming the fracture systems and stylolites.

Both lithological characteristics and the tectonic position of the Avroman Formation confirms its correlation to the megalodontaceae-bearing 'Bisotoun Formation' of the basal part of the Bisotoun Unit in the Kermanshah Zone, in agreement with the observations of Ali (2012) and Ali et al. (2014). Taking these observations and interpretations of both the radiolaritic and the sheared ophiolitic units into consideration, the Avroman Formation could have formed an 'exotic' block, separated by the Harsin Basin from the Arabian Platform. In this case both the Qulqula Formation and the Avroman Formation have oceanic basement and are not continental.

Despite the good tectonic and stratigraphic correlation, the Avroman Formation could only be a good equivalent of the lower part of the Bisotoun Unit (Enclosure I). According to the previous and recent observations (e.g. Bolton, 1958a; Buday, 1980; Jassim and Goff, 2006; Karim and Baziany, 2007; Karim, 2007), both the thickness and the confirmed age of the Avroman Formation seem to be different from those from the original Bisotoun Unit in Iran. The youngest age reported from the Avroman Formation is Rhaetian (Jassim and Goff, 2006) and its maximum thickness (Bolton, 1958a) is about

300 m. In the case of the Bisotoun Unit (e.g. Ricou et al., 1977; Braud, 1978), the youngest observed age was Late Cretaceous (Cenomanian and younger), and the lithological succession is much thicker (1,500–3,000 m).

Several interpretations can explain these differences: (1) The Zalm section is complete, and assumed younger units (with Early Jurassic to Cenomanian age) were eroded. (2) The Zalm section could be incomplete, and younger units (with Early Jurassic to Cenomanian age) could be expected in the area close to the Iraq-Iran border or in Iran. (3) The Bisotoun Unit type section (Braud, 1978, 1989) is tectonically disturbed and the Jurassic and Cretaceous units are not in an allochthonous position relative to the Upper Triassic units (this solution is shown in Figure 8a).

Age of Deformation

The age of deformation along the Lower and probably the Upper Mafic Body is younger than the ?Late Cretaceous (Early Maastrichtian) age of the Qulqula Formation (based on Karim et al., 2009). In the case of these shear zones, taking the analogue from Iran into consideration, a Late Cretaceous (Maastrichtian) or younger thrusting age could be suggested.

The Upper Avroman Unit is less deformed than the Lower and Middle Avroman units. However, the Upper Avroman Unit structurally cuts the folds of both Lower and Middle Avroman units, and as such, structural emplacement of the Upper Avroman Unit is definitely younger than the thrusting of the Lower Avroman Unit. It could be assigned to the same Late Cretaceous (Maastrichtian) deformation age, but using the same analogue from Iran, a Palaeogene deformation is also possible (Leterrier, 1985).

TETHYS-SCALE SEDIMENTOLOGICAL INTERPRETATION AND DISCUSSION

During the Carnian a large carbonate platform system developed along both the northern and the southern margins of the Neo-Tethys Ocean, leading to the accumulation of km-thick platform carbonates (e.g. Kiessling et al., 1999) with easily identified Upper Triassic megalodontaceae fauna. These platform carbonates were described by numerous authors along the Neo-Tethys suture zone from Austria to Japan, throughout Siberia, Australia, and from several tectonic units along the Panthalassa margin (Enclosure II). The remains of these sediments are well preserved in the Dachstein area of Austria, which is the type locality of the Dachstein Formation.

In this paper, the Avroman Formation of the Zalm area is correlated to the basal part of the Bisotoun Unit (type section at Kuh-e Bisotoun). According to the age, fossil content and depositional environment, the Avroman Formation is interpreted to be a Dachstein-type sediment, similar to the well-described Dachstein Formation of the Northern Calcareous Alps, Austria.

As a consequence of this interpretation, the basal part of the Bisotoun Unit type section could be an equivalent of the Dachstein Formation as well. Possible correlation of the Ubaid Formation needs further clarification, but accepting the original observations of Karim and Ctyroky (1981) on *Neomegalodon* sp. fragments from the Ubaid Formation (Wadi Hauram area), the Ubaid Formation can also be interpreted as a Dachstein Formation equivalent.

Dachstein Formation: Sediment of the Dachstein-type Platforms

One of the first identified and most typical Upper Triassic carbonate platform-related units is the megalodontaceae-bearing Dachstein Formation. The Dachstein Nappe of the Northern Calcareous Alps (*sensu* Plochinger, 1995) is named after the small village of Dachstein, and refers to both a tectonic unit and a facies zone (e.g. Mandl, 2000). The Dachstein Nappe is characterised by thick-bedded or massive platform limestones (Dachstein Limestone of Simony, 1847) and dolomites (Dachstein

Dolomite and/or Hauptdolomit). This unit and its equivalents have been studied since the 19th Century across Austria, Germany, Italy and Hungary (e.g. Simony, 1847; Peters, 1855; Gumbel, 1862), and this unit was identified and documented by several authors throughout the Neo-Tethys realm (e.g. Kiessling et al., 1999). Megalodontids were described from several tectonic units related to the Neo-Tethys realm (Enclosure II), allowing us to correlate these Tethyan sediments over much of the Tethyan margins.

Dachstein-type platforms (Haas, 2004) were developed on rapidly subsiding passive continental margins, indicating regional geodynamic control. In the latest Carnian (Tuvalian), a distinct transgressive pulse led to widespread flooding and sedimentation on top of the Lower Carnian Wetterstein carbonate platforms (e.g. Tollmann, 1976). The sea-level change caused a complex pattern of local reef patches separated by local depressions.

In the early stage of Dachstein platform growth (Late Carnian–Late Norian), the palaeogeographic setting controlled the facies polarity. Opening of the Neo-Tethys Ocean resulted in a fairly uniform, coastline-parallel, facies zonation. The outer platform is characterised by deposition of oncoidal and ooidal limestones and patch reefs. In the inner platform, deposition of a cyclic bedded, intertidal to subtidal carbonate succession took place. The inner platform was affected by pervasive early diagenetic dolomitisation under the prevailing semi-arid climate resulting in the deposition of the 'Dachstein Dolomit' and its equivalents ('Hauptdolomit', 'Dolomia Principale').

Chronostratigraphy of the Dachstein-type platform carbonates is based mainly on the megalodontaceae fauna (Végh-Neubrant, 1982): *Neomegalodon carinthiacus*, *N. boeckhi*, *N. triqueter pannonicus*, and *Corcucardia hornigii hirnigii* are indicative of the Carnian. The presence of *Neomegalodon complanatus complanatus*, *N. guembeli guembeli*, *N. boeckhi*, *Gemmellarodus seccoi seccoi* and *Dicerodardium curionii* indicate a Norian age. The locally rich foraminifera assemblage (e.g. Oravecz-Scheffer, 1987) allows subdivision at the stage and locally at the substage level.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

This study confirms that the Qulqula Formation and the Avroman Formation in the Avroman Mountains, Iraq, have identical tectonic position to the Radiolaritic Nappe and the Bisotoun Unit of the Kermanshah Zone, Iran. Sheared mafic bodies between the Avroman units are interpreted as deformed units with oceanic crust origin, acting as a Qulqula/Avroman and intra-Avroman detachment planes. This study suggests the tectonic independence of the Avroman Formation from the Arabian Platform margin. We propose that they are separated by the northerly continuation of the Harsin Basin, which formed the depocentre of the Qulqula Formation. The age of the deformation may be Late Cretaceous (Maastrichtian), but using analogues from Iran, a Palaeogene age is also possible.

The Qulqula Formation was deposited in a deep-marine environment, similar to the setting of the Harsin Basin to the south, and is interpreted as coeval to the Radiolaritic Nappe in the Kermanshah Zone of Iran. The Avroman Formation is interpreted as the lateral equivalent of the basal part of the Bisotoun Unit of the Kermanshah Zone. These correlations are based on their age-indicative fossil contents, similarity of facies, and tectonic positions. The Harsin Basin may therefore have separated the Avroman-Bisotoun Platform from the Arabian Platform, and represents the continuation of the Hawasina and Hamrat Duru basins of Oman (Glennie et al., 1974; Béchennec, 1987; Béchennec et al., 1990; Pillevuit et al., 1997).

Based on their Late Triassic age, fossil content and similar facies, the Avroman Formation and Bisotoun Unit could be associated with Dachstein-type deposition, similar to the Dachstein Formation of the Northern Calcareous Alps of Austria. Using these proposed correlations, the well-studied Alpine reference sections could be used to gain a better understanding of the Triassic of the Middle East and Peri-Tethyan regions.

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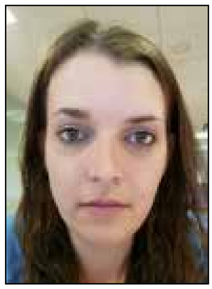

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Dachstein-type Avroman Formation:
An indicator of the Harsin Basin in Iraq
Agoston Sasvari, Laura Davies, Andrew Mann,
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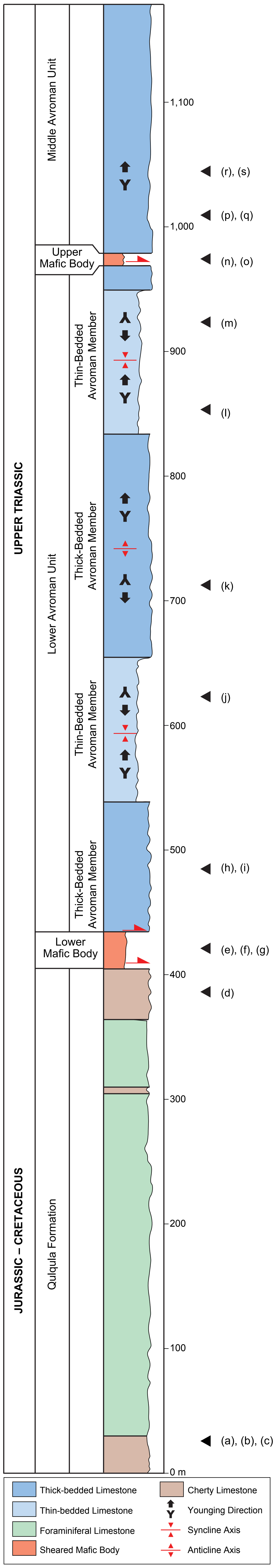
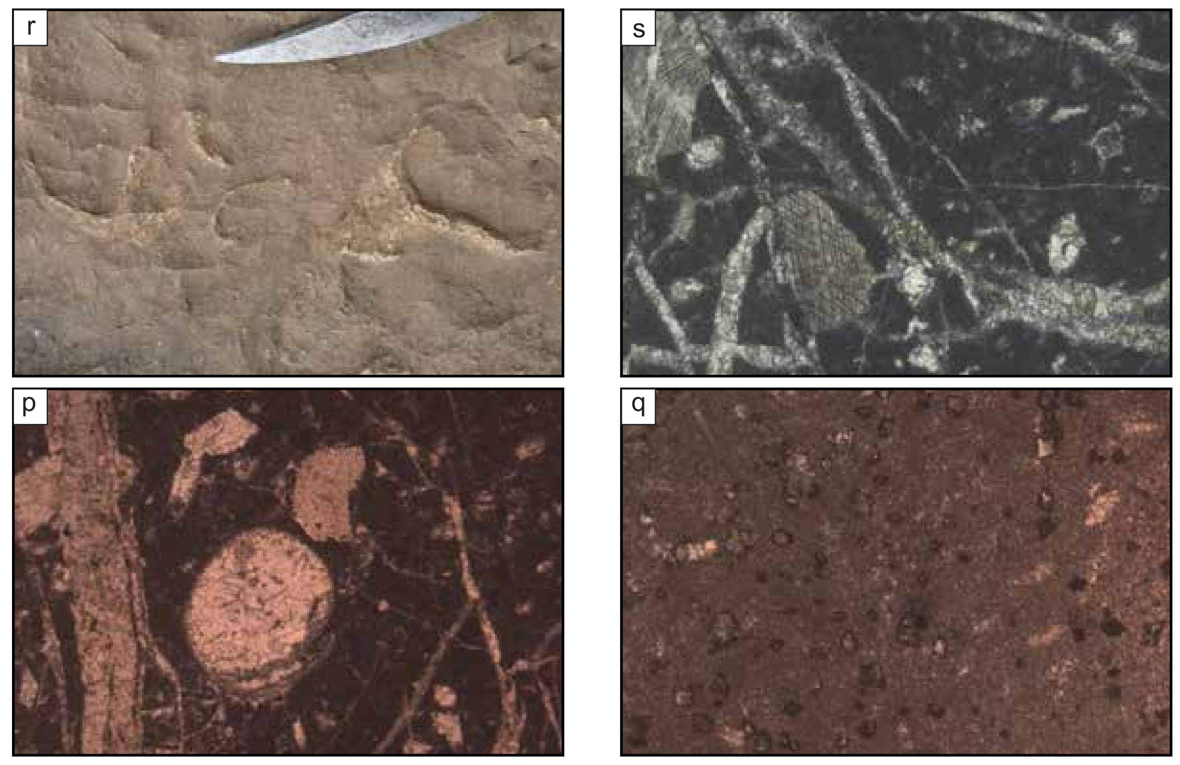
GeoArabia, 2015, v. 20, no. 4, p. 17-36, with 2 Enclosures

ENCLOSURE I



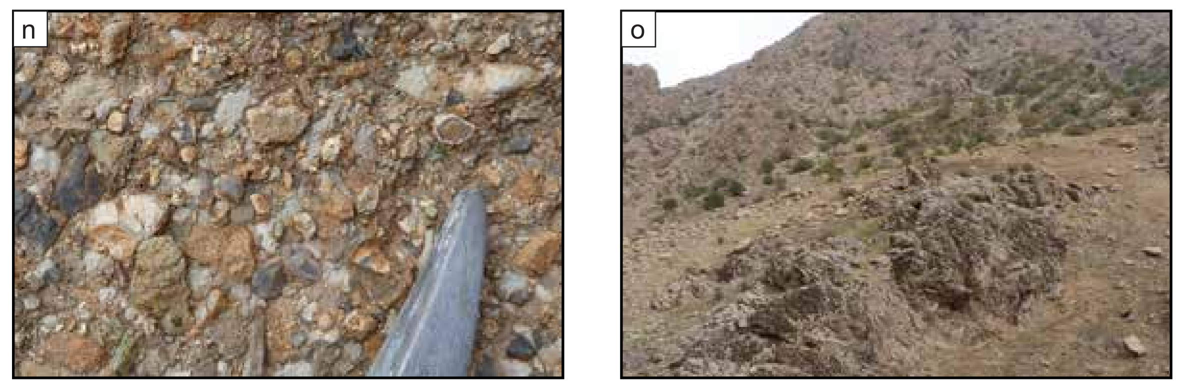
Enclosure I: Lithological column, field pictures and microphotographs. Letter "Y" shows younging upwards direction. Photos by Agoston Sasvari, Andrew Mann and Jawad Afzal.

Middle Avroman Unit



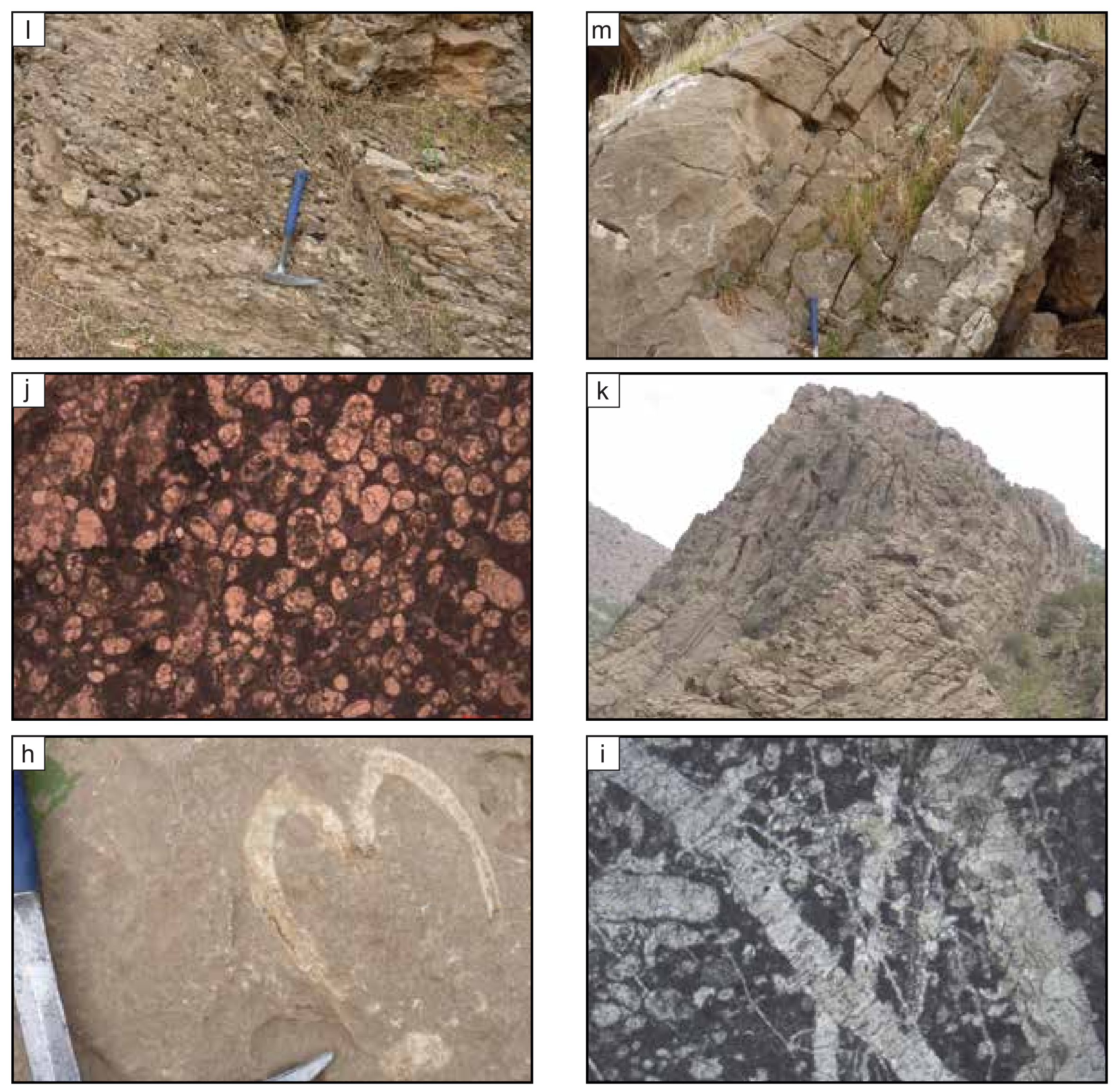
Middle Avroman Unit:
(p) peloidal wackestone/packstone, showing recrystallised peloids in a lime mud matrix;
(q) skeletal packstone, comprising lime mud, unaltered skeletal grains, in addition to grains leached and cemented by an early drusy non-ferroan calcite;
(r) large megalodontaceae shells on the weathered rock surface;
(s) neomorphic skeletal wackestone with patchy matrix replacive rhombic dolomite; lime mud is the major constituent and the majority of the skeletal material has been replaced by non-ferroan calcite.

Upper Mafic Body



Upper Mafic Body:
(n) chert and mafic rock bearing polymict breccia, base of the Upper Mafic Body;
(o) Upper Mafic Body, over- and underlain by the Avroman Formation.

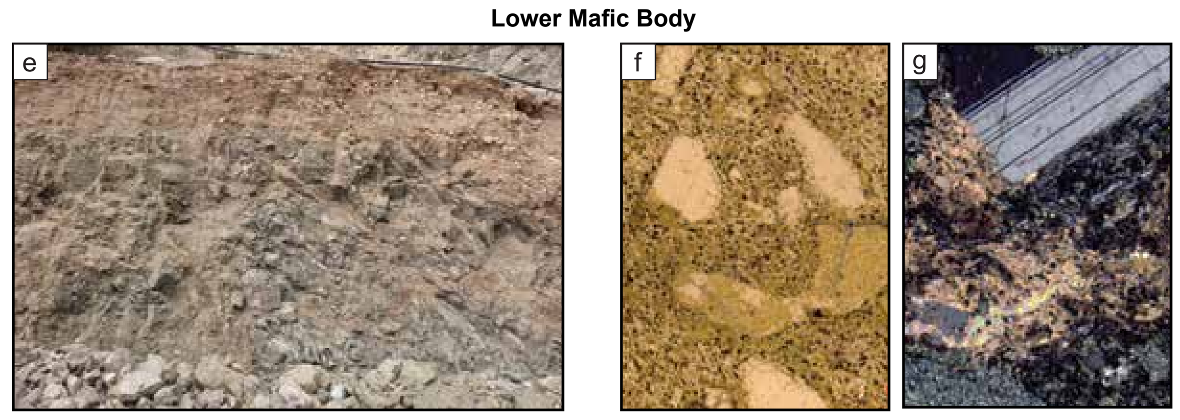
Lower Avroman Unit



Lower Avroman Unit, Thin-Bedded Member:
(j) Mud-lean packstone, primarily constituting recrystallised ooids. Peloids and lime mud provide the remainder of the framework with minor gastropods, faecal pellets and intraclasts.
(l) blocky texture of sheared Avroman Formation, indicative for bedding-parallel deformation;
(m) thin-bedded unit of the Avroman Formation, Lower Avroman Unit.

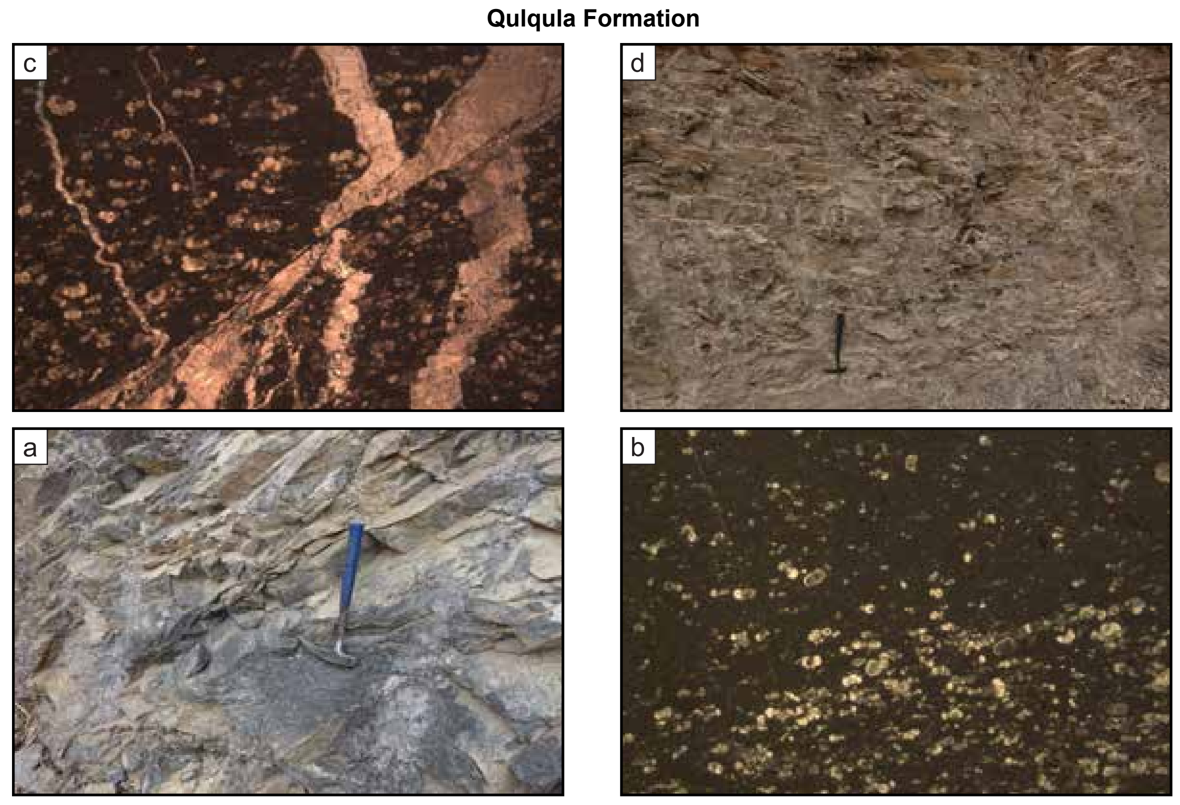
Lower Avroman Unit, Thick-Bedded Member:
(h) Megalodontid shell cut;
(i) ooidal mud-lean packstone, primarily comprising recrystallised ooids. Peloids and lime mud provide the remainder of the framework with minor gastropods, faecal pellets, green algae, echinoids and intrabioclasts.
(k) Cliff formed by Thick-Bedded Avroman Member, Lower Avroman Unit.

Lower Mafic Body



Lower Mafic Body:
(e) road cut, West of Zalm Village;
(f) gabbroic, porphyritic texture with fine plagioclase groundmass and phenocrysts of plagioclase feldspar and heavy chlorite overprint in green, lower mafic detachment body;
(g) lower mafic detachment plane showing gabbroic, porphyritic texture with fine plagioclase groundmass and phenocrysts of plagioclase feldspar.

Qulqula Formation



Qulqula Formation:
(a) field photo of cherty Qulqula Formation;
(b) wackestone with a lime mud matrix and an abundance of planktonic foraminifera and more specifically globigerinid;
(c) highly fractured wackestone with globigerinids;
(d) field photo of the upper, chert-bearing part of the Qulqula Formation.

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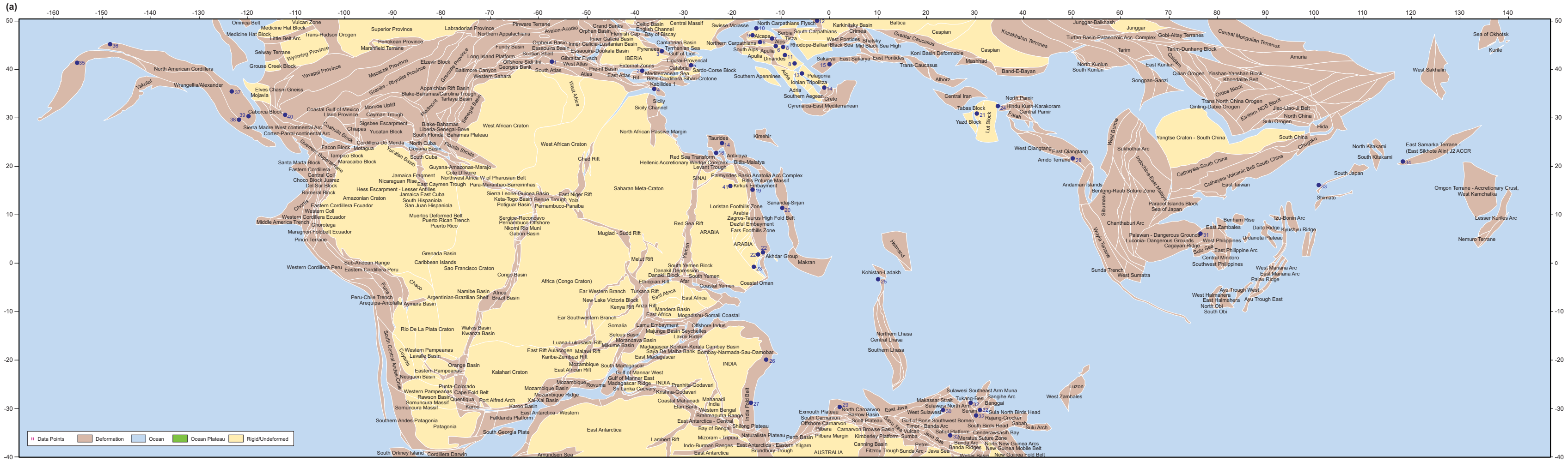
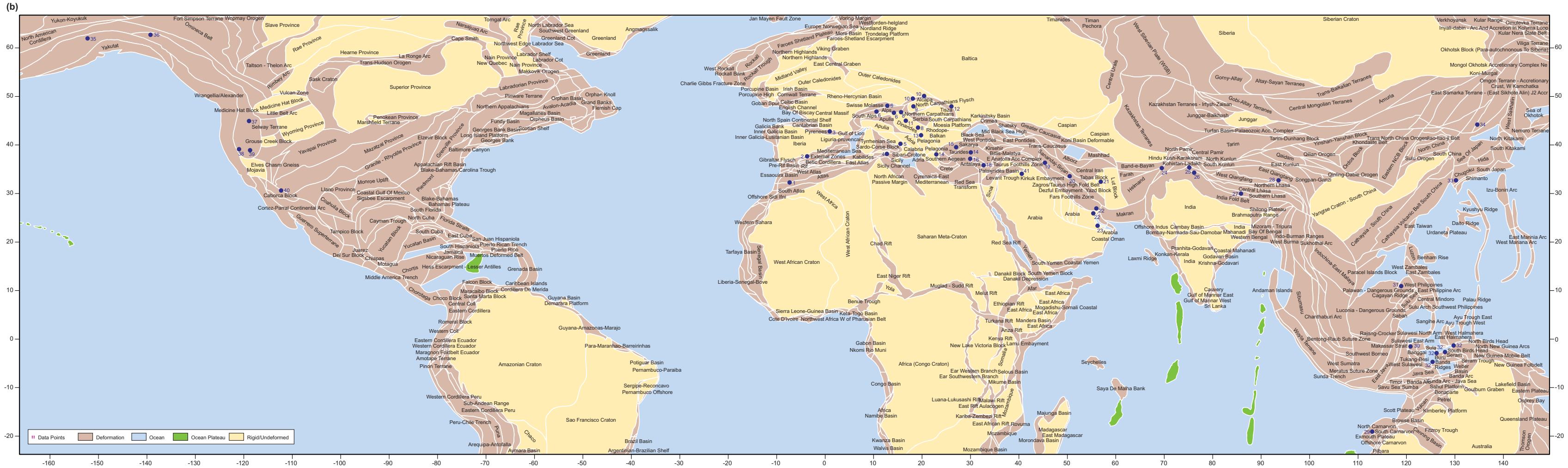
ENCLOSURE II

(a)



Enclosure II (a): Norian paleogeographic position of the Dachstein Formation-equivalent megalodontaceae-bearing carbonates on a topographic and tectonic background.

(b)



Enclosure II (b) Recent position of the Dachstein Formation-equivalent megalodontaceae-bearing carbonates on a topographic and tectonic background. See Table 1 for locations.

Table

Locality	Unit and/or region	Country	Reference
1	Central High Atlas	Morocco	Septfontaine (1986)
2	Alpujarride (Internal Zones of Betic Cordillera)	Spain	Martin and Braga (1987)
3	Southern Pyrenees	Spain	Mensink and Tichy (1977)
4	Trapanese-Sacceanse Unit (Western Sicily)	Italy	Di Stefano et al. (2002), Pallini et al. (2004)
5	Apulia	Italy	Iannace et al. (2007)
6	South Alpine Unit (Adria-Dinaria Megaunit)	Italy	Bossellini (1967), Jadoul et al. (1992), Ogorelec and Buser (1996)
		Slovenia	Ogorelec and Rothe (1992), Ogorelec and Buser (1996), Novak and Dozet (2002), Novak (2003), Dozet (2009)
7	Northern Calcareous Alps (Alcapa Megaunit)	Austria and Germany	Simony (1847), Peters (1855), Gumbel (1862), Zankl (1967), Tollmann (1976), Fruth and Scherreiks (1984), Gawlick et al. (1999), Mandl (2000)
8	Dinaridic Unit (Adria-Dinaria Megaunit)	Croatia and Serbia	Simunic and Simunic (1997), Dimitrijevic and Dimitrijevic (1991)
9	Transdanubian Range (Alcapa Megaunit)	Hungary	Végh-Neubrant (1957, 1960, 1982), Fulop (1976), Haas (1982), Haas et al. (1995)
10	Central and Inner Western Carpathian Units (Alcapa Megaunit)	Poland and Slovakia	Gazdzicki (1971, 1983), Michalik (1980, 1993)
11	Sana-Una Unit (Vardar Megaunit)	Serbia	Protic et al. (2000)
12	Perşani Unit (Transylvanian Nappe System, Vardar Megaunit)	Romania	Patrulius (1966)

Continuation →

(Continued).

13	Lura Massif (Mirdita Zone, Internal Albanides)	Albania	Gjata et al. (1980), Shallo et al. (1986), Godroli (1992)
14	Hellenides	Greece	Schafer and Senowbari-Daryan (1982), Pomoni-Papaioannou et al. (1986), Haas and Skourtsis-Coroneou (1995)
15	Fragments of the Anatolide-Taurid Platform	Turkey	Okay and Altiner (2007)
16	Beydağları Autochthon (Anatolide-Taurid Platform)	Turkey	Tunaboylu (2008), Eren et al. (2002, 2007), Lukeneder et al. (2012)
17	Lycian Nappes Unit (Anatolide-Taurid Platform)	Turkey	Dumont (1976), Ager et al. (1980), Tunaboylu (2008)
18	Kyrenia Range	Northern Cyprus	Martini et al. (2009)
19	Qulqula-Khuwakurk Zone	Iraq	Karim and Baziany (2007), Karim (2007), Ma'ala (2008), Al-Qayim et al. (2012), Ali (2012), Davies et al. (2014), Ali et al. (2014)
20	Zagros Fold and Thrust Belt	Iran	James and Wynd (1965), Szabo and Kheradpir (1978), Seyed-Emami (2003),
21	Tabas Block	Iran	Hautmann (2001), Seyed-Emami (2003),
22	Musandam Group (Hajar Supergroup)	United Arab Emirates and Oman	Hudson and Jefferies (1961), Sandy and Aly (2000), Maurer et al. (2008), Senowbari-Daryan and Maurer (2008)
23	Kawr Group (Hawasina Nappe)	Oman	Glennie et al. (1974), Bernecker (1996), Senowbari-Daryan et al. (1999)
24	Khengil Series (Kabul Block)	Afghanistan	Slavin (1971), Bohannon (2010)
25	Atark Unit (East Hindu Kush-Wakhan Zone)	Pakistan	Gaetani et al. (1996), Zanchi and Gaetani (2011),

Continuation →

(Continued).

26	Kioto Group (Zanskar Unit, Tethyan Himalayas)	India	Baud et al. (1982), Gaetani et al. (1985), Fuchs (1987), Jadoul et al. (1990), Garzanti et al. (1995)
27	Tethyan Himalayas	Tibet Autonomous Region of China	Jadoul et al. (1988)
28	Qinghai-Xizang Plateau (Quintang Terrane)	Tibet Autonomous Region of China	Yao et al. (2007)
29	Wombat Plateau	Australia	Rohl et al. (1991), Kristan-Tollmann and Gramann (1992)
30	Celebes (East Sulawesi)	Indonesia	Cornée et al. (1994)
31	Kalampisanan Island (North Palawan Block)	Philippines	Kiessling and Flugel (2000)
32	Buru-Seram, West Irian Jaya	Republic of Indonesia	Cornée et al. (1994), Villeneuve et al. (1994)
33	Sambosan Accretionary Complex	Japan	Tamura (1972, 1981, 1983), Kristan-Tollmann (1991) Chablais et al. (2010)
34	Tetyukhe Terrane (Honshu-Sikhote-Alin Unit)	Russia	Kojima (1989)
35	Chiltuna Terrane	United States	Jones et al. (1980), Yancey et al. (2005)
36	Stikinia Terrane	United States	Yancey et al. (2005)
37	Wallowa Terrane	United States	Yancey et al. (2005), Stanley et al. (2008)
38	Paradise Subterrane (Walker Lake Terrane)	United States	Silberling and Jones (1989), Roniewicz and Stanley (1998)
39	Sand Spring Terrane	United States	Satterfield (2002)
40	Sierra Alamo (Antimonio Terrane)	Mexico	Yancey et al. (2005)
41	Wadi Hauram (Arabian Plate)	Iraq	Karim and Ctyroky (1981), Sissakian and Mohammed (2007)