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The Permian-Triassic Boundary in the Kurdistan Region of Northern Iraq

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Abstract

The well-preserved Upper Permian-Lower Triassic succession in the Kurdistan region of northern Iraq has provided an opportunity to study the Permian-Triassic boundary. This study presents the first ever stable isotope data for these rocks. One hundred and sixty-five samples from the Ora-Beduhe and CZO sections located within the Ora structure in the Thrust Zone were studied for lithological, stable isotope, trace fossil and invertebrate fossil variations. Carbon and oxygen isotopic signals ($\delta^{13}C$, $\delta^{18}O$) and %$CaCO_3$ indicate dramatic changes within the CZO section (between samples 29 and 30) where $\delta^{13}C$ records a negative excursion of 6‰ VDP in a portion of the section previously interpreted as late Permian. The P-T boundary matching the lithic changes and extinction of Permian fauna, in addition to another boundary or contact were identify between (samples 16 and 17) which is marked due to severe decreasing in late Permian fauna and appearance of early Triassic. Paleontological record suggests a gradational extinction pattern for the boundary in northern Iraq. Faunal changes are consistent with other regional and global studies for the Permian-Triassic boundary.

Keywords: Permian-Triassic boundary, Kurdistan, Northern Iraq, Stable Isotopes, Neo-Tethys

1. Introduction

The Permian-Triassic boundary has been intensively studied because it represents the most devastating extinction event in earth's history (Erwin, 1993, 2006; Yin *et al*., 1996). The mechanisms and processes suggested for extinctions include a bolide impact, ocean poisoning, large-scale methane release, massive volcanism, and sudden rise and fall in temperature. A recent study by Smith and Botha-Brink (2014) documented the role of drought in massive die-offs of land vertebrates at the P-T boundary in the Karoo Basin in South Africa. The period following the extinction event has been much less intensely studied and all available data indicate that the Lower Triassic was a transitional period between the greatest mass extinction ever and the faunal recovery of the subsequent Mesozoic ecosystems (Flugel, 1994; Erwin, 2001; Wignall, 2001). Marine carbonate rocks have proved invaluable in the effort to understand the changes associated with the Permian-Triassic (P-T) transition because marine calcite incorporates the organic carbon of the ambient seawater with little fractionation. When not subjected to extensive diagenesis, these rocks most likely retain carbon isotope signatures close to their original isotope compositions (Horacek, 2006). Consequently, the $\delta^{13}C$ value of marine carbonates is often a robust proxy of past ocean $\delta^{13}C$ variations. Many mass extinction events including the Permian-Triassic are accompanied by shifts in the marine $\delta^{13}C$ composition, indicating that these events are accompanied by environmental changes that involve the carbon cycle or the extinction itself might be responsible for changes in the global carbon cycle (e.g. Walliser, 1996; Yin *et al*., 1996; Veizer *et al*., 1999; Cui *et al*., 2013; Meyer *et al*., 2013).

Following the study of the Paleozoic-Mesozoic succession in Iraq by Bellen *et al*. (1959) several other studies have described the regional geology of the country (e.g. Buday, 1980; Buday and Jassim, 1987; Hassan *et al*. 1990; Al-Hadidy, 2001, 2007). The Kurdistan region in the northern part of the country comprises well-exposed outcrops of Permian-Triassic sedimentary rocks that have received little attention. The few studies published about these rocks have focused on aspects of lithostratigraphy, paleogeography, sea level changes, and biostratigraphy, and they include Elliott (1954, 1957, 1959, 1959), Kaddouri (1988), Youkhana and Shathaya (1988), Gayara (1992) and Nader *et al*. (1993). Access to the outcrops spanning the Permian-Triassic interval in the Ora Thrust Zone provided the opportunity for detailed analysis of grain size, sedimentary structures, trace fossils, microfossils, macrofossils and stable isotopes in the Ora-Beduhe and CZO sections. The aims of this study were to integrate stable isotope signals with faunal and lithologic records to refine the placement of the Permian-Triassic boundary (PTB) in the region and enlightenment the path for future high resolution studies and to consider this section as one of the best P-T boundaries in the world.

2. Geologic Setting

The studied section within the Ora Thrust Zone is part of the Unstable Shelf in northern Iraq. It is located along the border with Turkey and trends as a narrow belt between the Hazil Su Valley in the west and the Dirri area in the east (37°16'20"N, 43°21'58"E; Fig. 1). The main section studied was the Ora-Beduhe, and the supplementary section used for stable isotope analysis was the CZO. Both sections comprise Upper Permian and Lower Triassic rocks (Chia Zairi Formation through the Mirga Mir Formation). They are mainly carbonate rocks totaling about 1,000 m of thin-, medium-, and thick-bedded limestones that appear to have been deposited on a Tethyan carbonate ramp or platform (Al-Hadidy, 2007). This thick carbonate sedimentation pattern extends into Iran and Turkey.

Neo-Tethys Ocean opened in the Late Permian when one or more narrow blocks of continental crust drifted away from the northeastern margin of Gondwana; hence, the Late Permian– Liassic Megasequence AP6 was deposited in the north- and east-facing passive margin of the Arabian plate, also the lower boundary of the megasequences at the base of the Chia Zairi Formation and Megasequence AP6 in North Arabia unconformably overlies sequences ranging from the Precambrian to Early Permian age (Jassim and Goff, 2006).

The Ora-Beduhe and CZO sections in northern Iraq were located within the Iranian micro continent, which occupied central Tethys near the equator. This micro continent, together with parts of Turkey, Afghanistan and Tibet, belonged to a chain of terrains referred to as the Cimmerian archipelago, and formed a barrier between paleo-Tethys and Neo-Tethys (Besse *et al*., 1998). Sengor and Atayman (2010) suggested that paleo-Tethys appeared to have had a much larger impact than any of its successors owing to its immense size and played a key role in the end-Permian mass extinction event.

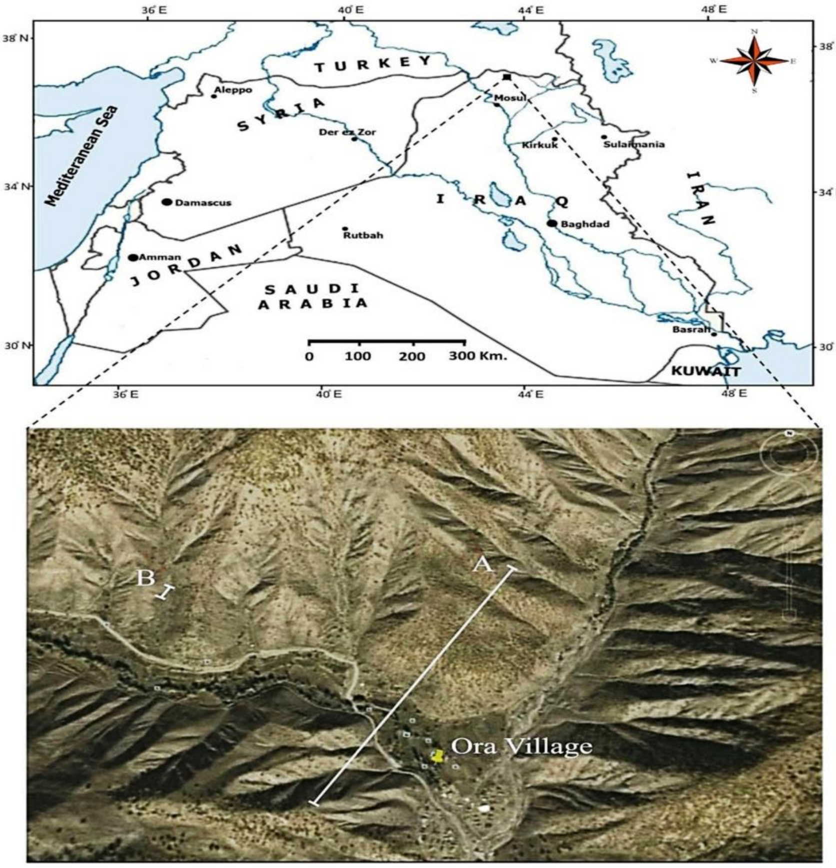

Figure 1. Satellite image showing the locations of the Ora-Beduhe section (A) and CZO section (B) in the Ora Thrust Zone, northern Iraq.

3. Methods

The Ora-Beduhe and CZO sections (Figs. 2, 3) are located less than 1 kilometer apart in the Ora Thrust Zone within a geologically intricate and hardly accessible for study. Each section was measured using a Jacob's staff. Lithology, grain size, sedimentary structures, trace fossils and invertebrate fossil information were recorded in the field. The Ora-Beduhe section (Fig. 2) was sampled with non-systematic pattern for the purpose of evaluation the lithological and faunal variations during the Late Permian – Early Triassic. The CZO section (Fig. 3) was sampled mainly for stable isotope analysis. A total of 165 samples were collected from both sections for study, and 350 thin sections were prepared at the University of Baghdad. Thin section analysis and photography were performed at Missouri University of Science and Technology using a Nikon Eclipse 50iPOL microscope with a Nikon DS-Fi1 Digital Sight Camera connected to a Dell computer with NIS Elements D 3.2 software. All thin sections are stored in the Geology Department at Baghdad University, Iraq.

The samples used for isotopes analysis were carefully obtained from fresh, unweathered surfaces without veins and stylolites. Working on the assumption that the nature of the Permian-Triassic boundary was gradational, 40 samples were collected with variable distance in between at the CZO section 25 m below and 15 m above the suspected boundary, and analyzed for $\delta^{13}C$, $\delta^{18}O$, and $\%CaCO_3$ at the Stable Isotope Mass Spectrometer Laboratory, University of Florida. Each bulk sample was acidified with hydrochloric acid to remove the inorganic carbon fraction before being rinsed with water three times, dried at 50 ℃, and ground. A Carlo Erba NA1500 CNS elemental analyzer was used to measure the percentage of the organic carbon. Carbon ($\delta^{13}C_{org}$) and oxygen ($\delta^{18}O$) isotopes were measured using a Thermo Finnigan Delta Plus XL isotope ratio mass spectrometer with a Con Flo III interface linked to a Costech ECS 4010 Elemental Combustion System with Zero Blank autosampler (elemental analyzer). $\delta^{13}C$ and $\delta^{18}O$ values are quoted relative to VPDB as in (Table 1). Results were processed using MS Excel and extracted graphics smoothed using Origin-0.7 and RockWork-15.

4. Results

4.1 Lithostratigraphy

Field and thin section descriptions of grain size, mineralogy, sedimentary structures, trace fossils, microfossils and macrofossils formed the bases for lithostratigraphic interpretation (Figs, 2, 3). The Upper Permian Chia Zairi Formation and Lower Triassic Mirga Mir Formation (Wetzel, 1959) are present at both study locations. The Chia Zairi Formation comprises three calcareous, fossil-rich units totaling 811 m, while the Mirga Mir Formation consists mainly of marly limestone and sandy dolomitic limestone totaling 200 m. The lower and middle part of the Chia Zairi Formation is mainly mudstone. The upper part of the Chia Zairi Formation and the Mirga Mir Formation comprise wackestone - packstone and floatstone with abundant biota. However, there appears to be significant faunal changes between the Chia Zairi biota and the Mirga Mir biota above the Permian-Triassic boundary (see section 4.2).

Table 1.Datasheet of Stable Isotopes Analysis

Sample ID	d13C (‰, vs VPDB)	d18O (‰, vs VPDB)	%CaCO3
Ora1	0.277125	-13.905	96.51
Ora2	-0.057875	-14.928	68.67
Ora3	-0.258875	-11.949	76
Ora4	-0.144875	-15.448	83.02
Ora5	0.134125	-15.812	90.25
Ora6	-0.144875	-15.494	88.98
Ora7	-0.856875	-14.171	28.23
Ora8	0.306125	-15.434	92.28
Ora9	-0.173875	-14.895	95.81
Ora10	-0.303875	-14.026	84.95
Ora11	-1.113875	-12.995	80.74
Ora12	-0.090875	-13.685	87.635
Ora13	-0.249875	-14.042	88.125
Ora14	0.212125	-13.322	89.405
Ora15	0.410125	-13.293	90.445
Ora16	-0.806875	-12.162	88.335
Ora17	0.312125	-13.24	87.225
Ora18	0.205125	-13.042	86.055
Ora19	-2.029875	-10.625	82.655
Ora20	-0.036875	-12.606	93.605
Ora21	-1.346875	-11.359	80.905
Ora22	1.804125	-12.088	92.325
Ora23	0.765125	-11.522	83.565
Ora24	1.001125	-11.311	88.405
Ora25	0.808125	-11.087	81.605
Ora26	0.280125	-11.021	89.665
Ora27	1.217125	-11.293	87.705
Ora28	-0.828875	-10.451	92.435
Ora29	-3.820875	-9.322	90.745
Ora30	1.196125	-10.792	79.175
Ora31	1.809125	-10.876	91.105
Ora32	1.295125	-10.849	93.415
Ora33	1.369125	-10.83	91.235
Ora34	0.991125	-10.721	95.775
Ora35	1.382125	-10.949	93.995
Ora36	1.357125	-10.876	93.495
Ora37	1.252125	-10.101	92.865
Ora38	0.074125	-10.075	89.005
Ora39	0.556142857	-10.29242857	89.378
Ora40	0.027142857	-10.15442857	79.728

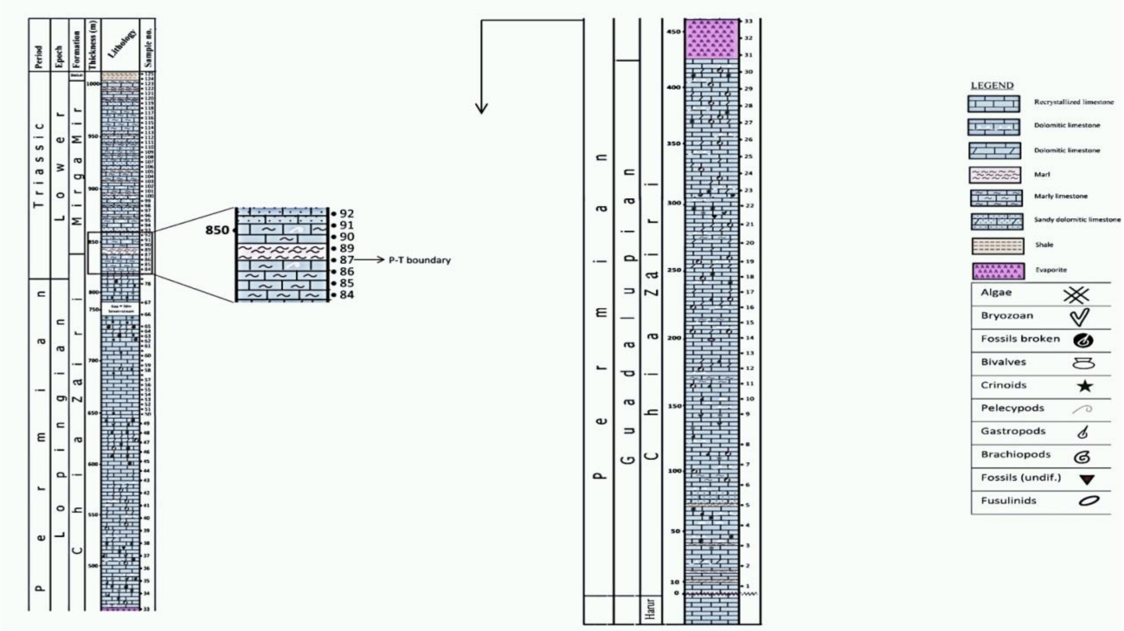

Figure 2. Upper Permian – Lower Triassic stratigraphic succession (showing the P-T boundary) in the in Ora-Beduhe section.

4.2 Biostratigraphy

Thin sections were used to identify microfossils and macrofossils in the studied sections. The Permian-Triassic boundary was identified between samples 29 and 30 in the CZO section based mainly on 6‰ negative excursion of δ^{13}C, the disappearance of most Permian fauna and consistent with the lithic contact between the two formations. The appearance of Triassic fauna were earlier recorded between samples 16 and 17 and going together with vigorous diminution in late Permian faunal assemblages, this is marked to be a Bio-contact or the P-T event horizon (Fig. 3). Upper Permian fossil groups identified in the Chia Zairi samples include calcareous algae, foraminifera, bryozoans, brachiopods, gastropods, pelecypods, ostracodes, crinoids, stromatoporoids, and conodonts (Plates 1, 2). Elliott (1954) was the first study to describe calcareous algae in the Chia Zairi Formation and subsequently described several species in Elliott (1957, 1958, 1959). In our study, stromatoporoids have been identified for the first time in the Upper Permian rocks in northern Iraq; these fossils were common during the Ordovician to Devonian (Scholle and Scholle, 2003). Conodonts are also reported here for the first time in both Upper Permian and Lower Triassic rocks. They are well documented as index fossils in several parts of the world, including Turkey, Iran and China (Lehrmann *et al*., 2003; Angiolini *et al*., 2007; Metcalfe *et al*., 2007; Yousefirad *et al*., 2013).

4.3 Isotope Geochemistry

The δ^{13}C curve from the CZO section (Fig. 3) is generally fairly uniform but fluctuates between samples 22 and 28. The data then records a negative excursion of 6‰ VDP between samples 29 and 30. The negative excursion represents the major extinction event in this region and coincides with a major lithologic change from fossiliferous limestone (Chia Zairi Formation) to marly and dolomitic limestone (Mirga Mir Formation). This boundary is succeeded by a positive excursion of 1.3‰ VDP between samples 30 and 31, after which the curve remains fairly uniform through the Lower Triassic. The δ^{18} O data in this study did not show any abrupt pattern.

A similar sharp negative δ^{13}C excursion has been reported worldwide, although their magnitudes and stratigraphic placement around the PTB vary (Margaritz *et al*., 1988; Holser *et al*., 1989; Baud *et al*., 1989; Wang *et al*., 1994; Jin *et al*., 2000; Twichett *et al*, 2001; Angiolini *et al*., 2007; Isozaki, 2009).

The δ^{18} O data in this study did not show any abrupt pattern. The climate in this region, which was South of Gondwana, experienced a warming trend during the Late Permian-Early Triassic as confirmed by most studies. The identified faunal groups (Fig. 3) indicate warm, shallow marine environment with good water circulation and high amounts of nutrients during the Upper Permian.

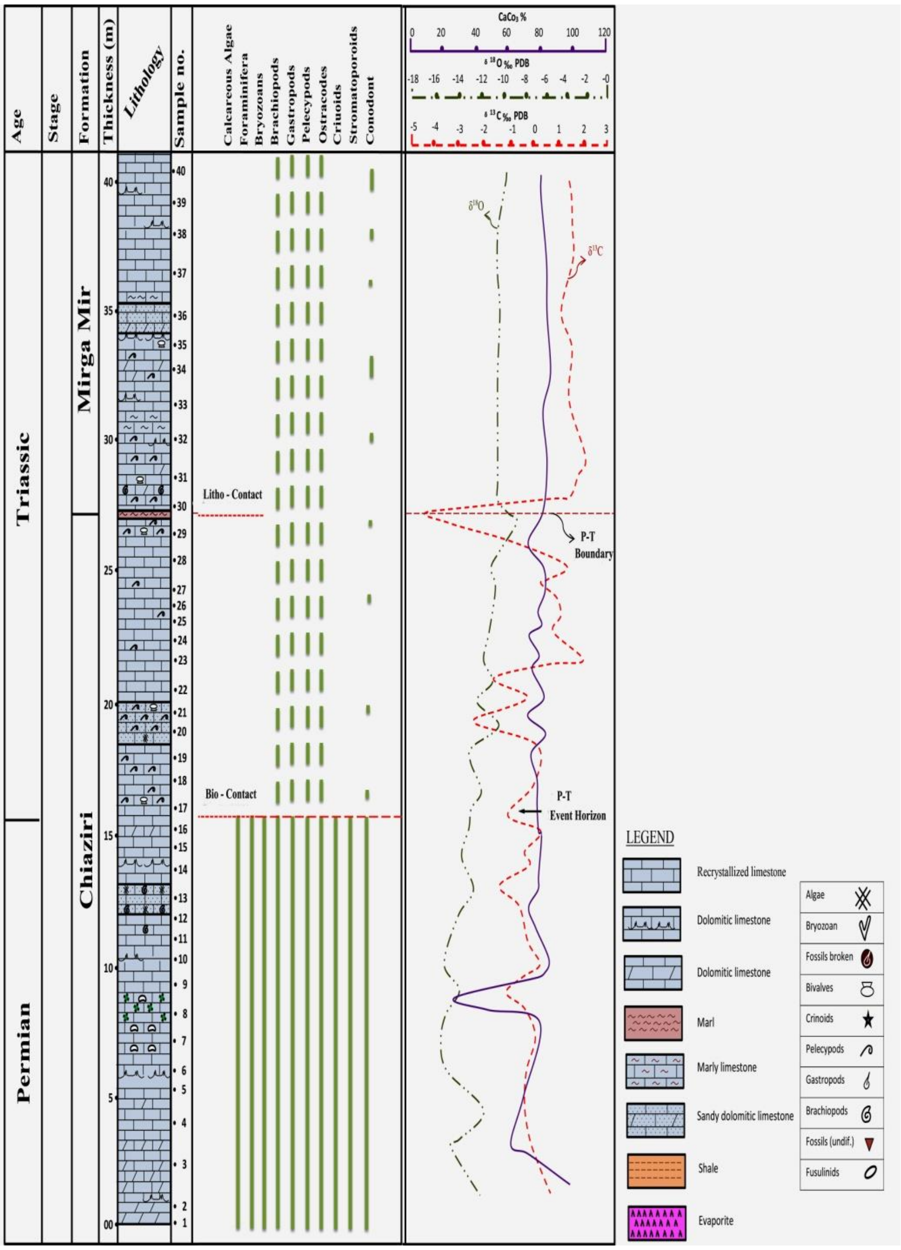

Figure 3. The CZO stratigraphic section illustrating faunal abundance and extinction pattern, and stable isotope curves. A drastic reduction in faunal abundance marks the traditional P-T boundary (herein called the P-T event horizon or Bio – contact) . A negative $\delta^{13}C$ excursion, lithic changes and disappearance of Permian fauna has been used to redefine the P-T boundary or the Litho-contact higher up-section between the Chia Zairi and Mirga Mir formations.

4.4 Global Significance of the CZO Section

This study highlights similarities in stable isotope and faunal data in northern Iraq with other sections in the world. Sections in China and Iran have been compared in detail with the CZO section. Using biostratigraphic, geochemical and sedimentological data in three marine sequences deposited in one section known as the Selong Xishan section in southern Tibet, China (Fig. 4), Shen *et al*. (2006) discussed the PTB mass extinction pattern in this northern peri-Gondwanan region. This end-Permian event in Tibet shows an abrupt marine faunal shift from benthic to nektonic dominated communities occurring slightly beneath the PTB. Also, $\delta^{13}C$ and $\delta^{18}O$ data record a sharp negative excursion around the PTB. In Iran, Horacek *et al*. (2006) studied the carbon cycling in the Tethys Sea during the Early Triassic in the Abadeh, Amol and Zal sections (Fig. 5) located in different parts of the country. All three sections document the negative $\delta^{13}C$ excursion uppermost Permian and across the PTB.

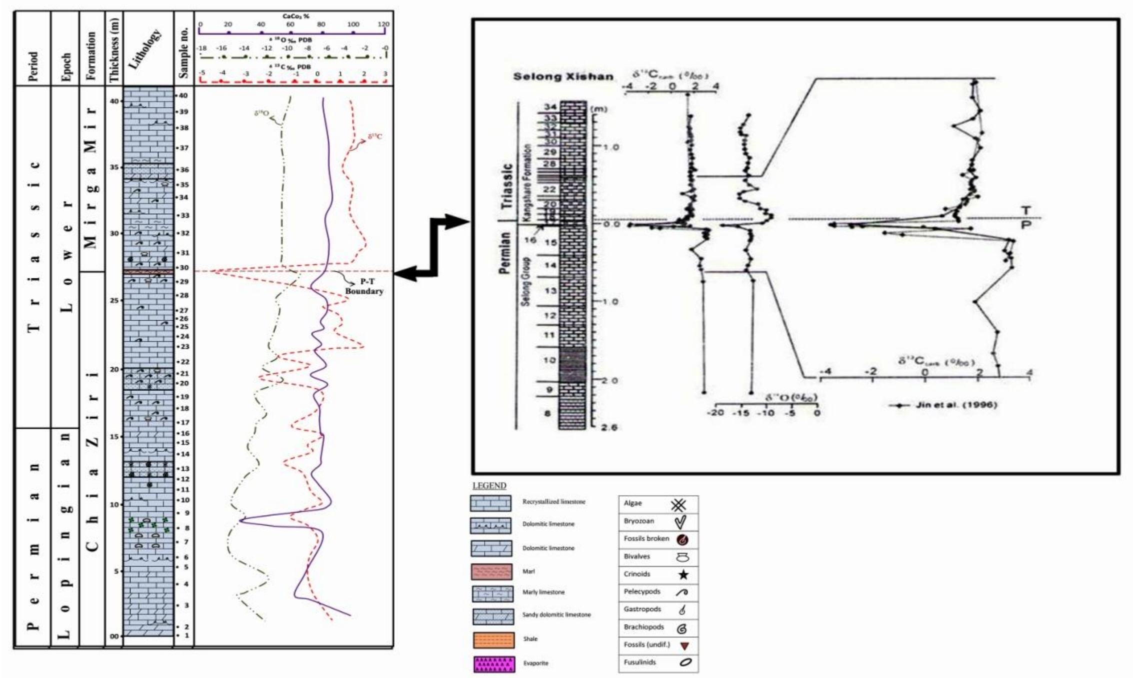

Figure 4. Comparison between the CZO section in Iraq and the Selong Xishan section in southern Tibet, China showing between both sections.

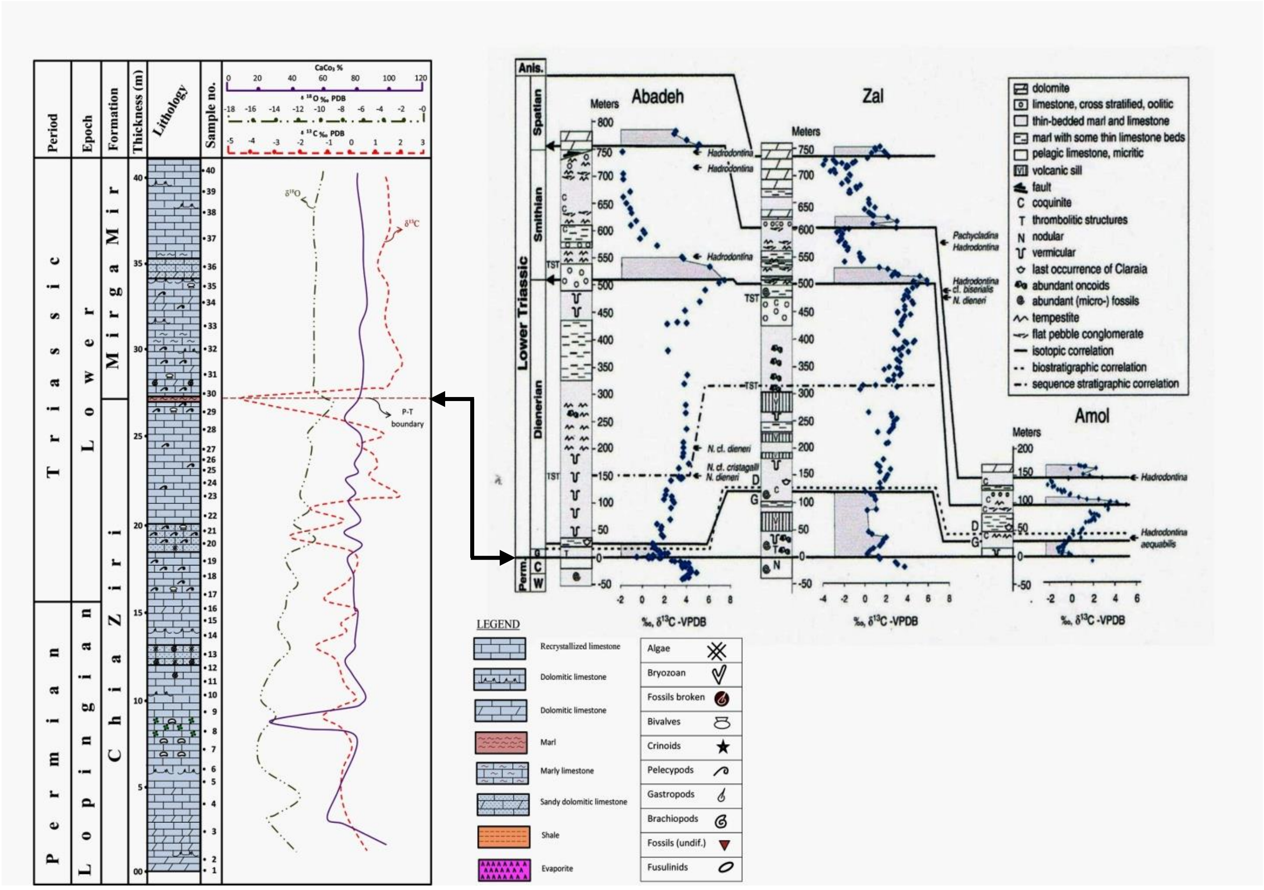

Figure 5. Comparison between the CZO section in Iraq and sections in Iran illustrating the negative δ^{13}C excursion at the P-T boundary.

5. Discussion

Several studies of Permian-Triassic boundary sections in other parts of the world have discussed the possible influence of plate tectonics on lithostratigraphy, faunal changes, extinctions and chemostratigraphy (e.g., Zhang *et al*., 2006; Shen *et al*., 2010). Focusing on an interval of limestone with a general dendroid appearance in the Permian-Triassic boundary section at Laolongdong, Chougqing in South China and found in several other sections, Hongxia and Yasheng (2013) discussed the digenesis of the microbialites preserved in the section. Another study of the Permian extinction by Celâl Senghor and Atayman (2010) noted that paleo-Tethys had a much larger impact than any of its successors due to its immense size and was likely the key player in the so called “end Permian” extinction. They also suggested that the Permian extinction happened in at least two phases.

Isozaki (2009) inferred a double-phased extinction for this time based on two stratigraphic scenarios in Panthalassa: accreted deep-sea pelagic cherts which recorded remarkable faunal reorganization across the Guadalupian-Lopingian boundary and PTB, The prolonged deep-sea anoxia (superanoxia) from the Late Permian to early Middle Triassic that recorded a peak around the PTB. In addition, accreted mid-oceanic paleo-atoll carbonates on seamounts recorded definite changes in late Paleozoic shallow marine benthos diversity (especially fusulinid foraminifera) and a negative shift in stable carbon isotope ratio at the PTB.

Zhang *et al*. (2006) studied the Dongpan section in south China to obtain a high-resolution definition of the deep-water PTB and correlate it with the shallow marine PTB. They based this correlation on lithostratigraphic, event-stratigraphic, biostratigraphic (radiolarian fossil assemblages) and chemostratigraphic (organic carbon isotope excursion) data. Lehrmann *et.al*. (2003) studied the PTB sections in isolated platforms in the Nanpanjiang basin of South China in order to unravel oceanic conditions associated with the end-Permian mass extinction and its aftermath.

Angiolini *et.al*. (2007) used brachiopods to identify the PTB in Turkey. They recognized two assemblages: an assemblage of Early Wachiapingianin age comprising *Spinomarginifera* cf. *S. helica* and *Spinomarginifera* cf. S. *iranica,* and Upper Changhsingian assemblage containing these two species, in addition to *Spinomarginifera* cf. *S. spinosocostata,* and the conodont *Hindeoudus* cf. *H. praeparvus.* The brachiopod fauna noted above confirms the Changhsingian age (Upper Permian) represented by the Pamucak Formation, which also comprises calcareous algae, foraminifera, brachiopods, ostracods, conodonts, echinoderms, and bryozoans.We note here that this Turkish study is similar to our study in CZO section in Iraq. The faunal content at the transition of the Pamucak and Kokarkuyu formations in Turkey records biotic survival in the aftermath of the end-Permian extinction. These units illustrate facies evolution from lower energy inner platform wackestones and packstones to higher energy open platform oolitic grainstones. The lithofacies indicates a transgression at the top of the Pamucak Formation, which continues into the Lower Triassic Kokarkuyu Formation. The present study shows a similarity in the Upper Permian faunal assemblage and extinction pattern.

Lehrmann *et al*. (2003) studied the fauna in two Nanpanjiang Basin sections. In the Upper Permian Heping section and the Taiping PTB section, the crinoid, fusulinid foraminifera, dasycladacean algae, ammonoids, bivalves, gastropods and ostracodes were recorded for the Permian formations. The PTB event horizon was marked by the last occurrence of diverse Permian fossils, although the biostratigraphic boundary is defined by the first appearance of the conodont *Hindeodus parvus* slightly higher in the lower part of the calcimicrobial framestone.

Some studies (e.g., Margaritz *et al*., 1998; Wignall and Twitchett, 1996; Wignall and Newton, 2003) have shown a gradual extinction pattern for the P-T. While Wignall and Twitchett (1996) suggested an 80,000-year duration for this end-Permian extinction, a later study by Wignall and Newton (2003) noted a half million-year duration for the diachronous nature of the extinction event. This study supports this concept because Upper Permian fauna decreased in general from sample 16 representing the PTB event horizon and completely disappeared at the P-T boundary between samples 29-30 about 4 m above event horizon. Figure 3 shows the extinction of calcareous algae, bryozoans, crinoids, stromatoporoids and fusulinid foraminifera; few species of brachiopods, gastropods, pelecypods and ostracodes are recorded in the Early Triassic. Results obtained for the CZO section support the global and regional models of the causes of the P-T boundary extinctions focusing on climate warming in resulting from methane from gas hydrates (Hedari and Hassan Zadeh, 2003; Angiolini *et al*., 2007).

6. Conclusions

The CZO section yielded stable isotopic data for the first time in the Upper Permian and Lower Triassic sedimentary sequence in northern Iraq. By integrated stable isotopes with paleontological data from this section and the Ora-Beduhe section, it was possible to undertake a comprehensive interpretation of the PTB in this part of Tethys, such as those conducted in the neighboring countries of Turkey and Iran. The present study placed the P-T event horizon or Bio-contact between samples 16 and 17 while the P-T boundary or Litho-contact is placed higher-up between samples 29 and 30 matching with a negative δ^{13}C excursion of 6‰ VPD, late Permian fauna disappearance and the lithological boundary between the Chia Zairi and Mirga Mir formations. The Upper Permian faunal assemblage dominated by calcareous algae, foraminifera, bryozoans, brachiopods, gastropods, pelecypods, ostracodes, crinoids, stromatoporoids, and conodonts indicates transgression and warm shallow well-oxygenated depositional environment for this part of Gondwana. Upper Permian fauna disappeared gradually and a much less diverse assemblage occurs above the PTB. This gradual extinction pattern and Late Permian transgression coincides with the findings of several studies regionally and globally. Additional detailed studies are needed to confirm this new placement of the PTB in Iraq.

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FIGURE CAPTIONS

Figure 1. Satellite image showing the locations of the Ora-Beduhe section (A) and CZO section (B) in the Ora Thrust Zone, northern Iraq.

Figure 2. Upper Permian – Lower Triassic stratigraphic succession (showing the Permian-Triassic boundary) in the in Ora-Beduhe section.

Figure 3. The CZO stratigraphic section illustrating faunal abundance and extinction pattern, and stable isotope curves. A drastic reduction in faunal abundance marks the traditional P-T boundary (herein called the P-T event horizon or Bio – contact) . A negative δ^{13}C excursion, lithic changes and disappearance of Permian fauna has been used to redefine the P-T boundary or the Litho-contact higher up-section between the Chia Zairi and Mirga Mir formations.

Figure 4. Comparison between the CZO section in Iraq and sections in Iran illustrating the negative δ^{13}C excursion at the P-T boundary.

Figure 5. Comparison between the CZO section in Iraq and the Selong Xishan section in southern Tibet, China showing between both sections.

PLATE CAPTIONS

Plate 1. Photomicrographs of fossils recovered in the Upper Permian – Early Triassic rocks. **1**. *Mizza velebitatna* Schubert, sample 36. **2**. *Gymnocodium bellerophontis* (Rothpletz), sample 5. **3**. *Permocalculus fragilis* (Pia) sample 2. **4**. *Ungdarella uralica* (Masolv), sample 71. **5**. *Lunucamina geinitzina* SpandeL, sample 64. **6**. *Pachyphloia* Lange, sample 13. **7, 8** *Schwagerina* sp., samples 24, 33. **9**. Fenestrata, sample 7. **10** Trepostomata, sample 9. **11**. Brachiopod, sample 25. 1**2**. Brachiopod, sample 4. **13**. Gastropod, sample 5. **14**. Gastropod, sample 17. **15.** Pelecypod, sample 27.

Plate 2. Photomicrographs of fossils recovered in the Upper Permian – Early Triassic rocks. **1**. Pelecypod, sample 4. **2.** Ostracode, sample 12. **3**. Ostracode, sample 90. **4, 5**. Crinoids, samples 25, 26. **6, 7, 8**. Stromatoporoids, samples 2, 8, 14. **9, 10, 11**. Conodonts, samples 10, 12, 20.

Plate 1

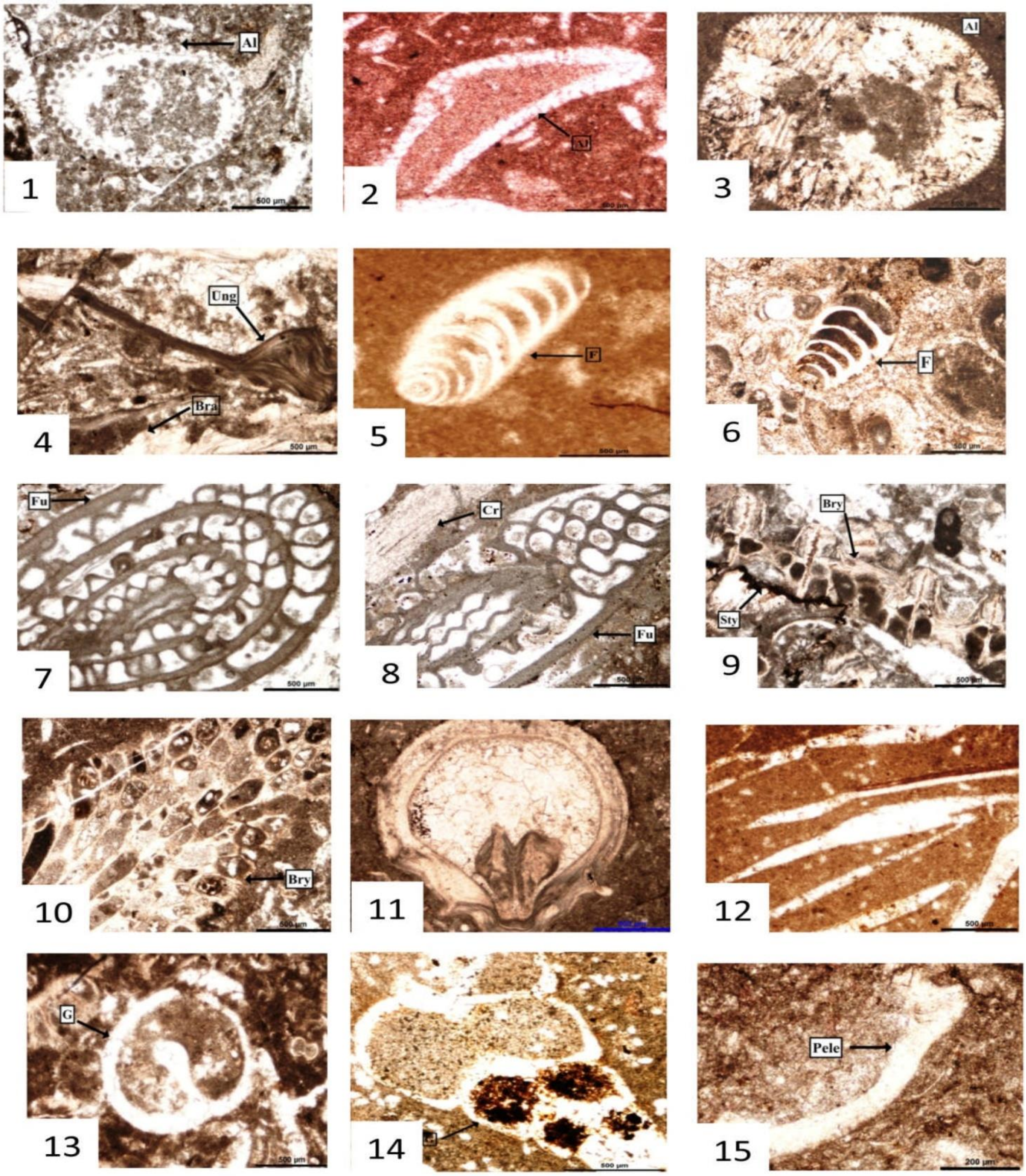

Plate 1. Photomicrographs of fossils recovered in the Upper Permian – Early Triassic rocks from Ora - Beduhe section.

1. *Mizza velebitana* Schubert, Sample 36. **2**. *Gymnocodium bellerophontis* (Rothpletz), Sample 5. **3**. *Permocalculus fragilis* (Pia), sample 2. **4**.*Ungdarella uralica* (Masolv), sample 71. **5**. *Lunucamina geinitzina* Spandel, Sample 64. **6**. *Pachyphloia* Lange, Sample13. **7, 8**. *Schwagerina* sp., samples 24, 33. **9** .Fenestrata (Bryozoan), sample 7. **10.** Trepostomata (Bryozoan) Sample 9. **11**. Brachiopod, Sample 25. **12**.Brachiopod, Sample 4. **13**. Gastropod, Sample 5. **14**. Gastropod, Sample 17. 1**5.** Pelecypod, Sample 27.

Plate 2

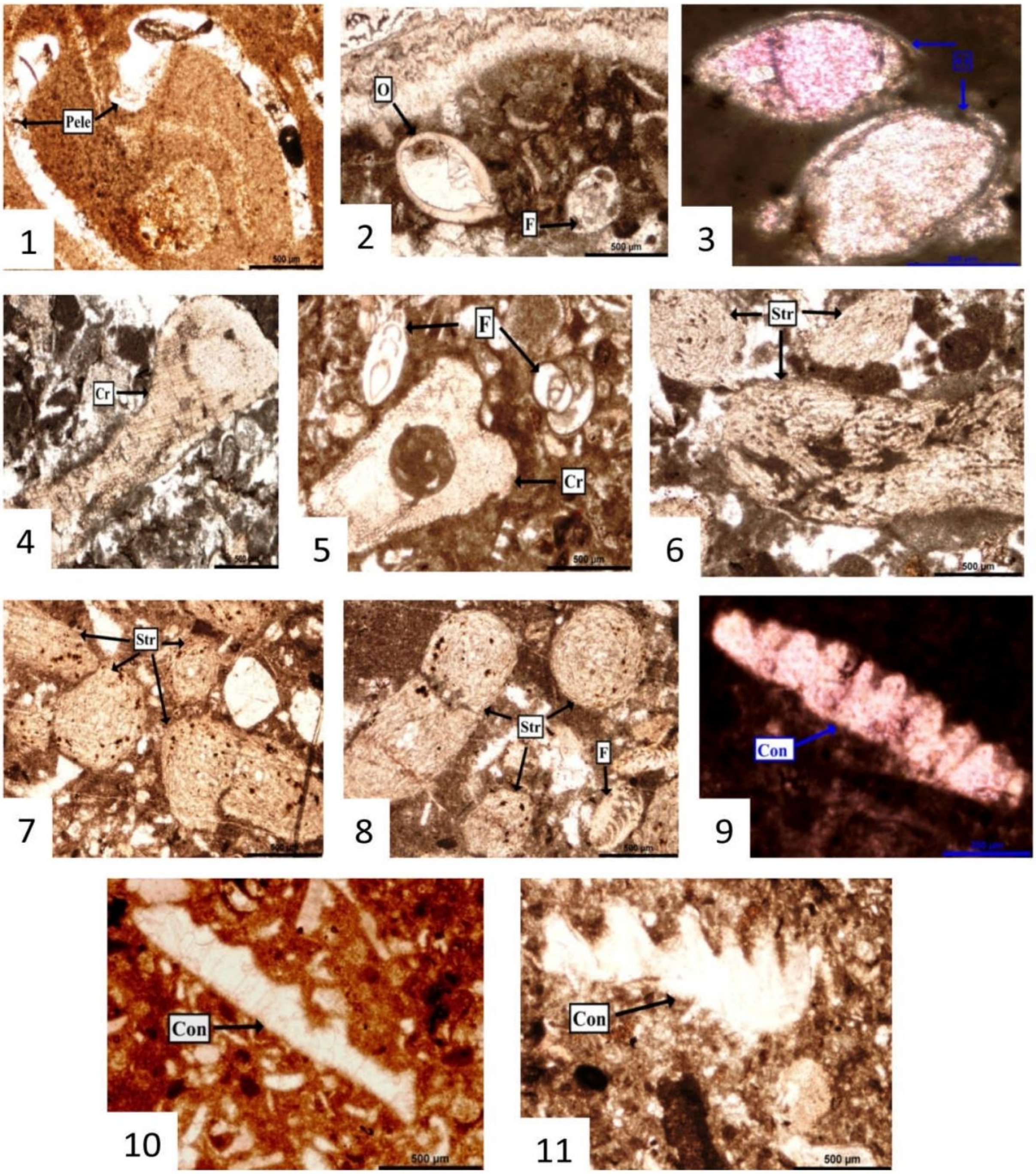

Plate 2. Photomicrographs of fossils recovered in the Upper Permian – Early Triassic rocks from Ora- Beduhe section.

1. Pelecypod, Sample 4. **2.** Ostracode, Sample 12. **3**. Ostracode, Sample 90.
4,5. Crinoids,Samples 25, 26. **6,7,8**. Stromatoporoids, Sample 2,8,14**.**
9, 10, 11. Conodonts, Samples 10, 12, 20.

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