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Biostratigraphy of Devonian-Carboniferous boundary in Tuyeh-Darvar section, north of Iran

Mohammad Taghi Najjarzadeh[1], Ali Reaza Ashouri*[2], Mehdi Yazdi[3], Ali Bahrami[3]

1. Department of Geology, Science and Research Branch, Islamic Azad University, Tehran, Iran
2. Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran
3. Department of Geology, Faculty of Science, University of Isfahan, Isfahan, Iran

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Abstract
Devonian-Carboniferous boundary is not clear in the Eastern Alborz Mountains. In the current study Tuyeh-Darvar section with about 170 m, thickness is selected. In this investigation, the primary goal is revision of Devonian/Carboniferous Boundary (known as DCB) and the other goal is the redefinition of the DCB as a famous necessity (based on ICS program in 2008 for defining the boundary and to find a new GSSP). According to Conodont data from acid-leaching 53 carbonate samples(by acid acetic) that obtained from Late Devonian and Early Carboniferous deposits in this section, and based on standard conodont Zonation 6 Zone are recognized; 1. *Bi.ultimus/or Si.praesulcata* Zone, 2. *Pr.kockeli /or Si.sulcata Zone,* 3. *Si.duplicata to Si.sandbergi bio interval,* 4. *Si.crenulata* Zone, 5.*Gnathodus-P.inornatus* Zone, and 6.*Ps.multistriatus* Zone. Considering to the Conodont Zones above mentioned, Conodont faunas and other evidences, in the Tuyeh-Darvare section the DCB, is located within cream to grey silt stone beds, which are lies between K_6 limestone and K_8 dark carbonate beds (about 7.10 m above the base of recent studied section).
Keywords: *Carboniferous, Conodont, Devonian, Jeirud, Mubarak.*

1. Introduction
In the new geochronology studies, discrerninant of stratigraphic boundaries, special the lower boundaries, is very fundamental for correlation and production of smaller divisions (Remane 2003). At present, geochronological and/or ecological boundaries, generally, identified by Index fossils such as; Foraminifera, calcareous Nanno-planktons and Conodonts. According to palynology and micropaleontology studies (Strayer et al. 2003, Racki 2005), were distinguished two types of boundaries, that these are include; "Biotic boundaries" and "A biotic boundaries". Biotic boundaries in the fact are equal to bio stratigraphic boundaries, these kinds of borders, discriminated by occurrences of, appearance, disappearance or organic changing in biota, whereas; A biotic boundaries are identic to lithological boundaries, these boundaries, are known with occurrence of environmental changing that usual have been engraved within the sedimentary rocks. According on ICS the base of Carboniferous system, as defined by the first Appearance Datum (FAD) of the conodont species *Siphonodella sulcata* within the *Siphonodella praesulcata- Siphonodella sulcata* lineage and the GSSP (Global Boundary Stratotype Section and Point) is located in the La Serre Trench E' section, Montage Noire, France (Paproth et al. 1991). Flajs and Feist (1988) published a biometric study of *Si.praesulcata* and *Si.sulcata* based on the La Serre faunas, demonstrating that transitional forms are very common.

Despite these taxonomic uncertainties, the FAD of *Si.sulcata* was chosen to define the base of the Tournaisian, but difficulties in discriminating *Si.praesulcata* from *Si.sulcata* arose immediately (*e.g.*, Wang and Yin 1984; Ji 1985; Ji and Ziegler 1992; Ji 1987; Ji and Zeigler 1993; Flajs and Feist 1988; Casier et al. 2002; Corradini 2003), Further studies on the stratotype section have revealed a series of problems such as; lack of other important stratigraphic guides and the existence of reworking (e.g., Flajs and Feist 1988; Ziegler and Sandberg 1996; Kaiser 2009).

In the Late Devonian, Iran Microplate along with Afghanistan, Turkey, Arabian plate, and other adjacent area had established a part of north edge of Gondwana supercontinent, and was situated at the southern margin of Paleo-Tethys basin. In this time a platformic marine, were dominated from intermediate environment between the shallow, near shore waters to the much deeper waters as upper slope (Brice et al. 1973; Stampfly 1978; Brice et al. 1978; Khosrow-Tehrani 1985; Ghavidel-Syooki and Moussavi 1996; Gholamalian et al. 2009; Kebriaiezadeh and Gholamallian 2004; Becker et al. 2004; Wendt et al., 2002 and Wendt et al. 2005). Devonian-Carboniferous marine deposits, have been marked in this basin, that therefore, today, in various parts of Iran platform (Fig 1), such as Northern Mountain Ranges (Central Alborz, Eastern and Western Alborz) Central, Eastern and South parts of Iran, (Tabas, Ozbak-Kuh, Ardekan and Bandar-Abbas), Upper Devonian-Early Carboniferous sediments, have presence (*e.g.,* Stocklin 1959, 1968; Asserto 1963; Stocklin *et al.* 1965; Brice et al. 1973;

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*Corresponding author.
E-mail address (es): ashouri@um.ac.ir

Jenny 1977a, 1977b; Ahmadzadeh-Heravi 1983; Ashouri 1990; Ghavidel-Syooki and Moussavi 1996; Wendt et al. 2005; Yazdi 2000).

After the creations of Paleo-Tethys basin, the Devonian-Carboniferous marine sediments were deposition. The presence of Middle to Upper Devonian marine faunas, such as: brachiopods, coral, crinoids, gastropoda, briozoan, fish-remains and conodonts, within this age deposits, are indicates that marine condition clearly was appeared from Middle Devonian and culminated at last part of Devonian age, and this was provider a promise for the connection and relation of interior separated basins, (Khosrow-Tehrani 1985; Brenckle 1991; Wendt et al. 2005). The Late Devonian-Early Carboniferous strata are have spreading very well, in Northern parts of Iran, especially in Central and Eastern Alborz, so that, several authors have believe that, Devonian-Carboniferous boundary at numbers of areas, is visible without sedimentary-break/or interruption (Yazdi and Turner 2000; Hosseyninezhad 2008).

Some of known Upper Devonian and close to DCB outcrops, at the Eastern Alborz, are have shallow, near shore and tidal plateau water characters (Asserto 1963; Bozorgnia 1973; Yazdi 2000; Wendt et al. 2005; Ashouri 2006). These terrigenous marine siliciclastics, consisting predominantly of siltstone, shale, sandstone, and sandy lime sequences, represents shallow, near shore high energy and oxygen rich waters. These facieses generally, are represents for decrease of sea level that can be explained to a regression, which have been occurred due Uppermost Famennian glaciation in southern hemi sphere. (Yazdi et al. 2000; Decombeix et al. 2011a, 2011b). Oure main goal in this study is to investigate the D/CB condition and to obtain the continuity status of the Famennian-Tournaisian sequences. Other goals of the project are to recognize of the paleo-sedimentary basin status and to identify the Hengenberg event in the eastern Alborz Mountains (Tuyeh-Darvare area).

2. Previous studies

In various parts of Iran the Late Devonian and Early Carboniferous deposits are have out crops (Fig 2), that terrigenous carbonates, organic carbonates, and other siliciclastic deposits such as siltstone, shale and sandstone beds, are current component of these out crops, which have appeared within a shallow marine environment, the present of marine macro faunas including of: brachiopod, cephalopod, crinoid, bryozoa, coral, fishes , and micro faunas such as, foraminifera, fish remains and conodonts were presenting in possible condition of shallow continental shelf environments, that were have changed from near shore to outer shelf, toward the upper slope (Lasemi 2001; Wendt et al. 2005).

Late Devonian sequences in the East, Center and some areas in North of Iran, display evidences of bio-events and sea level changes that can be aligned with those identified elsewhere (Stampfly 1978; Becker 1993; Yazdi and Turner 2000; Yazdi 2000; Becker et al. 2004; Wendt et al. 2005). Several authors have focused on these strata with the goal of explanatory stratigraphy in this age (Ashouri 1990, 1995, 1997, 2001, 2002, 2004, 2006; Yazdi 1999, 2000; Bahrami et al. 2011a, 2011b) .Consider that, in consequence of fine concentration of several D/C outcrops in the Central-East Iran microplate, mainly in the regions around Tabas such as, Shootori Ranges, Ardekan and Ozbak-Kuh, intrinsically was to cause to attract of some authors to selection of conodont biostratigraphy subjects, in these areas, some of these authors are such as; Ashouri (1990, 1997b, 2001, 2002, 2004, 2006), Yazdi (1999 and 2000); Bahrami et al. (2011c). All these authors agrees on the occurrence of a gap between the Devonian-Carboniferous, but provided different data on the extension of that hiatus in the various sections, for example Wendt et al. (2005), on the basis a few conodont samples claimed a gap which includes the Upper most Famennian and the basal Tournaisian. Boncheva et al. (2007), illustrated a Lower Carboniferous conodont fauna from the Ramsheh section, in southern Isfahan.

In the northern Iran, the same as to Alborz, several authors were published else data. For example, Ahmadzadeh (1971) studied Devonian to Lower Carboniferous conodonts and brachiopods from central Alborz, but he did not found any conodont from Lower most Tournaisian. Weddige (1984) illustrated conodonts from Northeast of Iran. Najjarzadeh (1998) studied Devonian-Lower Carboniferous conodont stratigraphy in Zoo section (Northeast of Jajarm city, in the eastern Alborz). Ashouri (2006) illustrated conodonts from the Khoshyeilagh Formation in the eastern Alborz. Shoushtarizadeh (2005) and Hosseyninezhad (2008) had studies Devonian-Lower Carboniferous conodonts and brachiopods from eastern Alborz in around of Damghan. Habibi et al. (2008) reported Tournaisian conodonts from the Mubarak Formation in the Central Alborz. Mohammadi (2009) studied a lack Devonian- Early Carboniferous conodont fauna from the Central Alborz.

In most researches mentioned above, scarcity of bio stratigraphic relevant faunas (specially conodonts) due to dominated of shallow water litho-facieses and bereavement of conodont containing strata to successively form and much interval between sampling, are determining factors that did not provide the precise age of the various Formation and exact determination of DCB (Bozorgnia 1973; Brice et al. 1973; Hamdi and Janvier 1981; Ghavidel-Syooki and Moussavi 1996; Gholamalian et al. 2009).

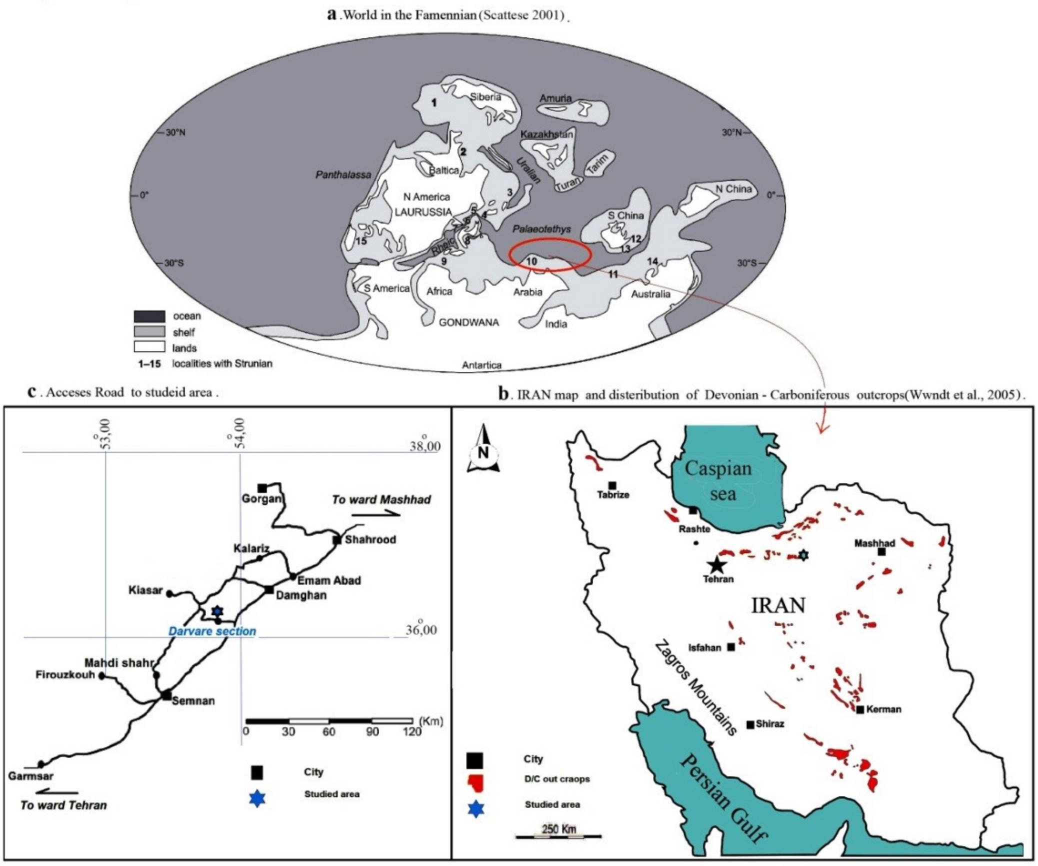

Fig 1. a. The word in the Famennian age (after Scotese 2001). b. Map of dispersion of successions of Upper Devonian-Lower Carboniferous out crops in various parts of Iran, (Wendt et al., 2005) and c. map of access road to Tuyeh-Darvare section in southwest of Damghan.

Fig 2. Geological map of Tuyeh-Darvare area (Post Paleozoic rocks, included Jeirud & Mubarak Formations) and the studied section.

A redefinition of the Devonian/Carboniferous boundary was famous necessity, and in 2008, the international commission on stratigraphy established a working group with the goal to propose new criteria for defining the boundary and to find a new GSSP (Corradini et al. 2011). In this project, taxonomic revision of conodont taxa with some potential as possible tools for defining the boundary are in progress (early *siphonodellids*, Kaiser and Corradini 2011; *protognathodids,* Corradini et al. 2011) and several new sections are under investigation around the world. So, the conodont faunas, are one of the useful tools to distinguishing of "biotic boundaries" special in Late Paleozoic, we were forced to use of this fossils for Devonian-Carboniferous boundary bio stratigraphic studies at Tuyeh-Darvare section and comparison with other adjacent sections in Iran and neighbor countries.

3. Geological setting

In this study, the investigated area is located in the East toward Central Alborz Mountain Ranges. More precisely, the Tuyeh-Darvare section is located about 1.5km north east of Darvare village, adjacent a rock mine, at Global satellite position coordinates: 53°,53'-53°, 51' and 36°,0' - 36°,4′. This section is mapped in the Kiassar quadrangle of the Geological map of Iran (See Shoushtarizadeh 2005), in this area, all of the litho-stratigraphic units from Precambrian to Jurassic are exposed in more or less parallel belts that extends from SE to NW direction.

3.1. Lithostratigraphic description

The oldest rock units in this area are Precambrian shale and limestone's rocks conformably overlaid by four units, that spanning from Cambrian to Lower Ordovician such as: The calcareous to shale sequences of Barut Formation, the Zagun shale's, the Lalun sandstones and the terrigenous of Mila Formation. The latter unit is unconformable overlaid by the Devonian Formation (Jeirud Formation), that followed by the Mubarak Formation, by Lower Carboniferous in age. (Kebriaiezadeh and Gholamallian 2004). This succession ends with Triassic calcareous sediments and Jurassic sandstone and shale's.

The Devonian-Early Carboniferous column in this area is consisting of about 190m of terrigenous and carbonates deposits (according to Shoushtarizadeh 2005, about 170m belonged to Jeirud and 20m belonged to Mubarak Formation). The Jeirud Formation here unconformable overlies the Cambro-Ordovician Mila Formation, and consists of mainly terrigenous and carbonate sediments that starting from the base to 102m above base, with conglomerate, cross bedded red sandstone, white sandstone with intercalation of shale beds, limestone, dolomite and sandy limestone, this part, on based strati graphical position, aligned to Devonian age (Shoushtarizadeh 2005) and from 102m to 175m above the base followed by sandy limestone and limestone strata, brachiopods, crinoids and fish remains are always abundant throughout the unit, and in some levels also bryozoans, rare gastropods and rare trilobites have been observed, as well as some micro fauna such as sclecodonts, echinoderm segments, fish micro remains and conodonts have been collected from this part (Shoushtarizadeh 2005). The Jeirud Formation in this area is overlain by carbonate sediments of Mubarak Formation, that consist of dark limestone beds, it followed by dark and dark grey shale's interbedded with thin fossiliferous marly limestone beds.

The studied section that named Tuyeh-Darvare is located in the north of Iran, in 45km southwest of Damghan city, close to Darvare village, (Figs 1 and 3). This section has been measured in about 1200m at northeast of Tuyeh-Darvare road, at adjacent of Tuyeh mine, at Global satellite position Coordinates: Base, N 36°,1′,17.99″, E 53°,53′,15.50″ and Top, N 36°,1′,17.18″, E 53°,53′,15.64″.

The stratigraphical Devonian column in this area, mainly is consist of about 172m marine deposits, these sediments can be divided in two parts, lower part is include of terrigenous deposits, mainly formed by alternation of sandstone, siltstone, shale , sandy limestone beds and number of mud carbonate beds. The upper part is composed from carbonate strata, such as; limestone, sandy limestone, and dolomite with alternation of shale, silt and numbers of sandstone thin beds. The studied section with about 18m thickness is selected at the Upper part of Devonian to the Lower Carboniferous column, at interval 165m to 190m above the lower boundary of the Jeirud Formation (Fig 4). This section in the base started with 2.5m grey sandy limestone and grey limestone that belonged to the Upper Devonian age. These are embraced by upper part of Jeirud Formation.

The carbonate strata in this section consist mainly of cream to brown sandy limestone beds (with crinoids fragments, brachiopods, bivalves, gastropods, ostracods, bryozoans, fish micro remains, foraminifera and conodonts), dark grey fossiliferous limestone, dark dolomite and dolomitic limestone (fossiliferous), with alternation of dark and dark grey thin-layer shales and siltstones. At close to the upper most of the Jeirud/or at base of Mubarak Formation is presented about 1.5m cream to brown rusty sandy limestone, which is contains relatively complete examples of crinoid's a few dark, thin, laminated carbonates, siltstone and shell beds, which are obviously intermittent thorough the section. Arrangement of strata from the base to the top as to follows :(Figs 3 and 4)

-2.5m gray thin to medium-bedded sandy limestone (K_0), rich in fossils, includes (brachiopods, crinoidal segments, and rare gastropods, fish micro remains and conodonts) with trace marks such as burrows, this facies in microscopic section is contained oolites. (K_0).

-110cm cream thin bedded silty shale.

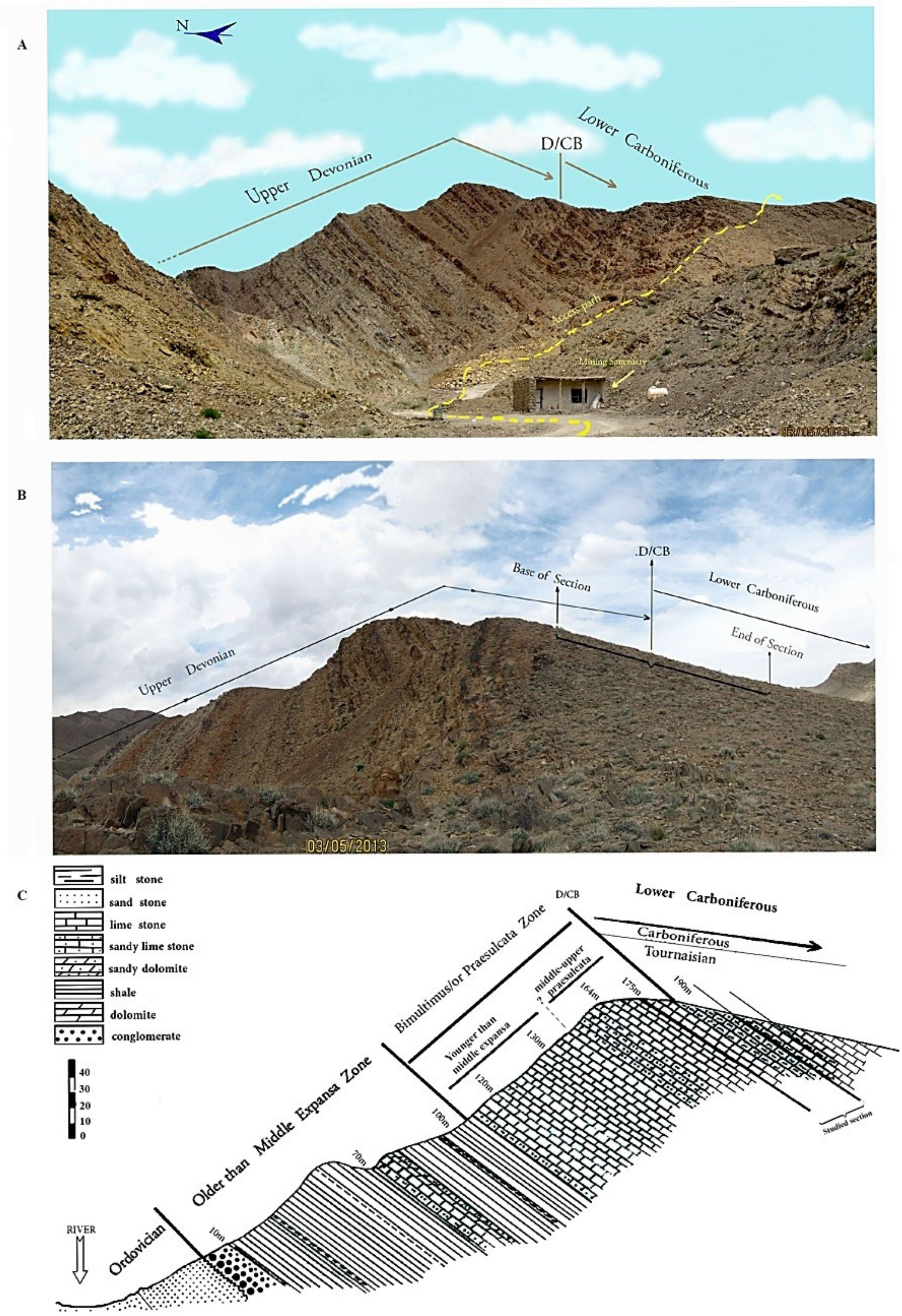

Fig 3. a and b. Selected views of the studied section, respectively northern and southern flanks of the Tuyeh-Darvare section and position of the Devonian/Carboniferous boundary. c. Diagrammatic geological section of the Tuyeh- Darvare section and indicating the approximate boundaries of the Jeirud and Mubarak Formation, (Modified after Shoushtarizadeh 2005).

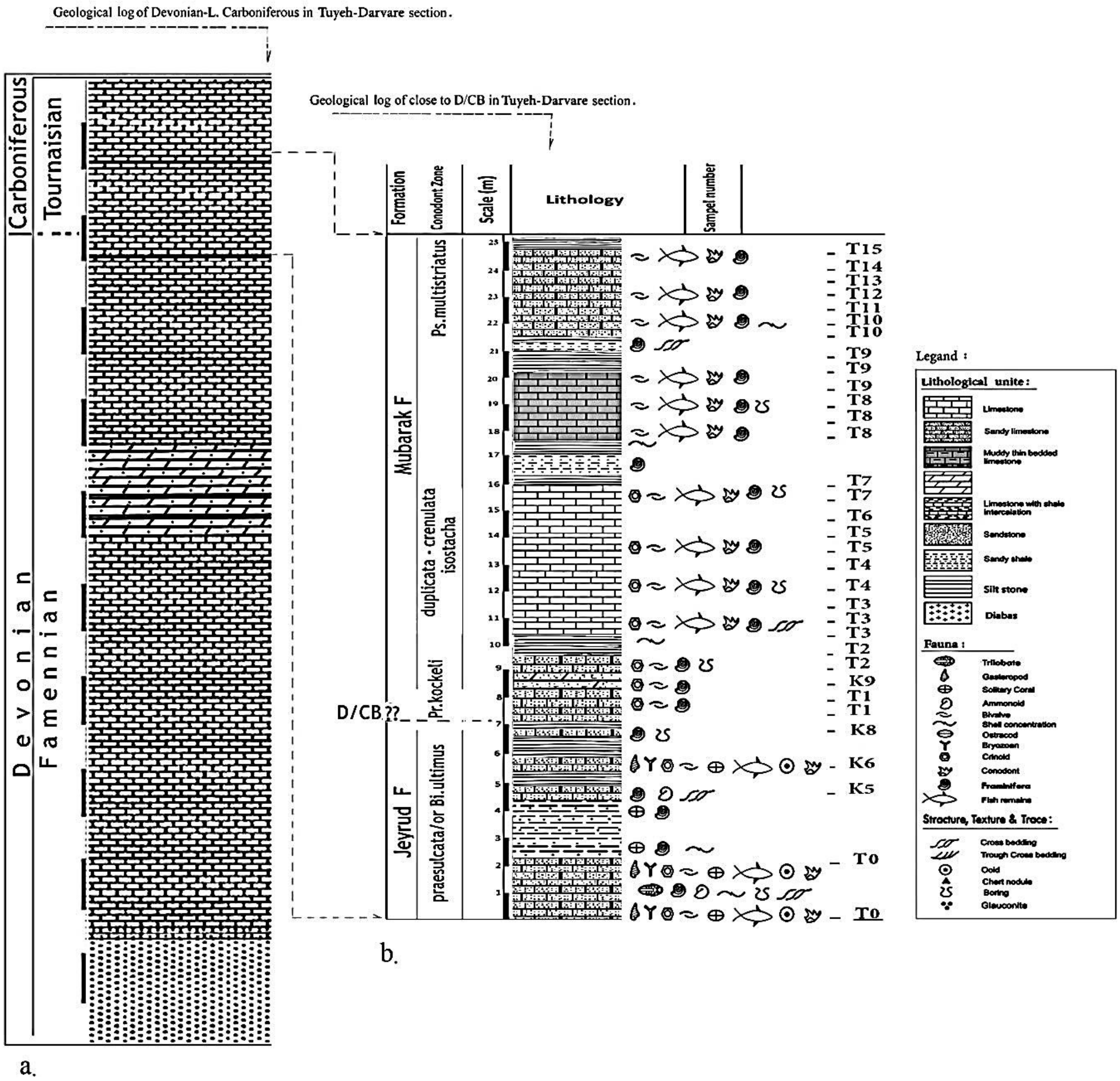

Fig 4. a. Stratigraphic column of Devonian-Early Carboniferous strata in the previous researching (Shoushtarizadeh 2005). b. Upper Devonian-Early Carboniferous stratigraphic column in Tuyeh-Darvar section in new studied.

2.5m dark thin to medium-bedded dolomites and sandy dolomites rich in fossils (brachiopods, bivalve, crinoidal segments, fish micro remains, and rare conodonts), (K_8-T_2).

-30cm gray dark silty shale's.

-5.40m gray dark medium bedded sandy oolitic Lime stones, rich in fossils contain brachiopods, crinoidal segments, fish micro remains and rare conodonts) (T_3 –T_7).

-2.30m gray to dark silty shale.

-2.20m dark gray thin to medium bedded organic lime stones, strongly condensed and laminated, contains fish micro remain, sclecodonts, crinoidal segment and rare conodonts), (T_8-T_9).

-110cm dark thin bedded silty shale.

-3.10m dark thin bedded carbonate mudstone, limestone, strongly condensed and laminated and fossiliferous (segments of crinoid, bryozoan, fish micro remains, ostracods shells, segments of trilobite, rare gastropods, sclecodonts and conodonts), (T_{10} – T_{15}).

-2m gray thin bedded silty shale.

-4.5m gray thin to medium bedded sandy limestone rich in fossils, includes (brachiopods, crinoidal segments, crinoids (piece stem), rare gastropods, micro fauna contains fish micro remains, sclecodonts and conodonts) (K_5).

-30cm gray to cream thin-bedded silty shale.

-30cm gray thin to medium limestone rich in fossils contain brachiopods, crinoidal segments, fish micro remains and conodonts) (k_6).

4. Material and Methods

In order to have more precise age control of Late Devonian to Early Carboniferous deposits and for determination of DCB situation, 53 samples (3-4 kg/each) were collected and processed for conodonts. The samples were processed with the conventional acetic acid technique, but for some silty samples and compacted limestones, formic acid 10% with a 10- hour period was used, (See Druce and Wilson (1967)). The sampling process was accomplished as much as passible adjacent and closely (close sampling distance).

5. Discussion

5.1. Conodont data and age assignment

After acid leaching these results were obtained; 23 samples were barren and more than 140 conodont elements were obtained from 30 other samples, conodont frequency is very low, only a few samples yielded mostly about 3 to 4 elements/per kg, the higher yields was occurred in the T_{10} sample 185m above the base of Devonian column (21.20m above to base of recent section), Maximum of elements abundance is 6el/kg, average of elements abundance is 1.4 el/kg. In the most part of section the preservation of conodont fauna is medium to good and without contamination, only in some of samples such as; sandy lime stones and oolitic sandy lime stones that are situated in the lower part of section (T_0 to T_2), most of species are encrusted by quartz, chamosite and other iron minerals. The color of conodont elements is black (C.A.I=5), among all of these 29 species / and 8 subspecies are belongs to 14 genera (*Bispathodus, Mehlina, Branmehla, Pelekysgnathodus, Polygnathus, Neopolygnathus, Pseudopolygnathus, Idiognathodus, Siphonodella, Klydagnathodus, Spathognathus, Gnathodus* and *Hindeodus),* that were discriminated, this association is dominated by the shallow water genera such as *Polygnathus* & *Neopolygnathus* (abundance 43%), *Mehlina, Branmehla, Bispathodus* & *Pseudopolygnathus,* are scare and common in the lower most part of the section, other deeper water genera such as *Siphonodella* with a low abundance (about 19%) most are visible at the medium part of the section. There has been considerable work done in recent years to refine the conodont zonation leading up to, and crossing, the D–C boundary (Corradini 2008; Kaiser 2009; Corradini et al. 2011; Kaiser and Corradini 2011). The current conodont zonation across the D–C boundary is presented in Fig 5. Part of the problem stems from the fact that the defining conodont species for the boundary, *Siphonodella sulcata,* is often absent from many outcrops worldwide (Kaiser and Corradini 2011). This has led to correlation difficulties when the marker species is absent. Exacerbating the problem is the problem of distinguishing between members of the *Siphonodella praesulcata* to *Siphonodella sulcata* lineage (Kaiser and Corradini 2011). Identification based on personal bias can lead to inconsistency in boundary placement when different outcrops are studied by different workers. This has necessitated a re-evaluation of the biostratigraphic definition of the D–C boundary, and possibly substituting a new species. There have been difficulties in finding replacement species because many potential candidates, like the *Protognathus* lineage, either do not have their first appearance (FA) precisely at the boundary, or are too inconsistently distributed globally to be of correlation use (Corradini et al. 2011). The current conodont zonation used to define the boundary includes the *Si.praesulcata/* or *Bi.ultimus*, *Pr.kockeli*/or *Si.sulcata*, *Si.duplicata – Si.sandbergi* interval, *Si.crenulata* Zone, *Gnathodus-P.inornatus* and *Ps. multistriatus* Zone (Somerville 2008; Corradini 2008; Perri and Spalletta 1998, 2001; Kaiser 2009; Corradini et al. 2011; Kaiser and Corradini 2011, Corradini et al. 2017 and Spalletta et al. 2017). Major proposed changes to the standard zonation include the deletion of the middle *Si.praesulcata* Zone, the addition of the costatus-kockeli interregnum, and the re-branding of the upper *Si.praesulcata* to the *Pr.kockeli* Zones. The middle *Si.praesulcata* Zone was discarded due to a lack of useful widespread marker fossils. The lower *Si.praesulcata* Zone was re-branded because of the widespread prevalence of *Protognathus kockeli* as opposed to the less abundant *Siphonodella praesulcata* (Kaiser 2009; Corradini et al. 2011).

In this investigating, has been used based on conodont occurrences from the section measured in the Tuyeh-Darvar. Through the -18m, from Upper Devonian to within Lower Carboniferous deposits, conodont Zones represented are as follows (Fig 6); *Si.praesulcata*/or *Bi.ultimus*, *Pr.kockeli*/or *Si.sulcata* Zones , *Si.duplicata* to *Si.sandbergi* interval, *Si.crenulata* Zone, *Gnathodus-P.inornatus* and *Ps.multistriatus* Zones (Fig 5).

5.2. *Si.praesulcata* /or *Bi.ultimus* Zone

According Spalletta et al. (2017) and Corradini et al. (2017), The Lower boundary: FAD of *Bispathodus ultimus* and the Upper boundary: FAD of *Protognathodus kockeli Remarks*. The re-defined zone is equivalent to the Upper *I.expansa*, Lower, and Middle *Si.praesulcata* Zones of Ziegler and Sandberg (1984) and Brenckle (1991), as well as to the Upper *I.expansa* and *Si.praesulcata* Zones and the *costatus–kockeli* Interregnum of Kaiser (2009). It corresponds also to the *Bi.ultimus ultimus* and *Si.praesulcata* Zones and *costatus–kockeli* Interregnum of Becker et al. (2016). The name *Bi.ultimus* Zone was first used regionally in the Pyrenees (Perret 1988) and then adopted internationally in the sense of the Upper *I.expansa* Zone by Hartenfels and Becker (2012).

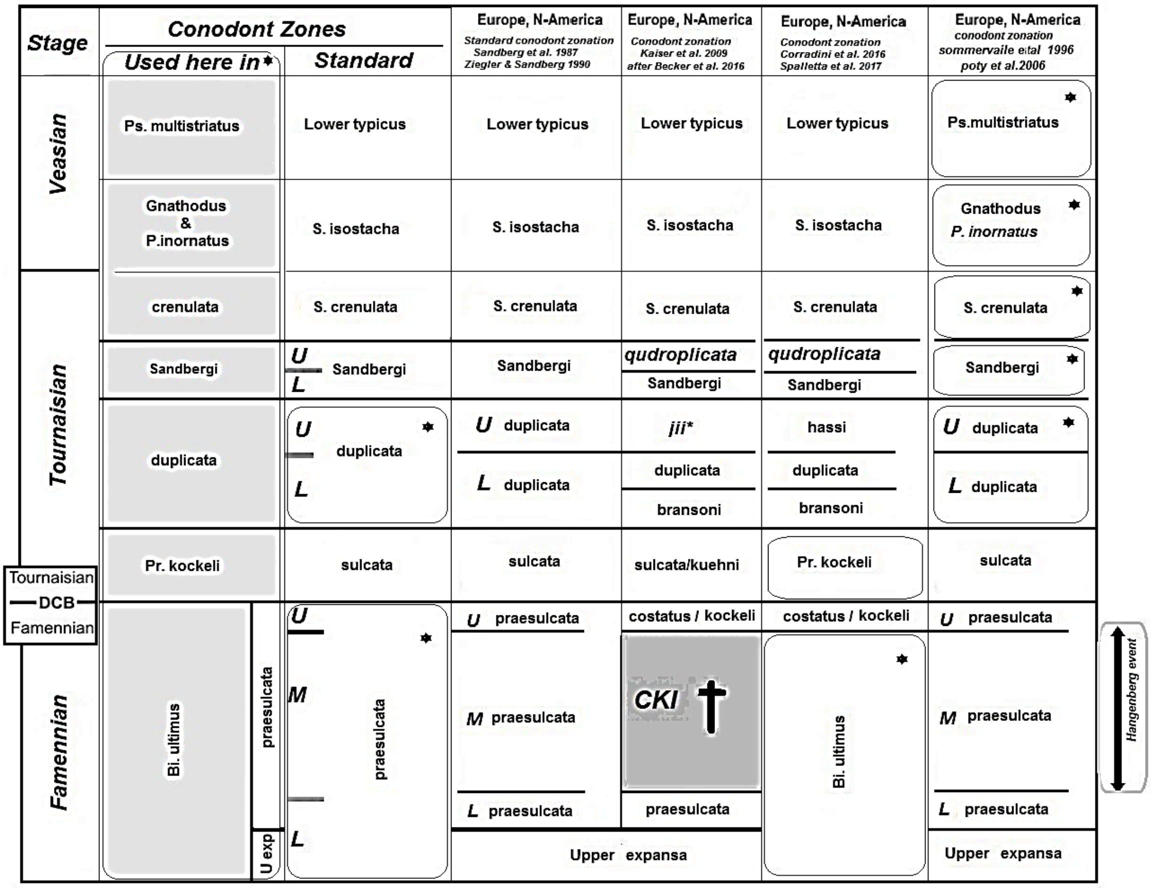

Fig 5. The conodont zonation that used in this study and its correlation with other point of the world.

The zone was then re-defined and enlarged by Corradini et al. (2017). It extends for an interval quite long when compared to the other Famennian Zones. Here it is not subdivided, as *Siphonodella praesulcata,* which entry was used by Ziegler and Sandberg (1984, 1990) to define the Lower *Si.praesulcata* Zone, is a taxon rare and difficult to identify (Kaiser and Corradini 2011). The occurrence of *Si.praesulcata* could be useful as an indication of the middle part of the Zone, which can be identified by the entry of *Protognathodus meischneri* and *Protognathodus collinsoni* (Kaiser and Corradini 2011). The lower and middle parts of the Zone are characterized by a fauna with high diversity. The upper part, corresponding to the "*costatus–kockeli* Interregnum" of Kaiser (2009), is characterized by an impoverished fauna following the extinction associated with the Hangenberg Event (Perri and Spalletta 2001; Racki 2005). Kononova and Weyer (2013) named a new subspecies of *Bi.ultimus-Bi.ultimus bartzschi* but here this subspecies is not considered valid.

5.3. Conodonts useful for the zonal identification

–*Branmehla suprema, Palmatolepis gracilis gonioclymeniae*, and *Pseudopolygnathus marburgensis trigonicus* enter near the base of the Zone; *Polygnathus purus purus*, and *Polygnathus symmetricus* enter in the lower part. The first occurrences of the two last species are probably not synchronous worldwide as delayed occurrences are common in the basal Tournaisian. *Protognathodus collinsoni*, *Pr.meischneri*, and *Siphonodella praesulcata* and other early *Siphonodella* species enter in the middle part of the Zone. *P. marginvolutus*, *P. perplexus*, *P. praehassi*, and *Ps.brevipennatus* become extinct in the basal part of the zone. In the middle part of the Zone *Bizignathus kaiseri*, *Branmehla bohlenana bohlenana*, *Br.fissilis*, *Icriodus darbyensis*, *Ps.marburgensis marburgensis*, and several Polygnathids became extinct (Kaiser and Corradini 2011). *Bispathodus bispathodus*, *Bi.costatus*, *Bi.jugosus*, *Bi.ultimus*, *Branmehla disparilis*, *Palmatolepis gracilis expansa, Pa.gracilis gonioclymeniae*, and *Ps.marburgensis trigonicus* disappear in the upper part. *Pa. perlobata postera*, *Pa. perlobata schindewolfi*, *Pa.rugosa ampla*, *Pa.rugosa rugosa* were reported by Ji and Ziegler (1992) to range to the top of the Upper *I.expansa* Zone, but according to Becker et al. (2016), these taxa come only from mixed fauna and the late findings are due to reworking.

Table1. Range chart of conodont species in Tuyeh-Darvar section .For graphical reason not all the species are reported. For abbreviations of conodont genera refer to Fig 6.

Samples / species	T0	K2	K3	K5	K6	K8	T1	K9	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
P. semicostatus	1																					
P. brevilaminus	1																					
P.com.dentatus										1							1	1				
P. com. carinus				1	1					1							1					
P. com. communis	1			1	1	2	1		2	2			1	1	4	1	2		3	1	1	
P. inornatus	1			1	2	1	3		2	1			3	2	3	2	2	2	1			
M. strigosa	1				1					2				2	2							
Gn.complectense										3				2	2				1			
Bi. stabilis	1									1	1			1	1				1			
Bi. ultimus		1		1																		
P. parapetus														2					1			
P. purus						1			1					1	2			1				
P. pur.subolanus															1		1	1				
P. symmetricus						1				2	1					1	1					
P. longiposticus							2	1				1	1	1	1		1				1	
P. bischoffi									1					1	1		1					
P. inor.rostratus									1					1	1							
Pr. meischneri						1			1													
Si. praesulcata	1			2		3	1			1	2		1	2	2							
Si. sulcata							1	2						2	1	1				1	1	
Si. crenulata															1	1						
Ps. dentilineatus		2																				
Ps. primus									2				1					1				
Ps. pinnatus															1			1				
Ps. triangulus																1	1					
Ps. multistriatus																					1	1
L. commutata										2			1					1	1			
Sp. cyrius										2				1			1	2				
Sp. crossidentatus													2				2	1				
Gn. bilineatus										2				1			1	2	1			

The *Si.praesulcata* /or *Bi.ultimus* Zone is recognized in the lower part of the Tuyeh-Darvar section (samples, T_{0-1} to K_8 from base to 7.10m above base the section or about 172m above the base of Devonian column), by occurrence of the *Bi.ultimus* (Spalletta et al. 2017), *Si.praesulcata* (Sandberg 1972) in base of section and association from *P. com. communis* (Branson and Mehl 1934), *P.inornatus* (Branson and Mehl 1934), *P. lanceolus* (Branson and Mehl 1934), *Pe.inclinatus* (Branson and Mehl 1934) and *M. strigosa* (Branson and Mehl 1934). Although, at non- attendance of the diagnostic conodont species, to cause of shallow water domination, in this part of the section, cannot specify Early, Middle and Upper *Si.praesulcata* subzones, to distinguish and separate, but based on the associated of conodont fauna and dominant conodont occurring the *Si.praesulcata* Zone with certainly is represented in the interval from the base to 7.10m above the base of section.

The *Siphonodella praesulcata* specimen first time appearance in the base of Lower *Si.praesulcata* Zone (Sandberg et al. 1978) and extended to Lower *Si.crenulata* Zone (Bardasheva et al. 2004), late occurrence and last occurrence of *Polygnathus symmetricus* (Branson and Mehl 1934) and *Polygnathus purus purus* (Voges 1959), were from Upper *Si.praesulcata* Zone through the *Si.sandbergi* Zone, to regard of mentioned above and occurrence of other species such as: *P.com.communis* (Branson and Mehl 1934), *P.lenticularis* (Klapper and Lane 1985), *P.brevilaminus* (Branson and Mehl 1934), *P. inornatus* (Branson and Mehl 1934), *Branmehla* sp., *M.strigosa* (Branson and Mehl 1934), that are illustrated in Table 1. The Upper *Si.praesulcata* Zone certainly is represented at interval T_0 toK_8 beds. The lithology in this bio interval Zone is consist mainly of grey to cream thin to medium sandy lime stones in alternation with grey silty shales, than these to upward gradually changed to cream colored beds which is associated with an increase in the amount of the ferruginous compound due the increasing to temperature, oxygen and decreasing to the sea level water.

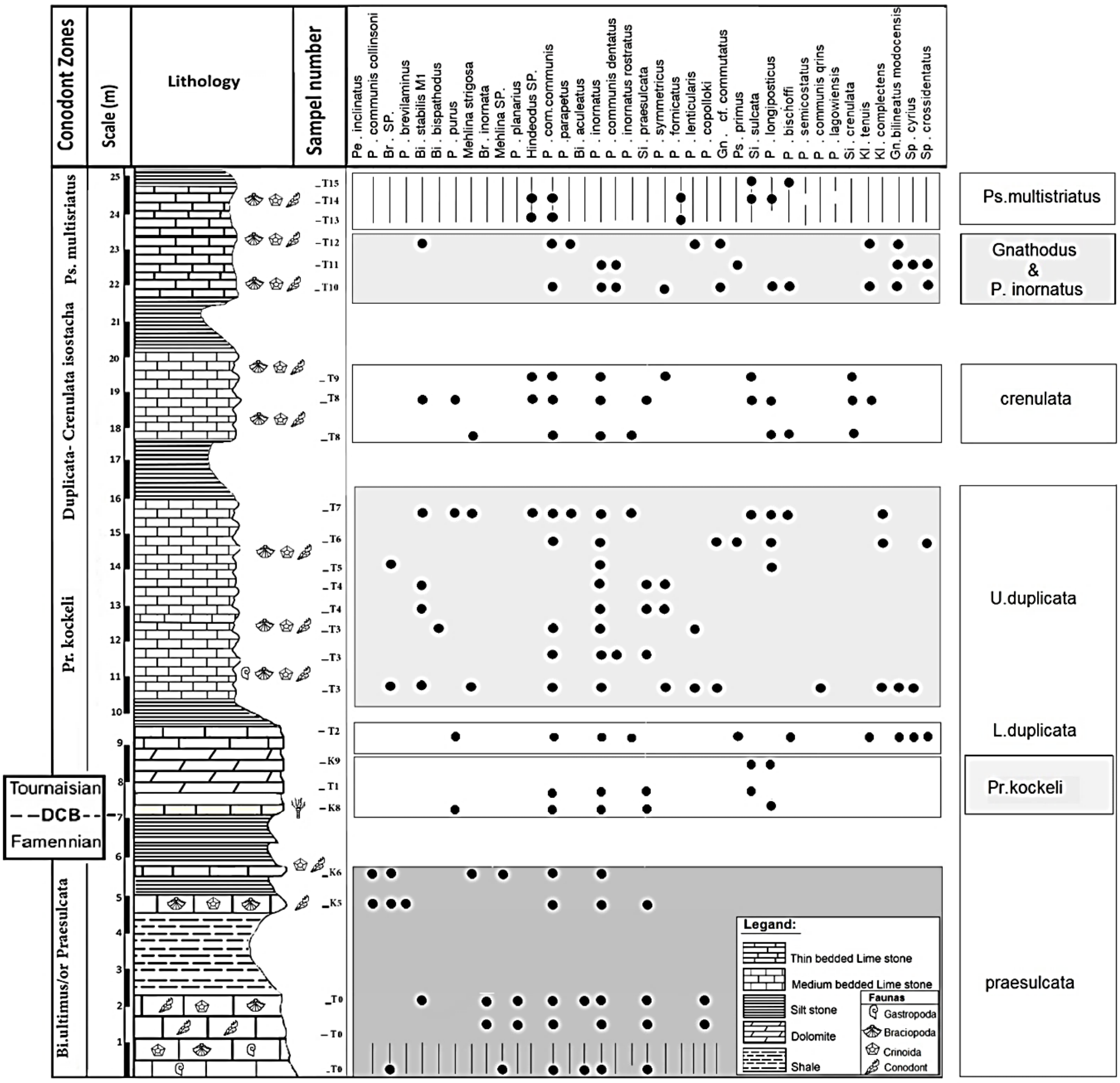

Fig 6. Stratigraphic log of the Tuyeh-Darvar section with indication of the stratigraphic units and occurrence of main taxa. Numbers of conodont sample, T_0 to $T_{15,}$ for graphical reason The Famennian conodont faunas (*Si.praesulcata* Zone) in this section dominated by species of Polygnathus (more than 51%), includes specimens of P. communis and P. inornatus that are accompanied by other present genera such as; *Siphonodella* (19%), *Mehlina, Branmehla* and *Bispathodus* each of them about 5%. With presence of this demographic composition in studied section and according to Ziegler and Sandberg (1990) and Sandberg et al. (1978), the Polygnathid bio facies is dominated in *Si.praesulcata* Zone. Not all the sample numbers are reported. For abbreviations of conodont genera refer to fallow; P.=*Polygnathus*, Neo.=*Neopolygnathus*, Ps.=*Pseudopolygnathus*, Pe.=*Pelekysgnathus*, Pr.=*Protognathodus*, Bi.=*Bispathodus*, M.=*Mehlina*, Br.=*Branmehla*, H.=*Hindeodus*, Id.=*Idiognathodus*, Cl./Kl.=*Klydagnathodus*, Gn.=*Gnathodus*, Sp./Spa.=*Spatognsthodus*, L.=*Locheri*.

The DCB discriminate in between K_6 and K_8 to caused lack of diagnostic conodont species is very difficult and needed to the contemporaneous usage of the other stratigraphic tools such as, palynology (according to previous paleontological studies no sample has been achieved in this section), or accomplish the further studies for organic-carbon percentage in the across boundary sediments.

5.4. *Si.sulcata /or Pr.kockeli* Zone

According to Spalletta et al. (2017) and Corradini et al. (2017), the Lower boundary: FAD of *Protognathodus* *kockeli* and the Upper boundary: FAD of *Siphonodella bransoni.*

Remarks. – The revised zone is equivalent to the Upper *Si.praesulcata* and *Si.sulcata* Zones of Ziegler and Sandberg (1984), and to the *Pr.kockeli* and *Si.sulcata/* or *Pr.kuehni* Zones of Kaiser (2009). The Zone in its present form was proposed by Corradini et al. (2017), which spans from the uppermost part of the Famennian to the lowest part of Tournaisian, including the present position of the Devonian/Carboniferous Boundary.

Conodonts useful for the zonal identification (based on Corradini et al. 2017). *Polygnathus purus subplanus* and *Protognathodus kuehni* enter in the Middle part of the Zone. Curved elements identified as representatives of *Siphonodella sulcata* enter within the Zone, most likely in the basal part. The stratigraphic position of the entry of typical *Siphonodella sulcata* is still uncertain.

In this section, *Si.sulcata/*or *Pr.kockeli* Zone is conformably with interval samples K_8, T_1, and K_9 at the interval 7.10m to 8.50m above the base of studied section (from 172m to 173.40 m above the base of Devonian column). The recovery of *Siphonodella cf.sulcata* in K_8 bed probably marks the base of the *Si.sulcata* Zone and allows to place the DCB just below of this level. These samples yielded some conodonts (see Table 1) such as; *Branmehla* sp. *(*Branson and Mehl 1934)*, Bi.stabilis* (Branson and Mehl 1934), *P.com.communis* (Branson and Mehl 1934), *P.com.dentatus* (Druce 1969), *P.purus purus* (Voges 1959), *P.longiposticus* (Branson and Mehl 1934), *P.inornatus* (Branson and Mehl 1934*), P.lenticularis* (Becker 1993), *M.strigosa* (Branson and Mehl 1934), *Lochriea cf. com.commutatus* (Branson and Mehl 1934)*, P.planarius* (Klapper and Lane 1985), *Si.praesulcata* (Sandberg 1972*)* and *Si.cf.sulcata (*Huddle 1934*).*The lower boundary of *Si.sulcata* Zone according of standard conodont zonation, to identify by the first occurrence of *Si.sulcata*. Thus on based mentioned above species/ subspecies and according to the sandbergi et al. (1978) Zonation, this part of the recent section is equal to *Si.sulcata* biozone and on based to other associated species/subspecies such as *Polygnathus purus subplanus*, *P.symetricus*, and *Pr. meischneri* (according to standard Zonation of Corradini et al. 2017 and Spalletta et al. 2017), belong to Early Carboniferous (Mubarak Formation). The lithological features of this part are included; dark grey thin to medium bedded dolomitic lime stones, rich in fossils contain brachiopods, crinoidal segments, fish micro remains and rare conodont.

5.5. *Si.duplicata* to *Si.sandbergi* interval

According to Sandberg et al. (1978) Lower boundary: FAD of *Siphonodella duplicata* M2 and on based Barskov et al. (1991) FAD *Polygnathus rostratus*, the Upper boundary: FAD of *Siphonodella quadruplicata (*on based Ji and Zeigler 1993) Remarks. The recovery of *P.inornatus rostratus* (Rhods et al. 1969) in sample T_2 (8.50m above the base section or 1.4 m above the DCB), marks the base of the *Si.duplicata* Zone and on other hand according to Sandberg et al. (1978), the existence of *Siphonodella crenulata* M_2 in sampleT_8 (17.4m above base section), indicated to lower boundary of *Si.crenulata* Zone.

Lack of age-diagnostic conodonts in this interval precluded from to discrimination and separation of Lower *Si.duplicata,* Upper *Si.duplicata* and *Si.sandbergi* Zones/or subzones boundaries, therefore this interval, according to mentioned above species and on based the present of other species/subspecies (Table1) such as *P.com.communis* (Branson and Mehl 1934)*, P.com.qrins* (Hass 1959), *P.inornatus* (Branson and Mehl 1934), *P.longiposticus* (Branson and Mehl 1934)*, P.symmetricus* (Branson and Mehl 1934), *P. lenticularis* (Branson and Mehl 1934), *P.bischoffi* (Bischoff 1957), *Si.*cf.*sulcata* (Huddle 1934)*, Bi.stabilis* (Branson and Mehl 1934) and *Gn.commutatus* (Higgins 1999; Higgins and Austin 1985), assignment to *duplicata* Zone into *sandbergi* Zone. This part of section has dark grey carbonates, including layer of sandy limestone, rich in crinoids similar to known crinoidal horizon to central Iran, (Wendt et al., 2005), these beds are traversed to up with grey thin to medium-bedded limestones, and rich in fossils contain brachiopods, crinoid segments, fish remains and rare conodonts.

5.6. *Si.crenulata* interval

According to Sandberg et al. (1978), Lower boundary: FAD of *Siphonodella crenulata* M2 and the Upper boundary: FAD of *Gnathodus typicus and Pseudopolygnathus oxypageous* (on based Lane et al. 1980) Remarks. In the Tuyeh-Darvar section from 17.60m above base toward 19.70 (interval between about 14m to 17m above DCB), this interval assignment to *Si.duplicata* Zone, to the fact that, according sandberg et al. (1978), this age limited by the first occurrence of *Siphonodella crenulata M_2* (Cooper 1939), for Lower *Si.crenulata* boundaries' at the base and First appearances of *Si.quadruplicata*, (based on Ji and Ziegler 1993) for Upper *Si.crenulata* boundary in top. Species of the *Si.crenulata* ranged from Lower *Si.crenulata* Zone in to the *isosticha-upper crenulata* Zone and *the Si.quadruplicata* ranged from the within the *Si.sandbergi* Zone into the *isosticha-Upper Si.crenulata* Zone.

With regard to the associated fauna that mentioned as follows, the range of this part could align with *Lower Si.crenulata* Zone. But the assemblages of other conodonts in this part are as follows*: Bi.stabilis* (Branson and Mehl 1934), *P.inornatus inornatus* (Branson and Mehl 1934) and *P.com.communis* (Branson and Mehl 1934), *P.com.dentatus* (Druce 1969), *P.bischoffi* (Bischoff 1957), *P.symmetricus* (Branson and Mehl 1934), *Gn. bilineatus* (Roundy et al. 1926), *Ps primus* (Branson and Mehl 1934), *Ps.pinnatus* (Voges 1959), and *Si.sulcata* (Huddle 1934). This part of section has dark grey carbonates, including layer of sandy limestone, rich in crinoids, these beds are traversed to up with grey thin to medium bedded lime stones, and rich in fossils contain brachiopods, crinoidal segments, fish micro remains and rare conodonts.

5.7. *Gnathodus - P. inornatus* Zone

According to Somerville (2008) and Perrei and Spalletta (2001) Lower boundary: FAD of *Gnathodus* co-occurrence with *Polygnathus inornatus* and the Upper boundary: FAD of *Gnathodus typicus* and *Pseudopolygnathus oxypageous* (on based Lane et al. 1980) and FAD of *Pseudopolygnathus multistriatus* (According Poty et al. (2006) Remarks. In Tuyeh-Darvar section from T_{10} bed (21.20 m above the base) toward T_{12} bed (interval between 21/.20 to 23.5m above the base of section), this interval assignment to *Gnathodus - P.inornatus* Zone (Table 1).

The assemblages of other conodonts in this part are as follows: *Bi.stabilis* (Branson and Mehl 1934), *P.inornatus inornatus* (Branson and Mehl 1934), *P.com. communis* (Branson and Mehl 1934), *P.com.dentatus* (Druce 1967), *P.bischoffi* (Bischoff 1957), *P.symmetricus* (Branson and Mehl 1934), *Gn.*cf.*commutatus commutatus* (Sweet 1988), *Gn.bilineatus* (Roundy et al. 1926), *Cl.complectens* (Clark 1958), *Cl.tenuis* (Branson and Mehl 1934), *Spathognathus crossidentatus* (Branson and Mehl 1934), *Sp.cyrius* (Zhuravlev 1991), *Ps.primus* (Branson and Mehl 1934), *Ps.triangulus* (Mehl and Thomas 1974), *Hindeodus* (Sweet 1988), *Idiognathodus,* and *Si.sulcata* (Huddle 1934).

This part of the studied section contains dark grey carbonates, including layer of sandy limestone, rich in crinoids, these beds are traversed to up with grey thin to medium-bedded limestones, and rich in fossils contain brachiopods, crinoid segments, fish remains and rare conodonts.

5.8. *Pseudopolygnathus multistriatus* Zone

According to Somerville (2008) and Perrei and Spalletta (2001) Lower boundary: FAD of *Pseudopolygnathus multistriatus* co-occurrence with *Gnathodus* and the Upper boundary: FAD of *Gnathodus typicus* and *Pseudopolygnathus oxypageous* (based on Lane et al. 1980) and FAD of *Pseudopolygnathus multistriatus* (According Perrei and Spalletta (2001)) remarks. In Tuyeh-Darvar section from T_{13} bed (23.50 m above base) toward T_{15} bed (interval between about 23/.50m to 24.60m above the base of section), this interval assignment to *Pseudopolygnathus multistriatus* Zone (Table1). The assemblages of other conodonts in this part are as follows: *Bi.stabilis* (Branson and Mehl 1934) and *P.com.communis* (Branson and Mehl 1934), *P.com. dentatus* (Druce 1969), *P.bischoffi* (Bischoff 1975), *P.symmetricus* (Branson and Mehl 1934), *Gn.*cf.*commutatus commutatus* (Branson and Mehl 1934), *Cl.complectens* (Clark 1958), *Cl. tenuis* (Branson and Mehl 1934), *Spa.crossidentatus* (Branson and Mehl 1934), *Spa.cyrus* (Zhuravlev 1991), *Ps.primus* (Branson and Mehl 1934), *Ps. Triangulus* (Mehl and Thomas 1974), *Hindeodus* (Sweet 1988), *Idiognathodus* and *Si. sulcata* (Huddle 1934).

This part of the section contains dark grey carbonates, including layer of sandy limestone, rich in crinoids, these beds are traversed to up with grey thin to medium-bedded limestones, and rich in fossils contain brachiopods, crinoid segments, fish remains and rare conodonts.

In here, the paucity of bio stratigraphic evidences, such as: lack of the age-diagnostic conodonts (at close to the DCB), low diversity of conodont species, allocation of these species in shallow waters, that causes for low diversity and lack of index specimen (such as *Palmatolepis* and *Ancyrodella*), bereavement of lithological composition for the conodont faunas partnership, and abundance of silica-clastic sediments, these are the reasons that distinguish of biozone subdivided, especially in Middle and Upper *Si.praesulcata*, Lower and Upper *Si.duplicata*, *Si.sandbergi*, and Lower/and Upper *Si.crenulata* Zones become very difficult. From the other side there is no evidence of main sedimentary interruption at close to DCB. Nevertheless, any definite expressing is controversial decision. This is better that, to said, we does not found any evidence that presently pointed to attendance of a substantial pausing, but we were found evidences that presently a little continental shelf's rising (due block faulting event) close to DCB. We believe that, are visible evidences of anoxic event at the black beds which are presence close to DCB (due shelf Drowning).

The DCB should be located somewhere in between the dark carbonate that be situated just upper the dark silt stones, belonging to Jeirud Formation.

5.9. Biofacies and Environment

According of biofacies studied (on based brachiopod/and conodont fauna) the Upper Devonian-Lower Carboniferous strata in Tuyeh-Darvar area were deposited in the shallow marine environment from inner shelf to upper slope (Shoushtarizadeh 2005) These strata are rich by marine macro fauna special brachiopods bio facies associated by other macro fauna such as solitary corals, crinoids, gastropods, rare trilobites and micro fauna such as sclecodonts, conodonts, ostracods, foraminifera and fish remains.

Most of the Early Carboniferous conodont fauna in this section ranging in *Si.*sulcata, *Si.duplicata-sandbergi* and *Si.crenulata* Zone which are dominated by species of *Polygnathus* by about 52%, the percentage of other genera is as follows; *Siphonodella* 19%, *Bispathodus*, *Mehlina*, *Branmehla*, *Klydagnathodus*, *Spathognathus* each of them 4% and *Gnathodus* by 5%. Although some of species such as; *P.com.communis, P. inornatus* and *Bi.stabilis* are considered as ubiquitous in near shore, But the increase of some species such as *Branmehla*, *Bispathodus, Gnathodus* and special *Siphonodella* suggest an increase in depth of basin in the studied section.

6. Conclusion

According the biofacies studies could recognize that sedimentary basin of the Upper Devonian-Early Carboniferous age was compared by shallow water marine environment from inner shelf to upper slope and the presence of silica clastic sediment assigned for predominately of high energy water.

The sedimentary changes from the light colored limestone to dark carbonates intercalated by dark to black shale beds and inter bedded of grey to dark marls, siltstone, fine sandstone and appearance of dark to black micritic limestone at the Uppermost part of Jeirud Formation (*Si.praesulcata* interval) were related by Hangenberg event "sea level rise" and tectonic movements after glacier stage at south hemisphere. Which has caused for several stages of drowning in the carbonate shelf and accelerating to the organic-carbon burial process, which the presence of pyrite minerals, ferruginous compounds and along with, removal in benthos fauna at the shale and/silty beds, reinforced this assumption. The anoxic/or hypoxia bottom condition in interval might be explained by somewhat restriction condition, combined with high plankton production in the surface waters and consequent high oxygenate consumption in the basin floor waters. The Upper Famennian deposits in here are undoubted some marine sediments as show by theirs fossils contents, which are clearly assigns transgressive unit, must be have spread rapidly over a flat area, these transgressive characters suggested a shallow-water environment for this part of the Jeirud Formation, view supported by the occurrence several conglomerate layers in the base of section and to upward (middle-upper *Si.praesulcata* interval) by occurrence of sea water rise, drowning shelf, temperature increasing, vegetation expansion and decreasing to the sediment production, the anoxic/or hypoxic bottom condition was created in this environment (shallow-water close to the shore and probably not deeper than 200m), in such an environment, its believed that sediments should be transported and expanded over the bottom of the sea (As some scholars like to Conant and Swanson (1961), have announced before). According to these authors the rate of sedimentation was extremely slow, and caused to forming dark to black organic mud/or shale beds, with pyrite and ferruginous contents. In the top of *Si.praesulcata* interval the sudden sea level drop caused for more or less thin bedded fine sandy limestone /or silt stone. This event probably related by a short ice-age as suggest by some authors (As some scholars like to Breziski et al. (2010) and Becker et al. 2016 in Europe have recognized it). Based on this research the results are as follows;

1- Recent studies of the conodont fauna from carbonate deposits at interval between 170m to 175m above base of Devonian column in this area, has shown that this fauna (which contained *Si.sulcata, Si.praesulcata,* the subspecies of *Neopolygnathus* genera such as; *Neo.com.communis, Neo.com.dentatus, Neo.purus purus* and *Bispathodus* genera such as; *Bi.stabilis* known as Lower most of Carboniferous age (Lower Tournaisian) and these interval beds should be accordance with the Famennian/Tournaisian (D/C) boundary.

2- Based on standard conodont Zonation 6 zone are recognized in this area; 1. *Bi.ultimus/or Si.praesulcata* Zone, 2. *Pr.kockeli /or Si.sulcata Zone,* 3. *Si.duplicata to Si.sandbergi bio interval,* 4. *Si.crenulata* Zone, 5.*Gnathodus-P.inornatus* Zone, and 6.*Ps.multistriatus* Zone.

3-Based on conodont data and lithological evidences, K_8 bed should be considered as Carboniferous in age (*Pr.kockeli*/or *Si.sulcata* Zone).

4-The Upper Devonian (Famennian) sequences in our studied area are undoubted belongs to marine shelf; as show by theirs fossil contents, it is clearly transgressive unit and must be have spread rapidly over a flat area. These transgressive characters are suggests a shallow-water environment for this part of Jeirud Formation. This view is reinforced by the occurrences of several conglomerate layers in the base of section and upward by increasing to deeper conodont genera.

5-Based on conodont biofacies studies and other relevant data (such as lithological researching) we conclude that reduced of sediment generation and sediment thicknesses can be due to undesirable changes (such as marine volcano genes, anoxic condition and sea level fall) in the water chemistry and/or water stratification in the end of *Si.praesulcata* Zone, which may have led to a long-term stress and retreat of all faunal groups from the basin.

6- The thickness of the Upper Famennian (*Bi.ultimus*/or *Si.praesulcata* interval) strata is much lower in the here than other similar sequences. This high reduction in thickness/and high sediment condensation at compared whit other points (central Iran ,Northern Iran and other world points such as Russia (See Barskov et al. 1991), is very remarkable and controversial, but however there are no signed of discontinuity or interruption, we have to accept the assumption that; it had been due the sediment condensation and sediment entry reduction, co-occurrences with sea water rise ,shelf drowning ,temperature increasing, humidity increasing, vegetate expansion, decreasing for sediment production and anoxic condition in the basin floor.

7- The critical interval near the DCB at the Tuyeh-Darvar section with the presence of dark gray shale's ,silt stones and dark carbonate beds shows some of the features that may be related to the Late Devonian Hangenberg and/or Carboniferous Lower Alum shale (see Becker 1993).

8- The consistent presence of neritic conodont fauna proves permanent open marine condition.
9- The partially overlaying brachiopod-float stones (shell beds) suggest an existence of the reef by drowning /or shelf drowning by T.S.T stage.
10- Bioclastic muds/ or wackestones with a very poor fossil record (ostracods, gastropods and shell fragments) indicate more restricted and calm realms with the lagoon (Just below the DCB, between K_6 and K_8).
11- We believe that abundance of dark gray shales with intercalation of siltstone, sandstone and bioclastic beds (filled with crinoid fragments) and lateral biofacies changes represent the carbonate plat form which are controlled by sedimentation and subsidence processes in a horst-graben system and tectonic disintegration during at Upper Famennian chron.

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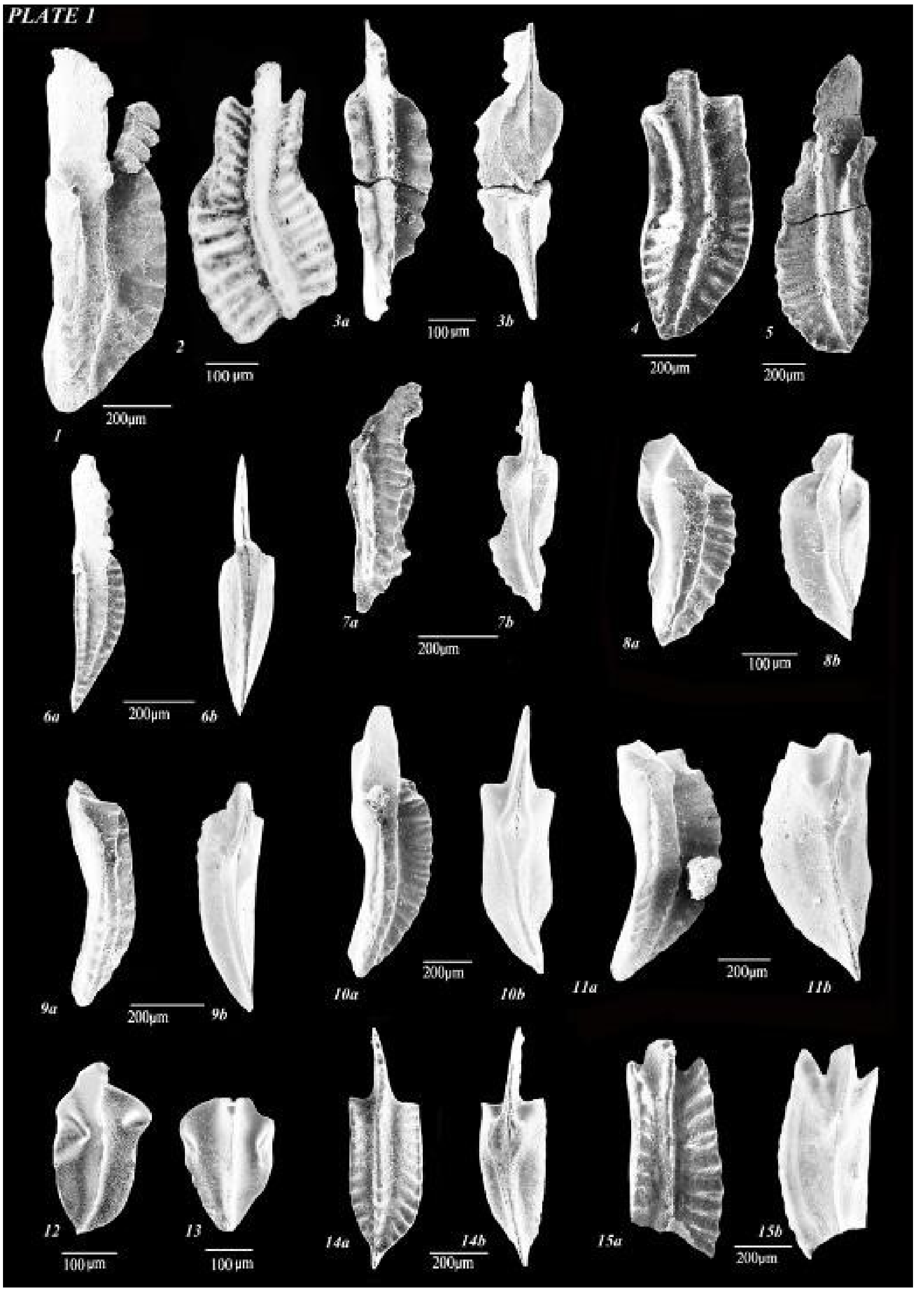

PLATE 1

Figs 1, 11, 15- *Polygnathus inornatus* Branson and Mehl (1934), (Fig 1. specimen AUIC15500, Sample T_0. Figs 11 (a, b) specimen AUIC155217, SampleT_8. Figs15 (a, b) specimen AUIC155215, SampleT8. Figs 2, 4, 5 –*Polygnathus* cf. *inornatus rostratus* Rhods et al. (1969). (Fig 2. specimen AUIC15502, Sample T_3, Fig 4. specimen AUIC15508, Sample T_1. Fig 5. Specimen AUIC15506, Sample T_1).Figs 3a, 3b- *Siphonodella praesulcata* Sandberg (1972). (Specimen AUIC155214, SampleT_1). Figs 6(*a, b)-Polygnathus semicostatus* Branson and Mehl (1934). (Specimen AUIC155200, SampleT_{11}). Figs 7, 8, 9- *Siphonodella sulcata* Huddle (1934). (Figs 7a, b) specimen AUIC155212, SampleT_{13}, Figs8 (a, b) specimen AUIC155248, SampleT_{13}, Figs 9(a, b), specimen AUIC155247, SampleT_{13}), Figs10 (a, b) - *Polygnathus symmetricus* Branson and Mehl (1934), (Specimen AUIC155232, SampleT_3), Fig 12- *Polygnathus communis qrins* Hass (1959). (Specimen AUIC155219, SampleT_3).Fig 13-*Polygnathus communis communis* Branson and Mehl (1934). (Specimen AUIC155217, SampleT_3). Figs 14 (a, b) - *Polygnathus bischoffi* Rhodes, Austin and Druce, 1969. Specimen AUIC155215, SampleT3).

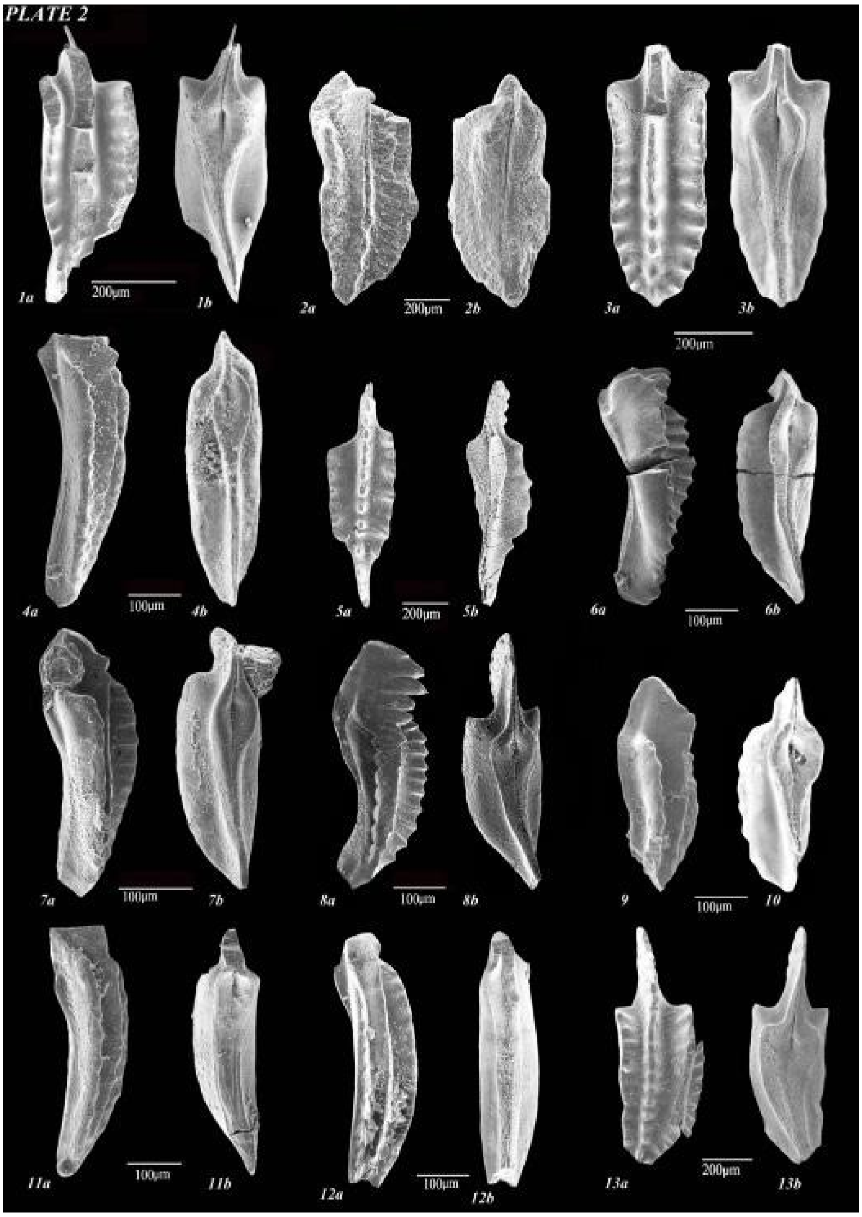

PLATE 2

Figs 1 (a, b), 3 (a, b) -*Polygnathus symmetricus* Branson and Mehl (1934). (Figs 1(a, b), specimen AUIC155221, SampleT$_{3}$, Figs 3(a, b), specimen AUIC155224, SampleT$_{3}$. Figs 2 (a, b) -*Polygnathus inornatus rostratus* Rhods et al. (1969). (Specimen AUIC155224 SampleT$_{3}$).Figs 4 *(a, b)* -*Polygnathus lanceolus* Branson and Mehl (1934). (Specimen AUIC155223, SampleT$_{3}$). Figs 5(a, b), 9and10 -*Siphonodella praesulcata* Sandberg (1972). (Figs 5a, 5b. specimen AUIC15554, SampleT$_{10}$), Fig 9 Upper view of specimen AUIC15581, SampleT$_{11}$, Fig 10 Upper view of specimen AUIC15565, SampleT$_{11}$). Figs 6, 7 and 8 -*Siphonodella sulcata* Huddle (1934). (Figs 6(a, b), specimen AUIC155214, SampleT$_{14}$. Figs 7 (a, b), specimen AUIC155206, SampleT$_{13}$. Figs 8 (a, b), specimen AUIC15593, SampleT$_{3}$). Figs 11(a, b) -*Polygnathus planarius* Branson and Mehl (1934). (Specimen EUIC155191, SampleT$_{13}$). Fig 12(a, b) -*Polygnathus lenticularis* Branson and Mehl (1934). (Specimen AUIC155195, SampleT$_{8}$). Fig 13 (a, b) -*Polygnathus bischoffi* Rhodes. (Specimen AUIC155229, SampleT$_{7}$)

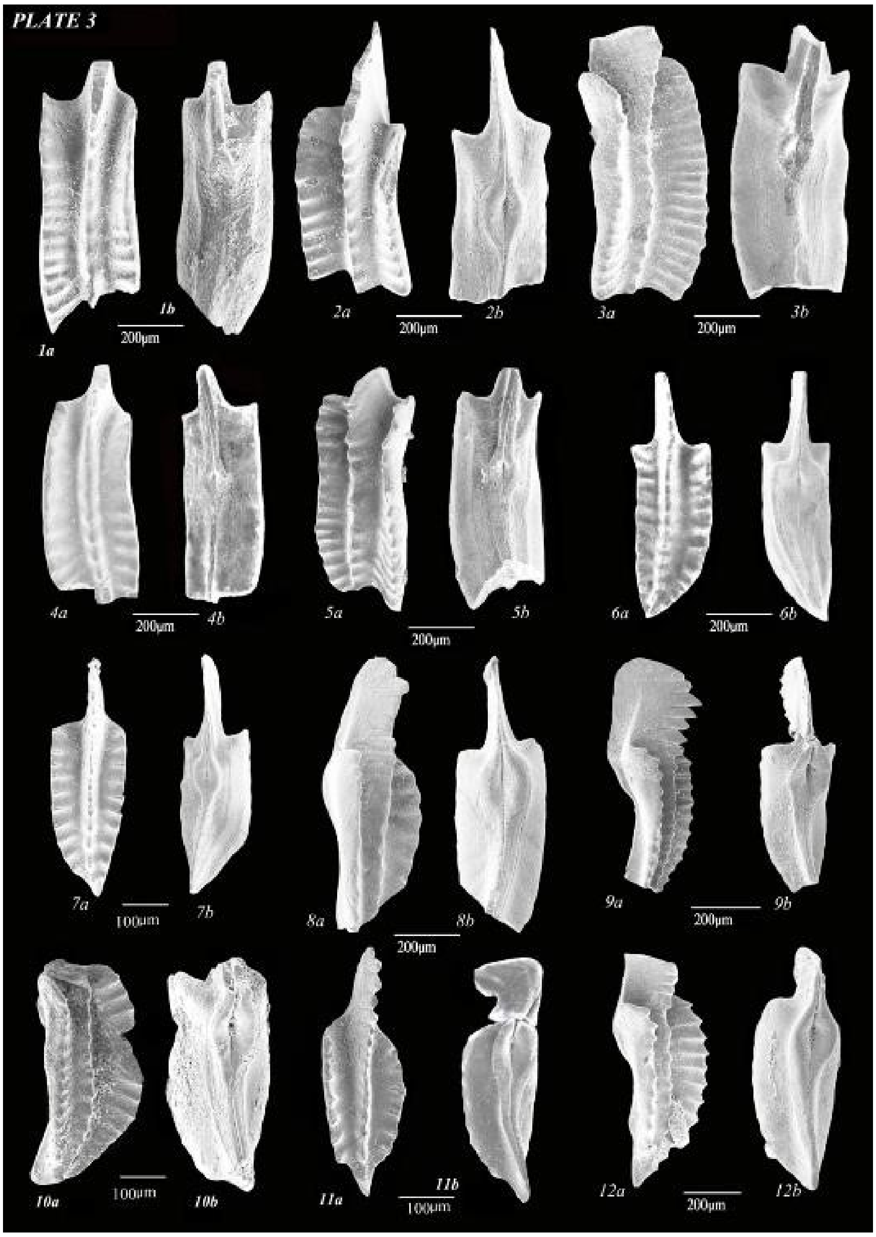

PLATE 3

Figs 1 (a, b), 2 (a, b) and 4 (a, b) -*Polygnathus longiposticus* Branson and Mehl (1934). (Figs1 (a, b), specimen AUIC155241, SampleT_{13}, Figs 2 (a, b), specimen AUIC155243, SampleT_{10}, Figs 4 (a, b), specimen AUIC155224, SampleT_{13}). Figs 3 (a, b), 5(a, b) -*Polygnathus inornatus* Branson and Mehl (1934). (Figs 3 (a, b), specimen AUIC155223, SampleT_{13}, Figs 5(a, b), specimen AUIC15554, Sample$T_{10)}$. Figs 6 (a, b), 7 (a, b) and 8 (a, b) -*Polygnathus bischoffi* Rhodes. (Figs 7 (a, b), specimen AUIC155216, SampleT_9, Figs 8 (a, b), specimen AUIC155230, SampleT_6). Figs 9 (a, b), 11 (a, b) and 12 (a, b) -*Siphonodella sulcata* Huddle (1934). (Figs 9 (a, b), specimen AUIC155227, SampleT4. Figs 11 (a, b), specimen AUIC155229, SampleT_5, Figs 12 (a, b), specimen AUIC155240, SampleT_8). Fig 10 -*Polygnathus sp.* (Specimen AUIC155212, SampleT_{12}).

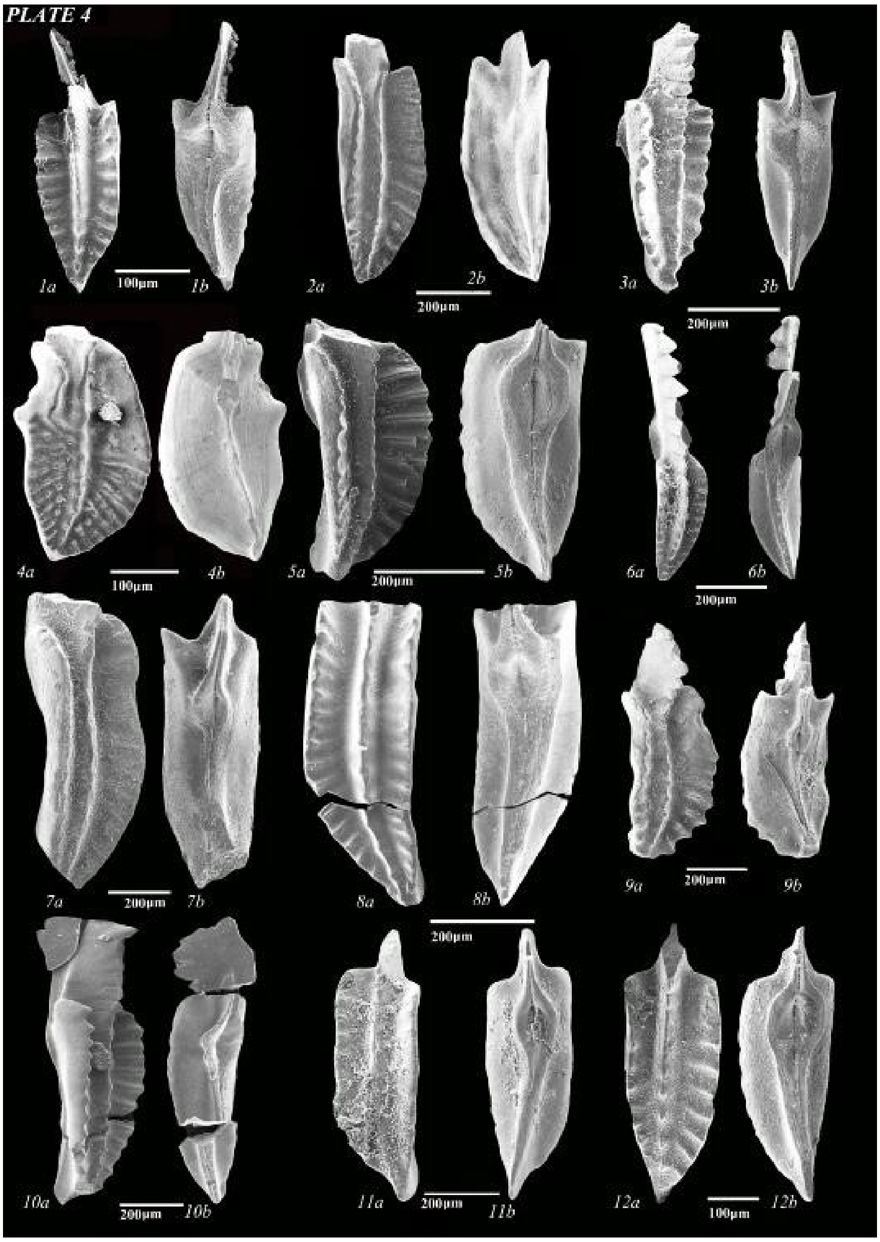

PLATE 4

Figs 1 (a, b), 3 (a, b), 11 (a, b) -*Polygnathus symmetricus* Branson and Mehl (1934). (Figs 1 (a, b), specimen AUIC155236, SampleT_7. Figs 3 (a, b), specimen AUIC155237, SampleT_7, Figs 11 (a, b), specimen AUIC155243, SampleT_8).Figs 2 (a, b) -*Polygnathus inornatus* Branson and Mehl (1934). (Specimen AUIC155235, SampleT_3). Figs 5 (a, b), 10(a, b) and 12 (a, b) -*Siphonodella* cf. *sulcata* Huddle (1934). (Figs 5 (a, b), specimen AUIC155239, SampleT_{13}, Figs 10 (a, b), specimen AUIC155242, SampleT_8, Figs 12 (a, b), specimen AUIC155226, SampleT_8). Fig 6 (a, b) -*Polygnathus communis communis* Branson and Mehl (1934). (Specimen AUIC155238, SampleT_8). Figs 7 (a, b), 8 (a, b) -*Polygnathus longiposticus* Branson and Mehl (1934). (Figs 7 (a, b), specimen AUIC155241, SampleT_8, Figs 8 (a, b), specimen AUIC155244, SampleT_8). Figs 9 (a, b) -*Polygnathus parapetus* Druce (1969). (Specimen AUIC155248, SampleT_8).

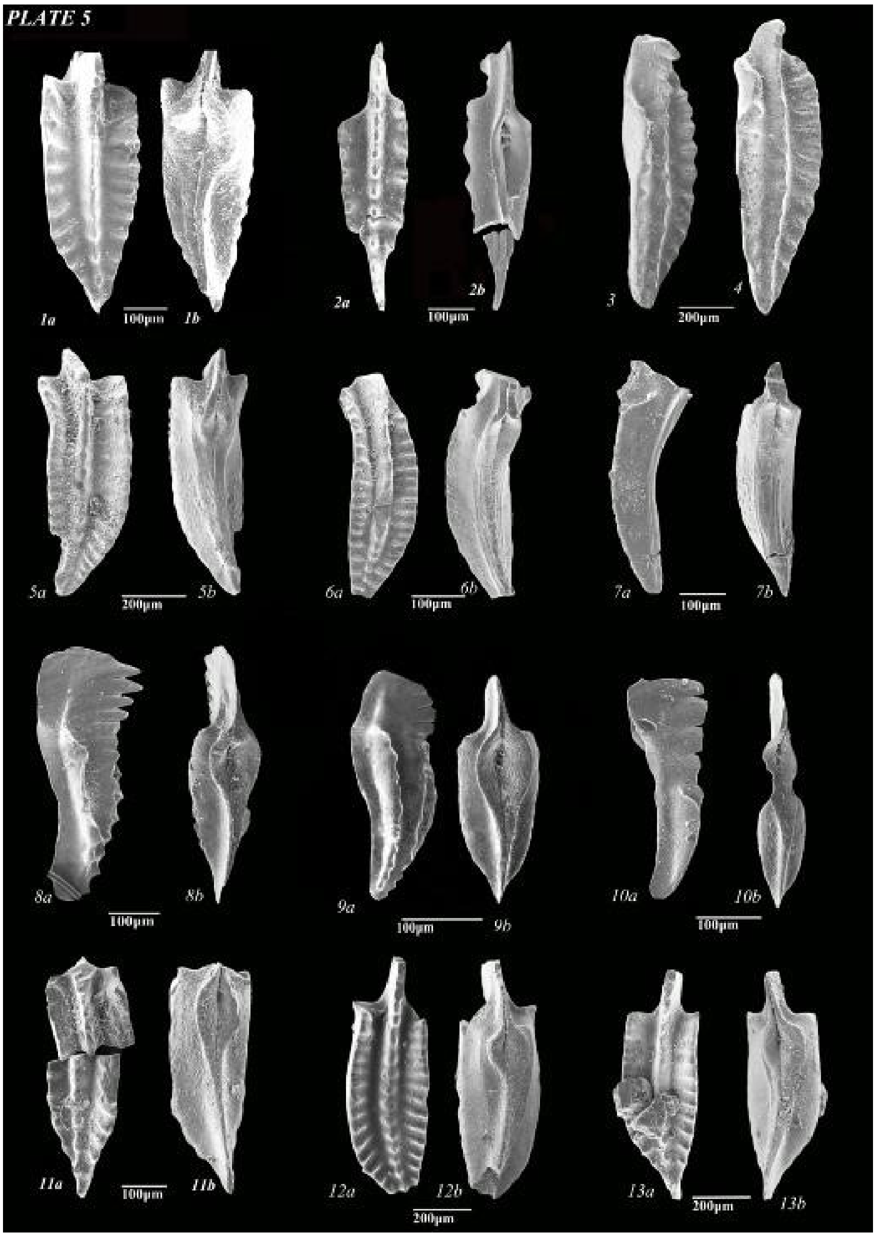

PLATE 5

Figs 1 (a, b), 2 (a, b) and 11 (a, b) -*Siphonodella praesulcata* Sandberg (1972). (Figs 1 (a, b), specimen AUIC155244, SampleT_8, Figs 2 (a, b), specimen AUIC155249, SampleT_{10}, Figs 11 (a, b), specimen AUIC15527, SampleT_{11}. Fig 3 -*Polygnathus lenticularis* Branson and Mehl (1934). (Specimen AUIC155251, SampleT_{10}). Fig 4 -*Polygnathus lanceolus* Branson and Mehl (1934). Specimen AUIC155250, SampleT_{10}).Figs 5 (a, b) -*Polygnathus longiposticus* Branson and Mehl (1934). (Specimen AUIC15521, SampleT_{11}). Figs 6 (a, b), 7 (a, b) -*Polygnathus semicostatus* Branson and Mehl (1934). (Figs 6 (a, b), specimen AUIC15522, SampleT_{11}). Figs 8 (a, b), 9 (a, b) -*Siphonodella sulcata* Huddle (1934). (Figs 8 (a, b), specimen AUIC15524, SampleT_{11}, Figs 9 (a, b), specimen AUIC15525, SampleT_{11}. Figs 10 (a, b) -*Polygnathus communis communis* Branson and Mehl (1934). (Specimen AUIC15526, SampleT_{11}). Figs 12 (a, b) -*Polygnathus inornatus* Branson and Mehl (1934). (Specimen AUIC15528, SampleT_{11}). Figs 13 (a, b) - *Polygnathus symmetricus* Branson and Mehl (1934). (Specimen AUIC15529, SampleT_{11}).

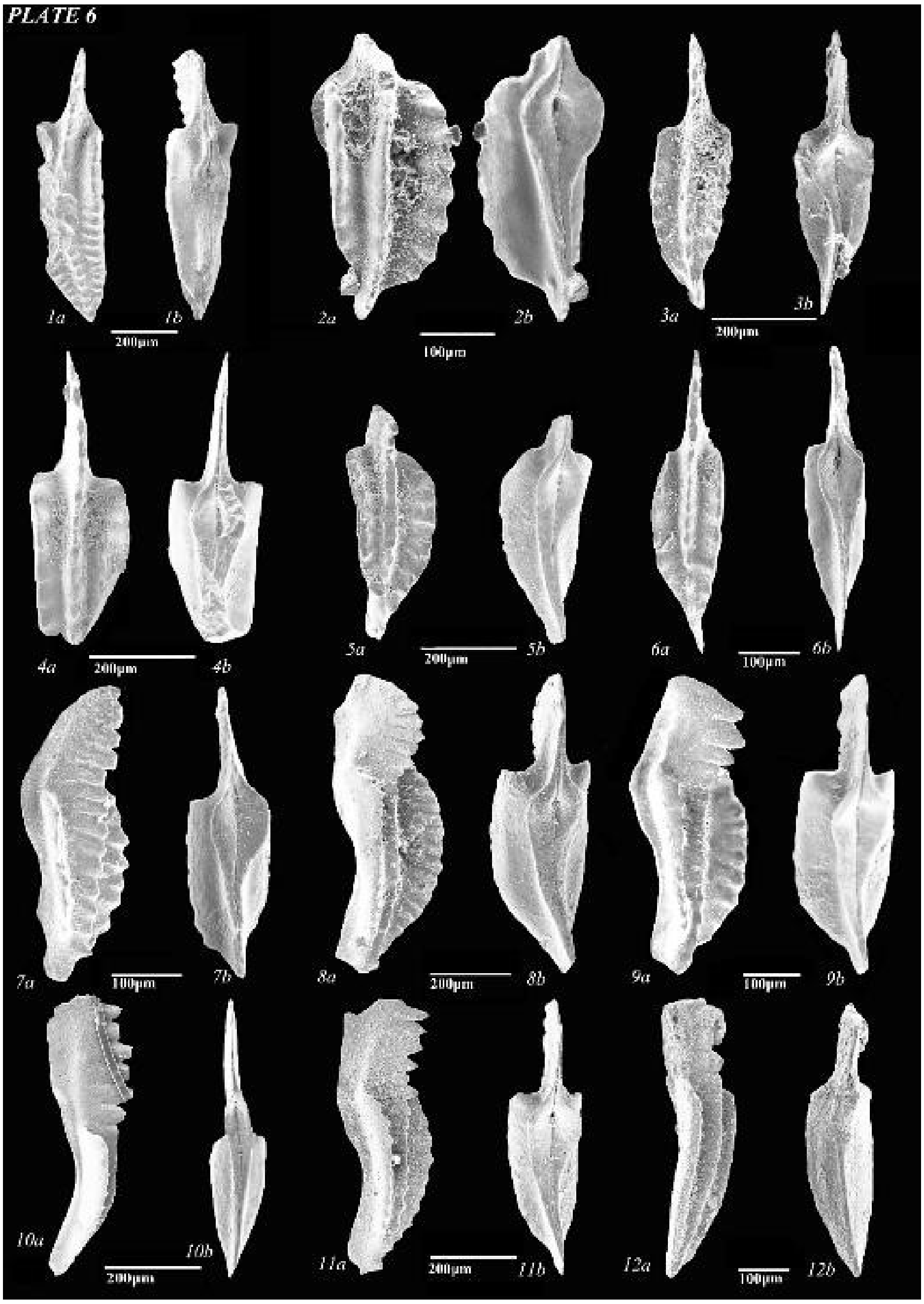

PLATE 6

Figs 1 (a, b) -*Polygnathus longiposticus* Branson and Mehl (1934). (Specimen AUIC15530, SampleT$_3$). Figs 2 (a, b), 3 (a, b) and 5 (a, b) -*Siphonodella sulcata* Huddle (1934). (Figs 2 (a, b), specimen AUIC15535, SampleT$_{11,}$ Figs 3 (a, b), specimen AUIC15531, SampleT$_3$. Figs 5 (a, b), specimen AUIC15536, SampleT$_{12}$). Figs 4 (a, b), 9 (a, b) and 11(a, b) -*Polygnathus symmetricus* Branson and Mehl (1934). (Figs 4 (a, b), specimen AUIC15532, SampleT$_{12}$. Figs 9 (a, b), specimen AUIC15540, SampleT$_{13}$. Figs 11 (a, b), specimen AUIC15542, SampleT$_{14}$). Figs 6 (a, b) and 7 (a, b)) -S*iphonodella praesulcata* Sandberg (1972). (Figs 6 (a, b), specimen AUIC15538, SampleT$_{12}$. Figs 7 (a, b), specimen AUIC15537, SampleT$_{12}$). Figs 8 (a, b) –*Polygnathus* cf.*fornicatu*s Ji and xiong, 1985. (Specimen AUIC15539, SampleT$_{13}$). Figs 10 (a, b) -*Polygnathus communis communis* Branson and Mehl (1934). (Specimen AUIC15541, SampleT$_{13}$). Figs 12 (a, b) -*Polygnathus bischoffi* Rhodes (Specimen AUIC15589, SampleT$_{14}$).

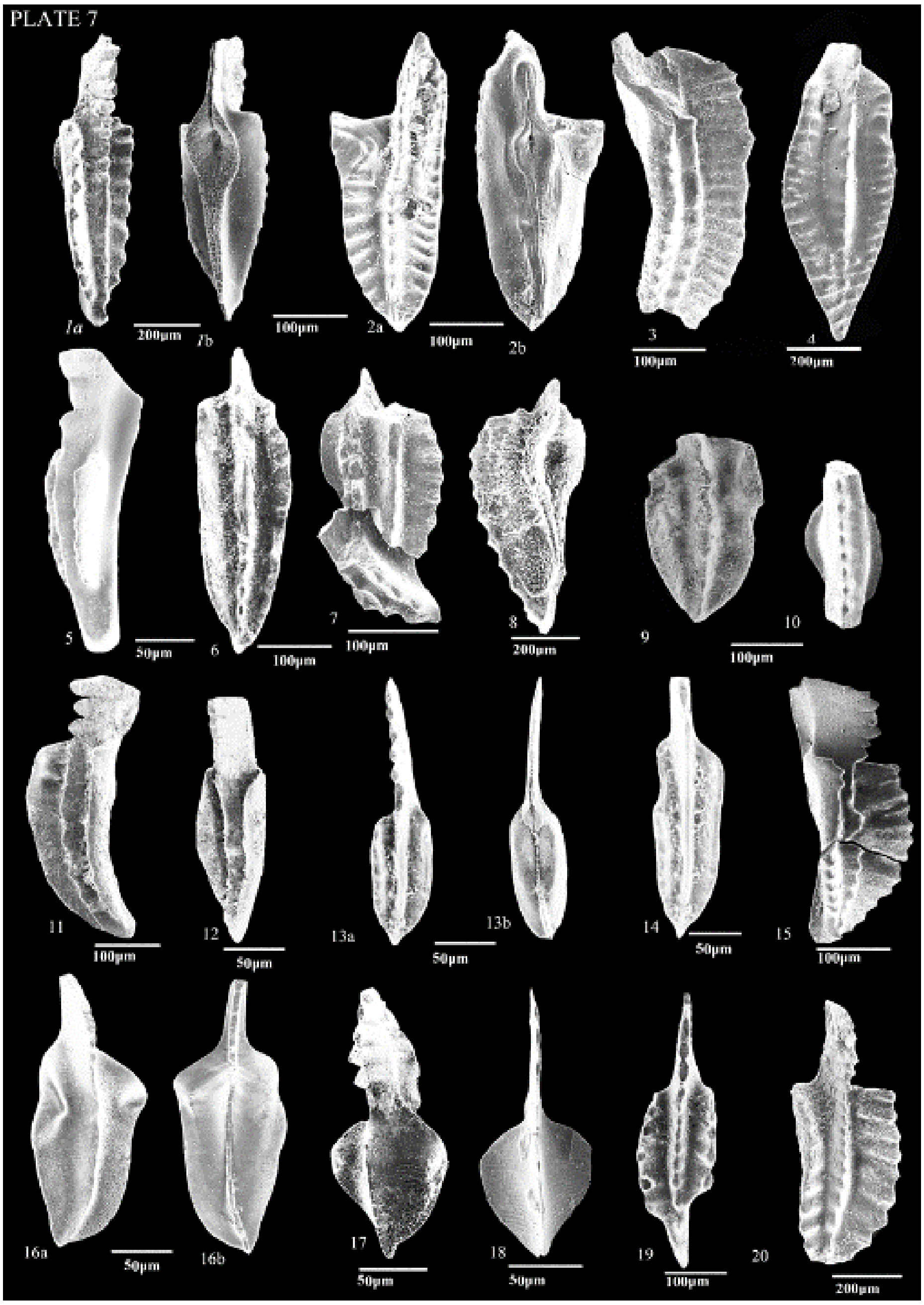

PLATE 7

Figs 1 (a, b) -*Siphonodella duplicate* Branson and Mehl (1934). (Specimen AUIC15547, SampleT$_8$). Fig 2 -*Polygnathus sp.* specimen AUIC15548, SampleT$_1$). Figs 3 (a, b), 20 -*Polygnathus parapetus* Druce (1969). (Figs 3 (a. b), specimen EUIC15572, SampleT$_{12}$, Fig 20 specimen AUEC, SampleT$_8$). Fig 4 - *Polygnathus lanceolus* Branson and Mehl (1934). (Specimen AUIC15552, SampleT$_6$). Figs 5 & 19 -*Polygnathus brevilaminus* Branson and Mehl (1934). (Fig 5 specimen AUIC15553, Sample K$_5$, Fig 19. specimen AUIC15571, SampleT$_8$). Figs *7, 8 and 9 (a, b) -Pseudopolygnathus primus* Branson and Mehl (1934). (Fig 7. specimen AUIC15565, Sample T$_7$, Fig 8. specimen AUIC15566, SampleT$_{10}$, Figs 9 (a, b), specimen AUIC15587, SampleT$_{10}$). Figs 10 (a, b), 12 - *Polygnathus communis dentatus* Druce, 1969. (Figs 10 (a, b), specimen AUIC15571, SampleT$_2$, Fig12. specimen AUIC15573, SampleT$_2$).Fig. 11- *Polygnathus purus purus* Voges, 1959. (Specimen AUIC15572, SampleT$_2$). Figs 13 (a, b) - *Polygnathus communis communis* Branson and Mehl (1934). (Specimen AUIC15557, SampleK$_6$). Fig 14 -*Polygnathus copolloki*, Yazdi 1999. (Specimen AUIC15550, SampleT$_{13}$). Fig 15 -*Polygnathus sp.* Branson and Mehl (1934). (Specimen AUIC15559, Sample, T$_2$). Figs 16 (a, b) - *Polygnathus communis qrins* Hass (1959). (Specimen AUIC15518, SampleT$_3$). Fig 17- *Polygnathus* cf.*communis* Branson and Mehl (1934), specimen AUIC15526, SampleK$_9$). Fig 18 -*Lochriea commutata* cf. Sweet (1988). (Specimen AUIC15525, SampleT$_{10}$).

PLATE 8

Figs 1, 2 - *Pseudopolygnathus primus* Branson and Mehl (1934). (Figs 1 (a, b). specimen AUIC155120, Sample, T_{14}. Fig 2. Specimen AUIC155205, Sample, T_9). Fig 3 -*Bispathodus stabilis* Branson and Mehl (1934), Morphotype M_1. (Specimen AUIC155275, Sample, T13). Figs 4, 5 and 21 -*Bispathodus aculeatus* Branson and Mehl (1934). (Fig 4. specimen AUIC15571, Sample, T_9. Fig 5. Specimen AUIC15550, Sample, T_9. Fig 21 specimen AUIC155197, Sample, T_{12}). Fig 6 -*Mehlina strigosa* Branson and Mehl (1934). Specimen AUIC15529, Sample, T_6). Fig 7 - *Branmehla inornata* Branson and Mehl (1934). (Specimen AUIC15519, Sample, T_3). Fig 8 - *Branmehla bohlenana* Branson and Mehl (1934). (Specimen AUIC15517, Sample, K_4). Fig 9 - *Polygnathus brevilaminus* Branson and Mehl (1934), (specimen AUIC155296, Sample, K_2). Fig 10 -*Spathognathodus crossidentatus* Zhuravlev (1991). (Specimen AUIC15544, SampleK_9). Fig 11 -*Spathognathodus* cf. *cyrius* Zhuravlev (1991). (Specimen AUIC15561, SampleK_9). Figs 12 and15 –*Kladygnathus sp.* Unknowed Sc elements, AUIC15534 SampleT_6). Fig 12, Unknowed Sc elements AUIC15534 SampleK_9. Fig 15 -Unknowed Sc elements AUIC15558 SampleT_6. Fig 13 -*Gnathodus bilineatus* Rexroad and Furnish (1964). (M element of specimen AUIC155251, SampleT_{13}). Fig 14 -*Gnathodus bilineatus modocensis* Rexroad and Furnish (1964). (Pa element of specimen AUIC15554, Sample T_{13}). Figs 16 -*Kladognathus complectens* Clarke (1979). (Sc element of specimen AUIC15539, Sample T_{10}). Figs 17, 18 -*Hindeodella sp.* Youngquist and Peterson 1974. Fig17Unknowed Sc elements AUIC15535 Sample K_9. Fig 18 -Unknowed Sc elements AUIC15531 SampleT_7. Fig 19- *Pelekysgnathus inclinathus* (Mehl and Thomas 1974), (specimen, AUIC155244, SampleT_1). Fig 20 -*Bispathodus bispathodus* Ziegler, Sandberg and Austin, 1974. (Specimen, AUIC155141, SampleT_{12}).

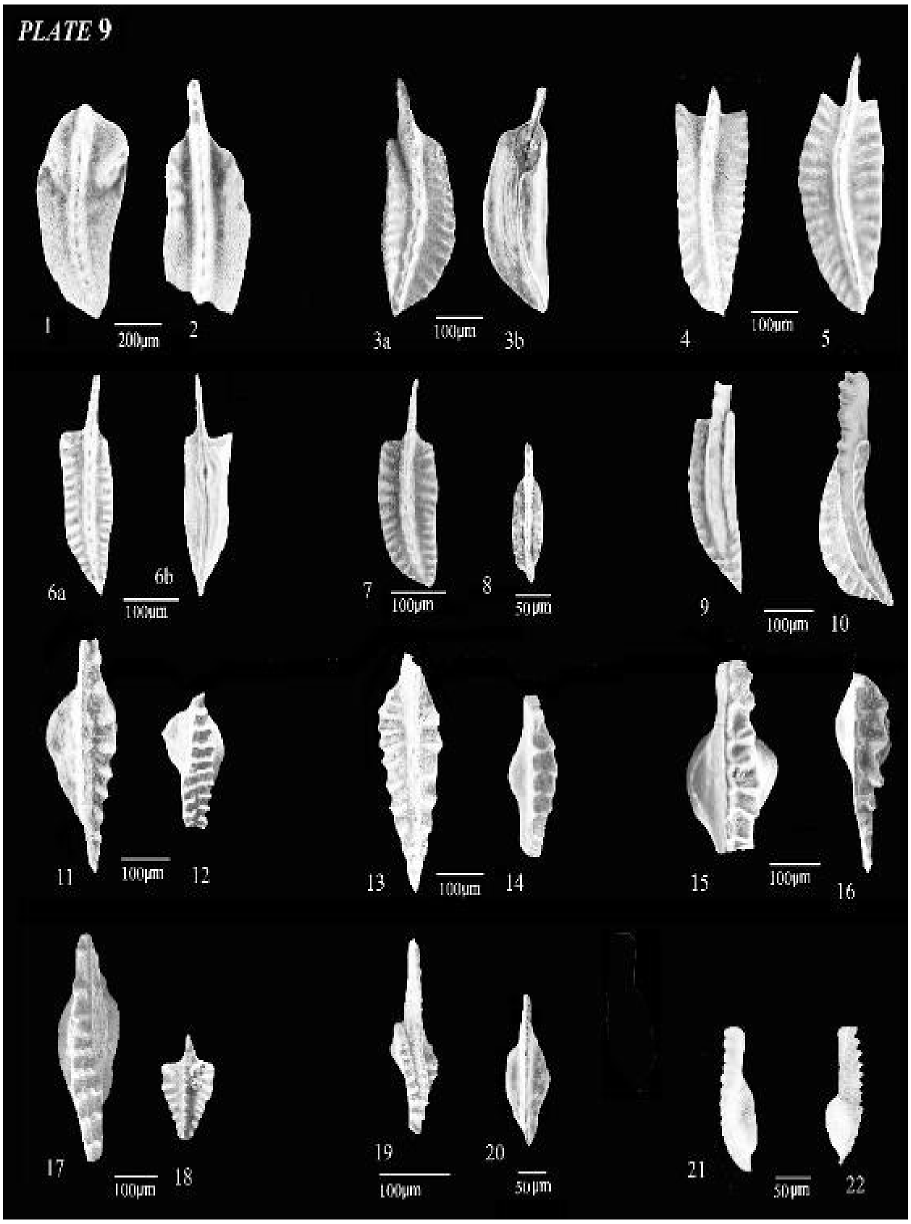

PLATE 9

Fig 1 -*Polygnathus com.carinus* Branson and Mehl (1934). (Specimen, AUIC.155340, sample k_3). Fig 2 - *Polygnathus com.dentatus* Branson and Mehl (1934). (Specimen, AUIC.155341, sample k_7). Figs 3 (a, b) -*Siphonodella* cf. *sulcata*, Huddle (1972). (Specimen, AUIC.155343, sample T_2). Figs 4 and 10 -*Polygnathus bischoffi* 1972. (Fig4 specimen, AUIC.155343, sample T_2, Fig 11 specimen, AUIC.155377, sample T_{10}). Figs 5 and 7 -*Polygnathus fornicatus* Xi 1998. (Fig 5 specimen, AUIC.155344, sample T_7, Fig 7, specimen, AUIC.155344, sample T_7). Figs 6 (a, b) –*Polygnathus longiposticus* 1972. (Specimen, AUIC.155346, sample T_6). Fig 8 - *Polygnathus brevilaminus* Branson and Mehl (1934), (specimen AUIC155371, Sample, T_0). Fig 9 -*Polygnathus semicostatus* Branson and Mehl (1934), (specimen AUIC155378, Sample, T_0). Figs 11 and 12 -*Bispathodus ultimus,* Spalletta *et al.* 2017. (Fig 11, specimen AUIC155379, Sample, T_0, Fig 12, specimen AUIC155381, Sample, T_0). Figs 14*, 15 and 16 -Pseudopolygnathus primus* Branson and Mehl (1934). (Fig14, specimen AUIC155379, Sample, T_0, Fig 15, specimen AUIC155381, Sample, T_2, Fig 16, specimen AUIC155384, Sample, T_5). Fig 13 -*Pseudopolygnathus multistriatus,* Mehl and Thomas (1974). *(*Specimen AUIC155389, Sample, T13). Fig 18 -*Pseudopolygnathus triangulus*, Branson and Mehl (1934). (Specimen AUIC155388, Sample, T_{11}). Fig 19 - *Pseudopolygnathus dentilineatus*, Branson and Mehl (1934). (Specimen AUIC155206, Sample, K_5). Fig 6 -*Mehlina strigosa* Branson and Mehl (1934). Specimen AUIC15529, Sample, T_6). Figs 20 -*Protognathus meischneri* Ziegler and Sandberg (1984). (Fig 20, specimen AUIC155250, Sample, T_2, Figs 21and 22 - *Locheri commutatus*, Sweet (1936). (Figs 21 specimen AUIC155256, Sample, T_{12}, Fig 22 Specimen AUIC155350, Sample, T_9).