Bollettino della Società Paleontologica Italiana, 50 (1), 2011, 35-53. Modena, 1 luglio 2011

Upper Devonian-Lower Carboniferous conodont biostratigraphy in the Shotori Range, Tabas area, Central-East Iran Microplate

Ali Bahrami, Carlo Corradini & Mehdi Yazdi

A. Bahrami - Department of Geology, University of Isfahan, Isfahan, I.R. Iran; Bahrami_geo@yahoo.com
C. Corradini - Dipartimento di Scienze della Terra, Università di Cagliari, via Trentino 51, 09127 Cagliari, Italy; corradin@unica.it
M. Yazdi - Department of Geology, University of Isfahan, Isfahan, I.R. Iran; Yazdimehdi@yahoo.com

KEY WORDS - Conodonts, Shotori Range, Iran, Devonian, Carboniferous.

ABSTRACT - A rich and diverse conodont fauna represented by fifty-six taxa belonging to fifteen genera is described from three sections (Ghale-kalaghu, Howz-e-Dorah 1 and Howz-e-Dorah 2) in the southern Shotori Range (central Iran). The association, dominated by Polygnathus, *has allowed a detailed biostratigraphy across the Devonian/Carboniferous boundary interval to be constructed, ranging from the Uppermost* marginifera *Zone to the* anchoralis-latus *Zone. The D/C boundary is narrowly constrained within a condensed interval at the base of the "Mush Horizon" between the Shishtu 1 and Shishtu 2 subformations.*

RIASSUNTO - [Biostratigrafia a conodonti attorno al limite Devoniano/Carbonifero nel Shotori Range, area di Tabas, Microplacca Iraniana Centro-Orientale] - *L'Iran è un insieme di varie microplacche che durante il Paleozoico costituivano parte del margine settentrionale del Gondwana e si trovavano a latitudini tropicali dell'emisfero sud. L'area studiata si trova nella microplacca iraniana centro-orientale, più precisamente nella parte meridionale dello Shotori Range, a sud-est di Tabas. Le rocce del Devoniano e del Carbonifero Inferiore sono principalmente costituite da calcari marnosi e arenarie depositatesi in un mare poco profondo.*

Le tre sezioni misurate (Ghale-kalaghu, Howz-e-Dorah 1 e Howz-e-Dorah 2) hanno fornito una fauna a conodonti abbastanza ricca e differenziata, in generale costituita da faune di piattaforma e di acqua bassa e dominata dal genere Polygnathus. *Complessivamente sono documentate oltre cinquanta specie, appartenenti a quindici generi. I dodici biointervalli individuati tra la Uppermost* marginifera *Zone e la* anchoralis-latus *Zone costituiscono la prima documentazione biostratigrafica di dettaglio del Famenniano superiore e del Tournaisiano inferiore in Iran. La lunga lacuna sedimentaria attorno al limite Devoniano/Carbonifero supposta da alcuni autori è in realtà limitata alla parte più alta del Devoniano.*

INTRODUCTION

During the Palaeozoic Iran was situated at the northern margin of Gondwana (Berberian & King, 1981; Scotese, 2001), with the only exception of a small area in the north-east, the Kope-Dagh, which was part of Laurussia (Berberian & King, 1981). The Gondwanan part was located about 20°-25° south of the equator (Golonka et al., 1994) and was covered by a large shelf sea (Wendt et al., 2002). Structurally Iran is a collage of several microplates, and it can be subdivided into six units.

The study area is within the "Central-East Iran Microplate", which is bound by major faults: the Great Kavir Fault in the NW, the Nain-Baft Fault in the SW, and the Hari rud Fault in the E. It is commonly accepted that this microplate was subject to a 135° anticlockwise rotation since the Late Triassic (Soffel et al., 1996; Wendt et al., 2005). One of the best Palaeozoic sequence of Iran is here exposed.

The Shotori Range is located in the northeastern part of the "Central-East Iran Microplate", east of Tabas, and is an almost 100 km long mountain chain, consisting of a sequence ranging from the Lower Devonian to the Palaeogene (Wendt et al., 2005), even if with several hiatuses. Devonian and Carboniferous strata are represented by thick sequences of shallow water sediments. Several sections were measured by various authors to describe the stratigraphy of the region, but never in detail, probably due to the thickness of the sections.

This paper is the first detailed report on conodont stratigraphy across the Devonian-Carboniferous boundary (DCB) in the Shotori Range, based on close sampling of three sections in the southern part of the chain (Fig. 1) and a contribution to the "International Working Group on the redefinition of the Devonian-Carboniferous Boundary", recently established by the International Commission on Stratigraphy.

THE DEVONIAN AND CARBONIFEROUS OF THE SHOTORI RANGE

One of the best Devonian and Carboniferous sequence of Iran is exposed in the Shotori Range. The base is marked by several tens of meters of red sandstone of the Padeha Formation. Fossils are rare in this unit and the Lower-Middle Devonian age is inferred on the basis of adjacent units (Wendt et al., 2002). The sequence continues with the Sizbar Formation, mostly dolomites with rare calcareous intercalations. Wendt et al. (2002) suggested a shallow subtidal to supratidal depositional environment, and defined a Givetian age on the basis of conodonts from Kalshaneh, in the southern part of the Central-East Iran Microplate.

ISSN 0375-7633

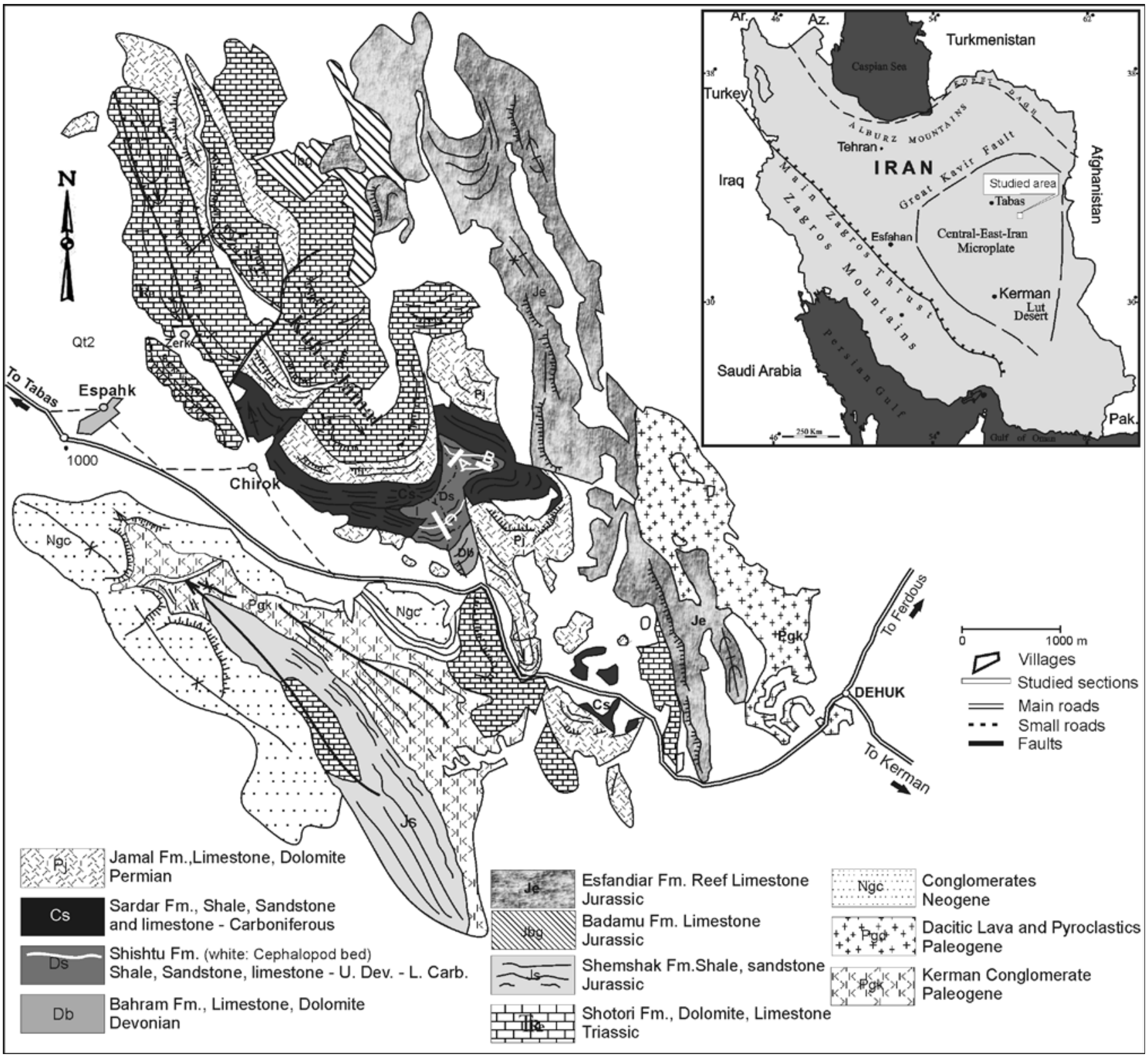


Fig. 1 - Geological map of the area around the Espahak village, Tabas Province, with indication of the studied sections (redrawn and simplified after Stocklin & Nabavi, 1969). The structural units of Iran show the position of studied area in Central-East-Iran Microplate (after Wendt et al., 2005).

The sequence continues with the Bahram Formation, up to 500 m thick. It consists of thick bedded dark grey limestone in the lower part and massive brown dolomite with minor green shale intercalations in the upper part. The limestones are very fossiliferous, and contain conodonts, brachiopods, tentaculitids, crinoids, bryozoans, rugose and tabulate corals, stromatoporoids, trilobites, and rare molluscs (Wendt et al., 2002). The age of the Bahram Fm in the Shotori Range is limited to the lower Frasnian, whereas in other parts of Iran it includes Famennian strata.

The Bahram Formation is conformably overlain by the Shishtu Formation, a unit of complex lithology (Stocklin & Nabavi, 1971), that is informally subdivided into two subformations: "Shishtu-1" and "Shishtu-2".

Shishtu-1 subformation is more than 300 m thick and includes dark green shale interbedded with quartzitic sandstones and intercalations of fossiliferous limestone; the topmost 28 m (beds 23-26 of Stocklin et al., 1965) are represented by highly fossiliferous shale, sandstone, oolitic limestone, and iron oolites, which have been named Cephalopod bed (Stocklin et al., 1965). This unit, composed of several variable lithological horizons, ranges from the middle Frasnian to the late Famennian. The base of the Cephalopod bed is diachoronus, and ranges from late Frasnian in Kale Sardar to Famennian in Howz e-Dorah (Wendt et al., 1997, 2005; Yazdi, 1999).

Shishtu-2 is about 250 m thick and consists of interbedded of limestone and shale. It starts with the so-called "Mush Horizon": a dark grey shale with an intercalation of strongly gypsiferous pink shale and a thin layer of brachiopod limestone, which can be used to correlate the base of the Tournaisian.

The Shishtu Formation as a whole ranges from late Frasnian to Visean and the Devonian-Carboniferous boundary can be traced between the Cephalopod Bed and the "Mush Horizon" at the boundary between Shishtu-1 and Shishtu-2 subformations. Several authors (e.g., Wendt et al., 2005) claim the occurrence of a large hiatus across the boundary, which may include part of the late Famennian and the early Tournaisian.

The Shishtu Formation in unconformably overlaid by the Sardar Formation, a succession of light-green shales with intercalations of sandstones, quarzite, and fossiliferous limestones (Stocklin et al., 1965) of Visean-Moscovian age.

In general the fossil contents of the Devonian and Carboniferous rocks in the Shotori Range is relatively abundant and have been described by several authors: goniatites (Walliser, 1966; Yamini, 1996; Becker et al., 2004; Ashuri & Yamini, 2006), brachiopods (Sartenaer, 1966; Rastkar, 1996), crinoids (Flügel, 1966; Webster et al., 2007), receptaculitids (Flügel, 1961), trilobites (Haas & Mensink, 1970; Haas, 1994; Morzadec, 2002; Feist et al., 2003), gastropods (Ashuri, 1997a), vertebrate micro remains (Yazdi & Turner, 2000; Hairapetian et al., 2000, 2008; Hairapetian & Ginter, 2010) and palynomorphs (Moussavi, 1995; Ghavidel-Syooki & Moussavi, 1996). Several papers address conodonts, mainly for biostratigraphical purposes (Ashouri, 1990, 1995, 1997b, 2002, 2004, 2006; Yazdi, 1996, 1999; Gholamalian, 2002, 2007; Gholamalian et al., 2009).

PREVIOUS PAPERS ON CONODONTS ACROSS THE D/C BOUNDARY IN IRAN

Sediments of Late Devonian and Early Carboniferous age are widespread in Iran, and several authors focused on these strata, mainly for stratigraphical reasons. However, most researches did not provide the precise age of the various formations due to either scarcity of biostratigraphic relevant fauna (mainly conodonts) or distance of sampling.

Several localities were studied in the Central-East Iran Microplate, mainly in the area around Tabas (Shotori Range, Ardekan and Ozbak-kuh Mts) by Ashuri (1990, 1997b, 1998, 2001, 2002, 2004, 2006), Yazdi (1999) and Hairapetian & Yazdi (2003). All these authors agree on the occurrence of a gap between the Devonian and the Carboniferous, but provided different data on the extension of that hiatus in the various sections. Wendt et al. (2005), on the basis of a few conodont samples, claimed a gap which includes the uppermost Famennian and the basal Tournaisian. More to the west, Boncheva et al. (2007) illustrated a lower Carboniferous conodont fauna from the Ramsheh section, south of Isfahan.

Other authors published data from north Iran: Ahmadzadeh (1971) studied Devonian and Lower Carboniferous conodonts and brachiopods from central Alborz; Weddige (1984) illustrated conodonts from NE Iran. More recently, Ashuri (2006) illustrated conodonts from the Khoshyeilagh Formation in east Alborz. Habibi et al. (2008) reported Tournaisian conodonts from the Mobarak Formation in Central Alborz. Finally, Mohammadi (2009) studied a Late Devonian-Early Carboniferous conodont fauna from the same area.

THE D/C BOUNDARY: CURRENT UNDERSTANDING

The base of the Carboniferous System is defined by the First Appearance Datum (FAD) of the conodont species *Siphonodella sulcata*, within the *S. praesulcata*-*S. sulcata* lineage and the GSSP is located in the La Serre Trench E' section, Montagne Noire, France (Paproth et al., 1991). Flajs & Feist (1988) published a biometric study of *S. praesulcata* and *S. sulcata* based on the La Serre faunas, demonstrating that transitional forms are very common. Despite these taxonomic uncertainties, the FAD of *S. sulcata* was chosen to define the base of the Tournaisian, but difficulties in discriminating *S. praesulcata* from *S. sulcata* arose immediately (e.g., Ji, 1987; Flajs & Feist, 1988; Wang & Yin, 1984). 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 & Feist, 1988; Ziegler & Sandberg, 1996; Casier et al., 2002; Kaiser, 2009).

A redefinition of the Devonian/Carboniferous boundary was reputed necessary, 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. In this scenario, taxonomic revisions of conodont taxa with some potential as possible tools for defining the boundary are in progress (early siphonodellids, Kaiser & Corradini, 2011; protognathodids, Corradini et al., 2011) and several new sections are under investigation around the world.

THE STUDIED SECTIONS

Three sections have been measured in the southern part of the Shotori Range, approximately 75 km southeast of Tabas, close to the village of Sorond and the Chiruk Silicic Sand mine (Fig. 1). The area is accessible by a unpaved track off the Tabas-Dihuk road.

The Ghale-kalaghu section

The Ghale-kalaghu section (Figs 2, 3a-c) is located about 1 km south of the Chiruk mine, at coordinates: base 33°20'40.86 "N - 57°20'09.72"E and top: 33°20'49.19"N - 57°20'05.84"E.

The section starts with about 30 m of Upper Devonian Shishtu 1 subformation, the "Cephalopod bed", here consisting of yellow to brown sandy limestone, yellow to gray limestone, and alternating sandy limestone and gray shale; the uppermost part of the section is represented by about 3 meters of rusty red iron oolitic sandy limestone. Fossils are quite abundant in the Cephalopod bed: ammonoids, brachiopods, bivalves, gastropods, ostracods, bryozoans, crinoids, vertebrate micro remains, and conodonts are present, sometimes covered by chamosite and iron minerals. At the upper surface of iron sandy oolitic limestone unit, polygonal sedimentary structures (Fig. 3e) are present. The microbial tubules show several concentric layers of stepwise growth around a core that were referred to bacterial activities by Mahmudy Gharaie et al. (2009).

Overlying the Cephalopod bed is a thick sequence (about 83 m) of the lower part of the Shishtu-2 subformation. It starts with the “Mush Horizon”, consisting of predominant blackish-gray to blackish-brown organic-rich pyritic shale and intercalation of strongly gypsiferous pink shale; a thin layer of phosphate brachiopod and gastropod limestone is in the lower part. The upper part of the Mush Horizon is characterized by alternation of limestone, marl, thin gray shale and sandy limestone. The section ends with a thick sequence of yellow to gray platy limestone. Brachiopods, solitary rugose corals, crinoids, rare trilobites, and bivalves occur in this unit.

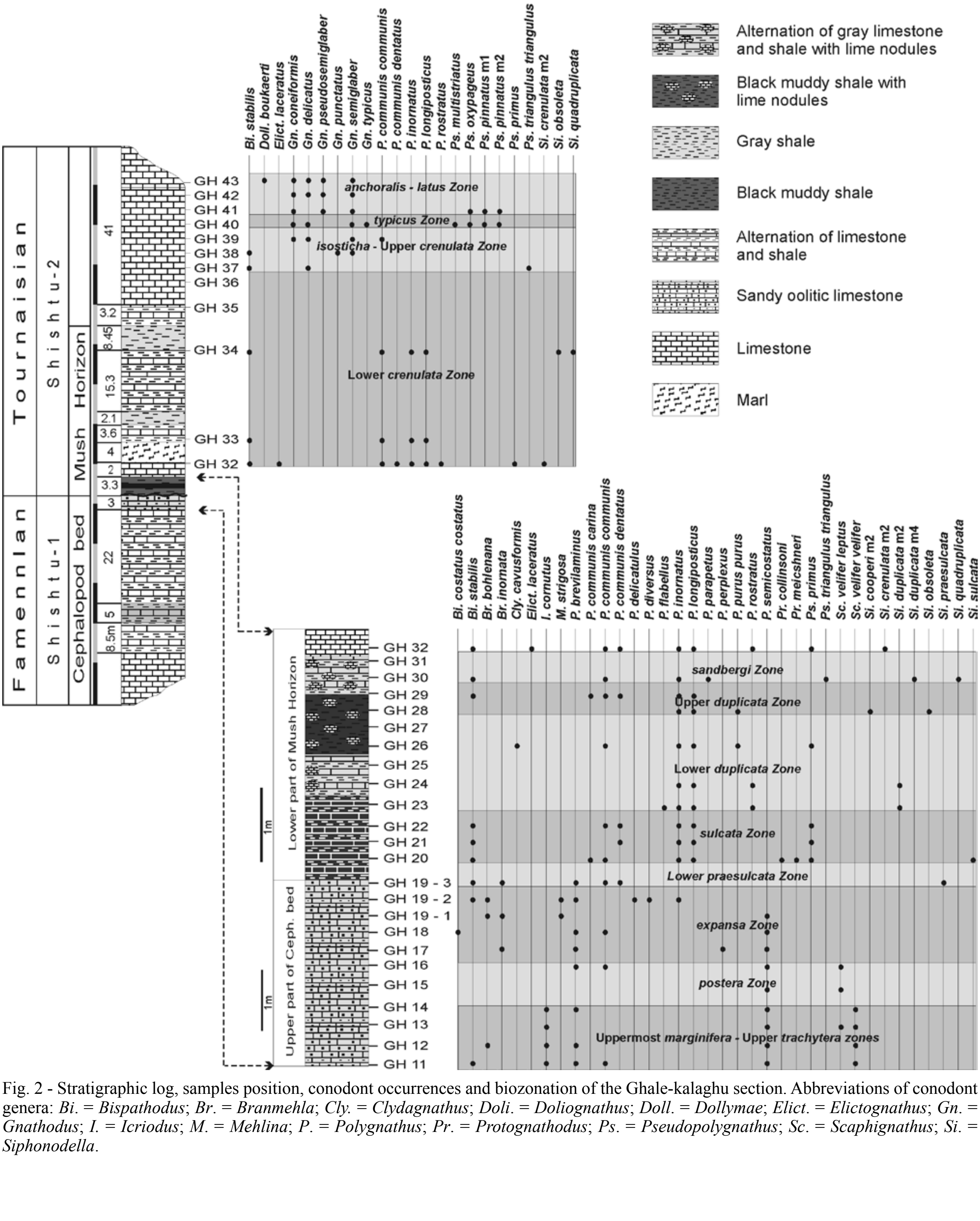


Fig. 2 - Stratigraphic log, samples position, conodont occurrences and biozonation of the Ghale-kalaghu section. Abbreviations of conodont genera: *Bi.* = *Bispathodus*; *Br.* = *Branmehla*; *Cly.* = *Clydagnathus*; *Doli.* = *Doliognathus*; *Doll.* = *Dollymae*; *Elict.* = *Elictognathus*; *Gn.* = *Gnathodus*; *I.* = *Icriodus*; *M.* = *Mehlina*; *P.* = *Polygnathus*; *Pr.* = *Protognathodus*; *Ps.* = *Pseudopolygnathus*; *Sc.* = *Scaphignathus*; *Si.* = *Siphonodella*.

Fig. 3 - Selected views of the studied sections: a: Panoramic view of the Ghale-kalaghu section, with indication of the lithostratigraphic units, the Cephalopod bed, the Mush Horizon and position of the Frasnian/Famennian and the Devonian/Carboniferous boundaries. b: View of the contact between the Cephalopod bed and the Mush Horizon in the Ghale-kalaghu section. c: Detail of the sampled interval in the Ghale-kalaghu section. d: Detail of the sampled interval in the Howz-e-Dorah 1 section. e: microbial tubules in the iron oolitic sandy limestones at the top of Cephalopod bed in the Ghale-kalaghu section. f: close up of iron oolitic sandy limestone in the Cephalopod bed in the Howz-e-Dorah 1 section.

Howz-e-Dorah 1 section

The Howz-e-Dorah 1 section (Figs 3d, 4) is located about 500 m northeast of the Chiruk mine, at coordinates: base 33°22'21.07"N - 57°20'22.85"E and top: 33°22'26.64"N - 57°20'29"E.

The measured section consists of 159.7 m of strata, including 33.5 m of upper part of Devonian Shishtu-1 subformation, and 126.2 m of lower part of Shishtu-2 subformation. This section was studied by Yazdi (1999) and Wendt et al. (1997, 2005), who gave a general age

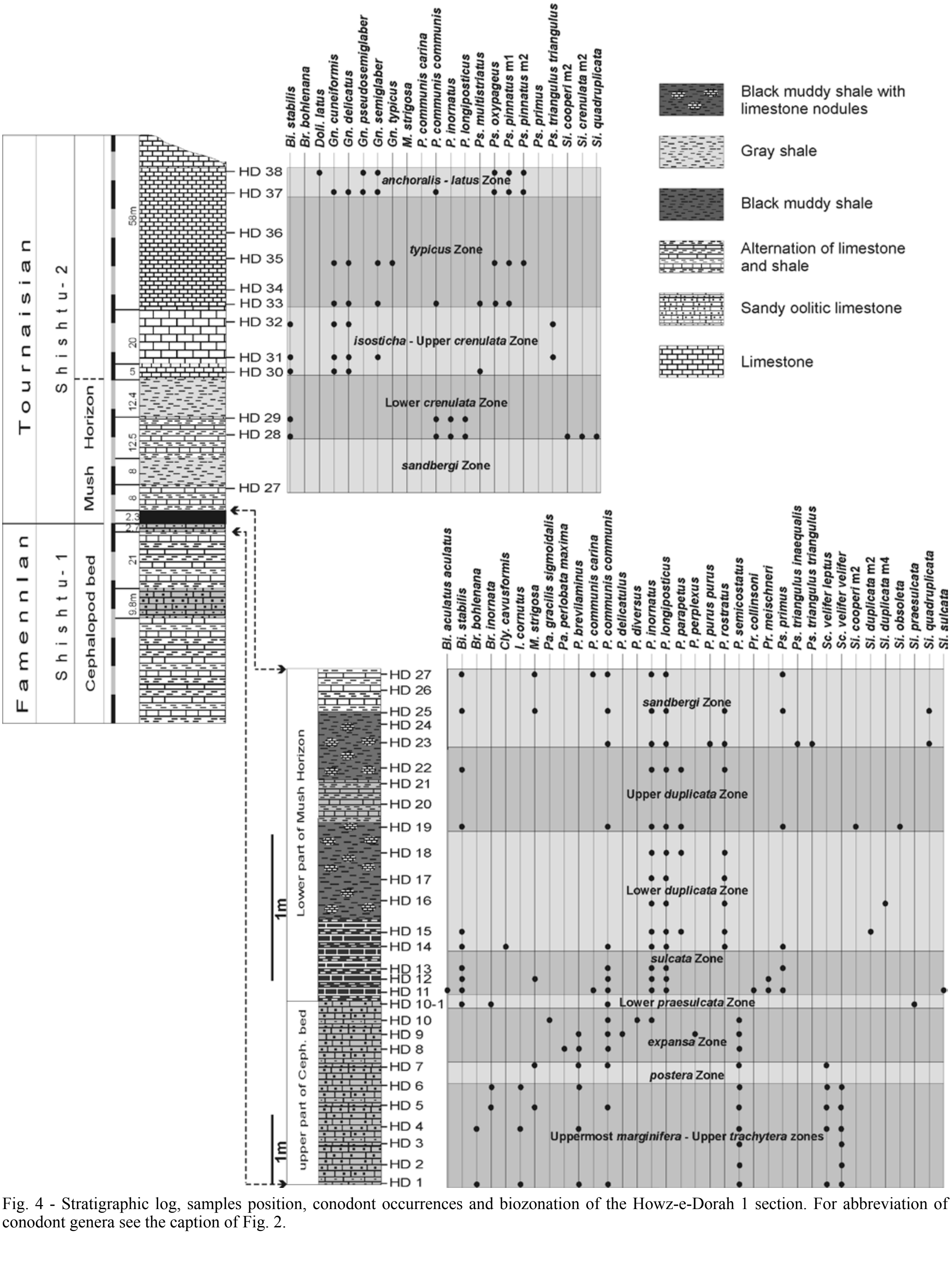


Fig. 4 - Stratigraphic log, samples position, conodont occurrences and biozonation of the Howz-e-Dorah 1 section. For abbreviation of conodont genera see the caption of Fig. 2.

to the units, but did not sample in detail across the DCB. The lithostratigraphy and fauna are very similar to the Ghale-kalaghu section.

Howz-e-Dorah 2 section

The Howz-e-Dorah 2 section (Fig. 5) is located close to section 1 in the same flank of the hill, at coordinates: base 33°22'16.67"N - 57°20'23"E and top: 33°22'26.24"N - 57°20'25.48"E.

The Howz-e-Dorah 2 section includes 3 m in uppermost of Cephalopod bed and 2.7 m thick of black shale at the base of the "Mush Horizon".

CONODONT DATA

Ninety-three conodont samples (3-4 kg each) were collected from the studied sections: 35 samples from the Ghale-kalaghu section, 39 samples from the Howz-e-Dorah 1 section and 19 samples from the Howz-e-Dorah 2 section). The samples were processed with the conventional acetic and/or formic acid technique. Sixteen samples were barren and 77 samples yielded conodonts.

More than 2900 conodont elements were collected (Tabs 1-3). Conodonts are not abundant, only a few samples yielded more than a dozen elements/kg, where higher yields occurred in the upper part of the studied interval, with a maximum of 139 elements/kg in HD 38, 108 elements/kg in GH 26, and 54 elements/kg in HB 10.

Preservation of the conodonts is generally good, and only in some levels of the red hematitic sandy oolitic limestone (Cephalopod bed) are specimens encrusted by chamosite and other iron minerals (i.e.: HB 3-5). In the lower parts of the Mush Horizon (i.e. HD 13-16 and GH 22-26) most of specimens are broken, eroded, and incomplete; in the upper part of the sections, samples GH 37-43 and HD 30-38 (*isosticha*-Upper *crenulata* Zone to *anchoralis-latus* Zone) the preservation of the fauna is quite good without any contamination or wear.

The color of conodonts is brown (C.A.I.=3.5-4) in the lower part of the section, up to sample GH 36 and HD 29, then suddenly turn to dark black (C.A.I.=5) in sample s GH 37 and HD 30 to the top of sections.

Fifty-six species and subspecies belonging to 15 genera (*Bispathodus*, *Branmehla*, *Clydagnathus*, *Dolygnathus*, *Dollymae*, *Elictognathus*, *Gnathodus*, *Icriodus*, *Mehlina*, *Palmatolepis*, *Polygnathus*, *Protognathodus*, *Pseudopolygnathus*, *Scaphignathus*, and *Siphonodella*) were discriminated (Tabs 1-3). The association is dominated by the shallow water genera

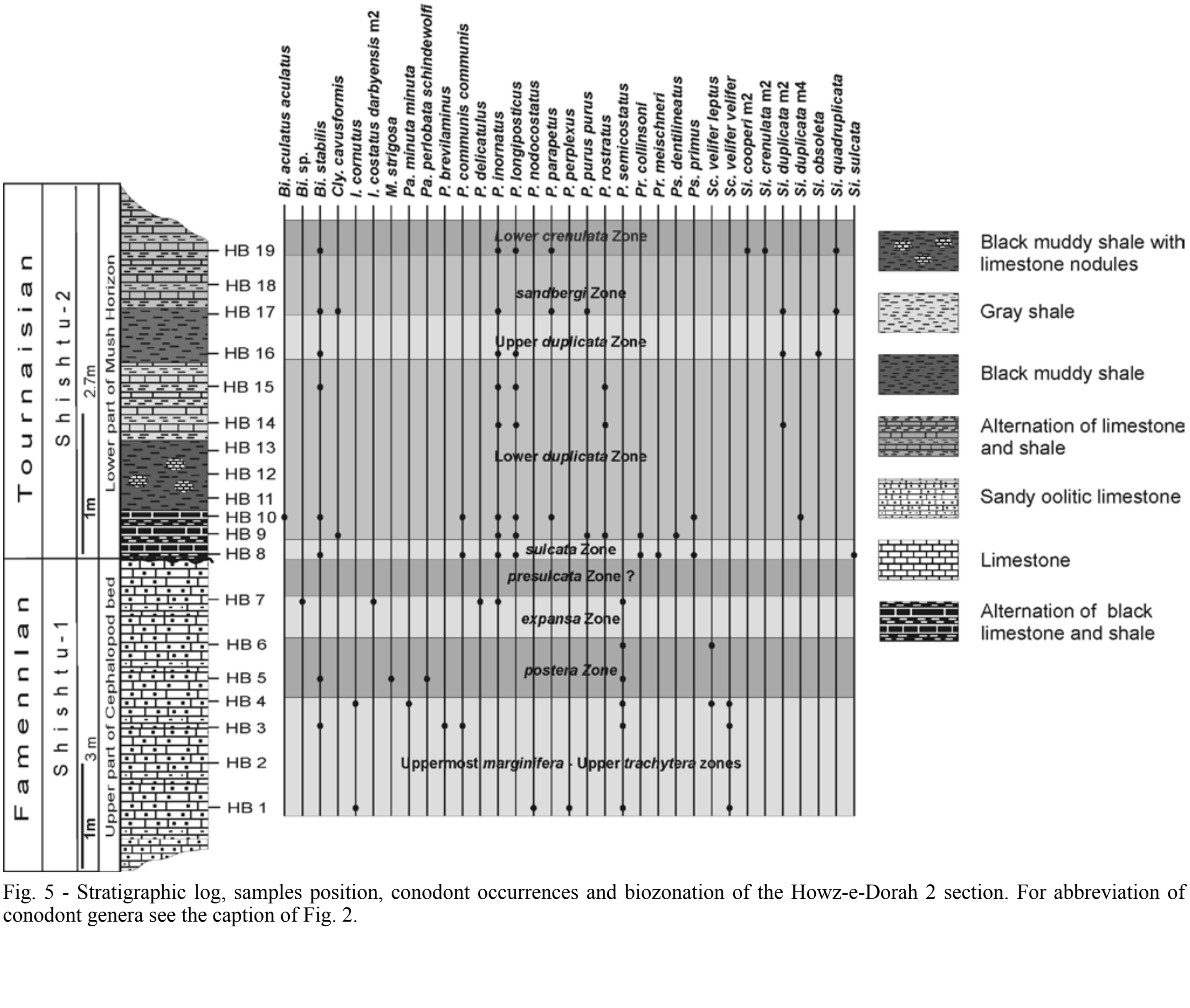


Fig. 5 - Stratigraphic log, samples position, conodont occurrences and biozonation of the Howz-e-Dorah 2 section. For abbreviation of conodont genera see the caption of Fig. 2.

GHALE KALAGHU	GH 11	GH 12	GH 13	GH 14	GH 15	GH 16	GH 17	GH 18	GH 19-1	GH 19-2	GH 19-3	GH 20	GH 21	GH 22	GH 23	GH 24	GH 26	GH 28	GH 29	GH 30	GH 32	GH 33	GH 34	GH 37	GH 38	GH 39	GH 40	GH 41	GH 42	GH 43	TOTAL
Bi. costatus costatus								1																							1
Bi. stabilis	2									1	4	4	2	2					1	1	3	3	4	15	3						45
Br. bohlenana		1							3	1																					5
Br. inornata							1		2		1																				4
Cly. cavusformis																	1														1
Doll. boukaerti																														1	1
Elict. laceratus																					1										1
Gn. cuneiformis																								4	2	3	3	2	1	1	16
Gn. delicatus																								5		3	2		2	3	15
Gn. psudosemiglaber																												88	63	47	198
Gn. punctatus																									1						1
Gn. semiglaber																									1	2	1	4	5	3	16
Gn. typicus																											1				1
I. cornutus	4	2	2	3																											11
M. strigosa									1	1																					2
P. brevilaminus	3	1		1		2	1	3		1	1																				13
P. communis carina												1																			1
P. communis communis	1					2		2			1	2		1			3		1	1	2	2	2			1					21
P. communis dentatus											2		1	1					1		1										6
P. delicatulus										1																					1
P. diversus										1																					1
P. flabellus															1																1
P. inornatus										2		3	3	5	10	35	44	20	5	2	2	3	3								137
P. longiposticus												2	5	7	17	20	58	52	15		5	7	3								191
P. parapetus																				1											1
P. perplexus							1																								1
P. purus purus																	1	1													2
P. rostratus															5	10					1										16
P. semicostatus	46	13	28	24	9	18	16	23	25																						202
Pr. collinsoni												2																			2
Pr. meischneri												1																			1
Ps. multistriatus																											2				2
Ps. oxypageus																											1	2			3
Ps. pinnatus m1																											3	2			5
Ps. pinnatus m2																											1	3			4
Ps. primus												1	1	1			1				1										5
Ps. triangulus triangulus																				2				2							4
Sc. velifer leptus			1		1	2																									4
Sc. velifer velifer	7	2	2	15																											26
Si. cooperi																		1													1
Si. crenulata m2																					1										1
Si. duplicata m2															1	1															2
Si. duplicata m4																				1											1
Si. obsoleta																		1					1								2
Si. praesulcata											1																				1
Si. quadruplicata																				1			1								2
Si. sulcata												1																			1
Unassigned elements	5	25	32	35	37	13	18	27	4															43	38	36		5		19	337
TOTAL	68	44	65	78	47	37	37	56	35	8	10	17	12	17	34	66	108	75	23	9	17	15	14	69	45	45	14	106	71	74	1316

Tab. 1 - Range chart of conodont species in the Ghale-kalaghu section. For abbreviation of conodont genera see the caption of Fig. 2.

Polygnathus and *Gnathodus*; palmatolepids and icriodids are scarce; *Scaphignathus* is common in the lowermost part of the sections.

The collection is stored in the Department of Geology of the Isfahan University under acronym EUIC. Repository numbers of the figured specimens can be obtained from the plate captions.

BIOSTRATIGRAPHY

The conodont zonation for the Late Devonian and the Early Carboniferous utilized was proposed by Ziegler & Sandberg (1990) and Sandberg et al. (1978), respectively. Recently two alternative schemes were proposed for selected regions (i.e.: Corradini, 2008) or time frame (Kaiser et al., 2009). A new scheme across the Devonian/Carboniferous boundary should be prepared as soon as the revision of the main taxa used for biostratigraphy in this time span is concluded.

All these zonal schemes are based on pelagic index species, mainly utilizing species of *Palmatolepis*, *Bispathodus* and *Siphonodella*, that are scarce in the shallow water sediments of the Tabas area. Therefore, when the markers are absent, species of *Polygnathus* and *Pseudopolygnathus* are used to identify some of the zonal boundaries. As a result it is not possible to recognize all the zones, but only longer biointervals that group some adjacent biozones.

Twelve biointervals have been discriminated.

Uppermost marginifera-*Upper* trachytera *zones*

The Uppermost *marginifera*-Upper *trachytera* zones are recognized in the lower part of the sections (GH 11-14, HD 1-6, HB 1-4), by the occurrence of *Scaphignathus velifer velifer*. This species is the marker of the Uppermost *marginifera* Zone (= *velifer* Zone sensu Corradini, 2008) and ranges to the Upper *trachytera* Zone (Ziegler & Sandberg, 1984). None of the associated species allow a further subdivision of this interval. *Scaphignathus vel. velifer* and *Polygnathus semicostatus* are very abundant in this interval.

postera *Zone*

An undifferentiated *postera* Zone is represented by a thin interval in the three sections (GH 15-16, HD 7, HB

HOWZ-E-DORAH 1	HD1	HD 2	HD 3	HD4	HD 5	HD 6	HD 7	HD 8	HD 9	HD 10	HD 10-1	HD 11	HD 12	HD 13	HD 14	HD 15	HD 16	HD 17	HD 18	HD 19	HD 22	HD 23	HD 25	HD 27	HD 28	HD 29	HD 30	HD 31	HD 32	HD 33	HD 35	HD 37	HD 38	TOTAL
Bi. aculatus aculatus												1																						1
Bi. stabilis											1	1	1	2	2	2				2	3		3	4	4	2	13	2	2					44
Br. bohlenana	2			1																														3
Br. Inornata					5	5					2																							12
Cly. cavusformis															2																			2
Doli. latus																																	1	1
Gn. cuneiformis																											3	2	3	1	4	6		19
Gn. delicatus																											4	4	2	2	3	3		18
Gn. psudosemiglaber																																9	71	80
Gn. semiglaber																												1		9	2	3	7	22
Gn. typicus																															1			1
I. cornutus	2			1		1																												4
M. strigosa					2		1						1										2	2										8
P. brevilaminus	1			2		2	1	2	1																									9
P. communis carina												1												1										2
P. communis communis	1				2		2	1	1	1	2	1	1	1	1					1		1	1	16	14	9				2		1		59
P. diversus										1																								1
P. inornatus										1		5	2	5	14	10	3	5	6	17	12	8	40	10	18	7								163
P. longiposticus												10	4	2	10	15	3	7	5	8	8	10	15	17	15	10								139
P. parapetus																1			2	3	2													8
P. perplexus									1																									1
P. purus purus																						2												2
P. rostratus															13	11	5	2	2		4	10	6											53
P. semicostatus	22	10	11	18	28	23	21	38	29	37																								237
Pa. gracilis gracilis										1																								1
Pa. perlobata cf. *maxima*								1																										1
Pr. collinsoni												1																						1
Pr. meischneri												1	1																					2
Ps. multistriatus																											1			1				2
Ps. oxypageus																														2	2	1	3	8
Ps. pinnatus m1																														2	2	2	4	10
Ps. pinnatus m2																															2	2	3	7
Ps. primus												1		1	1					2			2	2										9
Ps. triangulus inaequalis																						1												1
Ps. triangulus triangulus																						1						2	2					5
Sc. velifer leptus	1			1	1	2	1																											6
Sc. velifer velifer	18	3	3	3	1	30																												58
Si. cooperi																				1					2									3
Si. crenulata m2																									1									1
Si. duplicata m2																1																		1
Si. duplicata m4																	1																	1
Si. obsoleta																				1														1
Si. praesulcata											1																							1
Si. quadruplicata																						1	2		2									5
Si. sulcata												1																						1
Unassigned elements	2	2	5	1				10	21	25	25												3	2			41	3		3	8	20	50	221
TOTAL	49	15	19	27	39	63	26	52	53	66	31	23	10	11	43	40	12	14	15	35	29	34	74	54	56	28	62	14	9	22	24	47	139	1235

Tab. 2 - Range chart of conodont species in the Howz-e-Dorah 1 section. For abbreviation of conodont genera see the caption of Fig. 2.

5-6). The lower boundary is marked by the last occurrence of *Scaphignathus vel. velifer*, the upper boundary by the last occurrence of *Sc. vel. leptus*. *Sc. vel. leptus* have its last occurrence within the Upper *postera* Zone (Ziegler & Sandberg, 1984). This biozone is equivalent to the *styriacus* Zone of Ziegler (1962) and Corradini (2008). Several authors (i.e.: Ebner, 1980; Perri & Spalletta, 1991, 1998; Corradini, 2003) highlighted difficulties in discriminating it, because the markers are often not present, or have a restricted palaeogeographic distribution. In the Tabas area *Polygnathus semicostatus* is dominant in this interval.

expansa *Zone*

An undifferentiated *expansa* Zone is recognized in the upper part of the Cephalopod bed (samples GH 17-19-2, HD 8-10, HB 7). The lower boundary is marked by the Last Occurrence of *Scaphignathus vel. leptus*, the upper boundary by the first occurrence of *Siphonodella*

HOWZ-E-DORAH 2	HB1	HB 3	HB4	HB 5	HB 6	HB 7	HB 8	HB 9	HB 10	HB 14	HB 15	HB 16	HB 17	HB 19	TOTAL
Bispathodus sp.						5									5
Bi. aculatus aculatus									1						1
Bi. stabilis		1		1			11		3		2	1	3	2	24
Cly. cavusformis								1					1		2
I. cornutus	2		2												4
I. costatus darbyensis m2						2									2
M. strigosa				1											1
P. brevilaminus		2													2
P. communis communis		2					2		2						6
P. delicatulus						1									1
P. inornatus						1	4	30	25	10	30	10	10	5	125
P. longiposticus							3	10	17	25	28	5		13	101
P. nodocostatus	1														1
P. parapetus									4				2	1	7
P. perplexus	1														1
P. purus purus								2					1		3
P. rostratus								5		3	3				11
P. semicostatus	7	8	7	22	18	12									74
Pa. minuta minuta			1												1
Pa. perlobata schindewolfi				1											1
Pr. collinsoni								1							1
Pr. meischneri							1								1
Ps. dentilineatus								1							1
Ps. primus							1		1						2
Sc. velifer leptus			1		2										3
Sc. velifer velifer	1	5	11												17
Si. cooperi														1	1
Si. crenulata m2														1	1
Si. duplicata m2										1		1	1		3
Si. duplicata m4									1						1
Si. obsoleta												1			1
Si. quadruplicata													1	2	3
Si. sulcata							1								1
Unassigned elements			8	5	4										17
TOTAL	12	18	30	30	24	21	23	50	54	39	63	18	19	25	426

Tab. 3 - Range chart of conodont species in the Howz-e-Dorah 2 section. For abbreviation of conodont genera see the caption of Fig. 2.

praesulcata. *Polygnathus semicostatus*, which became extinct at the top of the zone (Ji & Ziegler, 1993), is always dominant, representing more than 50% of the association.

praesulcata *Zone*

An undifferentiated *praesulcata* Zone is identified by the occurrence of the marker *Siphonodella praesulcata* in the Ghale-kalaghu section (GK 19-3) and in the Howz-e-Dorah 1 section (HD 10-1). The zone is represented by a few centimetres of rock at the very top of the Cephalopod bed, that have not been sampled in the Howz-e-Dorah 2 section. The fauna is very scarce and poorly preserved.

sulcata *Zone*

The *sulcata* Zone is recognized at the very base of the Mush Horizon, based on the occurrence of a single specimen of *Siphonodella sulcata* in each of the sections (GH 20-22, HD 11-13, HB 8). The upper boundary is defined by the fist occurrence of either *Si. duplicata* or *Polygnathus rostratus*. *Polygnathus inornatus* and *Po. longiposticus* are common in this interval.

Lower duplicata *Zone*

The Lower *duplicata* Zone is recognized from in the lower part of the Mush Horizon (GH 23-26, HD 14-18,

---

EXPLANATION OF PLATE 1

Fig. 1 - *Palmatolepis perlobata* cf. *maxima* Müller,1956. Upper view of EUIC 5809, sample HD 8 (*expansa* Zone).
Fig. 2 - *Palmatolepis minuta minuta* Branson & Mehl, 1934. Upper (a) and lower (b) views of EUIC 5810, sample HB 4 (Uppermost *marginifera* - Upper *trachytera* zones).
Fig. 3 - *Palmatolepis gracilis gracilis* Ziegler, 1952. Upper view of EUIC 5811, sample HD 10 (*expansa* Zone).
Fig. 4 - *Palmatolepis perlobata schindewolfi* Müller, 1956. Upper view of EUIC 5812, sample HB 5 (*postera* Zone).

Figs 5-7 - *Polygnathus brevilaminus* Branson & Mehl, 1934.
5 - Upper lateral view of EUIC 5813, sample HB 3 (Uppermost *marginifera* - Upper *trachytera* zones),
6 - Upper view of EUIC 5814, sample GH 16 (*postera* Zone),
7 - Upper lateral view of EUIC 5815, sample HD 8 (*expansa* Zone).

Fig. 8 - *Polygnathus diversus* Helms, 1959. Upper view of EUIC 5816, sample HD 10 (*expansa* Zone).
Fig. 9 - *Polygnathus perplexus* Thomas, 1949. Upper oblique view of EUIC 5817, sample GH 17 (*expansa* Zone).

Figs 10-12 - *Icriodus cornutus* Sannemann, 1955.
10 - Upper view of EUIC 5818, sample HD 1 (Uppermost *marginifera* - Upper *trachytera* zones),
11 - Upper view of EUIC 5819, sample HB 1 (Uppermost *marginifera* - Upper *trachytera* zones),
12 - Upper view of EUIC 5820, sample HD 4 (Uppermost *marginifera* - Upper *trachytera* zones).

Figs 13-14 - *Icriodus costatus darbyensis* m2 Klapper, 1958.
13 - Upper view of EUIC 5821, sample HB 7 (*expansa* Zone),
14 - Upper view of EUIC 5822, sample HB 7 (*expansa* Zone).

Figs 15-16 - *Polygnathus delicatulus* Ulrich & Bassler, 1926.
15 - Upper view of EUIC 5823, sample HB 7 (*expansa* Zone),
16 - Upper view of EUIC 5824, sample GH 19-2 (*expansa* Zone).

Figs 17-20 - *Bispathodus stabilis* (Branson & Mehl, 1934).
17 - Upper view of EUIC 5825, sample HD 22 (Upper *duplicata* Zone),
18 - Upper view of EUIC 5826, sample HD 15 (Lower *duplicata* Zone),
19 - Upper view of EUIC 5827, sample GH 33 (Lower *crenulata* Zone).
20 - Upper view of EUIC 5828, sample GH 20 (*sulcata* Zone).

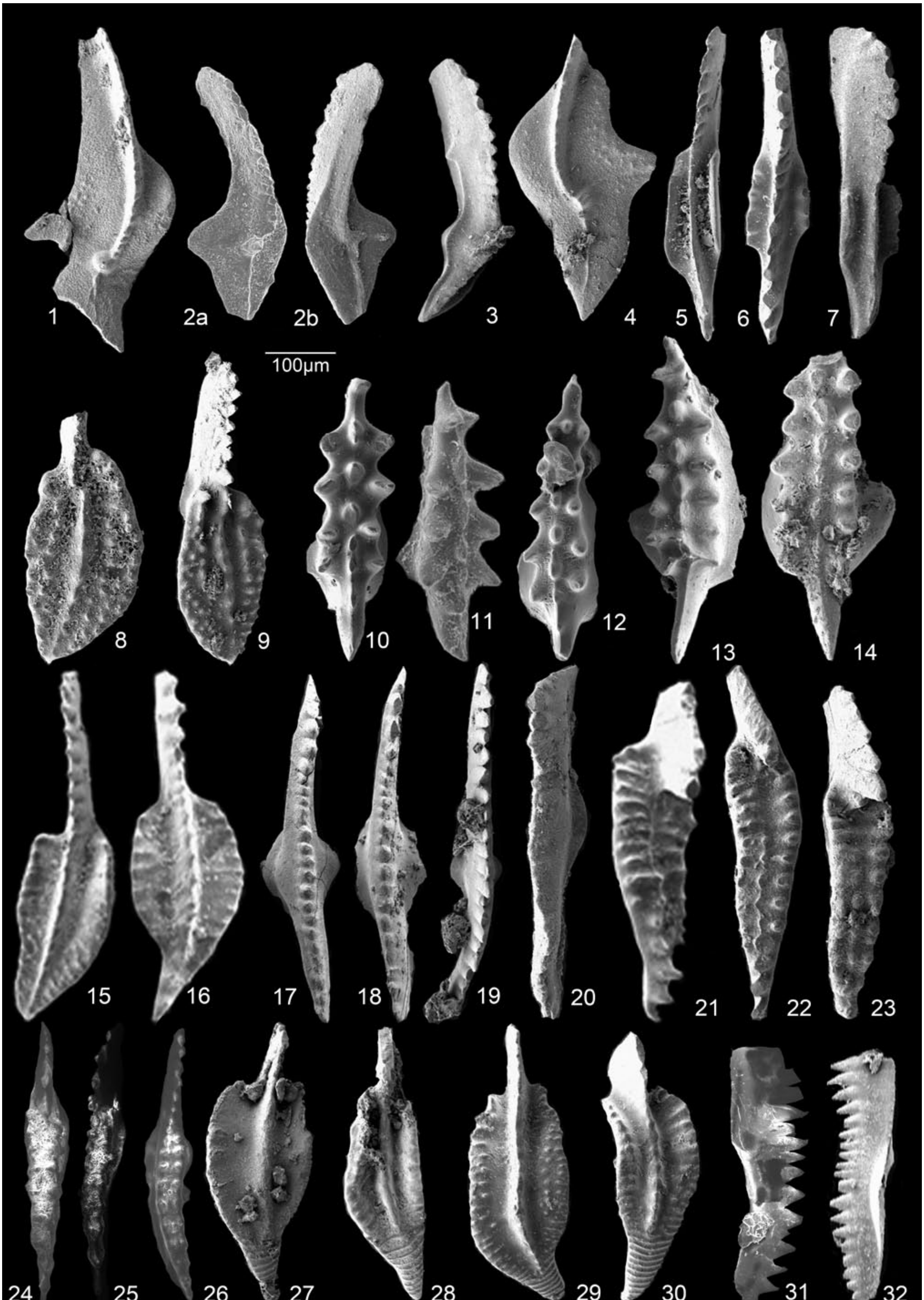
Figs 21-23 - *Scaphignathus velifer velifer* Helms, 1959.
21 - Upper view of EUIC 5829, sample HB 1 (Uppermost *marginifera* - Upper *trachytera* zones),
22 - Upper view of EUIC 5830, sample GH 14 (Uppermost *marginifera* - Upper *trachytera* zones),
23 - Upper view of EUIC 5831, sample HD 6 (Uppermost *marginifera* - Upper *trachytera* zones).

Figs 24-25 - *Scaphignathus velifer leptus* Ziegler & Sandberg, 1984.
24 - Upper view of EUIC 1924, sample GH 16 (*postera* Zone),
25 - Upper view of EUIC 1925, sample HD 7 (*postera* Zone).

Fig. 26 - *Bispathodus costatus costatus* (E. R. Branson, 1934). Upper view of EUIC 1927, sample GH18 (*expansa* Zone).

Figs 27-30 - *Polygnathus semicostatus* Branson & Mehl, 1934.
27 - Upper view of EUIC 5834, sample HD 10, (*expansa* Zone),
28 - Upper view of EUIC 5835, sample GH 16 (*postera* Zone),
29 - Upper view of EUIC 5836, sample HB 7 (*expansa* Zone),
30 - Upper view of EUIC 5837, sample HD 3 (Uppermost *marginifera* - Upper *trachytera* zones).

Figs 31-32 - *Mehlina strigosa* (Branson & Mehl, 1934).
31 - Lateral view of EUIC 5838 sample HD 5 (Uppermost *marginifera* - Upper *trachytera* zones),
32 - Lateral view of EUIC 5925 sample HD 5 (Uppermost *marginifera* - Upper *trachytera* zones).


1
2a
2b
3
4
5
6
7
100µm
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32

HB 9-15). The marker, *Siphonodella duplicata*, is always present, but only in the Ghale Kalaghu section does it enter at the base of the zone; in the Howz-e-Dorah 1 and 2 sections the lower boundary is identified by the entry of *Polygnathus rostratus*, which, according to Barskov et al. (1991) has its first appearance at the base of this zone. *Polygnathus inornatus* and *Po. longiposticus* are very abundant in this interval.

Upper duplicata *Zone*

The Upper *duplicata* Zone is recognized in a narrow interval (GH 28-29, HD 19-22, HB 16) by the entry of the marker *Siphonodella cooperi* M1 or that of *Si. obsoleta*, which, according to Sandberg et al. (1978) enters slightly higher in the zone. *Polygnathus inornatus* and *Po. longiposticus* are dominant in this interval.

sandbergi *Zone*

It is not possible precisely locate the base of the *sandbergi* Zone, but the occurrence of *Siphonodella quadruplicata* is used to discriminate it in beds GH 30, HD 23-27 and HB 17. *Siphonodella quadruplicata* have its first occurrence within the zone (Sandberg et al., 1978). The association is dominated by polygnathids, mainly *Po. inornatus* and *Po. longiposticus*, and in the Howz-e-Dorah 1 section *Po. c. communis*.

Lower crenulata *Zone*

The Lower *crenulata* Zone is based on the occurrence of *Siphonodella crenulata*, in the thick shaly interval in the upper part of the Mush Horizon (beds GH 32-34, HD 28-29 and HB 19) where the conodont fauna is in general scarce and poorly preserved. *Polygnathus inornatus*

EXPLANATION OF PLATE 2

Figs 1-2 - *Siphonodella praesulcata* Sandberg, 1972.
1 - Upper (a) and lower (b) views of EUIC 5839, sample HD 10-1 (*praesulcata* Zone),
2 - Upper (a) and lower (b) views of EUIC 5840, sample GH 19-3 (*praesulcata* Zone).

Figs 3-4 - *Siphonodella sulcata* (Huddle, 1934).
3 - Upper (a) and lower (b) views of EUIC 5841, sample HD 11 (*sulcata* Zone),
4 - Upper (a) and lower (b) views of EUIC 5842, sample GH 20 (*sulcata* Zone).

Fig. 5 - *Siphonodella duplicata* (Branson & Mehl, 1934) Morphotype 4. Upper view of EUIC 5843, sample HD 16 (Lower *duplicata* Zone).

Figs 6, 12 - *Siphonodella duplicata* (Branson & Mehl, 1934) Morphotype 2.
6 - Upper (a) and lower (b) views of EUIC 5844, sample GH 23 (Lower *duplicata* Zone),
12 - Upper (a) and lower (b) views of EUIC 5845, sample HD 15 (Lower *duplicata* Zone).

Figs 7-8 - *Siphonodella crenulata* Cooper, 1939 Morphotype 2.
7 - Upper view of EUIC 5846, sample HD 28 (Lower *crenulata* Zone),
8 - Upper view of EUIC 5847, sample GH 32 (Lower *crenulata* Zone).

Fig. 9 - *Siphonodella quadruplicata* Branson & Mehl, 1934. Upper view of EUIC 5848, sample HD 23 (*sandbergi* Zone).

Figs 10, 13 - *Siphonodella cooperi* Hass, 1959 Morphotype 2.
10 - Upper view of EUIC 5849, sample HB 19 (Lower *crenulata* Zone),
13 - Upper view of EUIC 5850, sample GH 28 (Upper *duplicata* Zone).

Figs 11, 14 - *Siphonodella obsoleta* Hass, 1959.
11 - Upper view of EUIC 5851, sample GH 30 (*sandbergi* Zone),
14 - Upper oblique view of EUIC 5852, sample HD 19 (U. *duplicata* Zone).

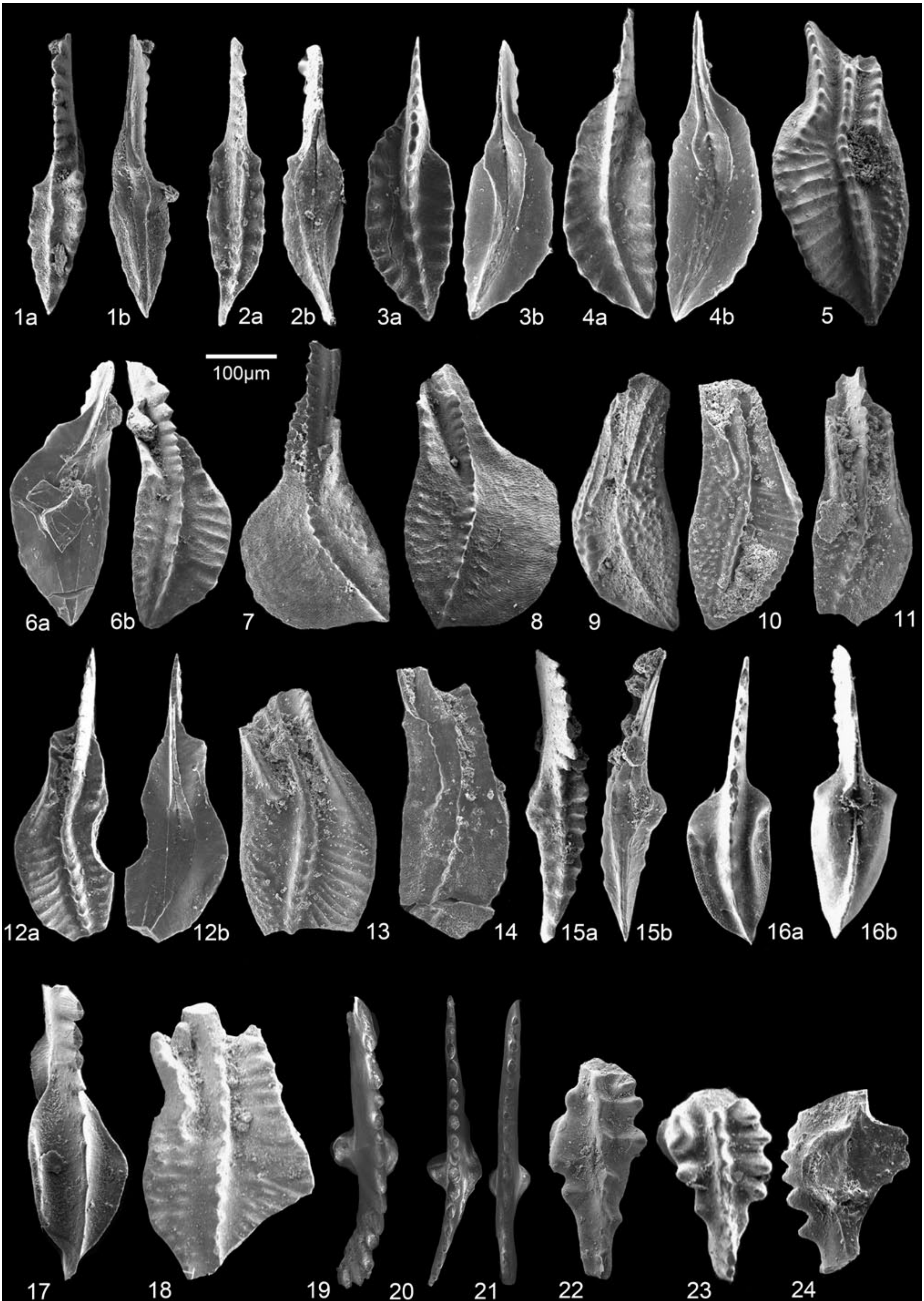
Fig. 15 - *Pseudopolygnathus dentilinateus* Branson, 1934. Upper (a) and Lower (b) views of EUIC 5855, sample HB 9 (Lower *duplicata* Zone).

Figs 16-17 - *Polygnathus communis communis* Branson & Mehl, 1934.
16 - Upper view (a) and Lower view (b) of EUIC 5833 sample HD 10-1 (*praesulcata* Zone),
17 - Upper view of EUIC 5832, sample GH 20 (*sulcata* Zone).

Fig. 18 - *Polygnathus inornatus rostratus* Rhodes, Austin & Druce, 1969. Upper view of EUIC 5856, sample HD 15 (Lower *duplicata* Zone).

Figs 19-21 - *Branmehla bohlenana* (Helms, 1959).
19 - Upper lateral view of EUIC 1922, sample GH 19-3 (Lower *praesulcata* Zone),
20 - Upper view of EUIC 1923, sample GH 19-1 (*expansa* Zone),
21 - Upper view of EUIC 1992, sample GH 19-1 (*expansa* Zone).

Figs 22-24 - *Pseudopolygnathus primus* Branson & Mehl, 1934.
22 - Upper view of EUIC 5878, sample HD 14 (L*ower duplicata* Zone),
23 - Upper view of EUIC 5879, sample GH 20 (*sulcata* Zone),
24 - Lower view of EUIC 5880, sample GH 20 (*sulcata* Zone).


1a
1b
2a
2b
3a
3b
4a
4b
5
100µm
6a
6b
7
8
9
10
11
12a
12b
13
14
15a
15b
16a
16b
17
18
19
20
21
22
23
24

and *Po. longiposticus* that were dominant in the lower Tournaisian became extinct in the upper part of the zone.

isosticha - *Upper* crenulata *Zone*

The entry of *Gnathodus delicatus*, in the lower part of the carbonate unit above the Mush Horizon allows to recognize the *isosticha* - Upper *crenulata* Zone (beds GH 37-39, HD 30-32). The association is quite scarce in this interval, where *Bispathodus stabilis*, *Ps. tr. triangulus* and the last representatives of *Siphonodella* have their last occurrence. *Gnathodus punctatus* has its first occurrence within this zone.

typicus *Zone*

An undifferentiated *typicus* Zone is defined by the occurrence of *Gnathodus typicus*, and of *Pseudopolygnathus oxypageus*. *Pseudopolygnathus oxypageus* marks the upper part of the Zone (Lane et al., 1980); it is difficult to precisely locate the base of the zone, due to poorness of conodont fauna and distance of samples.

anchoralis-latus *Zone*

The *anchoralis-latus* Zone is recognized in the upper part of the studied sections (beds GH 41-43, HD 37-38) by the entry of *Gn. pseudosemiglaber*, because the marker *Dolyognathus latus* enters in a higher level. According to Lane et al. (1980), *Gn. pseudosemiglaber* has its FAD within this zone. The fauna is abundant and conodonts are very well preserved in this interval.

EXPLANATION OF PLATE 3

Figs 1-2 - *Pseudopolygnathus pinnatus* Voges, 1959 Morphotype 1.
1 - Upper view of EUIC 5862, sample HD 37 (*anchoralis-latus* Zone),
2 - Upper view of EUIC 5863, sample GH 41 (*anchoralis-latus* Zone).

Figs 3-5 - *Pseudopolygnathus pinnatus* Voges, 1959 Morphotype 2.
3 - Upper view of EUIC 5864, sample HD 35 (*typicus* Zone),
4 - Upper view of EUIC 5865, sample GH 41 (*anchoralis-latus* Zone),
5 - Upper view of EUIC 5866, sample HD 37 (*anchoralis-latus* Zone).

Figs 6-7 - *Pseudopolygnathus oxypageus* Lane, Sandberg & Ziegler, 1980.
6 - Upper view of EUIC 5867, sample HD 35 (*typicus* Zone),
7 - Upper view of EUIC 5868, sample GH 40 (*typicus* Zone).

Figs 8-10, 15-16 - *Psudopolygnathus triangulus triangulus* Voges, 1959.
8 - Upper view of EUIC 5869, sample HD 23 (*sandbergi* Zone),
9 - Upper view of EUIC 5870, sample HD 32 (*isosticha* - Upper *crenulata* Zone),
10 - Upper view of EUIC 5871, sample GH 37 (*isosticha* - Upper *crenulata* Zone),
15 - Upper view of EUIC 5872, sample GH 30 (*sandbergi* Zone),
16 - Upper view of EUIC 5873, sample HD 23 (*sandbergi* Zone).

Figs 11-12 - *Pseudopolygnathus multistriatus* Mehl & Thomas, 1947.
12 - Upper view of EUIC 5874, sample HD33 (*typicus* Zone),
13 - Upper view of EUIC 5875, sample GH40 (*typicus* Zone).

Figs 13-14 - *Psudopolygnathus triangulus inaequalis* Voges, 1959.
13 - Upper view of EUIC 5876, sample HD23 (*sandbergi* Zone),
14 - Upper view of EUIC 5877, sample HD23 (*sandbergi* Zone).

Fig. 17 - *Polygnathus purus purus* Voges, 1959. Upper view of EUIC 5917, sample GH 26 (Lower *duplicata* Zone).

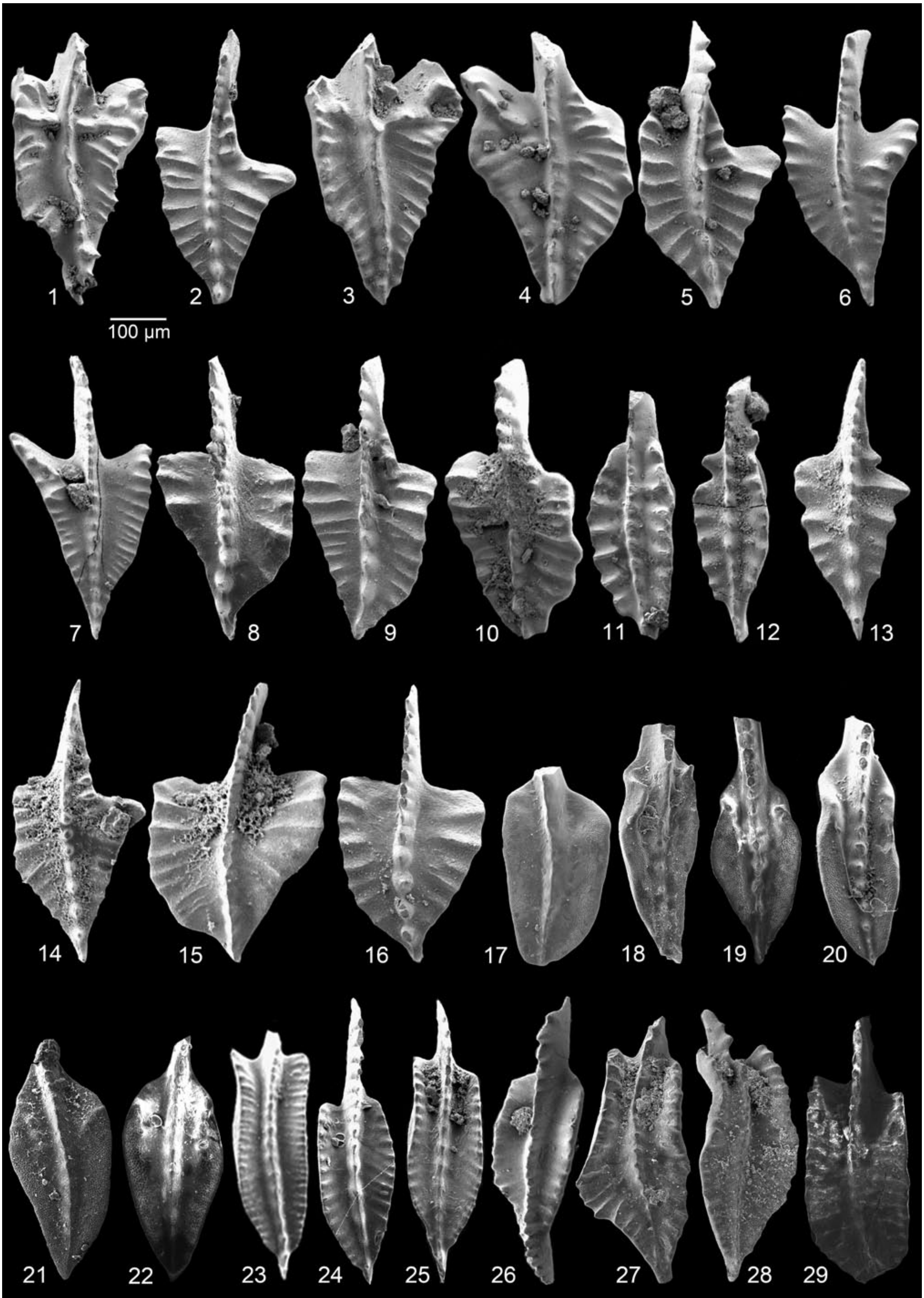
Figs 18-20 - *Polygnathus communis dentatus* Druce, 1969.
18 - Upper view of EUIC 5881, sample GH 21 (*sulcata* Zone),
19 - Upper view of EUIC 5918, sample GH 29 (Upper *duplicata* Zone),
20 - Upper view of EUIC 5854, sample GH 22 (*sulcata* Zone).

Figs 21-22 - *Polygnathus communis carina* Hass, 1959.
21 - Upper view of EUIC 5853, sample HD 11 (*sulcata* Zone),
22 - Upper view of EUIC 5919, sample GH 29 (Upper *duplicata* Zone).

Figs 23-26 - *Polygnathus longiposticus* Branson & Mehl, 1934.
23 - Upper view of EUIC 5860, sample HB 17 (*sandbergi* Zone),
24 - Upper view of EUIC 5859, sample HD 22 (Upper *duplicata* Zone),
25 - Upper view of EUIC 5858, sample GH 29 (Upper *duplicata* Zone),
26 - Upper view of EUIC 5857, sample GH 26 (Lower *duplicata* Zone).

Figs 27-28 - *Polygnathus inornatus inornatus* Branson, 1934.
27 - Upper view of EUIC 5882, sample GH 22 (*sulcata* Zone),
28 - Upper view of EUIC 5883, sample HD 17 (Lower *duplicata* Zone).

Fig. 29 - *Polygnathus flabellus* Branson & Mehl, 1938. Upper view of EUIC 5920, sample GH 23 (Lower *duplicata* Zone).


1
2
3
4
5
6
100 µm
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29

DISCUSSION AND CONCLUSIONS

The study of the Ghale-kalaghu, Howz-e-Dorah 1 and Howz-e-Dorah 2 sections documents relatively continuous sedimentation from the Late Devonian (Uppermost *marginifera* Zone) to the Early Carboniferous (*anchoralis-latus* Zone) in the southern Shotori range, with a gap limited to the upper part of the *praesulcata* Zone, and maybe the lower part of the *sulcata* Zone, much shorter than that claimed by other authors in the same area or even in the same sections between the Cephalopod bed and the Mush Horizon: the top of the Cephalopod bed belongs to the *praesulcata* Zone and the Mush Horizon starts within the *sulcata* Zone. Yazdi (1999) proposed a gap from the Lower *expansa* to the Lower *crenulata*, Wendt et al. (2005, p. 54) "from the uppermost Famennian to Lower Tournaisian", and Ashouri (1995, 1997b) from the latest Famennian (Middle *expansa* - Lower *praesulcata* zones)

EXPLANATION OF PLATE 4

Figs 1-5 - *Gnathodus pseudosemiglaber* Thomson & Fellows, 1970.
1 - Upper view of EUIC 5884, sample HD 37 (*anchoralis-latus* Zone),
2 - Upper view of EUIC 5885, sample HD 38 (*anchoralis-latus* Zone),
3 - Upper view of EUIC 5886, sample GH 42 (*anchoralis-latus* Zone),
4 - Upper view of EUIC 5887, sample GH 41 (*anchoralis-latus* Zone),
5 - Upper view of EUIC 5888, sample GH 43 (*anchoralis-latus* Zone).

Figs 6-9 - *Gnathodus semiglaber* Bischoff, 1957.
6 - Upper view of EUIC 5889, sample GH 40 (*typicus* Zone),
7 - Upper view of EUIC 5890, sample GH 42 (*anchoralis-latus* Zone),
8 - Upper view of EUIC 5891, sample HD 38 (*anchoralis-latus* Zone),
9 - Upper view of EUIC 5892, sample HD 35 (*typicus* Zone).

Figs 10-13 - *Gnathodus typicus* Cooper, 1939.
10 - Upper view of EUIC 5897, sample HD 35 (*typicus* Zone),
11 - Upper view of EUIC 5898, sample HD 35 (*typicus* Zone),
12 - Upper view of EUIC 5900, sample GH 40 (*typicus* Zone),
13 - Upper view of EUIC 5899, sample GH 40 (*typicus* Zone).

Figs 14-15 - *Protognathodus meischneri* Ziegler, 1969.
14 - Upper view of EUIC 5901, sample HD 11 (*sulcata* Zone),
15 - Upper view of EUIC 5902, sample GH 20 (*sulcata* Zone).

Figs 16-17 - *Protognathodus collinsoni* Ziegler, 1969.
16 - Upper view of EUIC 5903, sample HB 9 (*sulcata* Zone),
17 - Upper view of EUIC 5904, sample GH 20 (*sulcata* Zone).

Figs 18-21 - *Gnathodus cuneiformis* Mehl & Thomas, 1947.
18 - Upper view of EUIC 5893, sample HD 35 (*typicus* Zone),
19 - Upper view of EUIC 5894, sample GH 40 (*typicus* Zone),
20 - Upper view of EUIC 5895, sample GH 42 (*anchoralis-latus* Zone),
21 - Upper view of EUIC 5896, sample GH 42 (*anchoralis-latus* Zone).

Figs 22-24 - *Gnathodus delicatus* Branson & Mehl, 1938.
22 - Upper view of EUIC 5905, sample GH37 (*isosticha* - Upper *crenulata* Zone),
23 - Upper view of EUIC 5906, sample HD33 (*isosticha* - Upper *crenulata* Zone),
24 - Upper view of EUIC 5907, sample GH40 (*typicus* Zone).

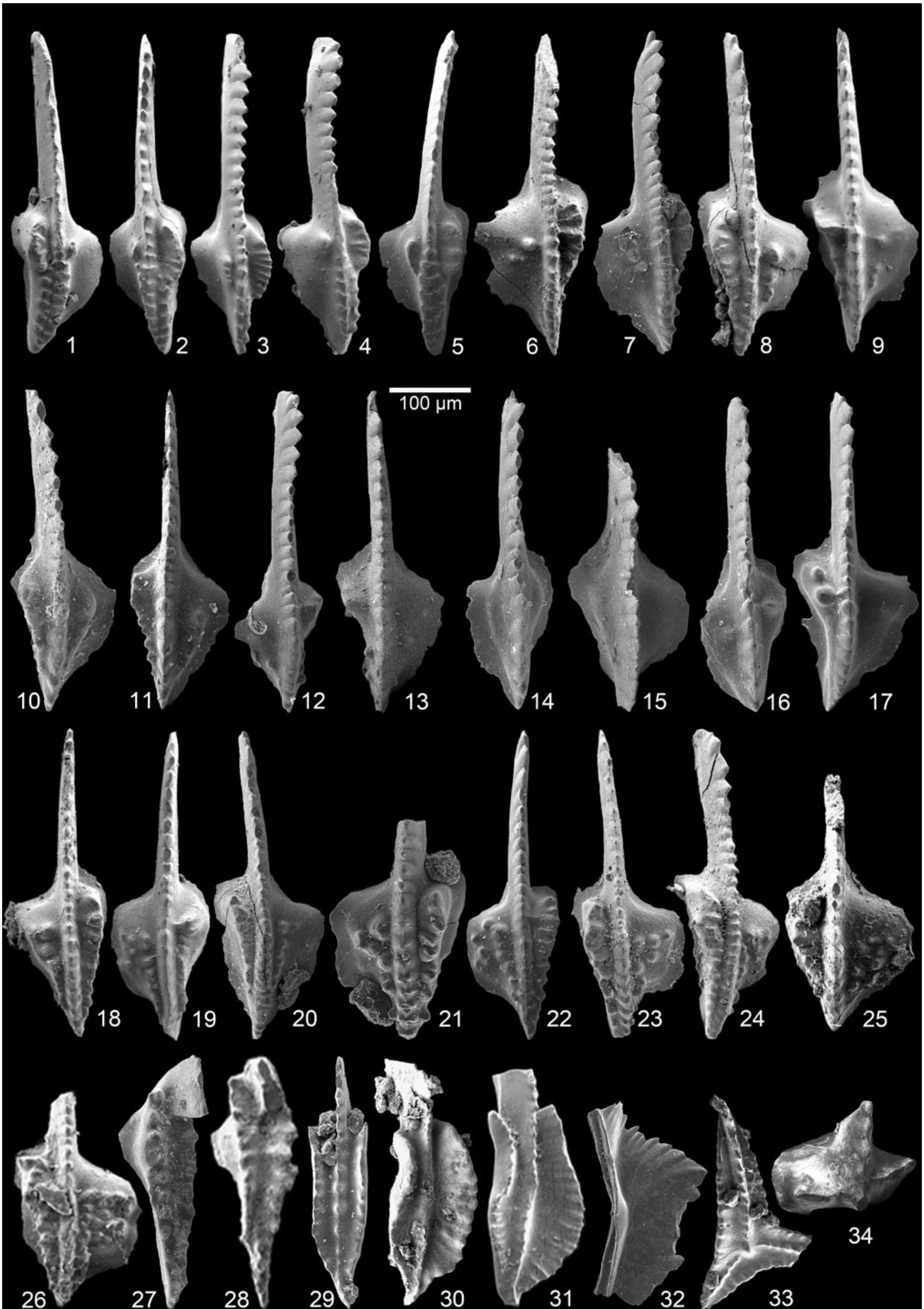
Figs 25-26 - *Gnathodus punctatus* (Cooper, 1939).
25 - Upper view of EUIC 5909, sample GH 38 (*isosticha* - Upper *crenulata* Zone),
26 - Upper view of EUIC 5910, sample GH 38 (*isosticha* - Upper *crenulata* Zone).

Figs 27, 28 - *Clydagnathus cavusformis* Rhodes, Austin & Druce, 1969.
27 - Upper view of EUIC 5915, sample HD 14 (Lower *duplicata* Zone),
28 - Upper view of EUIC 5861, sample HB 9 (Lower *duplicata* Zone).

Fig. 29 - *Polygnathus longiposticus* Branson & Mehl, 1934. Upper view of EUIC 5913, sample HD 17 (Lower *duplicata* Zone).

Figs 30-31 - *Polygnathus parapetus* Druce, 1969.
30 - Upper view of EUIC 5911, sample HD 15 (Lower *duplicata* Zone),
31 - Upper view of EUIC 5912, sample GH 30 (*sandbergi* Zone).

Fig. 32 - *Elictognatus laceratus* Branson & Mehl, 1934. Lateral view of EUIC 5914, sample GH32 (Lower *crenulata* Zone).
Fig. 33 - *Doliognathus latus* Branson & Mehl, 1941 Morphotype 2. Upper view of EUIC 5908, sample HD38 (*anchoralis-latus* Zone).
Fig. 34 - *Dollymae boukaerti* Groessens, 1971. Upper view of EUIC 5916, sample GH43 (*anchoralis-latus* Zone).


1
2
3
4
5
6
7
8
9
100 µm
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34

to the Tournaisian (*anchoralis-latus* Zone) in various sections. We believe that such incertitude was due to the poorness of the conodont fauna in the lower part of the Mush Horizon and/or the distance between samples.

ACKNOWLEDGEMENTS

This study is part of Ali Bahrami's PhD project at the Isfahan University (Iran) supported by the Office of Graduate Studies; the authors are grateful to the office for its support. The conodont study was completed during a six months research and study period at the Dipartimento di Scienze della Terra, Università di Cagliari (Italy). Thanks are due to Jeff Over, Iliana Boncheva, John A. Talent and Andrey Zhuravlev for giving support and providing copies of literature. Hossein Gholamalian, Mr. Ghaedi and Safdari helped in field work, sampling and acid leaching. Mr. Esmailzadeh and his family kindly hosted during field work in the Tabas area. We are deeply grateful to Jeff Over and Claudia Spalletta for critical revision of the manuscript.

This paper is a contribution to IGCP 596 - *Climate change and biodiversity patterns in the Mid-Paleozoic (Early Devonian to Late Carboniferous).*

REFERENCES

Ahmadzadeh H.M. (1971). Stratigraphische und paläontologische Untersuchungen im Unterkarbon des zentralen Elburs (Iran). *Clausthaler Geologische Abhandlungen*, 7: 1-114.

Ashouri A.R. (1990). Devonian and Carboniferous conodont faunas from Iran. Unpublished PhD Thesis, University of Hull. 351 pp.

Ashouri A.R. (1995). Conodonts and Cephalopod Bed and Devonian/Carboniferous boundary in Howz-e-Dorah. 14th Symposium of Geosciences. Tehran: 68-71 [in Persian].

Ashouri A.R. (1997a). Juvenile gastropods from the upper Devonian Cephalopod beds and adjacent strata of central Iran. *Journal of Science*, 8: 45-60.

Ashouri A.R. (1997b). Revision in stratigraphical position of the "Cephalopod Beds" and Devonian- Carboniferous boundary and introducing 5 conodont zones in Howz-e-Dorah (East Iran). *Geosciences*, 6: Geological Survey of Iran: 10-17 [in Persian].

Ashouri A.R. (1998). The Devonian-Carboniferous boundary in Ozbak-Kuh area. *Geosciences, Scientific Quarterly Journal*, 7: 47-53 [in Persian].

Ashouri A.R. (2001). Middle Devonian-Early Carboniferous conodont faunas from the Khoshyeilagh Formation, Alborz Mountains, north Iran. *In* Jansen U., Königshof P., Plodowski G. & Schindler E. (Eds), 15th International Senckenberg Conference, Joint Meeting IGCP 421/SDS, May 2001. Abstracts: 6.

Ashouri A.R. (2002). *Palmatolepis* (conodonta; Late Devonian) from the Tabas region, east Iran. *International Journal of Science, Iran* 3 (2): 187-220.

Ashouri A.R. (2004). Late Devonian and Middle-Late Devonian conodonts from eastern and northern Iran. *Revista Española de Micropaleontología*, 3: 355-365.

Ashouri A.R. (2006). Middle Devonian-Early Carboniferous conodont faunas from the Khoshyeilagh Formation, Alborz Mountains, north Iran. *Journal of Sciences*, 17: 53-65.

Ashouri A.R & Yamini A. (2006). Cephalopods and Stratigraphical Position of Cephalopod Bed of Shishtu Formation, Iran. *Geosciences Scientific Quarterly Journal*, 15: 178-187.

Barskov I.S., Vorontsova T.N., Kononova L.I. & Kuzmin A.V. (1991). Index Conodonts of the Devonian and Early Carboniferous. Moscow University, Moscow. 183 pp. [in Russian].

Becker R.T., Ashouri A.R. & Yazdi M. (2004). The Upper Devonian *Annulata* event in the Shotori range (eastern Iran). *Neues Jahrbuch für Geologie und Paleontologie, Abhandlungen*, 231: 119-143.

Berberian M. & King G.C.P. (1981). Towards a paleogeography and tectonic evolution of Iran. *Canadian Journal of Earth Sciences*, 18: 210-265.

Boncheva I., Bahrami A., Yazdi M. & Toraby H. (2007). Carboniferous Conodont biostratigraphy and Late Paleozoic Platform Evolution in South Central Iran (Asadabad Section in Ramsheh area - SE Isfahan). *Rivista Italiana di Paleontologia e Stratigrafia*, 113 (3): 329-356.

Casier J.-G., Lethiers F. & Préat A. (2002). Ostracods and sedimentology of the Devonian-Carboniferous stratotype section (La Serre, Montagne Noire, France). *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Science de la Terre*, 72: 43-68.

Corradini C. (2003). Famennian (Late Devonian) conodonts from the Corona Mizziu sections (SE Sardinia, Italy). *Palaeontographia Italica*, 89: 63-114.

Corradini C. (2008). Revision of Famennian-Tournaisian (Late Devonian-Early Carboniferous) conodont biostratigraphy of Sardinia, Italy. *Revue de Micropaleontologie*, 51: 123-132.

Corradini C., Kaiser S.I., Perri M.C. & Spalletta C. (2011). *Protognathodus* (Conodonta) and its potential as a tool for defining the Devonian/Carboniferous boundary. *Rivista Italiana di Paleontologia e Stratigrafia,* 116 (1): 15-28.

Ebner F. (1980). Conodont localities in the surroundings of Graz/Styria. *In* Schönlaub H.P. (Ed.), Second European Conodont Symposium - ECOS II. *Abhandlungen der Geologischen Bundesaltstalt*, 35: 101-127.

Feist R., Yazdi M. & Becker T. (2003). Famennian trilobites from the Shotori range, E-Iran. *Annales de la Société géologique du Nord*, 10 (2éme série): 285-295.

Flajs G. & Feist R. (1988). Index conodont, trilobites and environment of Devonian-Carboniferous Boundary beds at La Serre (Montaigne Noire, France). *In* Flajs G., Feist R. & Ziegler W. (Eds), Devonian-Carboniferous Boundary - results of recent studies. *Courier Forschungsinstitut Senckenberg*, 100: 50-107.

Flügel E. (1966). *Iranoblastus*, a new Mississippian blastoid from Iran. In: Contributions to the Paleontology of East Iran. *Geological survey reports*, 6: 75-81.

Flügel H.W. (1961). *Receptaculites neptuni* Defr. 1827 from the Upper Devonian Kuh-i-Shotori, east Iran. *Bulletin of the Iranian Petroleum Institute*, 4: 75-81.

Ghavidel-Syooki M. & Moussavi M.J. (1996). Palynostratigraphy and paleogeography study of Padeha, Bahram, Shishtu (1 & 2) and Sardar Formations in the Howz-e-Dorah (east of Tabas). *First Geological Congress of Iranian Universities*, Kerman: 45-46 [in Persian].

Gholamalian H. (2002). Biostratigraphy of Frasnian/Famennian Boundary in Esfahan & Tabas Areas. Unpublished Ph.D thesis, University of Isfahan. 118 pp.

Gholamalian H. (2007). Conodont biostratigraphy of the Frasnian-Famennian boundary in the Esfahan and Tabas areas, central Iran. *Geological Quarterly*, 51: 453-476.

Gholamalian H., Ghorbani M. & Sajadi S.H. (2009). Famennian conodonts from Kal-e-Sardar section, eastern Tabas, central Iran. *Rivista Italiana di Paleontologia e Stratigrafia*, 115: 141-158.

Golonka J., Ross M.I. & Scotese C.R. (1994). Phanerozoic paleogeographic and paleoclimatic modeling maps. *In* Embry A.F., Beauchamp B. & Glass D.J. (Eds), Pangea: Global environments and resources. *Canadian Society of Petroleum Geology, Memoir*, 17: 1-47.

Haas W. (1994). Eine neue Asteropyginae-art mit vier Seitenstacheln und die bedeutung der Zufallszahlen in der Morphogenese des Pygidiums der trilobiten. *Courier Forschungsinstitut Senckenberg*, 169: 225-238.

Haas W. & Mensink H. (1970). Asteropyginae aus Afghanistan (Trilobita). *Akademie der Wissenschaften und der Literatur,Mainz, Mathematisch-Naturwissenschaftlichen Klasse, Abhandlungen*, 1969: 155-211.

Habibi T. & Corradini C. & Yazdi M. (2008). Famennian-Tournaisian conodont biostratigraphy of the Shahmirzad section, central Alborz, Iran. *Geobios*, 41: 763-777.

Hairapetian V. & Ginter M. (2010). Pelagic chondrichthyan microremains from the Upper Devonian of the Kale Sardar section, eastern Iran. *Acta Geologica Polonica*, 60 (3): 357-371.
Hairapetian V., Ginter M. & Yazdi M. (2008). Early Frasnian sharks from central Iran. *Acta Geologica Polonica,* 58: 173-179.
Hairapetian V. & Yazdi M. (2003). Late Devonian conodonts from the Dalmeh sections, Northeast Ardekan, Central Iran. *Courier Forschungsinstitut Senckenberg*, 245: 209-225.
Hairapetian V., Yazdi M. & Long J.A. (2000). Devonian vertebrate biostratigraphy of central Iran. *Records of the Western Australian Museum*, *Supplement*, 58: 241-247.
Ji Q. (1987). New results from Devonian-Carboniferous boundary beds in South China. *Newsletters on Stratigraphy*, 17 (3): 155-167.
Ji Q. & Ziegler W. (1993). The Lali section: an excellent reference section for Late Devonian in south China. *Courier Forschungsinstitut Senckenberg*, 157: 1-183.
Kaiser S.I. (2009). The Devonian/Carboniferous stratotype section La Serre (Montagne Noire) revisited. *Newsletters on Stratigraphy*, 43 (2): 195-205.
Kaiser S.I., Becker R.T., Spalletta C. & Steuber T. (2009). High-resolution conodont stratigraphy, biofacies and extinctions around the Hangenberg Event in pelagic successions from Austria, Italy and France. *Palaeontographica Americana*, 63: 97-139.
Kaiser S. & Corradini C. (2011). The early Siphonodellids (Conodonta, Late Devonian-Early Carboniferous): overview and taxonomic state. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, 261:19-35.
Lane H.R., Sandberg C.A. & Ziegler W. (1980). Taxonomy and phylogeny of some Lower Carboniferous conodonts and preliminary standard post-*Siphonodella* zonation. *Geologica et Palaeontologica*, 14: 117-164.
Mahmudi Gharaie M.H., Ashouri A., Khanehbad M. & Ghaderi A. (2009). Ferruginous oolitic limestone in Shishtu Formation (Late Devonian) and the role of Microbial activities in their formation**.** *Sedimentary Facies*, 2 (1): 95-105 [in Persian with English abstract].
Mohammadi M. (2009). Biostratigraphy of Late Devonian-Early Tournaisian deposits (Jairud Formation), central Alborz. Unpublished PhD thesis, University of Isfahan. 165 pp. [in Persian].
Morzadec P. (2002). Trilobites asteropyginae dévoniens d'Iran. *Geobios*, 35: 411-427.
Moussavi M.J. (1995). Palynostratigraphy and paleobiogeography of Padeha, Shishtu and Sardar Formations in Howz-e-Dorah (East of Tabas). M.Sc. thesis, Tarbiat Moallem University. 244 pp. [in Persian].
Paproth E., Feist R. & Flajs G. (1991). Decision on the Devonian-Carboniferous boundary stratotype. *Episodes*, 14 (4): 331-336.
Perri M.C. & Spalletta C. (1998). Conodont distribution at the Tournaisian/Visean Boundary in the Carnic Alps (Southern Alps, Italy). *Paleontologia Polonica*, 58: 225-245.
Perri M.C. & Spalletta C. (2001). Hangenberg Event al limite Devoniano/Carbonifero al Monte Zermula, Alpi Carniche, Italia. *Giornale di Geologia*, ser. 3°, 62, suppl.: 31-40.
Rastkar G. (1996). Brachiopods and stratigraphical position of Cephalopod Bed of Shishtu Formation, Shotori Range. M.Sc. Thesis, Mashhad University, 124 pp. [in Persian].
Sandberg C.A., Ziegler W., Leuteritz K. & Brill S.M. (1978). Phylogeny, speciation, and zonation of *Siphonodella* (Conodonta, Upper Devonian and Lower Carboniferous). *Newsletter on Stratigraphy*, 7: 102-120.
Sartenaer P. (1966). Frasnian Rhynchonellida from the Ozbak-Kuh and Tabas regions (east Iran). *Geological Survey of Iran, Reports*, 6: 25-53.
Scotese C.R. (2001). Atlas of Earth-History. Paleogeography, Vol. 1. Paleomap Project, Arlington, Texas, 52 pp.
Soffel H.C., Davoudzadeh M., Rolf C. & Schmidt S. (1996). New palaeomagnetic data from Central Iran and a Triassic palaeoreconstruction. *Geologische Rundschau*, 85: 293-302.
Stocklin J., Eftekhar-Nezhad J. & Hushmand-Zadeh A. (1965, reprinted 1991). Geology of the Shotori range (Tabas area, east Iran). *Geological Survey of Iran, Reports*, 3: 1-69.
Stocklin J. & Nabavi M.H. (1971). Explanatory text of the Boshruyeh Quadrangle map 1:250.000. *Geological Survey of Iran, Geological Quadrangle*, J7: 1-50.
Stocklin J. & Setudehnia A. 1991. Stratigraphic Lexicon of Iran. *Geological Survey of Iran, Reports*, 18: 1-376.
Walliser O.H. (1966). Preliminary notes on Devonian, Lower and Upper Carboniferous goniatites in Iran. *Geological Survey of Iran, Reports*, 6: 7-24.
Wang C.Y. & Yin B. (1984). Conodont zonations of early Lower Carboniferous and Devonian-Carboniferous boundary in pelagic facies, South China. *Acta Palaeontologica Sinica*, 23 (2): 224-238.
Webster G.D., Maples C.G. & Yazdi M. (2007). Late Devonian and early Mississippian echinoderms from central and northern Iran. *Journal of Paleontology*, 81: 1101-1113.
Weddige K. (1984). Zur Stratigraphie und Paläogeographie des Devons und Karbons von NE-Iran. *Senckenbergiana lethaea*, 65: 179-223.
Wendt J., Hayer J. & Karimi Bavandpour A. (1997). Stratigraphy and depositional environment of Devonian sediments in northeast and east-central Iran. *Neues Jahrbuch für Geologie und Palaontologie, Abhandlungen*, 206: 277-322.
Wendt J., Kaufmann B., Belka Z., Farsan N. & Karimi Bavandpur A.(2002). Devonian/Lower Carboniferous stratigraphy, facies patterns and palaeogeography of Iran. Part I. Southeastern Iran. *Acta Geologica Polonica*, 52: 129-168.
Wendt J., Kaufmann B., Belka Z., Farsan N. & Karimi Bavandpur A. (2005). Devonian/Lower Carboniferous stratigraphy, facies patterns and palaeogeography of Iran. Part II. Northern and Central Iran. *Acta Geologica Polonica*, 55: 31-97.
Yamini A. (1996). Cephalopod and stratigraphical position of Cephalopod Bed of Shishtu Formation, Shotori Range M.Sc. Thesis, Mashhad University. 113 pp. [in Persian].
Yazdi M. (1996). Late Devonian-Carboniferous Conodont biostratigraphy of the Tabas area, Eastern Iran. Ph.D. thesis Macquarie University, Sydney. 221 pp.
Yazdi M. (1999). Late Devonian-Carboniferous conodonts from Eastern Iran. *Rivista Italiana di Paleontologia e Stratigrafia*, 105: 167-200.
Yazdi M. & Turner S. (2000). Late Devonian and Carboniferous vertebrates from the Shishtu and Sardar Formations of the Shotori range, Iran. *Records of the Western Australian Museum, Supplement,* 58: 223-240.
Ziegler W. (1962). Taxionomie und Phylogenie Oberdevonischer Conodonten und ihre stratigraphische Bedeutung. *Abhandlungen des Hessisches Landesamtes für Bodenforschung*, 38: 1-166.
Ziegler W. & Sandberg C.A. (1984). *Palmatolepis*-based revision of upper part of standard Late Devonian conodont zonation. *Geological Society of America, Special Papers*, 196: 179-194.
Ziegler W. & Sandberg C.A. (1990). The Late Devonian Standard Conodont Zonation. *Courier Forschungs-Institut Senckenberg*, 121: 1-115.
Ziegler W. & Sandberg C.A. (1996). Reflexions on Frasnian and Famennian Stage boundary decisions as a guide to future deliberations. *Newsletters on Stratigraphy*, 33: 157-180.

Manuscript received 15 March 2011
Revised manuscript accepted 17 May 2011