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ORIGINAL PAPER

Evaluating the Baluti Formation at Sararu village, Ora Anticline, Iraqi Kurdistan: a stratigraphic and geochemical approach

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Abstract Here, we report that a lithostratigraphic unit that outcrops at Sararu village, 6 km northeast of Qumri village that had previously been assigned to the Baluti Formation is not Triassic in age and therefore can not be a correlative equivalent of the Baluti Formation. The outcropping unit at Sararu comprises intercalation of calcareous mudstones and limestones, and is indeed lithologically similar to the Baluti Formation (Late Triassic). The Baluti Formation (also known as the Baluti Shale) is known from a typical section found at the Gara Anticline and from many deep drilled oil exploration wells. It is generally composed of alternations of the shales, limestones, dolomites, and dolomitic limestones. It is underlain by the Kurra Chine Formation (Upper Triassic) and overlain by the Sarki Formation (Lower Jurassic). In this study, detailed field observations, an assessment of stratigraphic successions, studies of microfossils such as age-specific planktonic foraminifera (e.g., *Globotruncana bulloides*), and age-specific biomarkers (oleanane index and C28/C29 regular sterane index) reveal that the lithostratigraphic unit at Sararu village can not be a correlative equivalent of the Baluti Formation, and it is more likely from the Upper Cretaceous. There are a number of Upper Cretaceous formations found in this part of Kurdistan, but based on fossil-type and palaeoenvironmental associations, the Hadiena Formation, from the Upper Cretaceous, is considered as the most likely correlative equivalent to the calcareous mudstone and limestone succession found at Sararu village.

Keywords Iraq stratigraphy · Kurdistan stratigraphy · Baluti Formation · Ora Anticline · Age-specific biomarkers · Foraminifera

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Introduction

The study area is located in the Kurdistan Region of northern Iraq (Fig. 1a). The studied unit (here after termed the X-unit) is located near Sararu village, 6 km northeast of Qumri village on the main road in Barwari Bala. The outcrops of the X-unit utilized for this study are found on the southern limb of the Ora Anticline (37° 14′ 54.6″ N, 43° 17′ 51.4″ E), in the Ora Thrust Zone (Numan 2000; Jassim and Buday 2006) (Fig. 1b). The Baluti Formation outcrops used for this study are found within the core of Gara Anticline, in the highly folded zone (Numan 2000; Jassim and Buday 2006) (Fig. 1b). There are a number of lateral equivalents to the Baluti Formation found across the region. The depositional environment of the Zor Hauran Formation in the west of Iraq is interpreted to have been similar to that of the Baluti Formation (at Sararu village), and the two formations are tentatively considered to be correlatable (Buday 1980; Jassim and Goff 2006; Aqrawi et al. 2010). The Mulussa-F Formation in Syria is considered to be a lateral equivalent to the Kurra Chine and Baluti formations in north Iraq (Brew et al. 2001). With regard to the Iranian part of the Zagros, there is not a distinctive rock unit of Late Triassic age that is an equivalent to the Baluti Formation. However, the Dashtak (Lower-Middle Triassic) and Neyriz (Liassic) formations might be tentatively

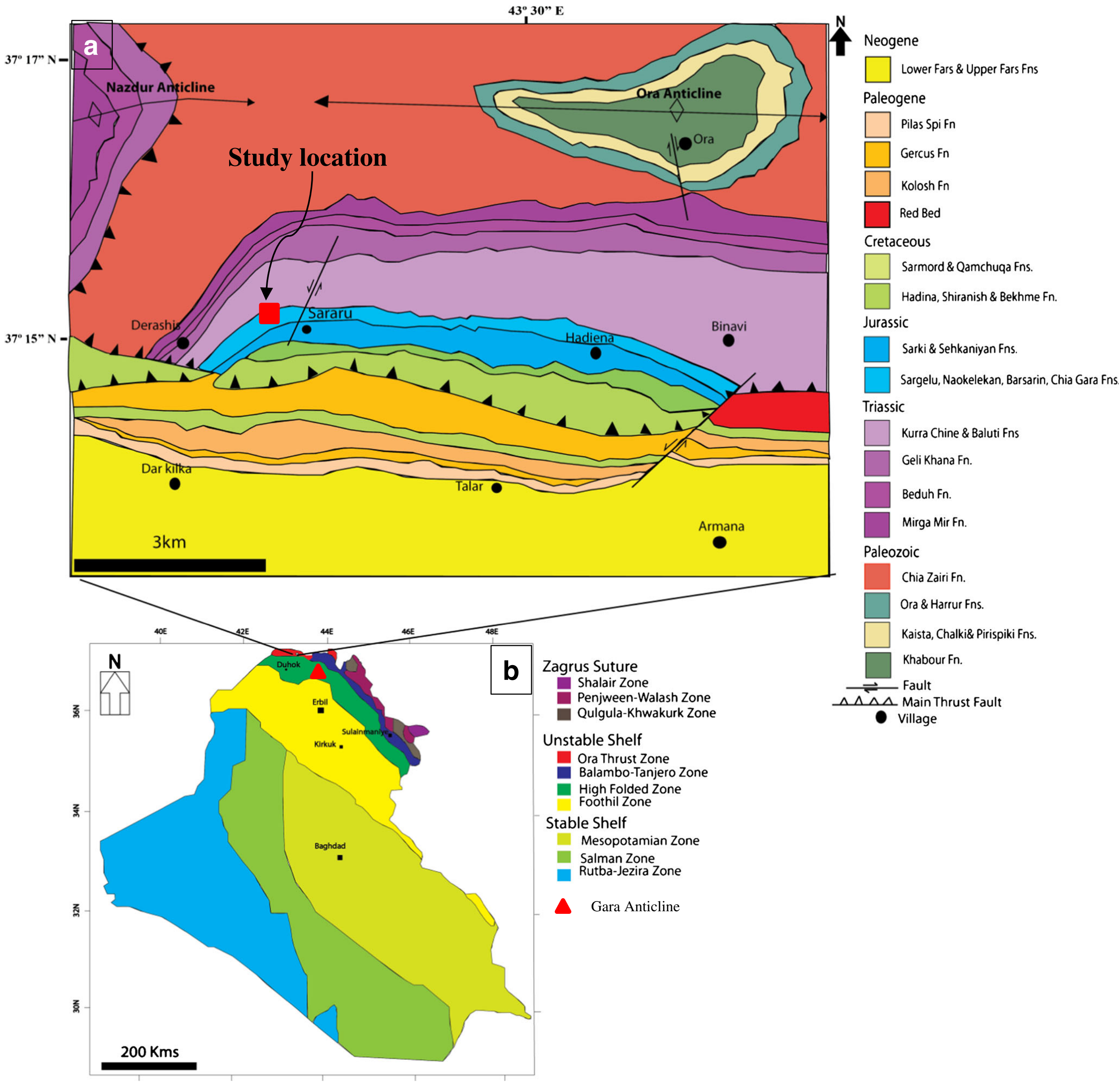

Fig. 1 **a** General geological map of the study area (map modified from Al-Mousawi et al. (2007). **b** Tectonic division of Iraq (map modified from Numan (2000) and Jassim and Goff (2006)

correlated to the Baluti Formation. In Kuwait and Saudi Arabia, the Minjur Formation of Upper Triassic to Lower Jurassic age has been tentatively correlated to the Baluti Formation (Al-Khamiss et al. 2012).

Iraqi Kurdistan is located in the Zagros fold and thrust belt where, due to extensive tectonic activity, the northern part of the Arabian Plate exhibits extreme styles of deformation including regions of recumbent folding, thrusting, and imbrication (Jassim and Goff 2006). In these regions, stratigraphically older formations can be found overlying younger formations. This considerably complicates fieldwork in the thrust and imbricated zones at locations such as the Northern (Ora) Thrust Zone. In this study, we present an example of one such case, where distinguishing two lithologically similar units was found to be extremely difficult based on field observations alone; the Baluti within the Gara Anticline and another currently unnamed (X-unit) succession of mudstones and limestones found near Sararu village within the southern limb of the Ora Anticline.

The main goal of this study is to provide evidence that the X-unit found at the Ora Anticline can not be the Baluti Formation, as previously proposed. This evidence is in the form of detailed fieldwork, biostratigraphy, and geochemical studies carried out on the X-unit. This study has focused only on a single narrow interval located near Sararu village, but clearly revisiting underlying and overlying formations would seem necessary. The work we present here provides clear evidence that a formation previously believed to be the Late Triassic, largely based on fossil content, lithostratographic, and inferred field relationships, can not in fact be Late Triassic. This is because it contains younger biota and can not therefore be a correlative equivalent of the Baluti Formation.

Geological background

Previous stratigraphic work

The Ora Anticline spans a large region from northern Iraq through Iraqi Kurdistan and into Southern Turkey. Paleozoic and Mesozoic-aged formations outcrop in the core and limbs of the anticline (Figs. 1 and 2, Table 1). In places, there are very high intensities of normal and reverse faulting, and within the Northern Ora Thrust Zone (Jassim and Buday 2006; Numan 2000), folding and thrusting has overturned stratigraphic succession and placed older formations above younger formations. The Baluti Formation was first described by Wetzel (1950 in Bellen et al. 1959). Its type locality is located in the Gara Anticline. According to Bellen et al. (1959), it comprises gray and green shale calcareous dolomite with intercalations of thinly bedded dolomites, dolomitic limestones, and silicified limestones which in places are brecciated. It is underlain by the Kurra Chine Formation and overlain by the Sarki Formation (Bellen et al. 1959). The boundary between Baluti and Sarki is interpreted to be unconformable because of several missing flora (spores and pollen), that span a considerable period of time (Norian, Rhaetic, and early Liassic) (Hanna 2007). The palynomorphs that have been observed suggest that the environment was likely shallow marine, and based on lithological evidence, the environmental conditions included shallow neritic lagoonal and evaporitic episodes (Hanna 2007). The dolomite of the Baluti Formation may have been deposited in an environment that ranged from peritidal to sabkha (Aqrawi et al. 2010). Al-Juboury and McCann (2013) believe that the depositional environments of the Baluti and Sarki Formations included subtidal to supra tidal and lagoonal to semi-arid tidal flat settings. Based on a regional correlation with the Zur Huran Formation (Bellen et al. 1959; Buday 1980; Jassim and Goff 2006 and more recently by Al-Halawachi 2014; Al-Khashab and Al-Halawachi 2014), the age of Baluti Formation is thought to be Upper Triassic and Rhaetian. The X-unit at Ora has not been studied to as great a level of detail as the Baluti Formation located at Gara Anticline, and its paleontology has not been studied yet. For a significant period of time, the unit has been considered as the Baluti Formation by most geologists that worked in this region and is shown as such on regional maps (Al-Mousawi et al. 2007) (Appendix 2). It is not surprising therefore that much recent work continues to identify the outcrop of the X-unit as the Baluti Formation (for example, Shingaly 2015).

Methods and materials

Organic geochemistry

As part of an ongoing study of source, rock potential samples from each section were analyzed by GC-MS (gas chromatography mass spectrometry) at the Organic Geochemistry Laboratory, in the Department of Geology and Petroleum Geology in the University of Aberdeen. Bitumen was extracted from powdered samples via soxhlet-extaction (samples were extracted for 48 h using a mixture of dichloromethane and methanol 93:70 v:v). Extracts were fractionated into saturated, aromatic, and polar compounds by silica gel column chromatography. The biomarker data referred to in the text was obtained from saturate fractions that were analyzed by GC-MS. GC-MS was carried out with an Agilent Technologies (AT) 6890N Network GC (pulsed splitless) system fitted with a 30.0 × 250.0 μm i.d, film thickness 0.25 μm fused silica column coated with DB-5 coupled to an AT 5975 quadrupole mass selector detector (electron energy 70 eV, source 250 °C) with He as carrier gas. The GC temperature program for saturated hydrocarbons was hold at 60 °C for 2.0 min, rising at 20 °C min^{-1} to 120 °C, and then rising at 4 °C min^{-1} to 290 °C and then holding for 23 min.

Fieldwork

Fieldwork was carried out in three sessions (April 2013 and May 2014, 2015). The samples were collected in traverses perpendicular to the strike of the beds. The weathered surfaces of limestones and dolomitic limestone were removed in the field so that fresh samples were collected. For samples of mudstone, upto 40 cm was removed to obtain unweathered samples. A total of 53 samples were collected for petrography and organic geochemistry.

Microscopy

Specialist thin sections were prepared by ALS Petrophysic laboratory with the following properties: 50 mm × 25 mm (2″ × 1″), finished to 30 μm, and impregnated by blue-dyed resin. Standard thin sections were also prepared at the University of Aberdeen. Some of these were oriented and stained with the combined staining following the procedure of Dickson (1966) to aid the clear identification of carbonate phases.

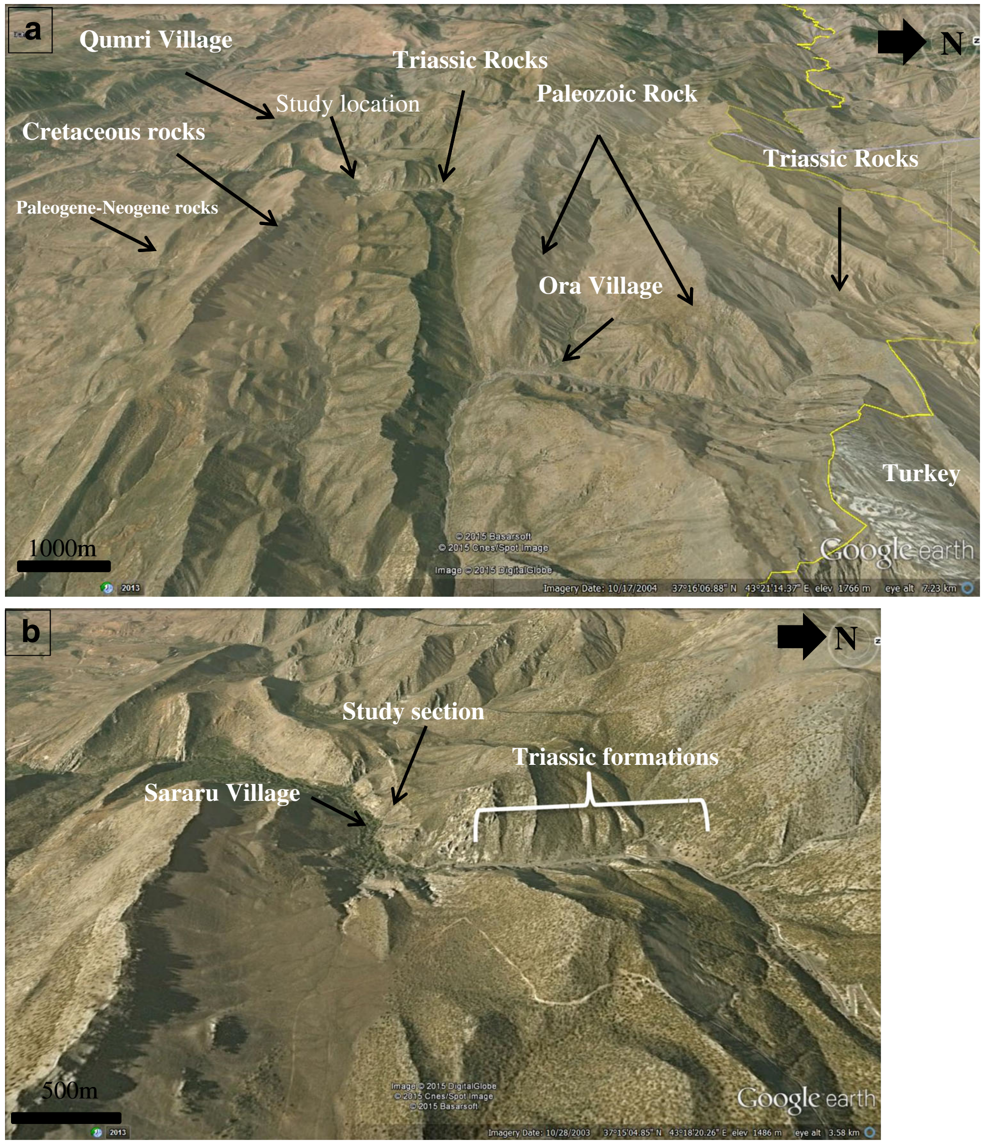

Fig. 2 **a** Satellite image of the Ora Anticline. **b** A closer view of the southern limb and study location (Google Earth version 7.5.1557, build date 5/20/2015. Imagery date 4/10/2013)

Results

Stratigraphic analysis

Lithologically, both the X-unit and Baluti share similar characteristics; they comprise successions of limestones, dolomitic limestones, and black calcareous mudstone that weather with a similar appearance, and both successions are bounded by thick carbonate units at their bases and tops. The X-unit that outcrops in Sararu village (Figs. 2 and 3) comprises alternating beds of calcareous mudstone and limestone, where the beds of mudstone tend to be thicker and more continuous than limestone beds. Likely based on lithostratigraphic considerations, the unit is believed to be the Baluti Formation by many geologists currently working in the area. It is also shown as a part of the Jurassic on a regional geological map (Al-Mousawi et al. 2007) (Fig. 1, Appendix 1).

A detailed lithological log of the X-unit at Sararu village is shown in Fig. 4. The lower 37 m is characterized by intercalating gray mudstones, calcareous mudstones, and argillaceous limestones. Individual beds of argillaceous limestones within this interval are between 80 and 100 cm thick (Figs. 4 and 5). This interval passes upwards into a section 43 m thick that comprises gray mudstone with intercalations of dark limestone (fresh surface). The thickness of the intercalating limestone beds within this interval is thinner (about 30 to 50 cm thickness). The mudstones are highly indurated and fresh surfaces have a blocky appearance and look compacted, but despite this, they split along laminations yielding tabular fragments indicating wavy or discontinuous lamination. The mudstone intervals are between 1.10 to 4.30 m thick. The upper 24.8 m of the section is quite similar to the lower part. It consists of alternating mudstones, calcareous

Table 1 Stratigraphic column of the formations that thought to be found in the Ora Anticline and study area

Era	Period	Epoch	Formation, Al-Brifkani (2008)	Formation, Al-Mousawi et al., (2007)
Cenozoic	Pliocene		Bakhtiari	Bakhtiari
	Miocene	Middle-Upper	Lower and Upper Fars	Lower and Upper Fars
	Eocene	Middle-Upper	Pila Spi	Pila Spi Limestone
		Middle	Gercus	Gercus
	Paleocene-Eocene	Upper Paleocene-Lower Eocene	………	…………
Mesozoic	Cretaceous	Upper	Hadiena	
			………..	Aqra-Bekhme
		Lower	Qamchuqa	…..
	Jurassic	Upper	Chia Gara	Chia Gara Barsarin Naokelekan
		Middle	………	Sargelu
		Lower	…………	Sarki and Sehkaniyan
	Triassic	Upper	Kurra Chine	Kurra Chine and Baluti
		Middle	Geli Khana	Geli Khana
		Lower	Beduh Shale	Beduh Shale
			Mirga Mir	Mirga Mir
Paleozoic	Permian	Upper	Chia Zairi	Chia Zairi
	Carboniferous	Lower	Harur Limestone	Harur Limestone
			Ora Shale	Ora Shale
	Devonian	Upper	Kaista	Kaista
	Ordovician		Pirispiki Red Beds	Pirispiki Red Beds
			Khabour Quartzite Sandstone	Khabour Quartzite Sandstone

The table is modified from Al-Brifkani (2008). The formation names were taken from the maps of Al-Brifkani (2008) and Al-Mousawi et al. (2007) in study area

mudstones and limestones, and argillaceous limestones. The limestone beds in the upper part of the X-unit are between 30 to 70 cm thick, and the dark argillaceous limestones contain veins of calcite. Upwards, the X-unit gradually transitions into beds of limestone and calcareous mudstone and then into thickly bedded dolomitic limestone (Figs. 3b, 4, and 6b).

The Kurra Chine Formation was first described by Wetzel (1950 in Bellen et al. 1959) as a succession of dark brown and black limestones that are alternately thin- and thick-bedded, with occasional intercalations of thickly bedded fetid dolomites and papery shales. Within the study area, the unit currently mapped as the Kurra Chine Formation (Al-Mousawi et al. 2007; Al-Brifkani 2008; Awdal et al. 2016) comprises massive gray dolomites and dolomitic limestones, with units of shale in its lowermost part.

At Sararu village, the limestones and mudstones of the X-unit have had their appearance heavily altered by weathering; the limestones weather to yield a paler yellowish surface (Figs. 4, 5, and 6), and the mudstones weather to create black tabular fragments that are highly fissile compared to fresh surfaces. Thus subsequent to weathering, the X-unit and Baluti Formation share a common appearance.

The southern limb of the Ora Anticline is cut by both dextral and sinistral strike-slip faults (Awdal et al. 2016). Additionally, there is intense overfolding and compression along a north-south direction that has inverted a number of units, and within the Sararu area, the Kurra Chine, Geli Khana, and Beduh dip to the south (Fig. 7b, c) (Awdal et al. 2016; Al-Brifkani 2008), while the X-unit, Chia Gara, and Sargelu dip to the north (Figs. 4 and 8b, d). Moreover, limestone and dolomitic limestone beds beneath the X-unit are near vertical and have an east-west strike. Consequently, based on the dip direction of the beds at both boundaries, we infer that the friable shale units and thin-bedded limestones of the X-unit, Chia Gara, and Sargelu have been slightly overturned in this specific area (Fig. 8).

Despite these lithological similarities, there are notable differences between the Baluti Formation at the Gara Anticline and the X-unit found on the Southern limb of the Ora Anticline. Within the Baluti Formation, the lower part contains a higher abundance of marls than the Ora X-unit. The upper part of the Baluti Formation has a more diverse range of lithologies with a greater range in thicknesses than that seen in the Ora X-unit. Some limestone beds of the Baluti exhibit box-work structures not found

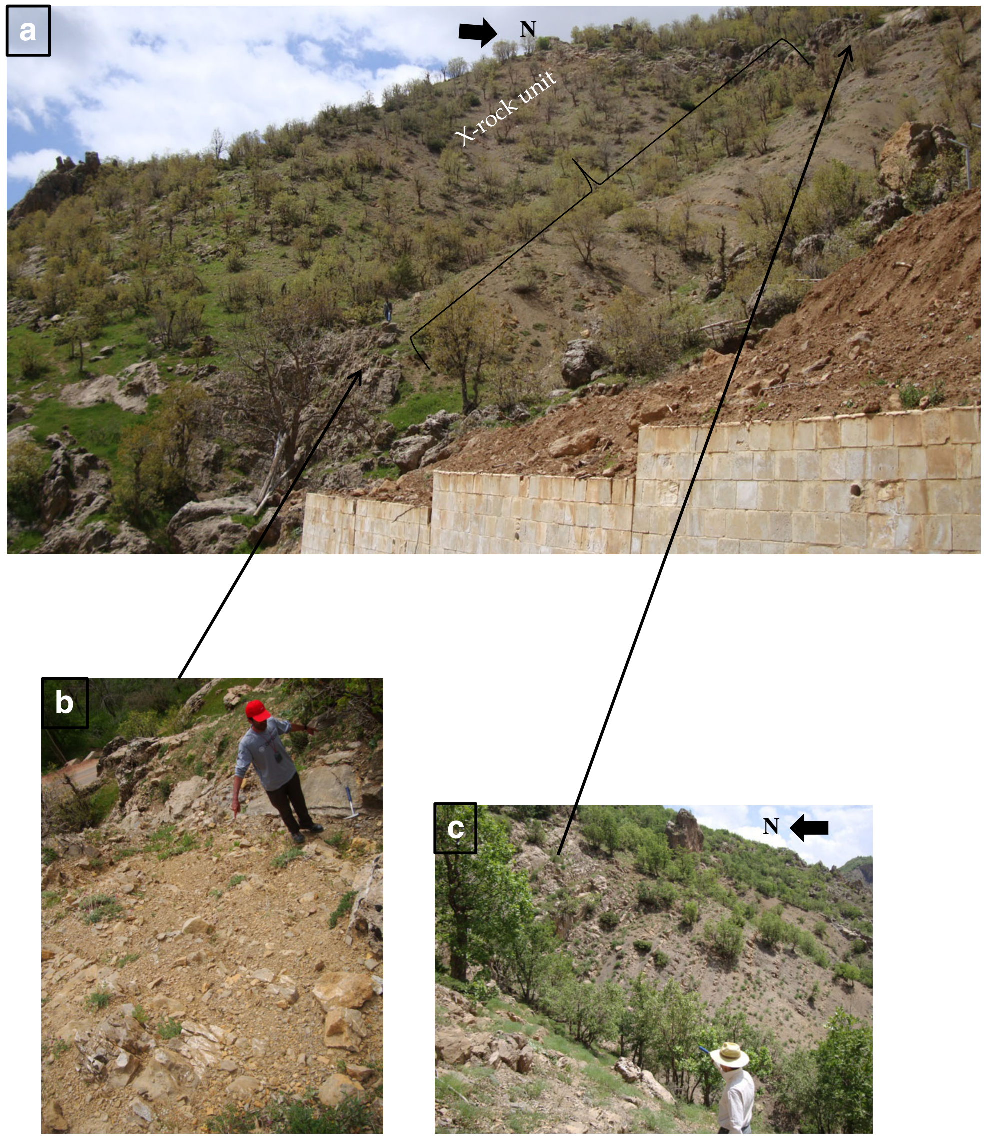

Fig. 3 **a** A view of the X-unit on the southern limb of the Ora Anticline. **b** The upper boundary between the X-unit and massive beds of limestone and dolomite. **c** The lower boundary between the X-unit and massive beds of limestones

in the X-unit, and the Baluti Formation mudstones have a softer texture. The total thickness of the Baluti Formation studied at Gara was 64.5 m, while the thickness of the X-unit is variable and the maximum thickness in Sararu village is 103 m. Dolomitization of the limestone beds within the Baluti Formation at Gara was pervasive, while the X-unit at Ora did not contain any completely dolomitized beds, and the only dolomitization noted was the presence of the floating grains within limestone beds.

Fossil content

Two main sources of biostratigraphic information were considered in this study: microfossils present within limestones and age-specific biomarkers extracted from mudstones.

Fossil content of limestones

The Baluti Formation is not fossiliferous and currently the main fossils reported include *Glomospira* sp., ostracods, and indeterminate molluscs (Bellen et al. 1959, Buday 1980). None of these fossils are diagnostic for specific ages to any usable degree (Wetzel 1950 in Bellen et al. 1959). Hanna (2007) reported the presence of spores and pollen facies within Baluti sediments that indicate a Late Triassic age. This is consistent with a finding supported by more recent work on the Baluti Formation in the Gara Anticline (Al-Khashab and Al-Halawachi 2014), that based on the presence of ostracods of the Genus Polycope, suggested that the Baluti Formation is Upper Triassic in age. Thin section studies of microfossils within limestone units during this study mostly found relict structures that were heavily affected by recrystallization of

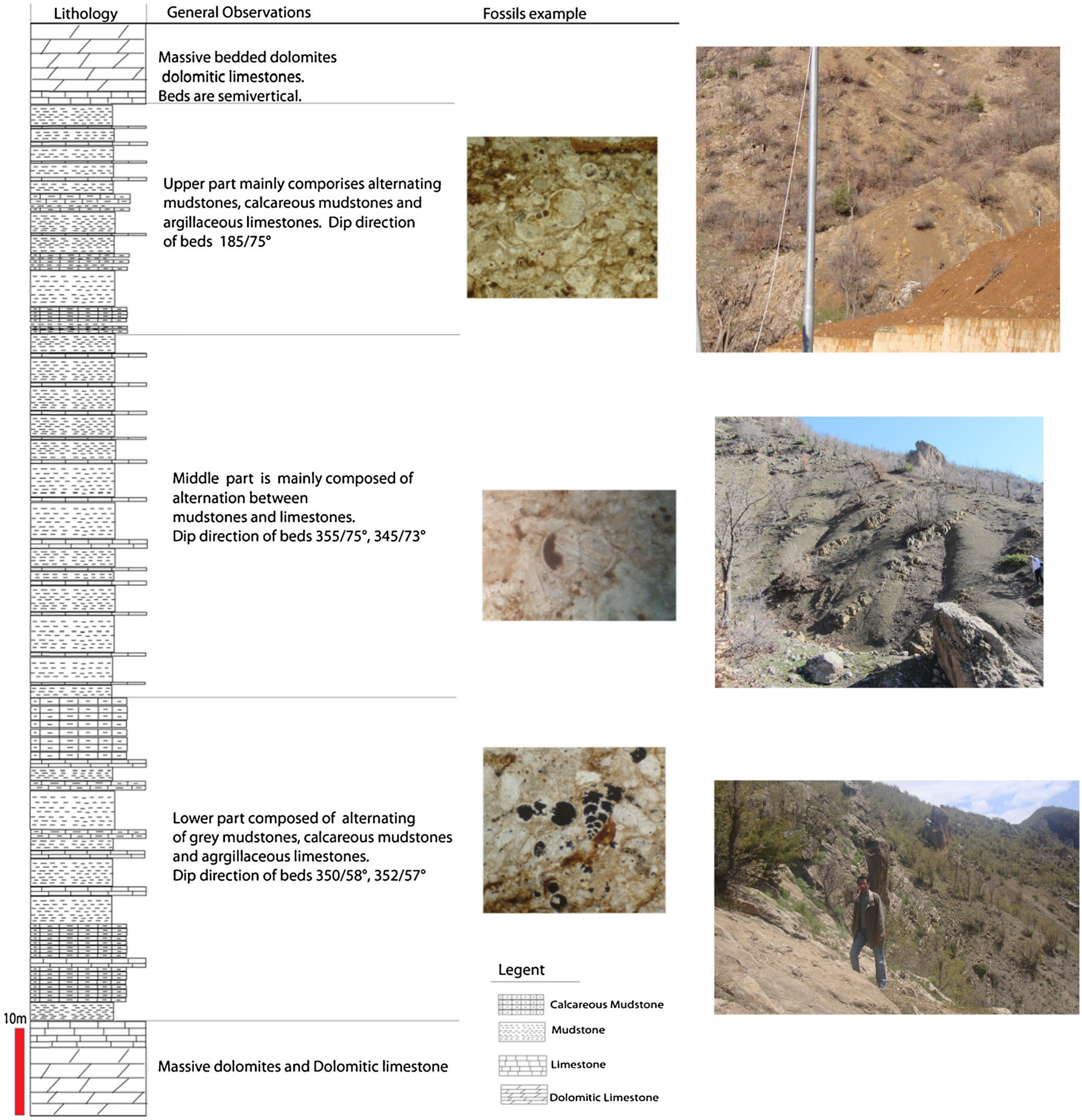

Fig. 4 Lithostratigraphic log of the X-unit from the southern limb of the Ora Anticline, at Sararu village. *Lower* and *upper parts* are composed of mudstones, calcareous mudstones, and limestones, while the *middle section* mainly comprises alternating mudstones and limestones. Note: the lithostratigraphic log was drawn from older to younger, not based on the topography

carbonate phases and could not be easily identified at the genus level (Fig. 10a1).

Unlike the Baluti Formation, the X-unit present in Sararu village is fossiliferous with respect to the microfossil content of limestone beds. The unit contains both benthic and planktonic foraminifera. The fossils are completely different from those in the Baluti Formation in terms of type and age. Many of the fossils that can be identified are at the most Late Cretaceous in age; therefore, the X-unit can not be Triassic in age and can not be correlated to the Baluti Formation. Specific fauna that date the X-unit include the following: *Globigerinelloides bollii* (Pessagno 1967) (Late Cretaceous), *Hedbergella monmouthensis* (Olsson 1964) (Late Cretaceous), *Rugoglobigerina* rugosa (Plummer 1926) (Late Cretaceous), *Heterohelix globulosa* (Ehrenberg 1840) (Late Cretaceous), *Globotruncanita elevata* (Brotzen 1934) (Late

Fig. 5 Lower part of the X-unit is characterized by thick beds of highly weathered calcareous mudstone, intercalated with limestones and argillaceous limestones

Cretaceous), *Marginotruncana sigali* (Reichel 1950) (Late Cretaceous), *Globotruncana bulloides* (Vogler 1941) (Late Cretaceous), and *Globotruncanita sp.* (Late Cretaceous) (Figs. 9 and 10).

The diversification of foraminifera to planktonic habitats is held to have taken place in the Late Mesozoic (BouDagher-Fadel et al. 1997). The relatively high abundance of planktonic foraminifera within the limestone beds of the X-unit at Sararu village (Appendix 2) provides strong evidence, internally consistent with itself, that the X-unit is not Upper Triassic in age and therefore not a correlative equivalent of the Baluti Formation.

Biomarkers as age indicators

The most useful age-specific biomarker that was detected within the mudstone units of the X-unit was oleanane. Oleanane derives from oleanene (and similar resins) found in modern day angiosperms, thus making oleanane a petroleum biomarker for angiosperms (Moldowan et al. 1994a). It has been shown that the relative amount of oleanane found within a range of marine mudstones increased from the Cretaceous to Cenozoic (Tertiary) in parallel with the increasing number of angiosperm taxa (Moldowan et al. 1994a), and that prior to the end of the Jurassic, the proportion of oleanane within sedimentary organic matter was negligible. Mudstones within the X-unit at Ora contain low but significant abundances of oleanane (Fig. 11), while the Baluti Formation mudstones at the Gara Anticline do not contain significant oleanane (Fig. 11).

Fig. 6 **a** Middle part of the X-unit which comprises alternating mudstones (calcareous mudstone) and limestones. The mudstones weather gray and the limestones are buff colored. **b** Calcareous mudstone and limestone in the upper part of the X-unit

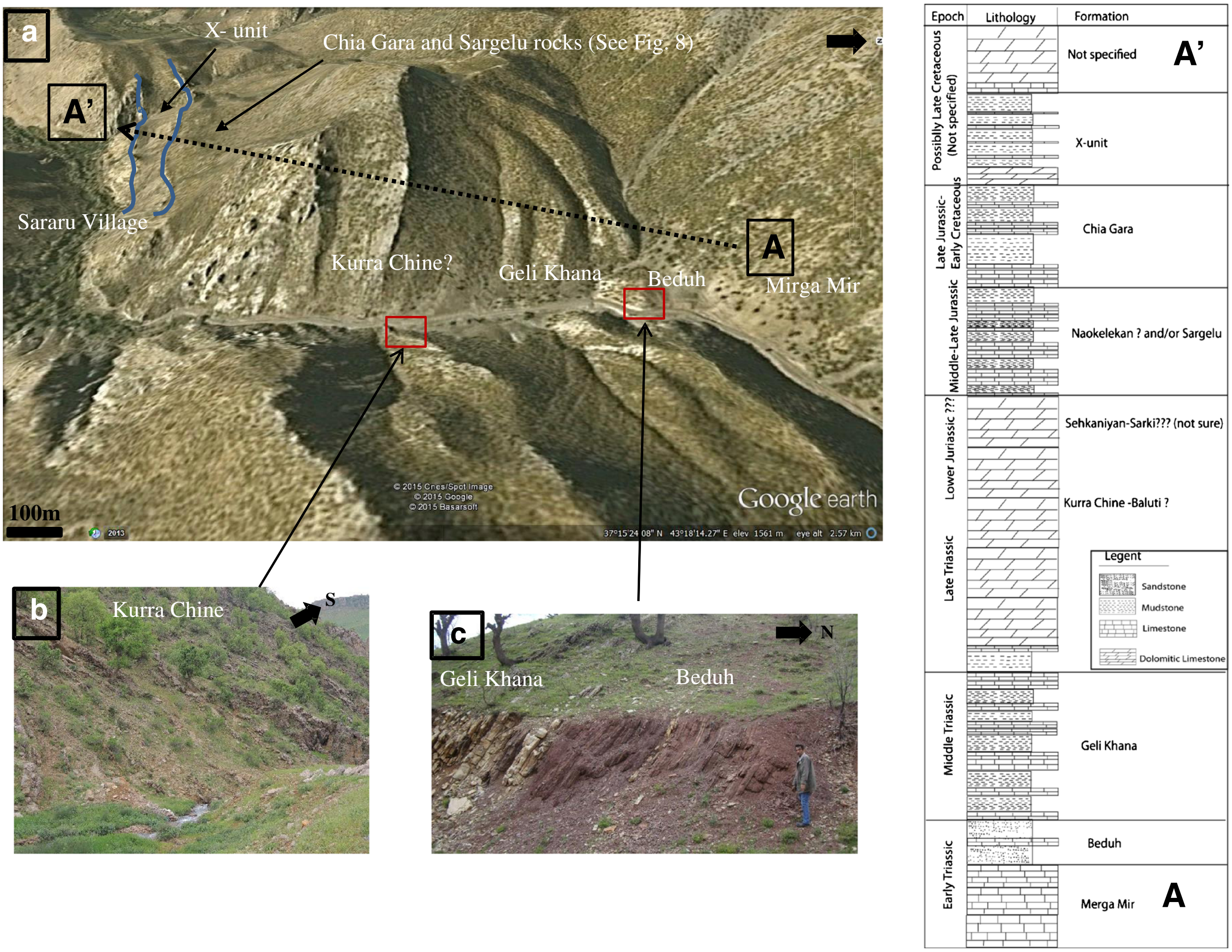

Fig. 7 **a** The Triassic succession at Sararu village and location of the X-unit (Google Earth version 7.5.1557, build date 5/20/2015. Imagery date 4/10/2013). **b** The lower part of the Kurra Chine Formation at Sararu village. **c** The contact between the Beduh and Geli Khana formations. Note: the column stratigraphy not to scale

Although the ratio of C28/C29 regular steranes is a less robust indicator of age, the ratio can be used to constrain the age of sedimentary organic matter deposited in marine environments because the types of eukaryotic organisms found among marine phytoplankton has changed throughout the Phanerozoic, leading to changes in proportions of different carbon-numbered sterols produced, thus the relative content of C28 steranes found in marine sedimentary organic matter increases, and the amount of C29 steranes decreases through geologic time (Moldowan et al. 1985; Grantham and Wakefield 1988 in Peters et al. 2005).

Changes in the ratio of C28/C29 steranes have been calibrated by several workers (Moldowan et al. 1985; Grantham and Wakefield 1988 in Peters et al. 2005), and based on these, the value of the parameter within the Baluti Formation (~0.75) indicates a Jurassic-Triassic age, while the X-unit appears Cretaceous and younger (Figs. 11 and 12).

Discussion

A succession of Triassic formations can be seen along the main road to Sararu-Ora (Figs. 3 and 7). Therefore, it was reasonable for previous workers, from a purely stratigraphic perspective, to expect that a succession of mudstones and limestones (the X-unit) found in Sararu village was a correlative equivalent to the Triassic-aged Baluti Formation (that also comprises mudstones and limestones). Furthermore, recent studies and current geological maps of the Ora Thrust Zone (Al-Mousawi et al. 2007, Al-Brifkani 2008, Awdal et al. 2016) show the Mirga Mir, Beduh, Geli Khana, and Kurra Chine (Fig. 1, Table 1). Thus, a worker in this area might reasonably expect to encounter Triassic-aged formations, and based on the stratigraphic succession of nearby units assume that the X-unit was the correlative equivalent of the lithologically similar Triassic-aged Baluti Formation. However, these

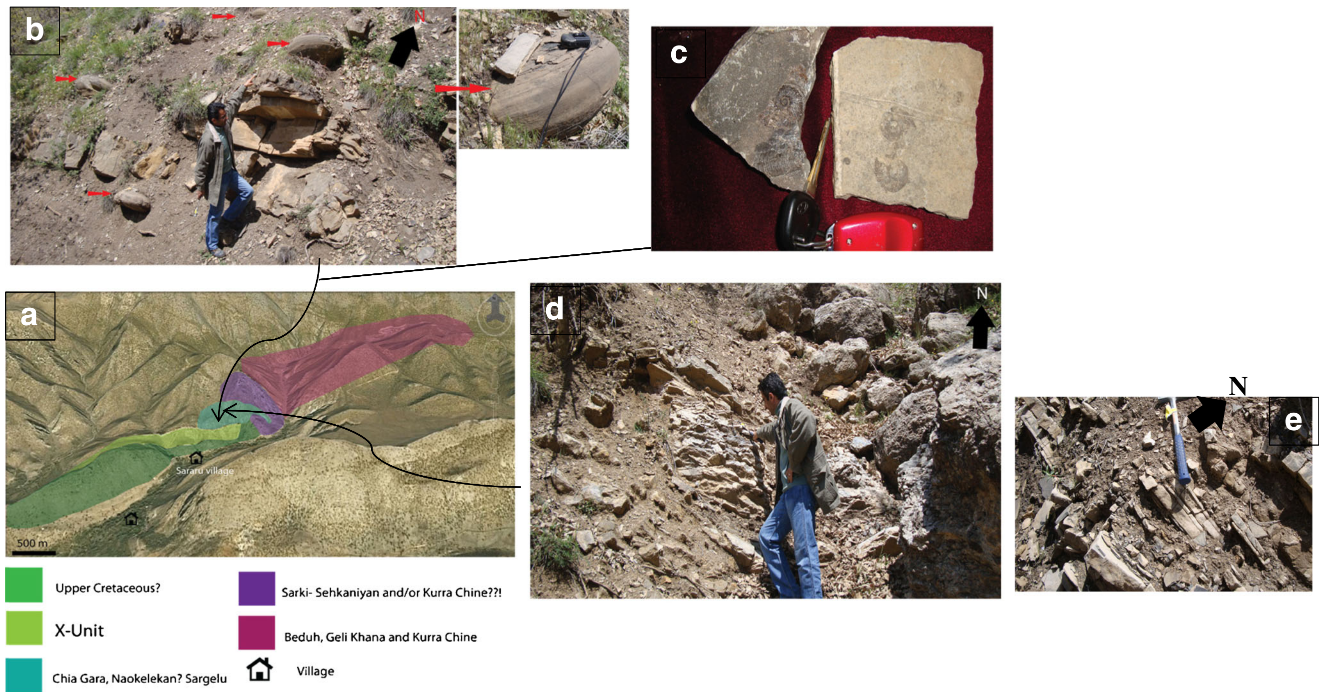

Fig. 8 **a** Satellite image of the study area (Google Earth version 7.5.1557, build date 5/20/2015. Imagery date 4/10/2013). The *violet-colored part* in the satellite image has not been identified and specified to be Sarki and Sehkaniyan formations or Kurra Chine Formation in this study. **b** Lower part of the Chia Gara Formation exhibiting ball and pillow structures at Sararu village (*red arrows*). **c** Ammonite fossils found in the Chia Gara Formation. **d** Thin beds of limestones intercalated with shale in study area. These beds can be considered as Naokelekan and/or Sargelu formation. Note: the dip direction of the beds is slightly toward the north

successions are not as strong as might be thought, and certainly not strong enough to overturn fossil evidence.

Some of the aforementioned formations can be relatively easily recognized and mapped, but the Kurra Chine Formation located toward the south is more difficult to map and identify in the field. Foremost, the area is a thrust zone and consequently the overturning of beds is common and strike-slip faulting (Awdal et al. 2016) means that the lateral continuity of beds over long distances cannot be assumed. Secondly, most formation such as the Kurra Chine, Sarki, and Sehkaniyan formations comprise carbonates that weather to yield visibly similar surfaces, or mudrock units that do not outcrop to a significant degree. Thus, considerable ground-truthing of outcrops and inferred subcrops is needed. This severely compromises the identification of mapable units from afar, which in the mountainous inhospitable terrain of the Ora area is difficult, thus making the mapping of units over long distances extremely difficult. Even where outcrops can be reached and fresh surfaces obtained, an additional complication is that within the Ora area, detail palaeontological studies have not been reported for the Geli Khana and Kurra Chine Formations, further weakening the identification of the Kurra Chine Formation in particular. A few thin sections were obtained for samples collected from the carbonate units underlying the X-unit (which were initially assumed to be the Kurra Chine) and were found to have microfossil assemblages similar to those of the X-unit (Fig. 9). Thus, at best, the presence of the Kurra Chine Formation underneath the X-unit is suspect, and the current evidence indicates that there is not any contact between the X-unit and the Kurra Chine at Sararu village. On review, it can be seen that the general stratigraphic succession of the locality that superficially seem to limit the X-unit to a Triassic age are not strong, and the X-unit does not overlie the Kurra Chine as would be expected for the Baluti Formation. Therefore, there is nothing inherent to the study area that mitigates against the lithological and biostratigraphic evidence that the X-unit is not Triassic in age (Figs. 9 and 10). Moreover, based on the abundance of oleanane present in the X-unit, it is not of Triassic age and can not be correlated to the Triassic-aged Baluti Formation (Figs. 11 and 12).

If the mudstone (Calcareous mudstone)-limestone succession (the X-unit) at Sararu village is not a correlative equivalent of the Triassic-aged Baluti Formation, with what other formations might it be correlated? Detailed fieldwork noticed a thinly bedded limestone and shale between the X-unit and underlying massive limestone unit (Figs. 8 and 9). This unit is more likely the Chia Gara Formation (Fig. 8b, c). It can be identified by the ubiquity and widespread occurrence of ball and pillow structures (phacoid beds) within its lowest members (Bellen et al. 1959; Mohyaldin 2007; Edilbi 2010)

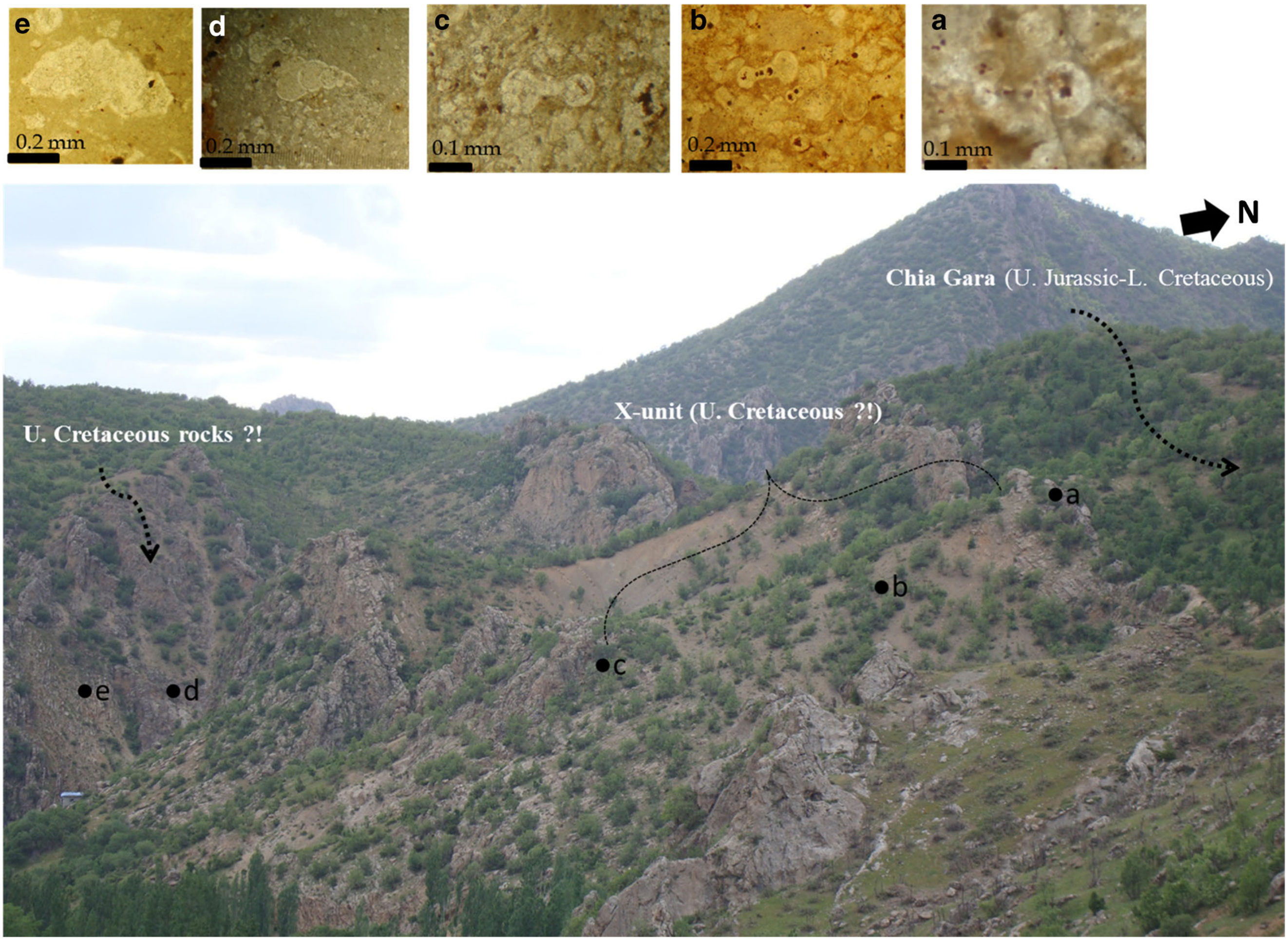

Fig. 9 The upper (*c*) and lower (*a*) boundaries of the X-unit contain the same fossil types and therefore likely to be the same age. To the south, the planktonic fossils are more diverse, and as discussed in the text, a more likely age can be Late Cretaceous. **a**, **b**, **c** *Macroglobigerinelloides bollii* (Pessagno 1967). **d** *Pseudotextularia elegans* (Rzehak 1891)

and a generally high abundance of ammonites. These features are common to the thinly bedded limestone and shale unit found separating the X-unit from underlying units (Fig. 8). At other locations (such as the Sargelu village, Gara Anticline, Banik and Barsarin villages), the Chia Gara Formation is underlain by brecciated and stromatolitic limestones of the Barsarin Formation, and the Barsarin is in turn underlain by other units of thin and medium-bedded limestones, shales, shaly limestones, and cherty limestones of the Naokelekan and Sargelu (Bellen et al. 1959; Balaky 2004; Mohyaldin 2007; Salae 2001; Edilbi 2010). These units belong to the Middle and Late Jurassic (Fig. 8). The presence of Chia Gara, Naokelekan (?), and Sargelu formations in this area is also raises another question about underlying carbonate units (currently mapped as the Kurra Chine Formation) because the Sargelu Formation would be expected to rest on top of the Sehkaniyan Formation. Therefore, it is reasonable to suggest that this massive carbonate unit might be the Sarki and Sehkaniyan (Figs. 7 and 8), although further biostratigraphic work would be needed to confirm this.

The stratigraphic succession (over- and underlying units) and fossil content help constrain likely correlative equivalents for the X-unit. The Hadiena Formation (first described by Wetzel 1950 in Bellen et al. 1959 at the Hadiena village, NW of Amediy) unconformably overlies the Chia Gara Formation (Bellen et al. 1959). From the current fieldwork at Sararu village, it appears that the X-unit is separated from the Chia Gara Formation by a massive dolomitic limestone unit of about 15–20 m thick (Figs. 7, 8, and 9). This massive dolomitic limestone contains the same fossils as the X-unit (Fig. 9a), so it is reasonable to assume that it is a part of it. Moreover, a high diversity of planktonic foraminifera like *Globigerina* sp. and other fossils such as *Inoceramus* spp. that are present in the X-unit are strong evidence that can be used to correlate the X-unit to the Hadiena Formation (Figs. 12 and 13, Appendix 2); the Hadiena Formation contains the same fauna, and its type locality is nearby to the east of Sararu village (Fig. 1).

It has been common to consider the Ora Anticline a unique area within the context of Iraqi geology because it was

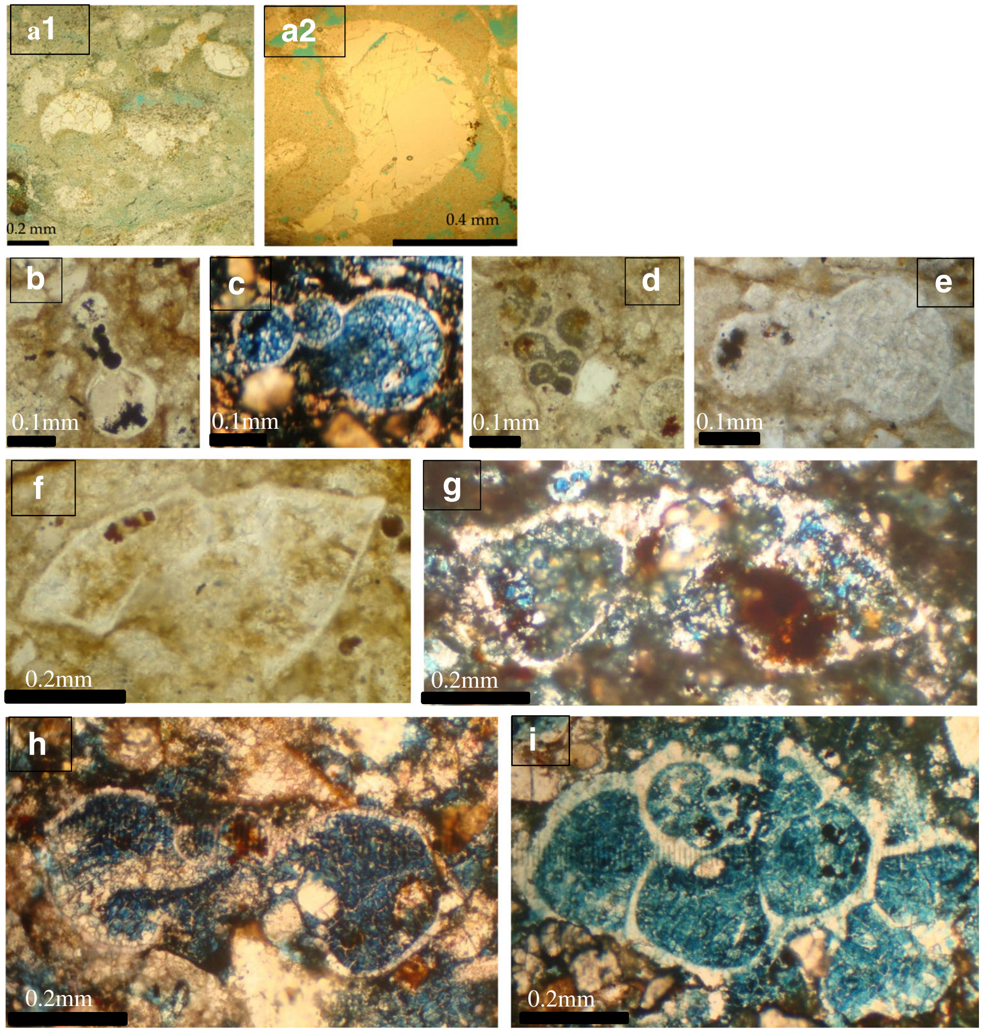

Fig. 10 **a1**, **a2** Ostracods? fossils of the Baluti Formation. The fossils are calcified and cannot be specified the genus. *Blue* is stained resin (blue-dyed resin). Some of the planktonic foraminifera of the X-runit. **b** *Globigerinelloides bollii* (Pessagno 1967) (Late Cretaceous). **c** *Hedbergella monmouthensis* (Olsson 1964) (Late Cretaceous). **d** *Rugoglobigerina rugosa* (Plummer 1926) (Late Cretaceous). **e** *Heterohelix globulosa* (Ehrenberg 1840) (Late Cretaceous). **f** *Globotruncanita elevata* (Brotzen 1934) (Late Cretaceous). **g** *Marginotruncana sigali* (Reichel 1950) (Late Cretaceous). **h** *Globotruncana bulloides* (Vogler 1941) (Late Cretaceous). **i** *Globotruncanita* sp. (Late Cretaceous). *Blue stain* is Alizarin red and Potassium ferricyanide

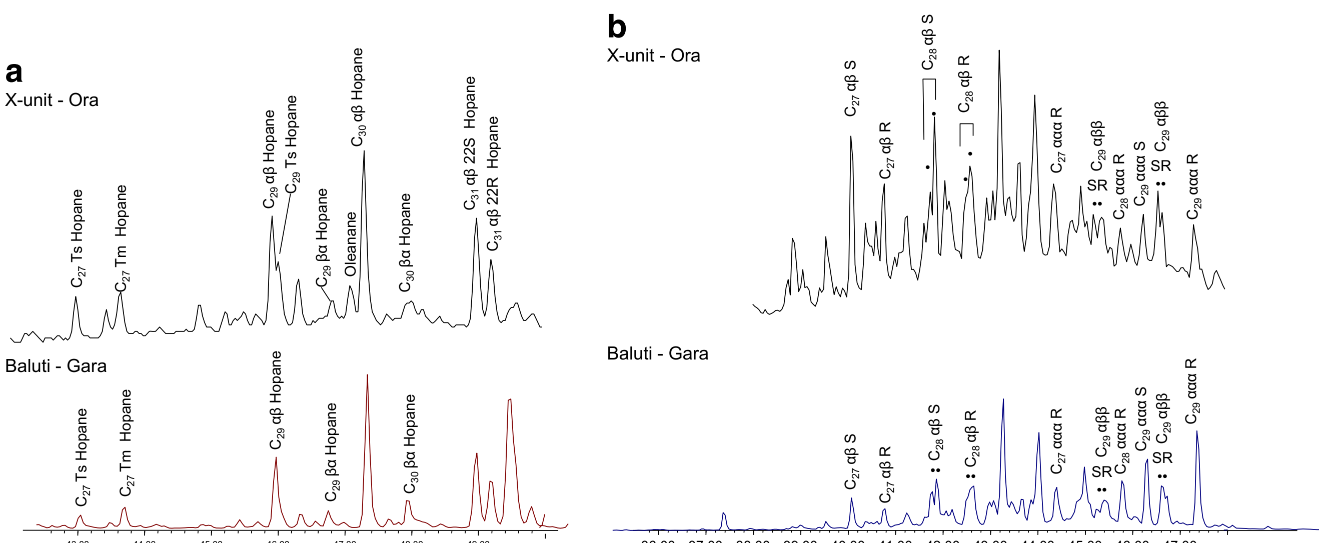

Fig. 11 GC-MS Ion Chromatograms of the Baluti and X-unit. **a** m/z 191 ion chromatograms for mudstone extracts on which it can be seen that the X-Formation contains oleanane while the Baluti formation does not. **b** m/z 217 ion chromatograms showing the different distributions of steranes

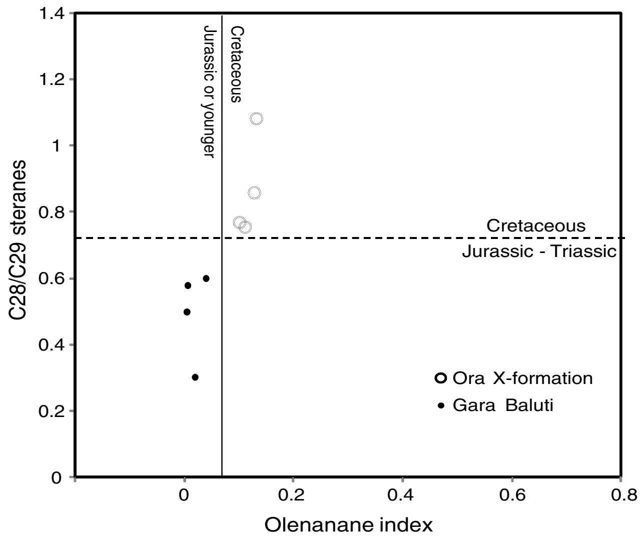

Fig. 12 Cross plot that discriminates the ages of the two formations (see text for discussion), the age boundaries for the C28/C29 regular sterane parameter are from Grantham and Wakefield (1988) and the age boundaries for the Oleanane index are taken from Moldowan et al. (1994a). From this cross plot, the X-Formation would be interpreted to be younger than the Baluti Formation

considered to have a stratigraphic succession that spanned the Paleozoic, Mesozoic, and Cenozoic. It was therefore not surprising that geological researchers attempted to utilize the apparently complete stratigraphic coverage outcropping within a single locality. However, the current study reveals that a complete stratigraphic succession does not outcrop in Sararu village (it may be found in other place in the Ora area) and demonstrates that outcrops previously held to be the Baluti can not be so because they are not Triassic in age. In an area with such complex structural geology (the imbricate and thrust zone), it will be necessary to subject a number of other outcrops to further study. An additional aspect of the work we present here is that the Hadiena may be more laterally extensive than previously thought.

Conclusion

Fieldwork observations, age-related biomarker, and microfossil content provide evidence that the X-unit encountered at Sararu village is unlikely to be the Upper Triassic Baluti Formation. Fieldwork observations indicate that there is no

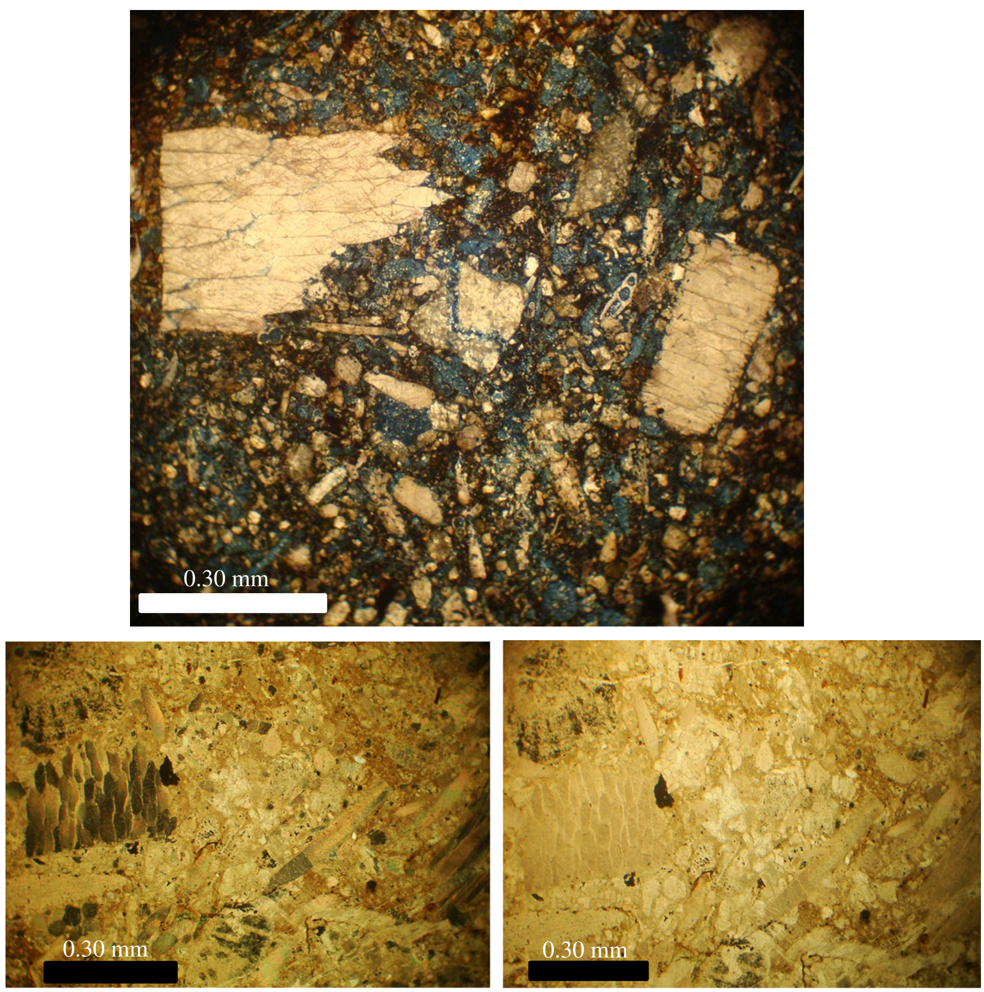

Fig. 13 Photomicrograph showing the prismatic microstructure and honeycomb pattern of the Inoceramid bivalves found in the X-unit. Inoceramid bivalves are known from the Jurassic to the Late Cretaceous. They were common during the Late Cretaceous and became extinct in the Maastrichtian, before the Cretaceous-Tertiary boundary (Flügel 2010). The fossils are important Cretaceous index fossils (McLeod and Ward 1990 in Flügel 2010). *Blue stain* is Alizarin red and Potassium ferricyanide

stratigraphic contact between the X-unit and the Kurra Chine Formation at Sararu village. The X-unit is underlain by the Chia Gara Formation and overlain by a younger carbonate unit that is likely Upper Cretaceous.

The presence of the age-specific biomarker oleanane and the high abundance of planktonic foraminifera suggest that the X-unit is Upper Cretaceous to Lower Tertiary and therefore can not be the Triassic Baluti Formation. The most likely correlative equivalent to the X-unit is the Upper Cretaceous Hadiena Formation. Further paleontology, stratigraphy, and structural geological studies are needed to both confirm our study and work through its implications.

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References

Al-Brifkani MJN (2008) Structural and tectonic analysis of the Northern Thrust Zone (East Khabour River) in Iraq, unpublished PhD thesis (in Arabic), University of Mosul, 174 p

Al-Halawachi J (2014) Ostracoda of Baluti Formation (Upper Triassic) from the Amadiya area in Dohuk, Northern Iraq. University of Mosul, unpublished MSc thesis

Al-Juboury AI, McCann T (2013) Petrologic and geochemical interpretation of a transitional Triassic-Jurassic boundary sections from north Iraq. Geol J 50(2):157–172

Al-Khamiss A, AbdulMalik S, Abel Hammed W (2012) Compositional Basin Model of Kuwait—Leads for Yet To Find Potential (Abstract). AAPG Search and Discovery Article #120098©2013 AAPG Hedberg Conference Petroleum Systems: Modeling the Past, Planning the Future, Nice, France, October 1–5, 2012

Al-Khashab S, Al-Halawachi J (2014) http://cypris.ostracoda.net/index.php/cypris-31-2013/35-cypris/cypris-latest/cypris31-2013/49-activities-cypris31#iraq

Al-Mousawi HA, Fouad SFA, Sissakian VK (2007) Geological map of Zakho Quadrangles, Sheet NJ-38-9 1: 250000: State Establishment of Geological Survey and Mining, Iraq. Baghdad

Aqrawi AAM, Goff JC, Horbury AD, Sadooni FN (2010) The Petroleum Geology of Iraq: Beaconsfield. Scientific Press Ltd, United Kingdom, 424 p

Awdal A, Healy D, Alsop GI (2016) Fracture patterns and petrophysical properties of carbonates undergoing regional folding: a case study from Kurdistan, N Iraq. Mar Pet Geol 71:149–167

Balaky SM (2004) Stratigraphy and sedimentology of Sargelu Formation (Middle Jurassic) in selected sections in Erbil and Duhok Governorates-Iraqi Kurdistan. MSc. Thesis, (unpub.), Salahaddin University , 110 p

Bellen RC, Dunnington HV, Wetzel R, Morton D (1959) Lexique Stratigraphique International, Vol. III, Asie. In: Dubertret, L., (director), Fasc. 10c, Iraq, Center Nat. Researche Scientifique, (Paris), p 333

Bolli H (1951) The genus Globotruncana in Trinidad, B.W.I. J Paleontol 25:187–199

BouDagher-Fadel MK, Banner FT, Whittaker JE (1997) Early evolutionary history of planktonic foraminifera, British Micropalaeontological Society Publication Series. Chapman and Hall Publishers, London, p 269

Brew G, Barazangi M, Al-Maleh AK, Sawaf T (2001) Tectonic and geological evolution of Syria. GeoArabia 6(4):573–616

Brönnimann P (1952) Globigerinidae from the Upper Cretaceous (Cenomanian- Maestrichtian) of Trinidad. B.W.I. Bulletins of American Palaeontology 34(140):1–70

Brotzen F (1934) Foraminiferen aus dem Senon Palastinas. Zeitschrift des Deutschen Palastina-Vereins 57:28–72

Buday T (1980) The regional geology of Iraq Vol.1: Stratigraphy and Palaeogeography. Publications of GEOSURVE, Baghdad, p 445

Cushman JA (1938) Cretaceous species of Guembelina and related genera. Cushman Laboratory for Foraminiferal Research 14:2–27

d'Orbigny A (1839) Foraminifères. In: Histoire physique, politique et naturelle de l'ile de Cuba. Atlas, de la Sagra, v, p 1–224

Dalbiez F (1955) The genus Globotruncana in Tunisia. Micropaleontology 1:161–171

Dickson JAD (1966) Carbonate identification and genesis as revealed by staining. Jour Sed Pet 36:491–505

Edilbi ANF (2010) Stratigraphy and petroleum potential of Chia Gara Formation (Tithonian-Berriasian) in selected sections in north Iraq: M.Sc. thesis, Salahaddin University, Erbil, 126 p

Ehrenberg GC (1840) Über die Bildung der Kreidefelsen und des Kreidemergels durch unsichtbare Organismen. Abhandlungen der Königliche Akademie der Wissenschaften zu Berlin 1838:59–147

Flügel E (2010) Microfacies of carbonate rocks, analysis, interpretation and application. Springer, Berlin, 976 p

Gandolfi R (1957) Notes on some species of Globotruncana. Contributions from the Cushman Foundation for Foraminiferal Research 8(2):59–65

Google Earth version 7.5.1557, build date 5/20/2015. Imagery date 4/10/2013

Grantham PJ, Wakefield LL (1988) Variations in the sterane carbon number distributions of marine source rock derived crude oils through geological time. Organic Geochemistry, 12, 61–73. In: Peters KE, Walters CC, Moldowan JM (eds) (2005) The Biomarker Guide. Volumes 1 and 2, Cambridge University Press, Cambridge, 1155 p

Hanna MT (2007) Palynology of the upper part of Baluti Formation (Upper Triassic) and the nature of its contact with the Sarki Formation (Lower Jurassic) at Amadyia District, northern Iraq: Ph.D. thesis, University of Mosul, Mosul, Iraq, 143 p

Jassim SZ, Buday T (2006) Latest Eocene-Recent Megasequence AP11. In: Jassim SZ, Goff J (eds) Regional Geology of Iraq. Dolin, Prague and Moravian Museum, Brno, Czech Republic, p 71–183

Jassim SZ, Goff JC (2006) Geology of Iraq: Dolin, Brno, Prague and Moravian Museum, 352 p

Loeblich AR (1951) Coiling in the Heterohelicidae. Contributions from the Cushman Foundation for Foraminiferal Research 2:106–110

McLeod KG, Ward PD (1990) Extinction pattern of Inoceramus (Bivalvia) based on shell fragment biostratigraphy. In: Flügel E (ed) (2010) Microfacies of carbonate rocks, analysis, interpretation and application. Springer, Berlin, 976 p

Mohyaldin IMJ (2007) Stratigraphy and sedimentology of organic rich limestones of the Chia Gara Formation, Rania area, Sulaimani, Kurdistan Region, NE Iraq. Journal of Zankoy Sulaimani 10A(1): 91–102

Moldowan JM, Seifert WK, Gallegos EJ (1985) Relationship between petroleum composition and depositional environment of petroleum source rocks. Am Assoc Pet Geol Bull 69:1255–1268

Moldowan JM, Dahl J, Huizinga BJ et al (1994a) The molecular fossil record of oleanane and its relation to angiosperms. Science 265: 768–771

Numan NMS (2000) Major Cretaceous tectonic events in Iraq. Rafidain Jour Sci 11(3):32–54

Olsson RK (1964) Late Cretaceous planktonic foraminifera from New Jersey and Delaware. icropaleontology, 10/2, p 157–188

Pessagno EA Jr (1967) Upper Cretaceous planktonic foraminifera from the western Gulf Coastal Plain. Paleontographica Americana 5:245–445

Peters KE Walters CC, Moldowan JM (2005) The Biomarker Guide. Volumes 1 and 2, Cambridge University Press, Cambridge, 1155 p

Plummer HJ (1926) Foraminifera of the Midway formation in Texas. University of Texas Bulletin 2644(1):1–206

Reichel M (1950) Observations sur les Globotruncana du grisement de la Breggia (Tessin). Ecoglae geologicae Helvetiae 42:596–617

Rzehak A (1891) Die Foraminiferenfauna der altertiáren Ablagerungen von Bruderndorf in Niederösterreich, mit Berücksichtigung des angleblichen Kreidevorkommens von Leitzersdorf. Annalen des K.K. aturhistorischen Hofmuseums, vol 6, p 1–12

Salae ATS (2001) Stratigraphy and sedimentology of the Upper Jurassic succession Northeastern Iraq. MSc. Thesis (unpub.), University of Baghdad, 95 p

Shingaly WS (2015) Lithology and diagenetic processes of the Baluti Formation (Upper Triassic) in the Amadyia area, Kurdistan region, Iraq. Journal of Zankoi Sulaimani JZS (2015) 17–2 (Part-A)

Sigal J (1948) Notes sur les genres de foraminifères Rotalipora Brotzen, 1942 et halmanninella, famille des Globorotaliidae. Révue de l' Institut français du Pétrole 3:95–103

Sigal J (1952) Aperçu stratigraphique sur la micropaléontologie du Crétace': 19th Congrés Géologique International, Monographies régionales, series. 1, Algérie, no 26, p 1–47

Vogler J (1941) Ober-Jura und Kreide von Misol (Niederländisch-Ostindien). Palaeontographica 4:243–293

Voorwijk GH (1937) Foraminifera from the Upper Cretaceous of Havana, Cuba. Koninklijke Nederlandse Akademie van Wetenschappen, Proceedings 40:190–198

White MP (1928) Some index foraminifera of the Tampico embayment of Mexico, part 2. J Paleontol 2(4):280–313