

Middle Permian (Guadalupian) fusulinid taxonomy and biostratigraphy of the mid-latitude Dalan Basin, Zagros, Iran and their applications in paleoclimate dynamics and paleogeography

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ABSTRACT

The Middle–Upper Permian (Guadalupian–Lopingian) Dalan Basin was part of a very large carbonate ramp/platform along the passive margin of the Arabian Plate, located at mid-latitude Neo-Tethys Ocean. As shown in the modern world the mid-latitudes are areas where climatic fluctuations and velocity of climate change are most significant. Consequently, the most significant variations in foraminiferal diversity occur at higher latitudes as already noted for the Middle Permian (Guadalupian) foraminifers' record. The fusulinids as a large, warm-water foraminifera were quite sensitive to water temperature. The optimal water temperature for recent warm-water benthic foraminifera with living symbionts, and consequently for fusulinids, is 20–30°C, while the lower limit is 14–16°C. Three climatically-determined assemblages were distinguished in Zagros and the surrounding areas. The first assemblage is characteristic of temperate, cool-water environments and contains smaller foraminifera with no symbionts, which possess resistance to such environments. Fusulinid staffellids, schubertellids, *Chusenella*, *Eopolydiexodina* and *Monodiexodina* can be found in the warmer water environments in a second climatic assemblage, transitional from temperate- to warm-water state. The third assemblage is characterized by the presence of verbeekinids in warm-water conditions in Zagros and appeared where surface-water temperature exceeded approximately 25°C. The proposed model of climate fluctuations and paleogeography in the Neo-Tethys is based on analyses of temporal and spatial distribution of fusulinids. Also, a temperate cool-water *Monodiexodina* is recorded in this area for the first time. Three new species of fusulinids are described.

INTRODUCTION

Carbonates in the Permian–Triassic Dalan and Kangan formations in the Zagros region in Iran and equivalents in the Arabian Plate are one of the major hydrocarbon reservoirs in the Middle East. Although numerous studies of Permian sequences were performed in the Zagros area (Szabo and Keradpir, 1978; Al-Jallal, 1987; Alsharhan and Nairn, 1995; Sharland et al., 2001; Insalaco et al., 2006) they were mostly focused on sedimentology, tectonics, sequence-stratigraphic and palaeoecological studies of the Upper Dalan Member and Kangan Formation (Upper Permian–Triassic) reservoirs in the Iranian offshore Fars area and their equivalent outcrops in the Zagros region. The biostratigraphy in these studies was quite limited and the major part of the Permian marine succession below the Upper Dalan Member was poorly studied. Recent foraminiferal biostratigraphic work in the area (Gaillot and Vachard, 2007; Kolodka et al., 2012) also dealt, in large part, with the Upper Permian (Lopingian) Upper Dalan (Khuff) Member and the lack of non-oriented fusulinids available from the Lower Dalan Member prevented a proper biostratigraphic documentation of this part of the succession. Overall, the biostratigraphic, chronostratigraphic and paleogeographic studies of the Middle Permian (Guadalupian) Lower Dalan Member in the Zagros area remained quite poor.

The Zagros area itself possesses a unique mid-latitude paleogeographic position within the transition from the margins of Gondwana to Neo-Tethys (Sharland et al., 2001), where climatic changes occur with considerable frequency and amplitude (Burrows et al., 2011). Thus, careful sedimentological and paleontological studies may significantly contribute to our knowledge and understanding of the paleogeography and paleoclimate of this region. The objectives of this paper are (Figures 1 and 2): (1) summarize the stratigraphy of the Dalan Formation in the Il-e Beyk Section; (2) analyze microfacies and paleoenvironments emphasizing bathymetry; (3)

present a comprehensive taxonomic study of fusulinids and smaller foraminifers (shown in taxonomic order in Plates 1–7); (4) provide a better biostratigraphic and chronostratigraphic age of the Dalan Formation based on fusulinids; and (5) improve the paleogeographic and paleoclimate reconstruction of Zagros and surrounding areas in Middle Permian (Guadalupian).

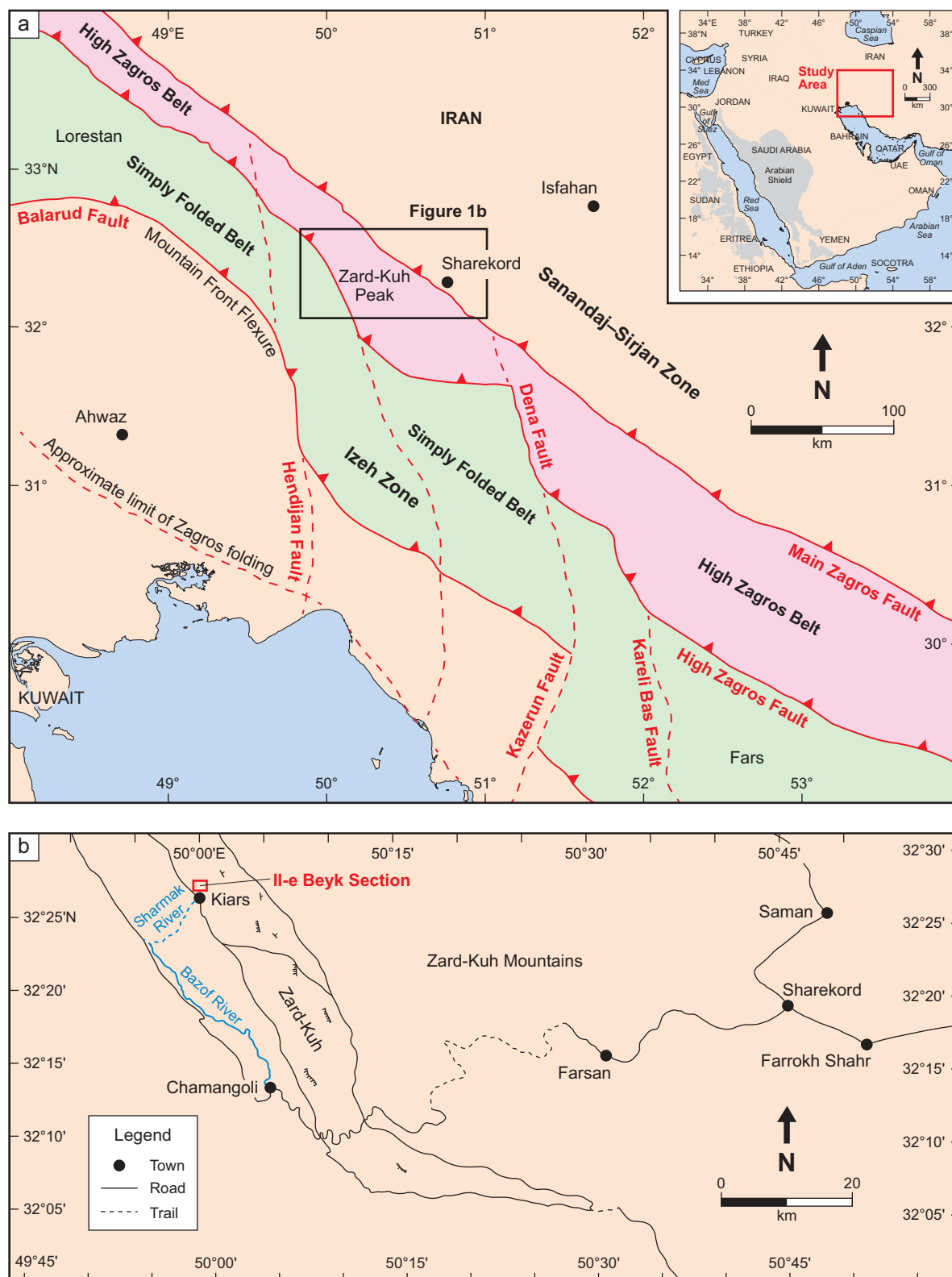


Figure 1: Location map. (a) Simplified tectonic map of Central Zagros Thrust-Fold belt. (b) Enlarged map with exact location of Il-e-Beyk section in Zard-Kuh Mountains.

PREVIOUS STUDIES

Permian–Triassic deposits in Zard-Kuh area (Figure 1) were preliminarily studied as the Khuff Formation equivalent (Sampo, 1969). The lithology and thickness of Permian strata in Zard-Kuh and Kuh-e Dena are rather different. In Zard-Kuh, Permian deposits are 932 m thick and consist of lower limestone and upper dolomite units whereas in Kuh-e Dena a middle sandstone unit rests between lower limestone and upper dolomites and the Permian sediments decrease in thickness to 332 m. Setudehnia (1975) considered the lower fossiliferous limestone to be Middle to Late Permian in age on the basis of fossil content (small foraminifers, few fusulinids, corals and algae). Szabo and Kheradpir (1978) studied the Permian–Triassic deposits in Kuh-e Surmeh and Kuh-e Siah No. 1 Well in the Fars Province and Kuh-e Faraghan in Bandar Abbas, naming the Permian carbonate and evaporite as the Dalan Formation. They subdivided it into three members: (1) Lower Dalan Member (carbonate); (2) predominantly anhydrite middle Nar Member; and (3) Upper Dalan Member consisting of anhydrite interbedded with carbonate.

Two assemblage zones (A and B) contain small foraminifers, fusulinids and algae and were recognized in the lower and upper members of the Dalan Formation. Based on the fossil content, a Middle Permian (Guadalupian) to early Wuchiapingian (early Late Permian) age was proposed for the formation. Zaninetti et al. (1978) studied Permian deposits in Kuh-e Gakhum, where the predominant lithologies of Midian (late Wordian) to early Wuchiapingian deposits are dolomitic with some interbeds of limestones especially in upper parts. Rosen (1979) revised the stratigraphy of Permian–Triassic deposits of the Fars–Gulf area and suggested that the Wuchiapingian fauna in the Upper Dalan and the Scythian (Early Triassic) fauna in the basal beds of the Kangan indicate no major erosional cycle. Moreover, he suggested that only a short period of cessation of carbonate deposition had occurred.

Johnson (1981) remeasured and resampled the Dalan Formation in Kuh-e Surmeh and studied this formation biostratigraphically. He recovered *Shanita* and several other smaller foraminifers in the Nar Member and assigned the formation as late Murgabian. Baghbani (1997) reported some fusulinids and small foraminifer assemblages in outcrops of the Dalan Formation in Kuh-e Surmeh, Kuh-e Dena and Qali Kuh and assigned middle Kubergandian to Dorashamian for the Dalan Formation. Additional biostratigraphic studies carried out by Insalaco et al. (2006) show the age to be Wuchiapingian–Changhsingian due to the foraminiferal content of the Upper Dalan Member in the Surmeh and Dena sections. Gaillot and Vachard (2007) provided a detailed biostratigraphic and microfacies study of the late Middle Permian to Early Triassic Khuff Formation, undertaken in three reference regions in the Zagros area (Iran), United Arabian Emirates (UAE) and Saudi Arabia.

Recently, Kolodka et al. (2012) published new results from the Dalan Formation of southeastern Zagros, where details of depositional environments of the entire formation and new biostratigraphic biozonation were described. The latter, however, is difficult to evaluate as the taxonomy in the paper is based on non-oriented and/or poorly preserved specimens. The latter are highly interpretive and some of the “species”, in our opinion, cannot be determined even at generic level (for example “*Chusenella* cf. *conycocylindrica*”, fig. 9R; or “*Ch.* cf. *brevipola*”, fig. 10C etc.). The morphology of the new genus *Praedunbarula*, in our opinion, is perfectly consistent with long-ranging *Schubertella*, indicating that the proposed age of the *Praedunbarula* Biozone is therefore questionable. Besides, in the genus description (in appendix by D. Vachard) the range of this genus is reported as Kungurian–Changhsingian, whereas in biostratigraphy (Kolodka et al., 2012) the age of the *Praedunbarula* Biozone established as late Wordian (?). We thus consider the proposed “zonation” to be mainly ecostratigraphic.

Weidlich and Bernecker (2007) and Koehrer et al. (2010) introduced integrated facial, stratigraphic and biostratigraphic framework from the Saiq Formation in Oman. Unfortunately, no details of biostratigraphy are provided and both papers are lacking of details of taxonomy. Forke et al. (2012) published a short abstract with some details of smaller foraminifera and fusulinids distribution within the Saiq Formation in the Jabal al-Akhdar area integrated with sequence-stratigraphic framework. The precise correlation with Tethyan Scale is also provided in the work.

GEOLOGIC SETTING

The Zagros orogenic belt of Iran, as part of the Alpine-Himalayan mountain chain, extends for about 2,000 km in a NW-SE direction from the East Anatolian Fault of eastern Turkey to the Oman Line in southern Iran (Alavi, 1994). The orogen is a product of Early Pliocene closure of the Neo-Tethys Ocean (Stöcklin, 1968; Hessami et al., 2001). This orogen consists of the Urumieh-Dokhtar Magmatic Arc (Stöcklin, 1968, 1974; Berberian et al., 1982; Alavi, 2007), the Sanandaj-Sirjan Zone (Stöcklin, 1968; Berberian et al., 1982; Alavi, 2007) as the internal part, and Zagros Fold-and-Thrust Belt (ZFTB) (the Zagros "simple folded zone" of Falcon, 1974) as the external part (Alavi, 2007) (Figure 1). The ZFTB can be divided into two structural domains: (1) an imbricate thrust belt or the High Zagros Belt (HZB), and (2) the Simply Folded Belt (SFB) that are separated by the High Zagros Fault (Berberian, 1995).

The studied area is located in the central part of the High Zagros Belt. One of the main features of the High Zagros Belt is the numerous thrust fault complex (Figure 1). Zard-Kuh-e Bakhtiari also includes the transitional zone from the internal (Sanandaj-Sirjan Zone) to the external parts (ZFTB) of the Zagros orogen, and is structurally characterized by several subhorizontal or gently NE-dipping and SW-verging thrusts (Alavi, 2007) (Figure 1). One of the main thrusts in the Zard-Kuh-e Bakhtiari is the Zard-Kuh thrust that has juxtaposed lowermost Paleozoic rock units with the Pleistocene Bakhtiari conglomerates (Alavi, 2007). A number of NW-trending, NE-dipping thrust sheets are the major structures of the Bakhtiari area (Nemati and Yassaghi, 2010).

STRATIGRAPHY

The Il-e Beyk Section is located on the Zard-Kuh Mountain (270 km west of Shahr-e Kurd city, Figure 1). In this section, the Lower Permian Faraghan Formation is missing and the Dalan Formation disconformably overlies the Ordovician shale of the Zard-Kuh Formation (Figure 2 Table 1). In other Dalan Formation outcrops within the Zagros area (in Tang-e Putak, Kuh-e Dena and Chal-I-Sheh) there is sharp contact between the red and gray shales interbedded with yellow weathering sandstones of the Faraghan Formation and the dark gray, sandy fossiliferous limestones of the Dalan Formation. The siliciclastics of the Faraghan Formation replaced by the carbonates of the Dalan Formation are also in sharp contact. The Dalan Formation is overlain by apparently conformable Triassic dolomites of the Kangan Formation (Insalaco et al., 2006). The Permian/Triassic boundary is not well-recognizable in the Il-e Beyk section (Setudehnia, 1975) since the upper part of the Dalan Formation is composed of dolomite. Because the Triassic Kangan Formation has the same lithology it is difficult to distinguish the clear boundary between the Dalan and Kangan formations. But the changing of bedding from massive dolomitic limestones to thin- to medium-bedded dolomites of the Kangan Formation is clear in the field. Conventionally we considered this boundary just above the sample Z-1 with the last occurrence of the Permian foraminifers (Figure 2).

The Dalan Formation in the section is 927 m thick and can generally be divided into two main parts (Figure 2). The lower part (484.5 m thick, including units 1–18) is composed mainly of gray to light brown, medium- to very thick-bedded, cliff-forming packstones and grainstones with rare horizons of mudstones. The middle and upper portions of this succession contain several fusulinid horizons (Table 2). The limestones within this lower part of the section also include brachiopods, corals, algae, bryozoans, gastropods and crinoid stems. The upper part of the Dalan Formation (442.5 m thick, including units 19–28, Figure 2) is predominantly made of cream-colored, cliff-making, medium- to coarse-grained dolomite with occasional chert nodules interbedded with dolomitic limestones, yielding one fusulinid horizon and remains of brachiopods, algae, crinoid stems, gastropods and small foraminifers.

The total thickness and lithology of the Dalan Formation in the High Zagros varies. It is thickest in the Zard-Kuh area (Il-e Beyk section) and thinnest in Kuh-e Dena (Setudehnia, 1975; Parvizi et al., 2008). In the latter area, a section of middle sandstone adds to the Dalan sequence. It should be noted that the well-developed evaporite deposits within the middle Nar Member of the Dalan Formation in the Zagros simply folded belt in the type section of this formation at Kuh-e Surmeh (Szabo and Kheradpir, 1978), are absent in the studied area.

Table 1
Dalan Formation, Il-e Beyk Section (Figure 2)

Unit 1 (9.5 m)	Base of Section, light brown, medium to thin bedded packstone to grainstone with brachiopods, crinoid stems and foraminifers.
Unit 2 (8 m)	Yellow to cream, medium bedded limestone with small foraminifers.
Unit 3 (7.5 m)	Gray, thick bedded, coarse grainstone with corals, crinoid stems, algae and foraminifers.
Unit 4 (5 m)	Gray to light gray, medium to thick bedded packstone to grainstone with chert nodules and abundant foraminifers, including fusulinids, crinoid stems, bryozoans, gastropods and algae. Medium bedded mudstone and ooid dolograins occur in the middle portion of this unit.
Unit 5 (8 m)	Covered.
Unit 6 (5 m)	Gray, medium bedded packstone with fusulinids, small foraminifers, crinoid stems, brachiopods and algae.
Unit 7 (37.5 m)	Covered.
Unit 8 (5 m)	Light gray, thick bedded wackestone to packstone.
Unit 9 (15 m)	light brown, medium to thick bedded wackestone with small foraminifers, brachiopods, crinoid stems, bryozoans, algae and Zoophycus.
Unit 10 (4 m)	Covered.
Unit 11 (7.5 m)	Gray, medium bedded mudstone to packstone with abundant fusulinids.
Unit 12 (25 m)	Gray to dark gray, medium bedded packstone with abundant fusulinids, crinoid stems, small foraminifers, brachiopod fragments.
Unit 13 (65 m)	Light brown to gray, medium bedded stylolitic wackestone with large and small foraminifers, brachiopods and crinoid stems.
Unit 14 (27.5 m)	Gray, medium bedded wackestone to packstone with abundant brachiopod fragments.
Unit 15 (65 m)	Gray, medium to thick bedded stylolitic wackestone with abundant fusulinids, small foraminifers, brachiopod fragments, crinoid stems and algae.
Unit 16 (15 m)	Dark gray, thin to medium bedded wackestone to packstone with small foraminifers, rare fusulinids, crinoid stems, algae and shell fragments.
Unit 17 (60 m)	Gray, thick bedded wackestone with chert nodules and small foraminifers and shell fragments with one thin (1 meter) horizon containing abundant fusulinids.
Unit 18 (25 m)	Light gray, thick bedded dolomitic limestone with small foraminifer and large scale stylolites.
Unit 19 (25 m)	Cream, medium bedded fine crystalline dolomite with oomold, rare skeletal fragments include brachiopods, crinoid stems and algae.
Unit 20 (50 m)	Gray to light brown, medium to thin bedded dolomitic limestone with oomold and shell fragments.
Unit 21 (45 m)	Gray, thin bedded fine to medium crystalline dolomite with rare shell fragments.
Unit 22 (30 m)	Covered.
Unit 23 (85 m)	Cream, medium bedded dolomitic limestone with fusulinids and small foraminifers in a very narrow horizon (1–1.5 m).
Unit 24 (35 m)	Covered.
Unit 25 (45 m)	Cream, medium to thin bedded dolomite with shell fragments, no foraminifers observed.
Unit 26 (15 m)	Covered.
Unit 27 (92.5 m)	Light brown, medium bedded fine to coarse crystalline dolomite.
Unit 28 (20 m)	Cream, medium bedded dolomitic limestone with abundant smaller foraminifers, staffellids and algae.

FUSULINID BIOSTRATIGRAPHY, CHRONOSTRATIGRAPHY AND CORRELATION

Forty-six samples from the entire Dalan Formation in the Il-e Beyk section were studied and 66 taxa of fusulinid and smaller foraminifers were recognized (Table 2). About 15% of these taxa are long-ranging smaller foraminifers. The fusulinids are unevenly distributed throughout the succession and were recovered from six stratigraphically restricted horizons (Figure 2). Taking into account

Table 2
Distribution of Foraminifera, II-e Beyk Section

		Meters above the base															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		920	687	657	445	440	435	432	427	417	410	407	400	397	395	385	363
Species name	Sample	Z1	Z11	Z14	Z30	Z31	Z32	Z33	Z34	Z36	Z38	Z39	Z41	Z42	Z43	Z45	Z49
<i>Staffella</i> sp.		x															
<i>Nankinella</i> sp.		x															
<i>Baisalina</i> sp.		x															continued
<i>Paraglobivalvulina</i> sp.		x															
<i>Dagmarita</i> sp.		x															
<i>Afghanella schencki</i>	Thompson, 1946		x	x													
<i>Sumatrana? brevis</i>	Leven, 1967		x														
<i>Yangchienia haydeni</i>	Thompson, 1946		x														x
<i>Pseudovidalina</i> sp.					x												
<i>Robuloides</i> sp.						x											
<i>Geinitzina</i> sp.							x		x								
<i>Monodiexodina hendersoni</i>	Davydov and Arefifard, new species								x								
<i>Monodiexodina kattaensis dalanensis</i>	Davydov and Arefifard, new species								x								
<i>Pseudodunbarula erki</i>	(Skinner, 1969)								x								
<i>Kahlerina ussurica</i>	Sosnina, 1956								x								
<i>Kahlerina</i> sp.									x								
<i>Schubertella rara</i>	Sheng, 1963								x								
<i>Schubertella</i> aff. <i>rara</i>	Sheng, 1963								x								
<i>Pachyphloia</i> sp.									x	x	x	x	x	x			x
<i>Dunbarula tumida</i>	Skinner, 1969								x								
<i>Dunbarula nana</i>	Kochansky-Devide and Ramovs, 1955								x								
<i>Dunbarula</i> sp.									x								
<i>Langella</i> sp.									x						x		x
<i>Neoendothyra</i> sp.									x		x						
<i>Neoendothyra ornata</i>	Sosnina, 1977								x								
<i>Chusenella</i> ex gr. <i>tieni</i>	(Chen, 1956)								x								
<i>Rugososchwagerina</i> sp.									x								
<i>Neoendothyra broennimanni</i>	Bozorgnia, 1973									x							
<i>Agathammina pusilla</i>	(Geinitz, 1848)											x					
<i>Chusenella cheni</i>	Sherbovich, 1974														x		
<i>Codonofusiella erki</i>	Rausser, 1965																x
<i>Yangchienia hainanica</i>	Sheng, 1963																x
<i>Abadehella</i> ex gr. <i>coniformis</i>	Okimura and Ishii, 1975																
<i>Chusenella tieni</i>	(Chen, 1956)																
<i>Chusenella sinensis</i>	Sheng, 1963																
<i>Chusenella conicocylindrica</i>	Chen, 1956																
<i>Chusenella urulungaensis</i>	Wang and Sheng, 1981																
<i>Chusenella douvillei</i>	(Colani, 1924)																
<i>Minojapanella</i> sp.																	
<i>Rugososchwagerina zagrosensis</i>	Davydov and Arefifard, new species																
<i>Yangchienia iniqua</i>	Lee, 1934																
<i>Chusenella dorashamensis</i>	Rosovskaya, 1963																
<i>Chusenella cheni</i>	Scherbovich, 1965																
<i>Chusenella minuta</i>	Skinner, 1969																
<i>Chusenella solida</i>	Skinner, 1969																
<i>Yangchienia</i> sp.														x			x
<i>Codonofusiella</i> sp.																	
<i>Chusenella schwagerinaeformis</i>	Sheng, 1963																
<i>Schubertella karasawensis</i>	Kobayashi, 2006																
<i>Lasiodiscus</i> sp.																	
<i>Rugososchwagerina</i> aff. <i>altimurica</i>	Leven, 1997																
<i>Globivalvulina</i> sp.																	
<i>Eopolydiexodina</i> aff. <i>persica</i>	(Kahler, 1932)																
<i>Eopolydiexodina persica</i>	(Kahler, 1933)																
<i>Hemogordius</i> sp.																	
<i>Rugososchwagerina</i> ex gr. <i>xanzensis</i>	Wang, Sheng and Zhang, 1981																
<i>Pseudomidiella</i> sp.																	
<i>Chusenella</i> aff. <i>tieni</i>	(Chen, 1956)																
<i>Skinnerella elliptica</i>	(Sheng, 1963)																
<i>Nodosaria</i> sp.																	
<i>Climacammina</i> sp.																	
<i>Praeskinnerella parviflucta</i>	(Zhou, 1982)																
<i>Chusenella? pseudocompacta</i>	(Sheng, 1956)																
<i>Neofusulinella lantenoisi</i>	(Deprat, 1913)																
<i>Cribogenerina</i> sp.																	continued
<i>Palaeotextularia</i> sp.																	

Stratigraphic position of samples shown in Figure 2. The distinguished zonal assemblages are described in the biostratigraphy section.

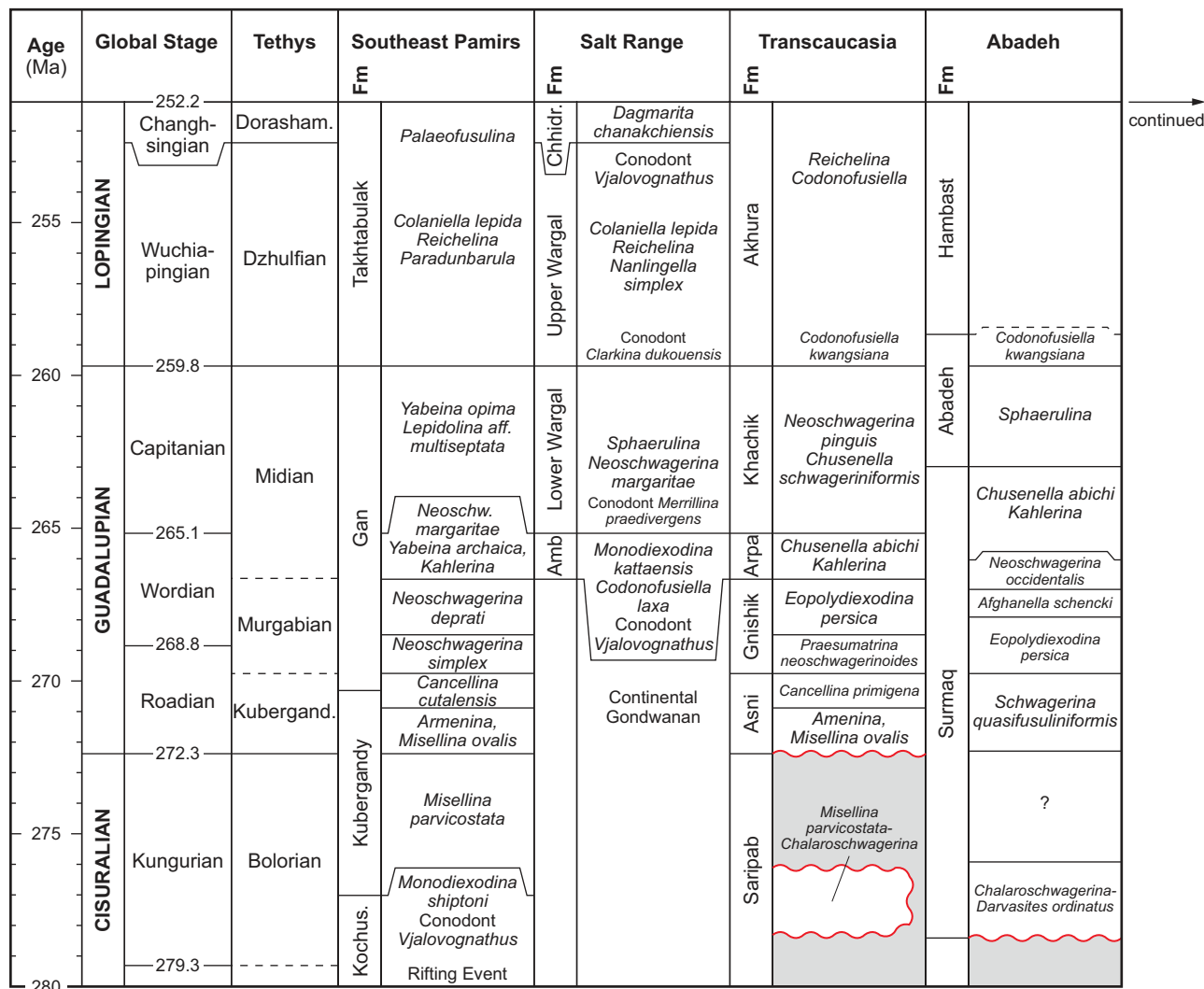


Figure 3: Correlation of Middle–Upper Permian (Guadalupian–Lopingian) sections within the western Neo-Tethys (see Figure 10 for locations). Data from Pamirs (Chedija and Davydov, 1980; Chedija et al., 1986); Salt Range (Douglass, 1970; Pakistani-Japanese Research Group, 1985; Mertmann, 2003); Transcaucasia (Kotlyar et al., 1989; Leven, 1998); Abadeh (Kobayashi and Ishii, 2003a); Zagros (this paper); Northeast Oman Para-Autochthonous Saiq Basin (Koehrer et al., 2010; Forke et al., 2012); Oman “Exotics” (Hawasina and Batain Nappes) (Baud et al., 2012; Blendinger et al., 1992; De Wever et al., 1988; Vachard et al., 2002; Weidlich and Bernecker, 2007); and Saudi Arabia (Vaslet et al., 2005; Hughes 2009).

See facing page for continuation.

the time-span of the entire Dalan Formation (Roadian through the top of the Permian, i.e. about 20 Myr) this characterization is inadequate. Nevertheless, at the moment it is the most comprehensive record of fusulinid biostratigraphy of the Lower Dalan Member in the entire Zagros.

In this paper we are using Tethyan chronostratigraphic terms rather than the global because of complexity in correlation with the Global Time Scale (Figure 3). Our correlation with the latter is the same as in the Geological Time Scale 2004 (Wardlaw et al., 2005), but different from what was proposed in the recently published Geological Time Scale 2012 (Henderson et al., 2012). It should be noted that the correlation between the Global and Tethyan scales in GTS 2012 is shown as provisional (dashed lines) and it was a compromise involving the co-authors between radical suggestions of Henderson and Mei (2003) and data from fusulinids and ammonoids (Chedija et al., 1986; Leven, 1992; Davydov, 1996). Recently, however, the differences between these two correlation

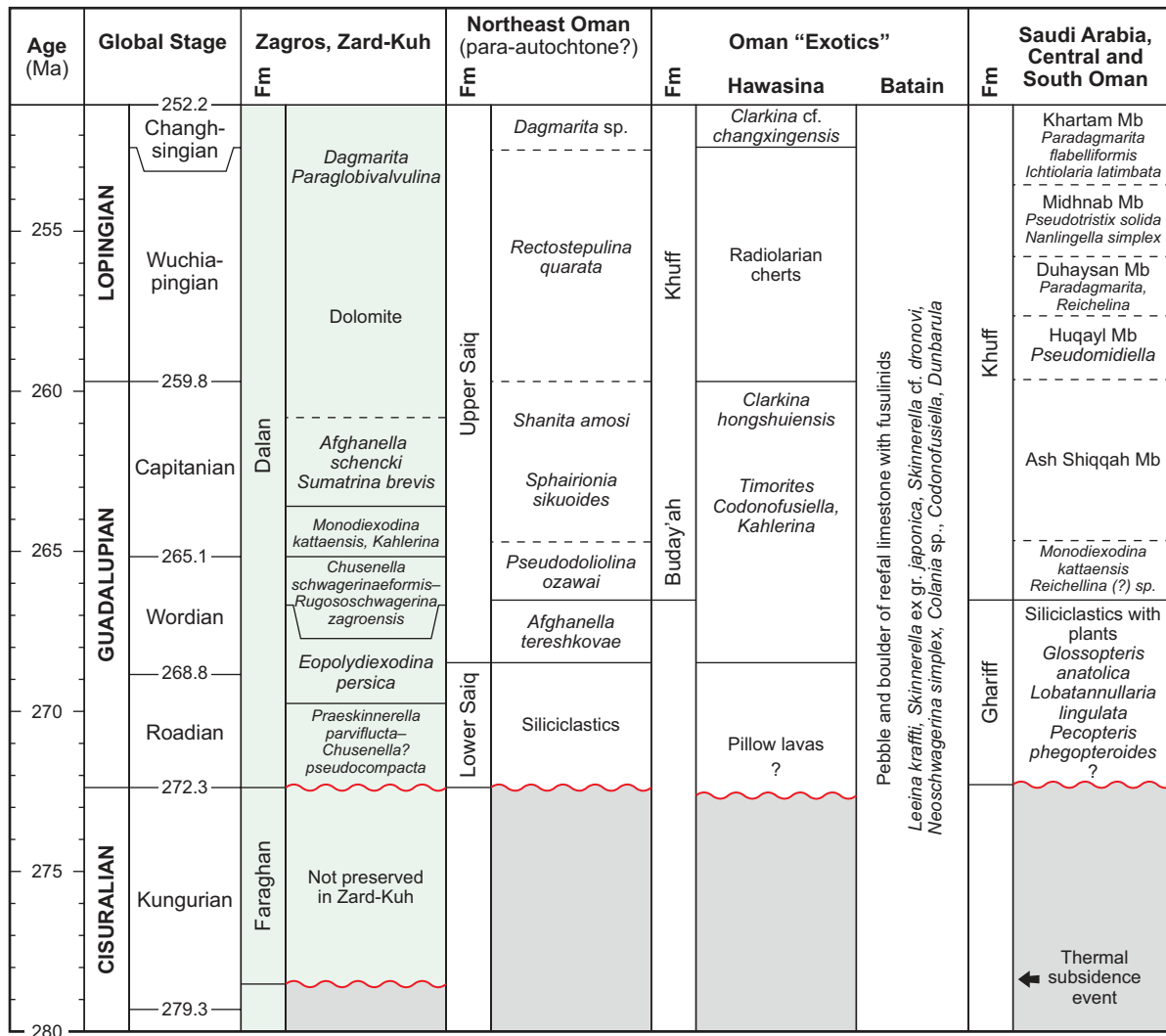


Figure 3 (continued):

models, particularly in Oman region were resolved (Kozur and Wardlaw, 2010; Baud et al., 2012), but still exist in South China (Shen et al., 2007) and thus in the Permian Chapter of GTS 2012.

Five biozones can be distinguished in the studied succession. The lower boundary of each zone can be identified by the presence of the characteristic assemblage. The upper boundary is sometimes conventional and placed at the base of succeeding zone.

Praeskinnerella parviflucta - *Chusenella? pseudocompacta* Biozone

The first biozone, *Praeskinnerella parviflucta* - *Chusenella? pseudocompacta*, is recognized in the lower 120 m of the succession (Figure 2, Table 2). The assemblage is relatively poor, possessing three species of fusulinids and a few smaller foraminifers. *Neofusulinella lantenoisi* is a widely distributed fusulinid in the Kubergandian–Murgabian (early Roadian to early Wordian) of the entire Tethys (Deprat, 1913; Toriyama, 1975; Kahler and Kahler, 1979; Leven, 1998, 1997; Xiao et al., 1986; Huang et al., 2009). *Praeskinnerella parviflucta* was originally described from the Chihhsia Formation (Yakhtashian–Kubergandian) in South China (Zhou, 1982) and later recovered in Bolorian (Kungurian) of Darvaz (Leven, 1992) and Kubergandian (early Roadian) in Transcaucasia (Leven, 1998). *Chusenella? pseudocompacta* is widely known in the lower-middle Maokou in South China (Sheng, 1956, 1963; Zhang and Dong, 1986) and in recent times has been reported in upper Middle Permian (Guadalupian) in the Lhasa Block of Peri-Gondwanan affinity (Zhang et al., 2010). We propose a Kubergandian (early Roadian) age for the *Praeskinnerella parviflucta*-*Chusenella? pseudocompacta* Biozone, because of the combination of the Bolorian–Kubergandian (Kungurian–



Plate 1: See facing page for continuation.

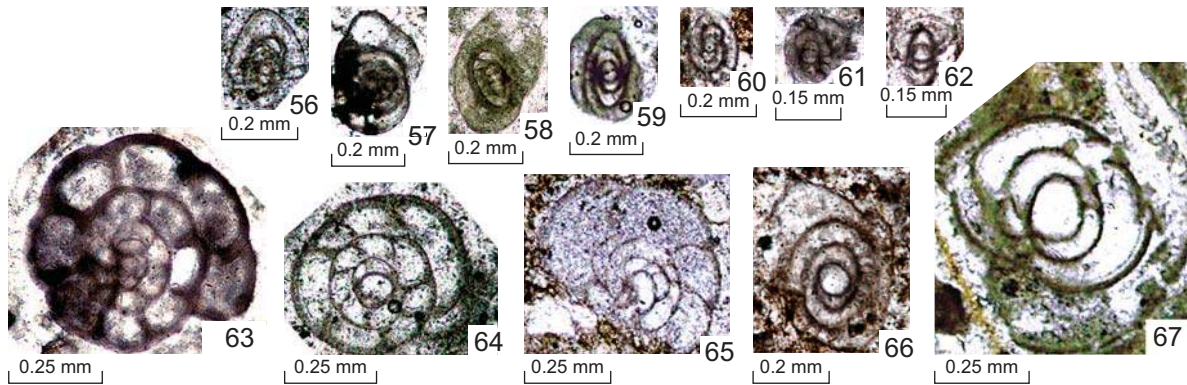


Plate 1 (continued): Smaller foraminifera and fusulinids from Lower Dalan Member, Zard-Kuh, Zagros, Iran. The collection stored in the University of Iowa Paleontology Repository (SUI).

- (1) *Agathammina pusilla*, Z38-7, SUI 127103.
- (2 and 3) *Pseudomidiella* sp., (2) Z111-27, SUI 127104; (3) Z111-1, SUI 127105.
- (4) *Abadehella coniformis*, Z50-1, SUI 127106.
- (5) *Neoendothyra ornata*, Z33-4, SUI 127107.
- (6 and 7) *Neoendothyra broennimanni*, (6) Z139-2, SUI 127108; (7) Z36-1, SUI 127109.
- (8) *Pseudovidalina* sp., Z30-1, SUI 127110.
- (9 to 11) *Langella* sp., (9) Z33-6, SUI 127111; (10) Z49-1, SUI 127112; (11) Z83-1, SUI 127113.
- (12 and 13) *Geinitzina* sp., (12) Z117-5, SUI 127114; (13) Z117-6, SUI 127115.
- (14) *Nodosaria* sp., Z117-7, SUI 127116.
- (15) *Pachyphloia* sp., Z33-23, SUI 127117.
- (16) *Globivalvulina* sp., Z71-1, SUI 127118.
- (17) *Paraglobivalvulina* sp., Z1-9, SUI 127119.
- (18) *Dagmarita* sp., Z71-18, SUI 127120.
- (19) *Baisalina* sp., Z118-2, SUI 127121.
- (20) *Staffella* sp., Z1-14, SUI 127122.
- (21) *Climacammina* sp., Z141-3, SUI 127123.
- (22) *Palaeotextularia* sp., Z151-1-2, SUI 127124.
- (23) *Cribrogenerina* sp., Z141-2, SUI 127125.
- (24) *Lasiodiscus* sp., Z58-6, SUI 127126.
- (25 and 26) *Neofusulinella lantenoisi*, (25) Z138-11, SUI 127127; (26) Z138-6, SUI 127128.
- (27 to 33) *Schubertella karasawensis*, (27) Z117-5, SUI 127129; (28) Z140-1, SUI 127130; (29) Z58-16, SUI 127131; (30) Z106-2, SUI 127132; (31) Z106-5, SUI 131976; (32) Z140-2, SUI 131977; (33) Z58-6, SUI 131978.
- (34 to 39) *Schubertella rara*, (34) Z33-14, SUI 131979; (35) Z57-11, SUI 131980; (36) Z33-17, SUI 131981; (37) Z33-32, SUI 131982; (38) Z33-12, SUI 131983; (39) Z33-13, SUI 131984.
- (40) *Schubertella?* sp., Z58-7, SUI 131985.
- (41) *Codonofusiella* cf. *sphaerica*, Z33-34, SUI 131986.
- (42 to 44) *Codonofusiella* sp., (42) Z33-37, SUI 131987; (43) Z57-2, SUI 131988; (44) Z57-3, SUI 131989.
- (45) *Codonofusiella erki*, Z49-34, SUI 131990.
- (46) *Pseudodunbarula?* sp., Z33-31, SUI 131991.
- (47) *Pseudodunbarula* sp., Z33-31, SUI 131992.
- (48 and 49) *Minojapanella* sp., (48) Z59-4, SUI 131993; (49) Z116-7, SUI 131994.
- (50) *Pseudodunbarula erki*, Z33-31, SUI 131995.
- (51, 56 to 62) *Dunbarula* sp., (51) Z33-33, SUI 131996; (56) Z33-27, SUI 13201; (57) Z57-2b, SUI 13202; (58) Z33-31f, SUI 13203; (59) Z33-31g, SUI 13204; (60) Z56-18, SUI 13205; (61) Z33-13, SUI 13206; (62) Z55-21, SUI 13207.
- (52 and 53) *Dunbarula nana*, (52) Z33-39, SUI 131997; (53) Z57-8, SUI 131998.
- (54 and 55) *Dunbarula tumida*, (54) Z33-34, SUI 131999; (55) Z33-27, SUI 132000.
- (63 and 64) *Kahlerina* sp., (63) Z33-10, SUI 132008; (64) Z33-10, SUI 132009.
- (65 to 67) *Kahlerina ussurica*, (65) Z33-b, SUI 132010; (66) Z54-11, SUI 132011; (67) Z33-31-5, SUI 132012.

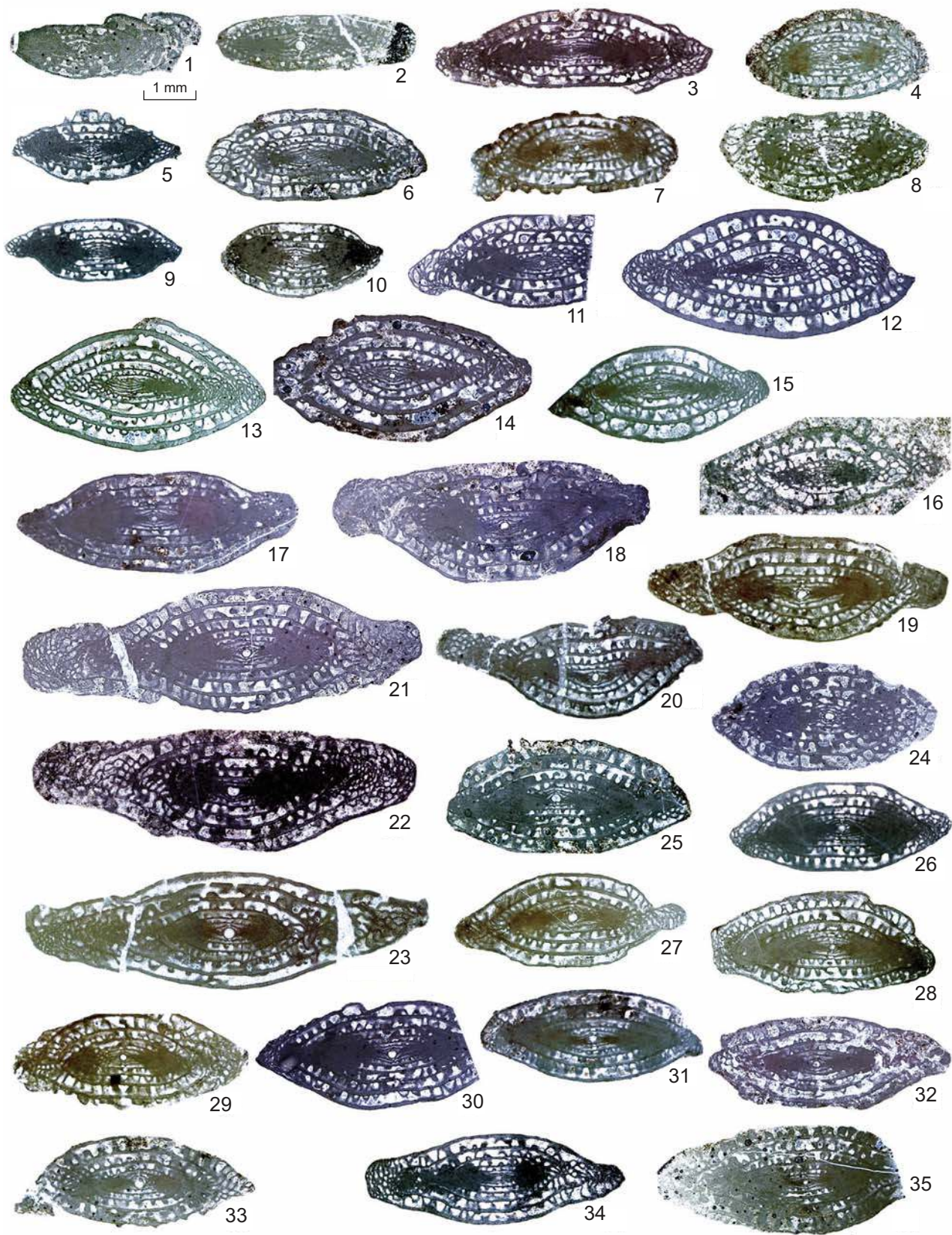


Plate 2: See facing page for caption.

early Roadian) *Praeskinnerella parviflucta* and the Kubergandian–Midian (early Roadian–Capitanian) *Chusenella? pseudocompacta*. We also suggest the Kubergandian (early Roadian) age since the biozone's stratigraphic position is below the beds we assigned to the Murgabian (late Roadian–early Wordian) (Figure 2, Table 2).

***Eopolydiexodina persica* Biozone**

The second *Eopolydiexodina persica* Biozone is established from 120 through 320 meters in the section. Although the upper 90 m of the biozone contain only long-ranging smaller foraminifers and one specimen of *Yangchienia iniqua* (Figures 2, Table 2), the fusulinids here are more diverse than that in the lower biozone. It includes several long-ranging smaller foraminifera (Table 2) and 12 fusulinid species: *Schubertella rara*, *Schubertella* aff. *rara*, *Minojapanella* sp., *Yangchienia iniqua*, *Yangchienia* sp., *Chusenella conicocylindrica*, *Chusenella urulungaensis*, *Chusenella dorashamensis*, *Chusenella* aff. *tieni*, *Skinnerella elliptica*, *Rugososchwagerina* ex gr. *xanzensis*, *Eopolydiexodina persica*, *Eopolydiexodina* aff. *persica*. The most characteristic species in this assemblage is *Eopolydiexodina persica*, as originally described from an unidentified horizon in Zagros (Kahler, 1933). The species was also reported in Turkey (Köylüoğlu and Altiner, 1989), Abadeh (Kobayashi and Ishii, 2003a, b) and Transcaucasia (Kotlyar et al., 1989; Leven, 1998) from deposits correlated with lower–middle Murgabian (upper Roadian–lower Wordian). *Eopolydiexodina* in all these regions occurs as a dominant faunal element in a relatively narrow horizon (Douglas, 1936; Leven, 1998; Kobayashi and Ishii, 2003a).

Similarly, in Il-e Beyk section two *Eopolydiexodina*-bearing horizons are 1–2 m thick. The genus ranges just within 25 m (Figure 2) in the section. The other characteristic species of this biozone are *Yangchienia iniqua* and several species of *Chusenella* (Table 2). *Yangchienia iniqua* has been described from the Maokou Formation in South China (Lee, 1927) and in the Southeast Pamirs. It is known to occur in upper Kubergandian (early Roadian) and lower–middle Murgabian (upper Roadian–lower Wordian) (Leven, 1967; Chedija et al., 1986). The *Chusenella* species were described from South China and Tibet (Chen, 1956; Wang et al., 1981) and in Transcaucasia (Rosovskaya and Rauser-Chernousova, 1965). In the latter region, these species occur in the upper Asni and lower Gnishik formations that correlate with lower–middle Murgabian (upper Roadian–lower Wordian) (Rauser-Chernousova et al., 1974; Kotlyar et al., 1989; Leven, 1998). The other indicative species are *Skinnerella elliptica* and *Rugososchwagerina* ex gr. *xanzensis*. Although the latter is represented by an atypical form, it is quite characteristic for the lower–middle Murgabian (upper Roadian–lower Wordian) *Eopolydiexodina persica* Biozone in the Abadeh Region (Kobayashi and Ishii, 2003b) and occurs in the lower Gnishik Formation in Transcaucasia (first author's personal data). Overall, the age of this biozone is lower–middle Murgabian of the Tethyan Scale or upper Roadian–lower Wordian of the Global Scale (Davydov, 1996; Wardlaw et al., 2005).

Plate 2 (continued): Fusulinids from Lower Dalan Member, Il-e Beyk Section, Zard-Kuh, Zagros, Iran. The scale of figure 1 applies to all figures.

(1 and 2) *Chusenella tieni*; (1) Z54-17, SUI 132013; (2) Z54-3, SUI 132014.

(3) *Chusenella* aff. *tieni* (Chen), Z116-180-1, SUI 132015.

(4 to 11) *Chusenella dorashamensis*, (4) Z58-10, SUI 132016; (5) Z58-15, SUI 132017; (6) Z58-6, SUI 132018; (7) Z57-1, SUI 132019; (8) Z56-25, SUI 132020; (9) Z116-4, SUI 132021; (10) Z57-7, SUI 132022; (11) Z58-5, SUI 132023.

(12 to 16) *Chusenella sinensis*, (12) Z54-9, SUI 132024; (13) Z58-11, SUI 132025; (14) Z56-17, SUI 132026; (15) Z57-14, SUI 132027; (16) Z61-1, SUI 132028.

(17 to 23) *Chusenella conicocylindrica* (17) Z54-7, SUI 132029; (18) Z54-5, SUI 132030; (19) Z57-6, SUI 132031; (20) Z55-11, SUI 132032; (21) Z57-3, SUI 132033; (22) Z116-1-1, SUI 132034; (23) Z117-7-1, SUI 132035.

(24 to 35) *Chusenella urulungaensis*, (24) Z55-3, SUI 132036; (25) Z56-13, SUI 132037; (26) Z117-4-1, SUI 132038; (27) Z57-12, SUI 132039; (28) Z57-9, SUI 132040; (29) Z57-4, SUI 132041; (30) Z56-15, SUI 132042; (31) Z56-23, SUI 132043; (32) Z54-14, SUI 132044; (33) Z56-2, SUI 132045; (34) Z116-11-1, SUI 132046; (35) Z56-19, SUI 132047.

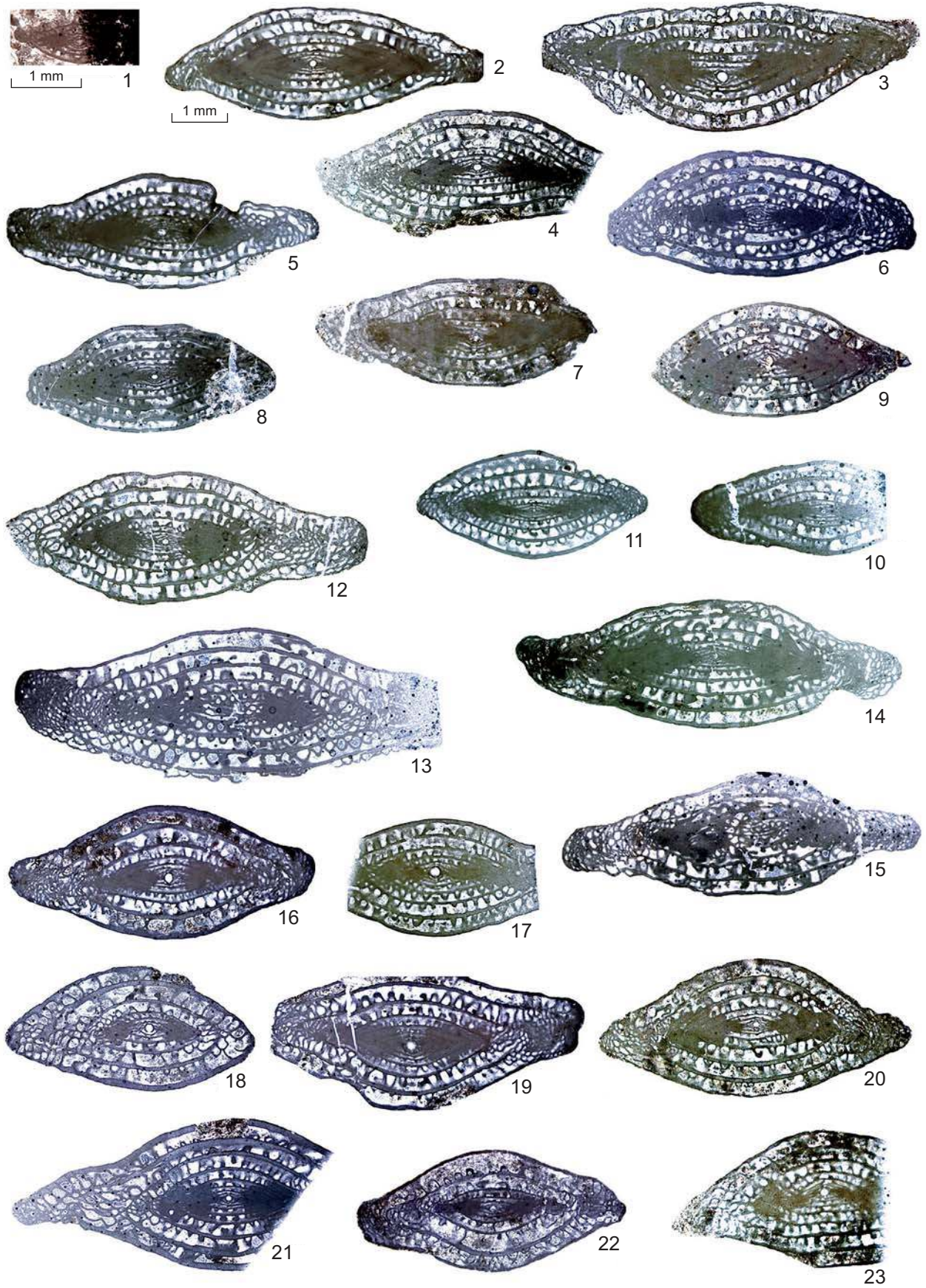


Plate 3: See facing page for caption.

***Chusenella schwagerinaeformis*-*Rugososchwagerina zagroensis* Biozone**

The third biozone, *Chusenella schwagerinaeformis*-*Rugososchwagerina zagroensis* occupies a relatively narrow horizon within 320–350 m of the succession (Figure 2). The assemblage there is quite diverse. *Minojapanella* sp. ranged from the previous biozone. The dominant forms are diverse *Chusenella* (10 species), among which some first appear in the previous biozone and range into the described one. The other species, such as *Yangchienia iniqua*, *Ch. minuta*, *Ch. solida*, *Ch. cheni*, *Ch. sinensis*, first occur in this assemblage. *Ch. sinensis* was originally described from the Maokou Formation in South China (Sheng, 1963), are widely distributed in the analogues of Murgabian to Midian (late Roadian–Capitanian) deposits in Tethys (Sun and Zhang, 1988; Leven, 1998; Kobayashi and Ishii, 2003a, b). *Ch. minuta*, and *Ch. solida* were described from upper Midian (Capitanian) of Central Turkey in association with *Kahlerina*, *Dunbarula*, an advanced *Neoschwagerina* and *Yabeina* (Skinner, 1969).

Also quite abundant in this biozone, *Schubertella karasawensis* was described in Japan from the upper Nabeyama Formation in association with *Reichelina*, *Dunbarula*, advanced *Yangchienia*, *Rauserella*, *Neoschwagerina*, *Pseudodoliolina ozawai*, and *Codonofusiella* (Kobayashi, 2006). The formation is of Midian (upper Wordian–Capitanian) age. Two species of *Rugososchwagerina* that were also recovered in this assemblage closely resemble *R. altimurica* Leven. The latter species was designated in Afghanistan from undoubtedly Midian (upper Wordian–Capitanian) deposits (Leven, 1997). Rare *Codonofusiella* also occurring in this biozone have been reported from Middle Permian (Guadalupian) of Transcaucasia (Leven, 1998). Common, yet primitive *Dunbarula* and a single specimen of *Kahlerina ussurica* clearly suggest that upper part of this biozone correlates with the Arpa Formation in Transcaucasia of early Midian (late Wordian) age (Kotlyar et al., 1989; Davydov, 1996; Leven, 1998) in the Tethyan Scale. We therefore correlate this biozone with the upper Murgabian and lower Midian of the Tethyan Scale, which is equivalent to the upper Wordian of the Global Scale (Davydov, 1996; Wardlaw et al., 2005).

Kobayashi and Altiner (2011) reported “*Dunbarula*” from the lower Murgabian (upper Roadian) in Turkey, though in our opinion this form does not belong to the genus. The initial stage of the development of these forms (skewed axis) clearly suggests that they are schubertellids rather than ozawainellids (*Dunbarula*). *Dunbarula* and *Kahlerina* were also reported from *Neoschwagerina occidentalis* Biozone in Abadeh (Kobayashi and Ishii, 2003a). However, they were neither described nor figured and thus the evaluation of these forms is not possible. Taking into account that Kobayashi (Kobayashi and Altiner, 2011) include some clear schubertellids into *Dunbarula* we are avoiding using this data.

***Monodioxodina kattaensis* Biozone**

The fourth upper Middle Permian (Guadalupian) fusulinid biozone *Monodioxodina kattaensis* in Il-e Beyk section was recovered from 360 to 435 m in the succession. Fusulinids are quite rare throughout the biozone, except for one thin (1–1.5 m) horizon where fusulinids are reasonably

Plate 3 (continued): Fusulinids from Lower Dalan Member, Il-e Beyk Section, Zard-Kuh, Zagros, Iran. The scale of figure 2 applies to all except for figure 1.

(1) *Chusenella* sp., Z33-4-1, SUI 132048.

(2 to 8) *Chusenella cheni*, (2) Z58-12a, SUI 132049; (3) Z58-10b, SUI 132050; (4) Z58-18, SUI 132051; (5) Z56-22, SUI 132052; (6) Z56-14, SUI 132053; (7) Z56-24, SUI 132054; (8) Z43-1, SUI 132055.

(9 and 10) *Chusenella schwagerinaeformis*, (9) Z58-13, SUI 132056; (10) Z58-1, SUI 132057.

(11) *Chusenella minuta*, Z56-15, SUI 132058.

(12 to 15) *Chusenella solida*, (12) Z56-8, SUI 132059; (13) Z56-10a, SUI 132060; (14) Z56-12, SUI 132061; (15) Z56_3, SUI 132062.

(16 to 23) *Chusenella douvillie*, (16) Z54-4, SUI 132063; (17) Z54-13, SUI 132064; (18) Z54-15, SUI 132065; (19) Z54-12, SUI 132066; (20) Z56-9, SUI 132067; (21) Z55-5, SUI 132068; (22) Z58-7, SUI 132069; (23) Z58-9, SUI 132070.



Plate 4: See facing page for caption.

diverse (Figure 2). *Chusenella cheni* and *Yangchienia hainanica* occur in the lower part of the biozone and ranged from the previous biozone. *Yangchienia haydeni*, found throughout this biozone, was described from Afghanistan in association with *Afghanella schencki* (Thompson, 1946). The former species is widely distributed in the upper Murgabian to Midian (Wordian–Capitanian) of the western Tethys (Leven, 1997). *Codonofusiella erki*, originally described from lower Wuchiapingian in Transcaucasia (Rosovskaya and Rauser-Chernousova, 1965), is also known to occur in the Midian (upper Wordian–Capitanian) of South Afghanistan (Leven 1997) and Turkey (Erk, 1942).

Dunbarula tumida and *Pseudodunbarula erki* were described from the Midian (upper Wordian–Capitanian) and possibly Wuchiapingian of Turkey (Skinner, 1969); they have also been reported from upper Midian (Capitanian) of Tunisia (first author's personal data) and Afghanistan (Leven, 1997). The latter species closely resembles *Pseudodunbarula arpaensis* from the lower Wuchiapingian of Transcaucasia (Kotlyar et al., 1983) but is definitely a more primitive representative of the genus. *Kahlerina* is common in sample Z33. This genus is quite characteristic of the Midian (upper Wordian–Capitanian) in the entire Tethys (Sosnina, 1968; Sheng, 1963; Leven, 1997, 1998; Han, 1980; Kobayashi, 2006, 2009). It is especially abundant in the upper Midian (Capitanian) and occurs only at this level in the type area of the Capitanian (Nestell and Nestell, 2006). The most intriguing aspect of this biozone is the occurrence of *Monodioxodina kattaensis* (new subspecies), the most abundant fossil in bed Z33 (Table 2). The species has been described from the Peri-Gondwanan cool-water Amb Formation in the Salt Range, Pakistan (Schwager, 1887; Dunbar, 1933; Douglass, 1970) together with *Codonofusiella laxa*. According to the conodonts, the age of this formation is Wordian (Wardlaw and Pogue, 1995).

***Afghanella schencki* Biozone**

The fifth and uppermost Middle Permian (Guadalupian) *Afghanella schencki* Biozone extends from 438 through 687 m, although the lower 200 m of this biozone possess only rare smaller foraminifers (Table 2). *Afghanella schencki* and *Sumatrina brevis* recovered in this biozone are the only verbeekiniids from this section (Plate 6, Figures 6–8). The first species is widely known from the upper Murgabian through the Midian (Wordian–Capitanian) throughout the Tethys (Thompson, 1946; Sheng, 1963; Xiao et al., 1986; Leven, 1997; Kobayashi, 2003). However, in Zagros *Afghanella* possesses a higher position in the upper Midian, i.e. Capitanian (Figures 2 and 3). *Sumatrina brevis* has been described in Southeast Pamirs from the upper Gan Formation (Leven, 1967) but has never been recovered elsewhere.

Uppermost Dalan Formation in Il-e Beyk Section

The foraminifers in the succession above 687 m in Il-e Beyk section are quite rare due to strong dolomitization (Figure 2). We recovered a very poorly preserved assemblage that includes *Paraglobivalvulina* sp. and *Dagmarita* sp. in the uppermost part of the Dalan Formation, suggesting a Late Permian (Lopingian) age for at least the upper 30 m of the section. The interval from 687

Plate 4 (continued): Fusulinids from Lower Dalan Member, Il-e Beyk Section, Zard-Kuh, Zagros, Iran. The scale of figure 1 applies to all figures.

(1–4) *Rugososchwagerina* aff. *altimurica*; (1) Z61-1, SUI 132071; (2) Z61-4, SUI 132072; (3) Z62-1, SUI 132073; (4) Z61-3, SUI 132074.

(5–12) *Rugososchwagerina zagrosensis* sp. nov., (5) Z55-10, SUI 132075; (6) Z56-18, SUI 132076; (7) Z55-23, SUI 132077; (8) Z57-5, SUI 132078; (9) Z55-20, SUI 132079; (10) Z55-1, SUI 132080; (11) Z56-16, SUI 132081; (12) Z55-19, SUI 132082.

(13) *Skinnerella elliptica*, Z116-16-1, SUI 132083.

(14–16) *Rugososchwagerina* ex gr. *xanzensis*, (14) Z106-d-1, SUI 132084; (15) Z106-20, SUI 132085; (16) Z33-37b, SUI 132086.

(17 and 18) *Praeskinnerella parviflucta*, (17) Z138-1, SUI 132087; (18) Z138-8, SUI 132088.

(19–22) *Chusenella pseudocompacta*, (19) Z138-9, SUI 132089; (20) Z138-6, SUI 132090; (21) Z138-4, SUI 132091; (22) Z138-5, SUI 132092.

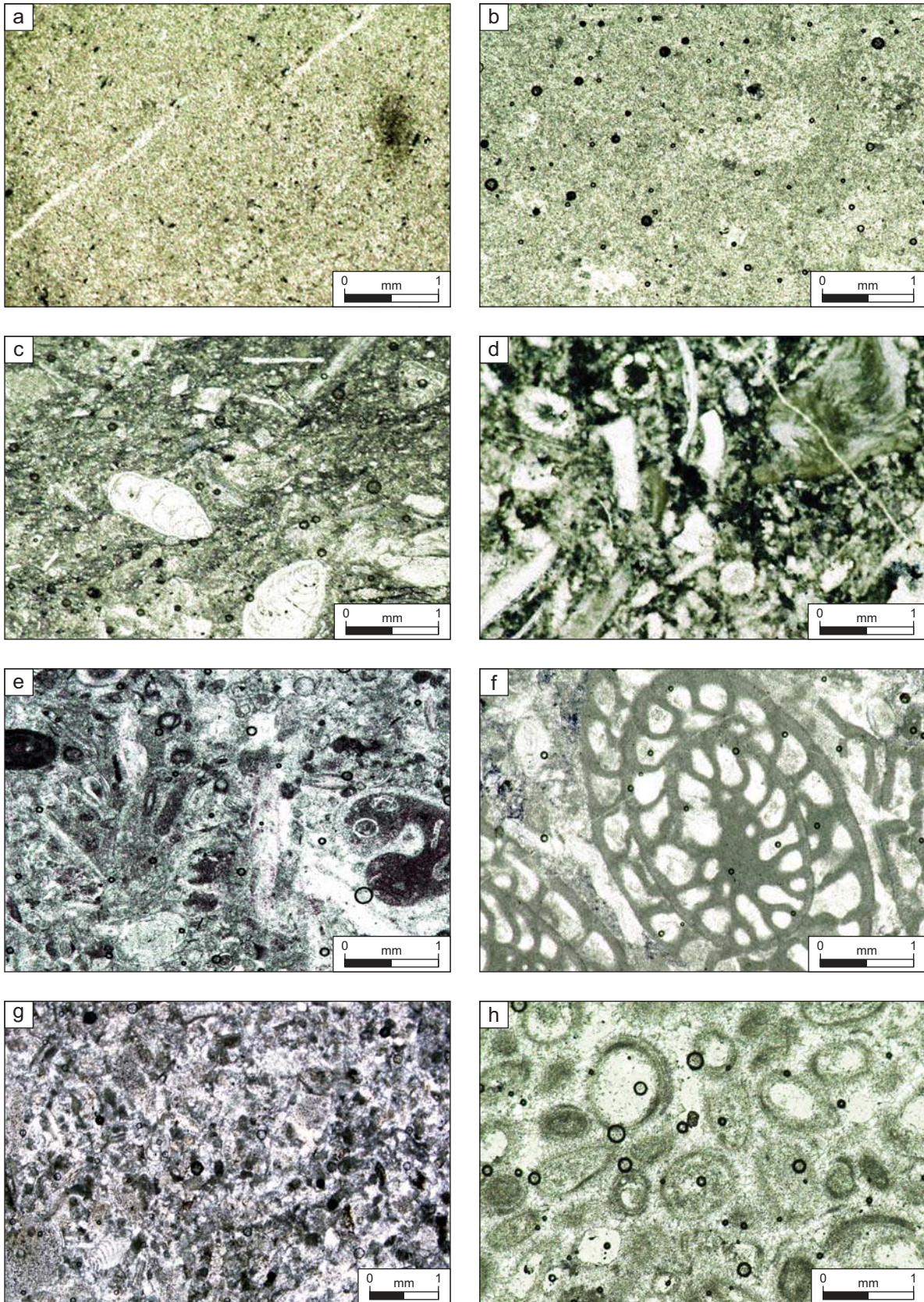


Figure 4: See facing page for caption.

through 920 m can, at the moment, be assigned either a Middle Permian (Guadalupian) or Late Permian (Lopingian) age. The entire Dalan Formation (952 m thick) and the Lower Dalan Member in this section (lower 687 m) are the thickest within entire Zagros.

Summary

In summary, the lower 120 m in Il-e Beyk Section belong to the Kubergandian (early Roadian) Stage and correlates with the Asni Formation of Transcaucasia; the succession from 120 through 320 m correlates with the Gnishik Formation of Transcaucasia and can be assigned to the lower–middle Murgabian (upper Roadian–lower Wordian); the beds from 320 through 350 m correlate with upper Gznishik and lower Arpa formations of Transcaucasia and can be assigned to the upper Murgabian and lower Midian (Wordian) of the Tethyan Scale. The sequence from 350 through 687 m, in our opinion, correlates with Khachik Formation of Transcaucasia and can be assigned to the upper Midian Stage (Capitanian) (Figure 3).

FACIES ANALYSIS AND INTERPRETATION OF DALAN FORMATION, ZARD-KUH SECTION

In order to better understand the environments and bathymetry of Middle Permian (Guadalupian) strata in the studied section, detailed petrographic analysis and microfacies examination of the Dalan carbonates in the Il-e Beyk Section were performed which led to record eight facies types and their subtypes. A total of 180 thin sections were prepared from collected samples in the field and studied for microfacies analyses.

Mud-dominated Facies

Dolomudstone

This facies is composed of thin to medium-bedded, dark gray beds. Quartz grains and skeletal fragments are absent or represent minor components. No bioturbation is visible. This dolomudstone has no evidence of subaerial exposure and shows that this kind of mudstones formed under subtidal condition. The rare skeletal grains (crinoid stems, ostracodes, brachiopods) and their low diversity indicate a landward position of this facies. This facies is present in the middle part of unit 4, unit 9, the lowermost portion of unit 12 and the lower part of unit 15 (Figure 4a).

Fenestral Dolomitic Mudstone

Textural changes, internal structure, and crystal shape indicate two kinds of dolostones in the Dalan Formation. These include very fine dolostones, or, dolomicrite, and medium crystalline dolostones, or, dolosparite. Dolomicrites yield no porosity and demonstrate xenotopic fabric. The dolosparites of the Dalan Formation do not retain any of the the primary sedimentary texture due to pervasive dolomitization. The dolosparite is formed at very high temperatures and replaced the limestones (Gregg and Shelton, 1990). The preservation of the original sedimentary structures such as fenestral fabric, evaporite molds and relics of primary allochems (including crinoid stems,

Figure 4 (continued): Photomicrographs of facies types of the Dalan Formation: (a) dolomudstone, sample Z-110; (b) fenestral dolomudstone, sample Z-18; (c) bioclastic wackestone, showing small foraminifers and shell debris, sample Z-89; (d) bioturbated bioclastic mudstone-wackestone, illustrating *gymnocodiaceans* and shell fragments, sample Z-73; (e) bioclastic wackestone-packstone, showing shell fragments and gastropod, sample Z-115; (f) bioclastic packstone-grainstone with fusulinids and small shell fragments, sample Z-33; (g) peloidal packstone-grainstone, angular to sub-rounded, poorly sorted peloids are common, sample Z-70; and (h) ooid dolograins showing oomolds, sample Z-21.



Plate 5: Fusulinids from Lower Dalan Member, Il-e Beyk Section, Zard-Kuh, Zagros, Iran. Scale bars for all figures are 1.0 mm. (1–8) *Eopolydiexodina persica*, (1) Z106-7, SUI 132093; (2) Z106-21, SUI 132094; (3) Z106-8, SUI 132095; (4) Z106-6, SUI 132096; (5) Z106-1, SUI 132097; (6) Z106-12, SUI 132098; (7) Z106-4, SUI 132099; (8) Z106-13, SUI 1320100.

brachiopods, small forams) in the dolomicrites of the Dalan Formation suggest that these dolomites were formed under near-surface low temperature conditions (Gregg and Shelton, 1990) and in arid upper intertidal settings (Shinn 1986). This facies was encountered in units 21, 25 and 27 (Figures 4b, 5a).

Bioclastic Wackestone

This facies is typified by light to dark gray, thin to medium thick beds of skeletal debris cemented mostly by micrite. Sedimentary structures include low-angle to wavy lamination and muddy (bioturbated) tops. Sorting is generally poor. Sparse skeletal fragments include crinoid stems, smaller foraminifera, echinoderms, ostracodes and calcareous algae. Minor components include fenestrate bryozoa fronds, ostracodes and rare staffellid foraminifera, forming between 10% to 15% of the rock. Quartz is a minor constituent (< 3%). This facies occurs in association with peloids (about 10%) and defines the peloidal bioclastic wackestone. Dolomitization has locally caused micrite to be partially altered to dolomicrite to dolosparite and therefore form dolo-bioclastic wackestones. The bioclastic wackestone indicates a restricted shelf region. The micritic groundmass and the low diversity of skeletal grains suggest deposition under low energy, very restricted lagoon. In some cases this facies is burrowed. Partial micritization of skeletal fragments indicate that the deposition occurred in a quiet water and lagoonal environment (Nichols, 1999; Flügel, 2010). Rare wavy laminations at the top suggest the influence of locally wave activity. This facies encompasses the greater percentage of unit 13, lower and upper parts of unit 17, and units 15, 18 and 23 of the studied section (Figure 4c).

Bioturbated Mudstone to Wackestone

This facies contains dark gray, thin-bedded, poorly sorted limestones with skeletal grains including echinoderms, small foraminifers, *gymnocodiaceans*, ostracodes, and brachiopods within a micritic mud matrix. Bioturbation is a common feature in this facies. Bedding characteristics and rock texture point to a low rate of sedimentation and a low energy environment. This facies is interpreted as open-marine deposits in an outer-ramp setting. This facies is not represented extensively in the Dalan Formation and is rarely observed in units 13 and 14 (Figures 4d, 5e).

Grain-Dominated Facies

Bioclastic Wackestone to Packstone

Light gray to yellowish gray, medium to thick beds are characteristic for this facies in the field. The skeletal grains consist of fusulinids, small foraminifers, brachiopods, green and red algae, corals (in growth position), *Tubiphytes*, gastropods, ostracodes, bivalves, crinoid stems in a micritic background. Minor allochems occur as intraclasts (3%). The skeletal grains have micritized boundaries. In some cases, skeletal grains are compacted in this facies and create a bioclastic packstone. Poorly to moderately sorted, angular to subrounded peloids (about 10%) form peloidal bioclastic packstones. The microfacies indicate that these sediments were deposited in a low energy lagoonal environment. This facies occurs in units 2, 3, 6, 8, 12, the upper part of unit 13 and unit 16 of the Il-e Beyk Section (Figures 4e, 5c).

Bioclastic Packstone to Grainstone

This facies consists of medium- to thick-bedded grayish brown to dark gray beds and include relatively abundant and diverse fauna dominated by fusulinids, brachiopods, echinoderms, unbroken fenestrate bryozoa fronds, crinoid stems, dacyclad algae, *Tubiphytes*, red algae and smaller foraminifers. This facies shows scour faces, low-angle laminations and normal grading and is moderately to poorly sorted. Ostracodes and peloids represent minor constituents. The presence of intraclasts (15%) in some cases modifies this facies to intraclast bioclastic packstone-grainstone. Chert nodules are common in some beds of this facies (only in lowermost portion of unit 1 of the studied section) and can be termed cherty bioclastic packstone-grainstone.

The bioclast composition is variable, and this facies includes the following lithologies: a dacycladacean staffellid packstone-grainstone, a foraminifer bioclastic packstone-grainstone, an algal bioclastic packstone-grainstone, and a fusulinid packstone-grainstone. Some beds indicate the

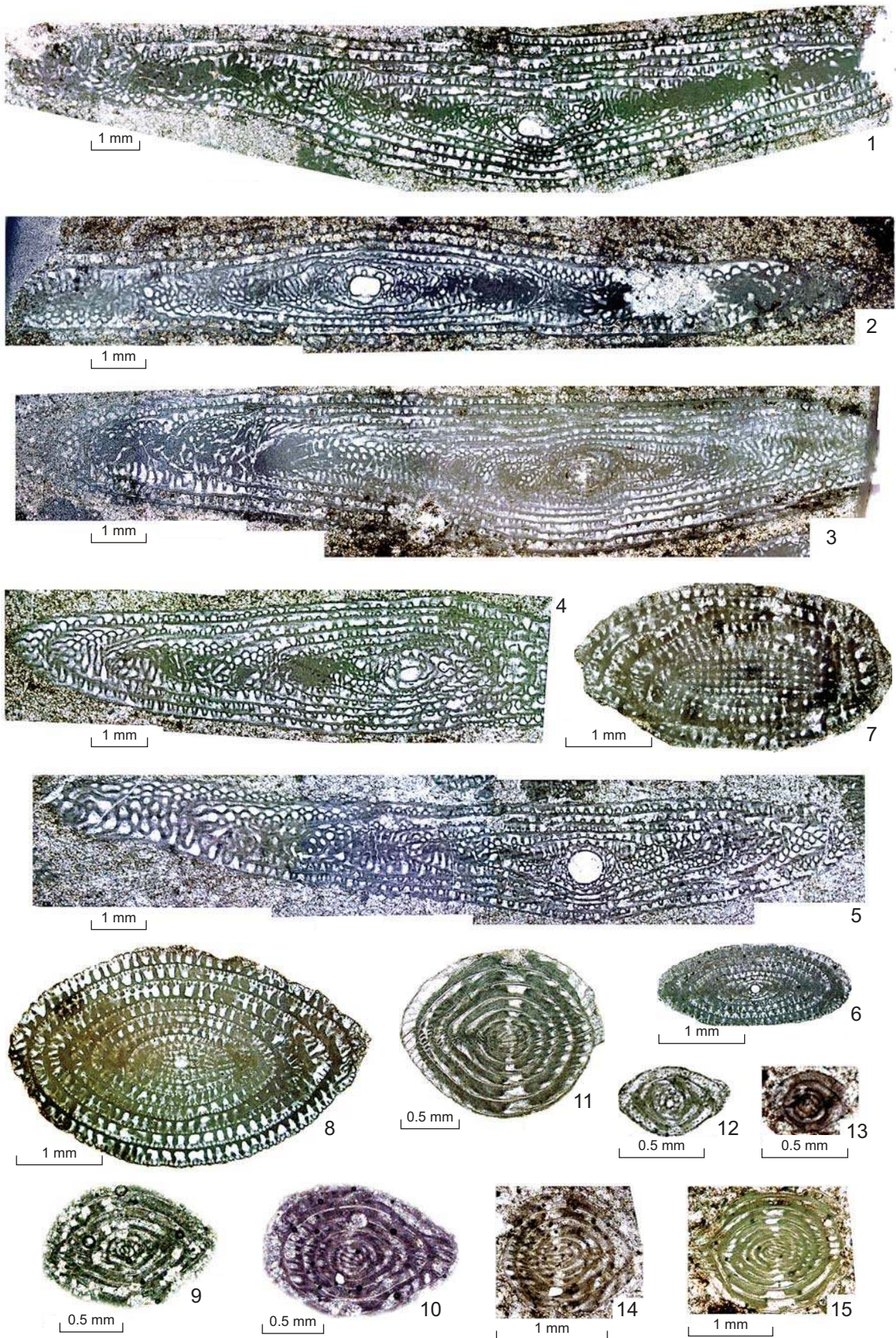


Plate 6: See facing page for caption.

occurrence of dolomitization. The degree of dolomitization ranges from dolomite cement growth in inter- and intraparticle pore space to pervasive dolomitization with dolomite rhombs entirely replacing the original rock fabric. The skeletal grains have commonly micritized boundaries that show evidence of boring by endolithic algae (Flügel, 2010). The coarse grain texture and high biodiversity in this facies imply that they were deposited in a moderate energy environment most likely a near-shoal subtidal setting, either foreshoal or backshoal. Cross-bedding represents storm reworking. This facies is identifiable in units 1, 14, 28, the lower and upper part of the unit 4, and the middle part of unit 17 (Figure 4f).

Peloidal Packstone to Grainstone

This facies is composed of light to dark gray medium beds of poorly to moderately sorted peloids. Hummucky cross-stratification, low-angle lamination, and faint normal grading are among common features in this facies. Peloids are the main components and minor constituents are dominated by brachiopods, bivalves, crinoids and gastropods and small foraminifers. Hummucky cross-stratification indicates a storm-dominated environment. This facies is observed in the middle part of unit 14 of the studied section and shows a moderate energy, open-marine setting representing a transition between mid- to outer ramp (Figure 4g).

Ooid Dolograinstone

The shoal sedimentary deposits are composed of an ooid dolograinstone with oomoldic porosity. This facies forms brown to cream, thick-bedded, massive-appearing, fine to coarse-beds and shows cross-bedding. In some beds intensive dolomitization obscures the original character of the microfacies. Where the original structure is preserved, ooids are recognizable as round grains with relics of internal concentric layering. Ooid moulds are filled with calcite cement (granular cement). In some cases, oomolds remain empty producing oomoldic porosity. Some oomolds have been filled with secondary dolomite and remain as ooid ghosts. Isopachous and blocky cements are common in this facies. Peloids and bioclasts are rarely observed. This facies indicates high-energy mid ramp shoal. Well-sorted oolitic grainstones are interpreted as shoal or bar complex deposits (Koehrer et al., 2010). This facies is observed in the middle part of unit 4 and in units 19 and 20 of the studied section (Figures 4h, 5b).

Depositional Model

The Dalan Formation is predominantly a shallow-marine carbonate succession of Middle to Late Permian age, formed during several third-order transgressive-regressive depositional sequences (Lotfpour et al., 2005). On the basis of facies distribution and associated microfaunas, a homoclinal ramp (Read, 1985; Burchette and Wright, 1992; Ahr, 1998) is proposed for the Dalan Formation in the studied section, especially for its lower limestone part. The upper portion of the formation is predominantly dolomitic and makes the microfacies analyses and the interpretation of the depositional environment exceedingly difficult. The formation consists of mud-dominated and grain-dominated facies encompassing eight lithofacies types. The encountered facies range from more protected backshoal to storm-dominated foreshoal to shoal deposits.

Plate 6 (continued): Fusulinids from Lower and Upper Dalan members, Il-e Beyk Section, Zard-Kuh, Zagros, Iran.

(1–5) *Eopolydiexodina darwasica*, (1) Z9341, SUI 1320101; (2) Z93-4, SUI 1320102; (3) Z94-3, SUI 1320103; (4) Z93-2, SUI 1320104; (5) Z93-1, SUI 1320105.

(6) *Sumatrina brevis*, Z11-1, SUI 1320106.

(7 and 8) *Afghanella schencki*, (7) Z14-1, SUI 1320107; (8) Z11-3, SUI 1320108.

(9-10) *Yangchienia hainanica*, (9) Z51-1, SUI 1320109; (10) Z49-3, SUI 1320110.

(11) *Yangchienia haydeni*, Z11-2, SUI 1320111.

(12, 13 and 14) *Yangchienia* sp., (12) Z105-2, SUI 1320112; (13) Z56-16, SUI SUI 1320132; (14) Z90-1, SUI 1320133.

(15) *Yangchienia iniqua*; (15) Z56-7, SUI SUI 1320134.

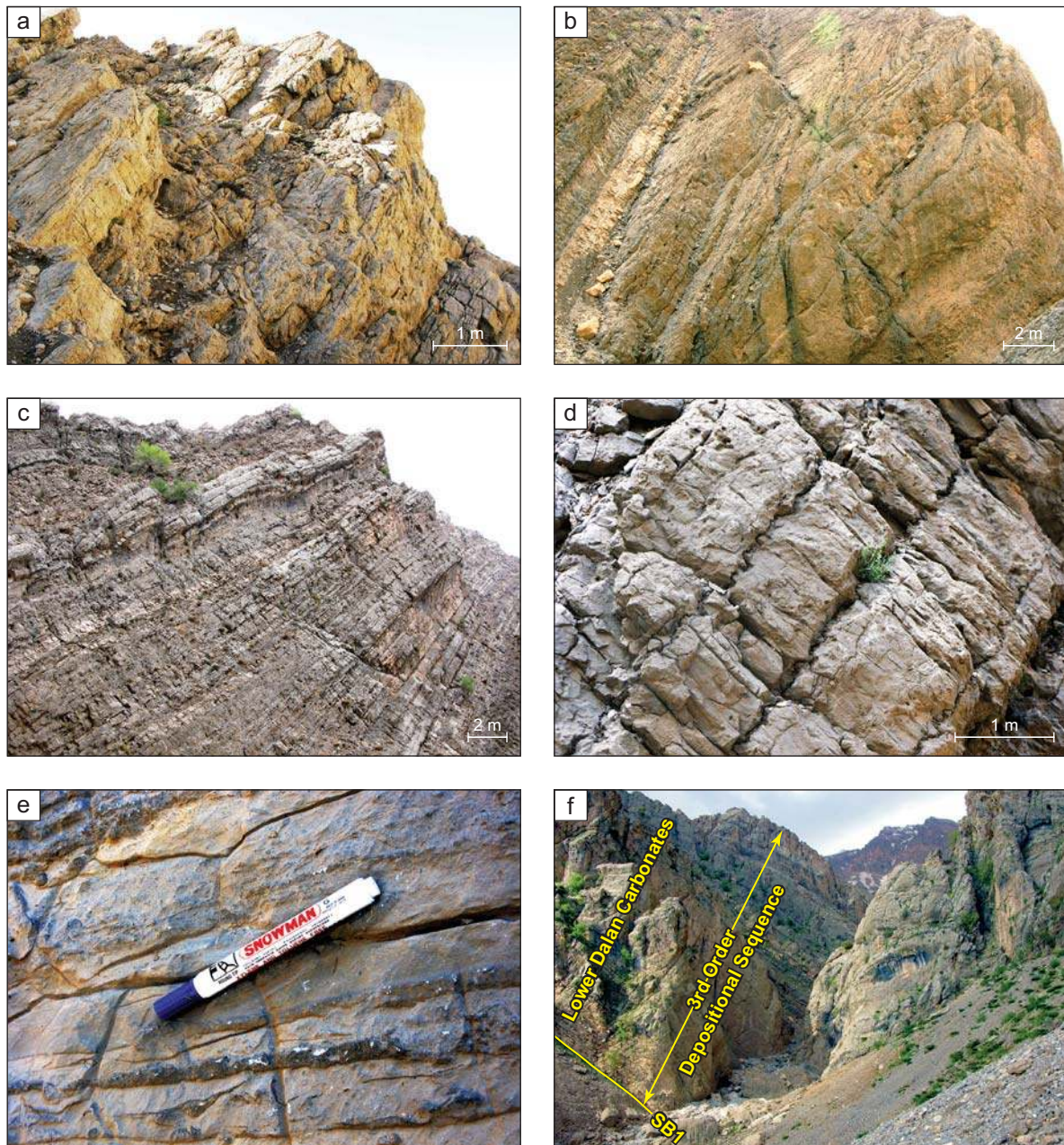


Figure 5: Il-e Beyk Section, outcrop details: (a) upper dolomitic part of the Dalan Formation, fenestral dolomudstone; (b) upper dolomitic part of the Dalan Formation, ooid dolograins with well-preserved moldic porosity; (c) lower limestone part of the Dalan Formation, bioclastic wackestone/packstone made of fusulinids, smaller foraminifers, crinoids and brachiopods; (d) lower limestone part of the Dalan Formation, mudstone to wackestones with large stylolites; (e) lower limestone part of the Dalan Formation, bioturbated mudstone with *Zoophycus* traces; and (f) lower limestone part of the Dalan Formation, showing the lower sequence boundary with the third-order depositional sequence, with view toward the northwest. The cliff of the first plane is about 20 m high.

Deeper-water shelf facies, for instance in the Surmeh Section (Insalaco et al., 2006), were very rare. In the Dalan Formation, deposits are composed mostly of bioclastic, peloid, ooid allochems. The scarcity of faunal components indicates the existence of a restricted environment during deposition of dolomudstones. The bioclastic wackestone-packstone possesses the highest biodiversity and represents most viable taxa. This facies was deposited in leeward shoals. The bioclastic wackestone and bioclastic wackestone-packstone suggest the existence of an open lagoon behind the windward

shoals and was the habitat for fusulinids, dasycladacean algae, crinoids, brachiopods, bivalve and gastropods. Ooid dolograins indicate a period of significant shoal development located on the windward side of inner ramp. Rare, open-marine facies are suggestive of deposition in calmer water of the mid ramp to possibly outer-ramp setting (Flügel, 2010).

It is noteworthy that staffellids are present in all these aforementioned lagoonal facies but their quantity varies. Below the *Eopolydiexodina*-bearing beds within the studied stratigraphic section, staffellids are abundant but their number decreases above the *Eopolydiexodina persica* Biozone and they become rare in facies between the *Eopolydiexodina persica* Biozone and *Chusenella schwagerinaeformis*-*Rugososchwagerina zagroensis* Biozone. Toward the *Afghanella schencki* Biozone they become absent altogether. Staffellids reappear in this facies upsection in the Upper Permian (Lopingian) towards the top of the Permian.

Depositional Sequences

We studied Middle Permian Dalan Formation in only one Il-e Beyk Section in the Zard-Kuh area where the formation provisionally can be divided into two third-order depositional sequences that shallow upwards (Figure 2). Sequence 1 is Kubergandian to middle Murgabian (Roadian), consists of units 1 to 14, and is 320 m thick. It was deposited during a transgression over the Carboniferous? Faraghan Formation siliciclastics (Figure 5f). Although the Faraghan Formation is covered in the studied section, it is present below the Permian carbonates in other outcrops within the High and Folded belts.

The transgressive systems tract (TST) deposits of sequence 1 occur in units 1 to 13. They are medium to thick-bedded and composed mainly of bioclastic wackestone, bioclastic wackestone-packstone, and bioclastic packstone-grainstone. The deposits contain abundant and diverse marine fauna such as fusulinids, small foraminifers, brachiopods, corals, crinoids, and gastropods. Bioturbation is also distinguishable in some microfacies. Higher up in the section, thin- to medium bedded burrowed mudstones and wackestones appear and show low-energy deeper water *Zoophycus* ichnofabrics. This part of the sequence shows a transition from shallow-marine to the open-marine carbonates.

The maximum flooding surface (MFS) occurs in the upper part of unit 13. It is represented by massive bioturbated mudstone to wackestone with large stylolites (Figure 5d) that shows lowest energy condition and sedimentation below storm wave base. The highstand systems tract (HST) occurs in unit 14, which consists of peloidal cross-bedded wackestone-packstone. Bioclasts decrease and include a low percent of small foraminifers and some rare shell fragments. It shows the shallowing upward deposits in which peloidal packstone to grainstone set over open-marine massive mudstones with bioturbation. The lower boundary of sequence 1 is a type 1 but its upper boundary is a type 2 as there is no evidence of a long-term withdrawal of sea level in the studies area.

Sequence 2 is late Murgabian to Midian (Wordian-Capitanian), includes units 15 to 23 and is 400 m thick. Its lower part consists of limestone and its upper part is dolomitized. The TST occurs in units 15 to 17 and is characterized by medium-bedded bioclastic packstone-grainstone with abundant brachiopod shells that further up in the section are replaced by bioclastic mudstone to wackestone with fusulinids, small foraminifer, brachiopods and crinoids. The maximum flooding surface occurs in the upper of part unit 17. It is thin and rarely preserved, and represented by dark beds containing bioturbation and open-marine skeletal fragments.

The HST of sequence 2 occurs in units 18 to 23 and is dominated by oolitic dolograins that pass upward into beige bioclastic dolomitized packstone/grainstone containing fusulinids *Afghanella* and *Sumatrina*. These facies show shore and back shore settings. The overlying beds are dolomitized. The upper part of this sequence coincides with the lack of distinct Middle Permian fusulinids. Because of dolomitization, the sequence-stratigraphic analysis of the upper 170 m of the Dalan Formation is unresolved. The upper boundary of sequence 2 is a type 1.

The Middle Permian to Early Triassic Khuff Formation is a widespread rock unit in the Arabian Basin. It represents a second-order transgressive-regressive sequence, which is composed of several third-order composite sequences (Sharland et al., 2001; Strohmenger et al., 2002; Alsharhan, 2006; Insalaco et al., 2006). In a sequence-stratigraphic study of Khuff-equivalent deposits (Saiq and Mahil formations) in Oman, Koehrer et al. (2010, 2012) interpreted six third-order sequences, named KS6 to KS1. KS6 and KS5 are interpreted to correspond to the Kubergandian (?) to Midian (early Roadian–Capitanian). Sequences KS4, KS3 and lower KS2 correspond to the Late Permian (Wuchiapingian and Changhsingian).

Based on the overall lithostratigraphic, microfacies features and microfossils contents (Kubergandian fusulinids) of the middle part of the Dalan Formation (see biostratigraphy section) in the studied section, we suggest that this part of the formation can be correlated with the upper part of KS6 and KS5. This suggestion requires further sequence-stratigraphic studies, especially for the Lower Dalan and Nar members in other outcrops within the Folded and High Zagros belts. Moreover, the Kubergandian (early Roadian) age of the lower part of Sequence KS6 has to be confirmed elsewhere in Zagros, Oman and surrounding areas. Further investigation of facies, depositional environments and sequence stratigraphy in the Zagros area is essential in order to understand the overall Permian stratigraphy in the region.

DISCUSSION

Paleogeographic and Paleoclimate Applications

Studies of the Middle Permian (Guadalupian) succession in Zagros reveal a particular problem that was briefly mentioned but not explained by the previous studies (Altiner et al., 2000, and discussions in Ueno, 2003; Kolodka et al., 2012): namely, the exceptionally rare occurrences of fusulinids within the Middle Permian (Guadalupian) in the region. Although extinct, fusulinid paleobiology and their environmental constraints are relatively well-understood (Stevens, 1971; Ross, 1982, 1995; Vachard et al., 2004; Leppig et al., 2005). Fusulinids were advanced, single-celled, symbiont-carrying organisms distributed in late Paleozoic tropical-subtropical belts (up to 35–40 degree south/north latitude) within carbonate to mixed carbonate-siliciclastic shallow-water settings (Ross, 1995; Kobayashi and Ishii, 2003a). This paleogeographic distribution, their known sensitivity to paleoenvironments (Figures 6 and 7), coupled with their high-resolution spatial and temporal framework provides the basis for the study presented here.

Most benthic foraminifera (including all larger foraminifera such as fusulinids) became extinct at the end of the Permian. As such, their paleobiology and paleoecology can only be inferred from studies of recent benthic foraminifera or other marine microfaunas with living symbionts. It is assumed that the majority of the fusulinids hosted photosynthetic symbionts, as is true for many living tropical larger foraminifera (Ross, 1982; Vachard et al., 2004; BouDagher-Fadel, 2008). The symbiosis could explain the rapid growth of fusulinids and their enormous single-cell size (up to 15 cm), as well as their rapid evolution, lower latitudinal geographical distribution, and shallow-water ecological patterns.

Recent symbiont-bearing benthic foraminifera are restricted to the euphotic zone of tropical and warm-temperate seas (Hohenegger, 2004; BouDagher-Fadel, 2008). Their species distribution is controlled by their primary limiting factors: temperature, light, water movement, substrate and nutrients (Beavington-Penney and Racey, 2004). Temperature determines geographic distribution and depth distribution of larger foraminifera by the development of a shallow thermocline that truncates the distribution of shallower water species, thus excluding species adapted to the deepest euphotic zone (Figures 6 and 7). Within these constraints, light is the other most important primary factor because larger foraminifera are at least partly dependent upon photosynthesis of their algal endosymbionts for growth and calcification (Hohenegger, 2004). Shallow-water assemblages of recent larger foraminifera with optimal water temperatures (20–30°C) are generally much more diverse than those with temperatures greater than 30°C and/or less than 20°C. (Beavington-Penney and Racey, 2004; Hohenegger, 2004; Murray, 2006).

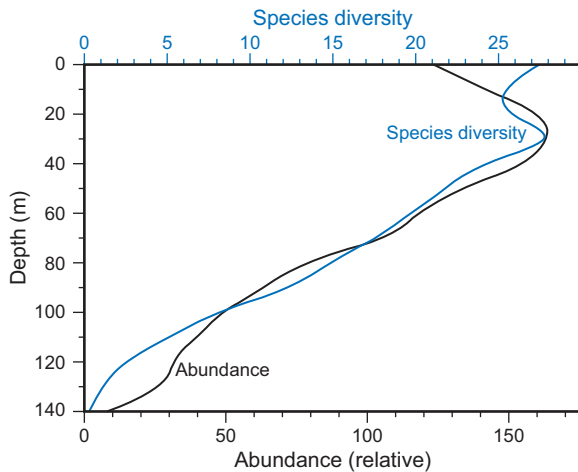


Figure 6: Fundamental depth distributions of northwest Pacific symbiont-bearing benthic warm-water foraminifera in clear ocean water (developed from Hohenegger, 2004).

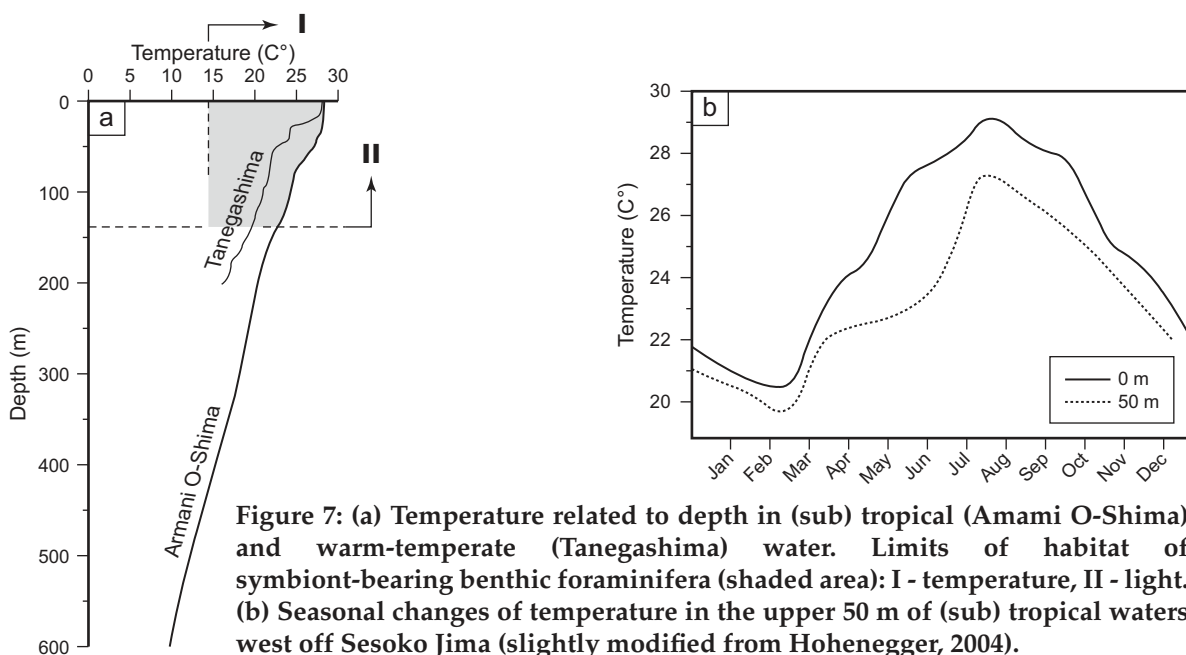


Figure 7: (a) Temperature related to depth in (sub) tropical (Amami O-Shima) and warm-temperate (Tanegashima) water. Limits of habitat of symbiont-bearing benthic foraminifera (shaded area): I - temperature, II - light. (b) Seasonal changes of temperature in the upper 50 m of (sub) tropical waters west off Sesoko Jima (slightly modified from Hohenegger, 2004).

Benthic foraminifera are poikilothermic, meaning that their body temperature is very close to that of the surrounding water, and they respond very quickly to the slightest changes in the ambient water temperature (Beavington-Penney and Racey, 2004). Temperature is generally considered to be the major physical factor influencing the distribution of species or assemblages (Hohenegger, 2004; Murray, 2006; BouDagher-Fadel, 2008). Fuhrman et al. (2008) clearly determined that the richness of shallow-marine bacteria with living symbionts (warm-water, shallow thermoclinal micro-organisms environmentally analogous to fusulinids) strongly and positively correlates with water temperature at the time of sampling, and even more strongly with average annual sea-surface temperature. Equally strong correlations of marine bacterial diversity with latitude and temperature suggest that latitudinal gradient directly reflects the effects of solar energy flux on sea-surface temperature. These data and analyses (Fuhrman et al., 2008) support the hypothesis that bacterial diversity in a given habitat is largely generated and maintained by the effects of temperature on the kinetics of metabolism.

The metabolic rate, which increases exponentially with increasing temperature, sets the pace of life and hence the rates of nearly all biological activities. Thus, we can hypothesize that during warming episodes warm-water foraminifera for given latitude and depth reached their maximum diversity and world-wide distribution, with tropical-subtropical taxa migrating to higher latitudes.

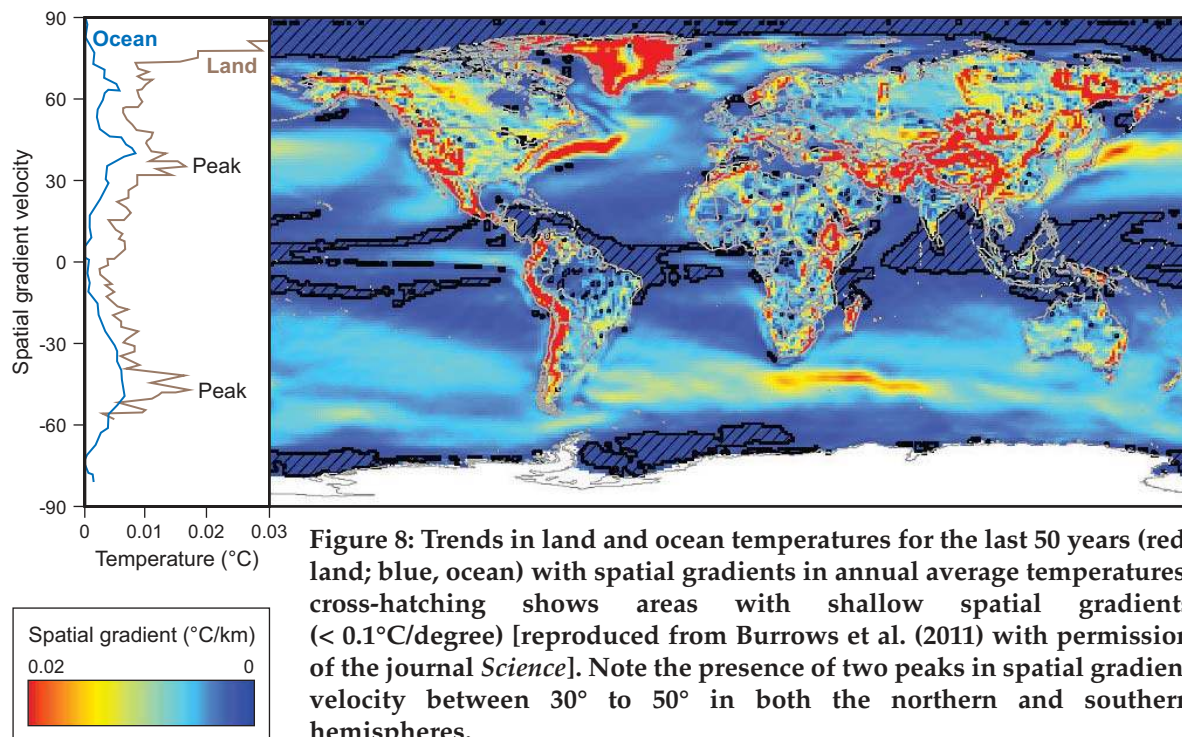


Figure 8: Trends in land and ocean temperatures for the last 50 years (red, land; blue, ocean) with spatial gradients in annual average temperatures; cross-hatching shows areas with shallow spatial gradients ($< 0.1^{\circ}\text{C}/\text{degree}$) [reproduced from Burrows et al. (2011) with permission of the journal *Science*]. Note the presence of two peaks in spatial gradient velocity between 30° to 50° in both the northern and southern hemispheres.

By contrast, cooling led to migration of foraminiferal fauna from higher to lower latitudes, their stepwise extinction, increasing provincialism and the preferential survival of euryfacial faunas (Stanley, 1984; Kalvoda, 2002; Fuhrman et al., 2008). We believe that fusulinid faunas provide a particularly sensitive index of climate changes within marginal conditions at the transition from subtropics to temperate mid-latitudes, such as existed in Zagros, Oman, Abadeh Transcaucasia, Salt-Range, Southeast Pamirs and other regions of the Neo-Tethys.

Mid-latitudes are areas where climatic fluctuations and the rapidity of climate change are most significant as it was shown in modern world (Burrows et al., 2011) (Figure 8) and in the Permian models (Winguth et al., 2002) (Figure 9). Consequently, the greatest variations in foraminiferal diversity occur at mid-latitudes as has been demonstrated in modern brachiopods (Powell, 2009) and already noted for the record of Middle Permian (Guadalupian) foraminifers (Bond and Wignall, 2009). Recent development in Permian climate simulation models (Winguth et al., 2002) suggest a significant latitudinal shift in sea-surface temperature and associated climatic belts under hypothetical atmospheric pCO_2 concentrations attributable to glacial *versus* non-glacial climate states (Figure 9). This model proposes the most significant changes in temperature at mid-latitudes (approximately between 30° – 60° north and south from equator). The isotherms in mid-latitudes are much tighter and thus change more frequently than in polar regions (approximately between 60° – 90° in the south and the north) or tropical belt (approximately between 30°S and 30°N). Modeled fluctuations in atmospheric pCO_2 of up to 8x the threshold for permanent polar ice are apparently warranted by recent compilations of its variability through the Early Permian from proxy records (Montañez et al., 2007).

Three climatically-determined assemblages can be distinguished in Zagros and surrounding areas (Figure 8). The first one, characteristic for the cool-water environments includes inhabiting cool-water environment smaller foraminifera. The surface water in Zagros and surrounding areas of the habitats of this climatically-determined assemblage perhaps was temperate. This assemblage includes only benthic smaller foraminifera and may indicate cool climate episode or strong cold-water upwelling. The facies where this assemblage occurs usually is considered as heterozoan (James and Clarke, 1997; Weidlich, 2007).

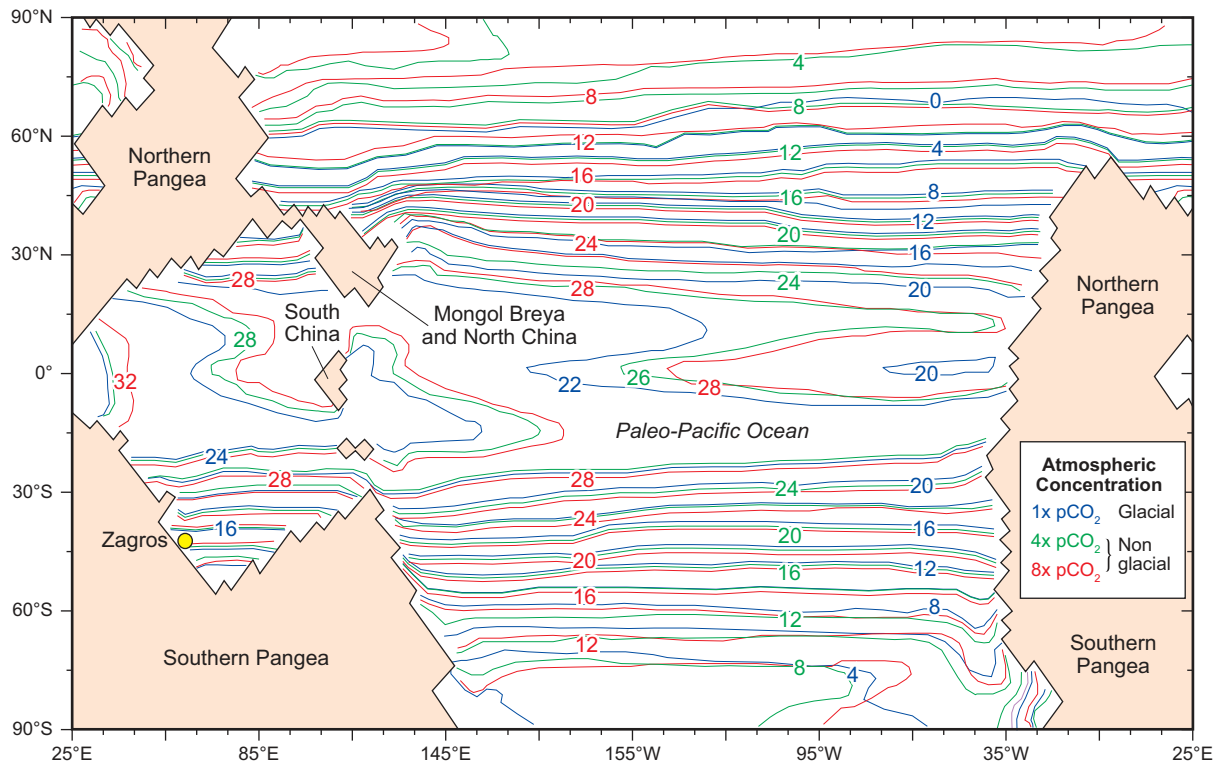


Figure 9: Coupled ocean general circulation–atmospheric energy balance model results showing variations in mean subtropical sea surface temperature (e.g. ca. 15° latitudinal shifts in isotherms) under varying atmospheric pCO₂ concentrations attributable to glacial (1x, blue lines) versus deglacial (4 to 8x, green and red lines, respectively) boundary conditions (modified from Winguth et al., 2002). The most dramatic changes in climate fluctuations occur within the zone of 30° to 50° in both the northern and southern hemispheres. Approximate Zagros position shown as a yellow dot.

Fusulinids occur in the region at warmer water environments. This second climatically-determined assemblage is dominated by staffellids, schubertellids and *Chusenella* (Table 2, Figure 2). It seems that *Eopolydiexodina* also belongs to this assemblage, which is transitional from cool/cold to warm water. Occurrence of fusulinids in limestone is usually interpreted to be a photozoan carbonates (James and Clarke, 1997; Weidlich, 2007). However, the fusulinids mentioned above generally occur at higher latitudes in (Kobayashi and Ishii, 2003b; Gaillot and Vachard, 2007).

Typical warm-water tropical condition in Zagros and surrounding areas (Figures 2 and 10) appears where surface-water temperature exceeded a level optimal for the recent warm-water larger foraminifera (Beavington-Penney and Racey, 2004). This third assemblage is characterized in Zagros by verbeekinids *Afghanella* and *Sumatrana*. However, the low taxonomic diversity in the assemblage (two verbeekinids genera represented by one species each) indicates that this warming episode in the region was short. The climate possibly shifted back to cool surface water near the end of the Capitanian or at the Capitanian/Wuchiapingian boundary (Figure 2) once the carbonate factory changed from protozoan to heterozoan type (Weidlich, 2007).

Paleoclimate and Paleogeography within the Neo-Tethys Ocean

The beginning of Permian sedimentation in Zagros is associated with a Middle Permian–Early Jurassic Arabian Plate (AP) tectonostratigraphic megasequence 6 (AP6) that is related to the onset of rapid thermal subsidence of the early Neo-Tethys passive margin in Arabia and Iran (Sharland et al., 2001). The sedimentation is also associated with the continental rifting and spreading of the Sanandaj-Sirjan and Central Iran terrains away from the Arabian Plate. Because of poor age



Figure 10: Paleogeography of Zagros and surrounding areas during Middle Permian (Guadalupian) time (the map in rectangular format from Ron Blakey site <http://www2.nau.edu>; modified from Ueno 2006). Abadeh and Transcaucasia regions are displayed as green squares to show the onlap of cooler water from upwelling into tropical warmer water shallow environments.

constraints of the Faraghan Formation the exact time of the beginning of the thermal subsidence and continental rifting is not clear. Kubergandian (early Roadian) fusulinids near the bottom of the Dalan Formation and the moderate thickness of the Faraghan Formation suggest that the thermal event is probably Bolorian–Yakhtashian (Kungurian–Artinskian); this is in agreement with the recent proposal by Gaillot and Vachard, (2007). At the same time, the most recent discovery of diverse assemblages of fusulinids in Moscovian–Gzhelian and in the Permian in Sanandaj-Sirjan Zone (Leven and Gorgij, 2008a, b, 2011) suggests the paleo-position of the region during this time was located within the tropics. Thus, we cannot exclude the possibility that the rifting of the Sanandaj-Sirjan region and Middle Permian (Guadalupian) thermal subsidence of the passive margin of Arabian Plate including Zagros occurred at different times.

The following paleogeographic and paleotectonic observations can be made from analyses of spatial and temporal distribution of foraminiferal assemblages from region to region within the Neo-Tethys (Figure 10).

Khuff Basin (Saudi Arabia and Haushi area, central Oman)

The beginning of Middle Permian (Guadalupian) sedimentation in the Arabian Plate consists of siliciclastics characterized by the Gharif Formation in Oman, from which diverse plant fossils of Cathaysian, Euramerican and Gondwanan affinities were recovered by Berthelin et al. (2006). They recognized two assemblages in units A and B of the Gharif Formation. Plants from the lower unit A do not provide a precise age, whereas those from unit B indicate an early Kubergandian (early Roadian) to Murghabian transition. The siliciclastics of the Gharif Formation correlate to the lower part of Dalan Formation in Zagros.

Table 3
Frequency of occurrences of schubertellids, schwagerinids, and verbeekinids
in the different Neo-Tethys regions

Age	Northeast Oman Nappes			Zagros			Salt Range			Transcaucasia			Abadeh			Southeast Pamirs		
	FEV	Vrb	Freq	FEV	Vrb	Freq	FEV	Vrb	Freq	FEV	Vrb	Freq	FEV	Vrb	Freq	FEV	Vrb	Freq
Changhsingian										2/2		2	2/2		2			
Wuchiapingian				1/1			4/5		18	5/20		2	5/20		2	9/21		8
Capitanian	1/1			1/1	2/2	2	3/3	1/1	6	6/17	2/2	6	7/5	1/1		3/5	3/4	5
Upper Wordian	6/8	4/4	5	9/11		4	2/2		2	8/16	2/2	4	7/12	6/10		3/3	4/5	3
Lower Wordian	3/4	1/1	2	7/18		6				9/17	5/6	3	5/6	1/1		11/24	9/26	9
Roadian				3/3		1				11/17	3/11	6	1/1			10/24	7/25	13
Kungurian										8/23	1/4	3				3/12	1/6	7

Data compiled for the Khuff Basin (Vachard et al., 2005; Koehrer et al., 2010); Zagros (this study; Gaillot and Vachard, 2007); Southeast Pamirs (Leven, 1967; Chedija et al., 1986); Salt Range (Pakistani-Japanese Research Group, 1985; Douglass, 1970; Mertmann, 2000); Abadeh (Kobayashi and Ishii, 2003a, b); Transcaucasia (Kotlyar et al., 1983, 1989; Leven, 1998). Abbreviations: FEV. - all fusulinids, except Verbeekinids; Vrb – Verbeekinids; Freq.- frequency of horizons with fusulinids.

Within the eastern shelves of the passive margin of the Arabian Plate (Khuff Basin, Figure 10) Middle–Late Permian (Guadalupian–Lopingian) fusulinids are extremely rare (Table 3). Very rare *Monodiexodina kattaensis* and *Reichelina* (?) were recovered from the lower Khuff Formation (Khuff D Member in subsurface near the Saudi-Oman border) and no fusulinids, except staffellids or dasycladacean algae, were observed in the upper part of the Khuff (Vaslet et al., 2005; Hughes, 2009). Bivalves, brachiopods, crinoids and bryozoans are the most abundant skeletal grains in the Khuff Formation at least in the Haushi area and the siliciclastic input is generally low. The biotic content is typical of the heterozoan association (Weidlich, 2007). Only rare staffellids, schubertellids and ozawainellids occur in the Upper Permian (Lopingian) (Gaillot and Vachard, 2007; Hughes, 2009) suggesting the existence of abnormal environments within the region (Table 2).

The rare occurrence of fusulinids in the Khuff Formation is explained either by strong terrigenous input (Angiolini et al., 2003) or by the onset of the end-Permian anoxia and/or warming related to a rapid change in the plate movements (Gaillot and Vachard, 2007). However, the occurrence of siliciclastics in the Khuff Formation is not significant (Vaslet et al., 2005) and thus the dispersal of fusulinids is possible. The siliciclastic component itself does not greatly influence the occurrence of fusulinids. Besides, it is quite high in fusulinid- and dasyclads-bearing carbonates in Abadeh, Transcaucasia (Kotlyar et al., 1989; Iranian-Japanese Research Group, 1981; Leven, 1998) and other regions. Therefore the siliciclastics are not responsible for the reduction of fusulinid occurrences.

The anoxia could be responsible for the diversity reduction in Khuff Basin, but no sedimentological evidence of anoxia (highly-organic black shales and/or framboidal pyrite) has been reported in the region (Vaslet et al., 2005; Insalaco et al., 2006). In our opinion the most probable explanation for the extremely poor taxonomic diversity of fusulinids, corals and dasyclads algae in the Khuff Basin are temperate (cool) shallow-water climate conditions that are consistent with carbonate sedimentology analyses (Vaslet et al., 2005). The temperate climate of the area could be attributed to the higher latitude position, around 40–45°S, of the Arabian Plate during Wordian–Capitanian time (Figure 9). Additionally, we cannot exclude the occurrence of strong and permanent upwelling currents that might have influenced the warm-water biotas.

Saiq Basin (para-Autochthon?) (Northeast Oman)

The Permian in north and northeast of Oman consist of tectonic nappes formed from the relicts of Middle Permian–Late Triassic carbonate platforms include the (para-) autochthonous (?) Saiq Formation. The formation consists of a lower, thin siliciclastic unit and an upper thick carbonate unit. The lower siliciclastics may correlate to the Gharif Formation of the Khuff Basin, although it is

quite thin (> 20 m) (Köhrer et al., 2010). Shallow-water, warm to temperate carbonate sedimentation of the Upper Saiq Member (over 600 m thick) started in the Wordian as indicated by the occurrence of typical warm-water verbeekids *Afhanella*, *Verbeekina* and *Pseudodoliolina* (Forke et al., 2012). The diversity of fusulinids there are consistent with early Midian (Wordian–early Capitanian) assemblages in Transcaucasia and Abadeh.

The Capitanian part of the Saiq Formation is characterized by smaller foraminifera only, including the prominent *Shanita amosi* and *Sphairionia sikuoides* (Forke et al., 2012). The post-Wordian part of the Saiq Formation is completely dolomitized and similar in lithology to the Upper Dalan Member in Zagros (Figures 2 and 3). The content of fusulinid fauna in the lower part of the Upper Saiq Member suggests its paleotectonic and paleogeographic position within a warmer climate, close to Zagros rather than the internal part of the Arabian Plate. This interpretation contradicts the commonly accepted view on these areas as autochthonous units at the eastern rim of the Arabian Shield (Glennie et al., 1973; Weidlich and Bernecker, 2007). This autochthon, however, could be a nappe as well (Blendinger, 1988; Chauvet et al., 2009).

Hawasina and Batain Nappes, Northeast Oman (Oman “Exotics”)

Each of these tectonic nappes of the Oman Mountains possesses a different stratigraphy and may represent two different basins. The Hawasina Nappes appear as a part of the Neo-Tethys breakup that is marked by pillow lavas up to 300 m thick (Glennie et al., 1973; Blendinger, 1988). The volcanoclastics that conformably covered the pillow lavas contain reefal conglomerates and boulders. Unfortunately, the reef debris and boulders, some of which are enormous (up to 200 m), are basically unstudied. Just *Neoschwagerina margaritae* and *Verbeekina* sp. were listed in the literature (De Wever et al., 1988; Weidlich and Bernecker, 2007). Within the lavas and above the volcanoclastics, a thin neritic limestone contains abundant Wordian ammonids (Blendinger et al., 1992), including evolute *Timorites* of Capitanian age (Baud et al., 2012). Fusulinids *Kahlerina* sp., *Dunbarulla* sp., and *Codonofusiella* sp. were recovered from the ammonoid matrix (first author’s personal collection). A late Capitanian *Clarkina postbitteri hongshinensis* conodont was found near the top of neritic limestone. A condensed, deep-water succession with radiolarian and rare conodonts extended into the Triassic (Baud et al., 2012). The existing data suggest the presence of a carbonate microplatform during the Wordian-Capitanian that later became the Hawasina Nappes; however, the nature, size and geometry of this platform remain uncertain due to very poor data.

The Batain Nappes consist of Lower Permian to Mesozoic sedimentary and volcanic rocks of the Batain Group that were obducted on top of the autochthonous sedimentary cover of the northeast Oman margin (Vachard et al., 2002; Weidlich and Bernecker, 2007). During the Permian the Batain Nappes may have been an isolated microplatform (sea-mounts or plateau?) that were located north from the Arabian Plate within the Neo-Tethys (Béchenec et al., 1990). The record of the platform is preserved as limestone conglomerates, boulders and blocks within the Mesozoic (Permian lost carbonate platform or Oman “exotics”). The record from these limestone blocks suggests the existence of the platform at least since Yakhtashian (Artinskian) through Capitanian (Vachard et al., 2002). The fusulinid diversity from the carbonates indicates the occurrence of the platform within the normal tropical belt. The record from the Batain Nappes, however, is still quite poor and additional studies are essential.

Zagros Mountains Region

The Zagros region was essentially part of the passive margin of the Arabian Plate, but located approximately at 35–40°S (Figure 10). The frequent occurrence of Roadian–Capitanian fusulinids and their significantly greater taxonomic diversity than in the Khuff Basin (Table 3) suggests that the surface-water temperature there was warmer than in Khuff Basin. Nevertheless, the region was located within the temperate or warm-to-temperate transitional climate zone. Most of the time the surface water was cool, and fusulinid dispersal was restricted to relatively short periods, when the shallow-water temperature exceeded acceptable levels for conditions suitable for fusulinids. Schubertellids, staffellids, and chusenellids dominate the Roadian–early Wordian fusulinid assemblages without verbeekinids. The fusulinid-bearing horizons are quite thin and thus the occurrence of fusulinids in the area was relatively short.

In general fusulinids occur in the very thin (1–3 m thick packages within the 700 m succession (Figure 2). The upper Wordian thin horizon (about one meter thick) with typical temperate *Monodiexodina kattaensis* contains a reasonably diverse assemblage of fusulinids (Figure 2); these are taxonomically quite similar to faunas from Sibumasu and Baoshan blocks (Ueno, 2003), such as *Rugososchwagerina*, *Kahlerina*, *Dunbarula*, *Yangchienia* and *Codonofusiella* (Tables 1 and 2). About 200 m between this horizon and the next fusulinid-bearing horizon, a succession of dolomites and dolomitic limestones occurs with very rare smaller foraminifera or lacking any preserved fossils. The presence of dolomites precludes making a statement with confidence regarding the environment.

Two very thin horizons (less than 1 m thick) occurring at 660 and at 690 m contain the first and the only verbeekinids in the entire succession (Table 2, Figure 2). Their taxonomic diversity however, is relatively low. Only two genera of verbeekinids with a single species each and one species of schubertellid *Yangchienia* were recovered. With confidence we interpret this as an indication that a definite warm but short event occurred in the region; further it suggests that the surface temperature was not extremely elevated. Only smaller foraminifera were recovered from the Upper Permian (Lopingian) in the section and thus the climate and the environment in Zagros can be interpreted to have been somewhat similar to that of the Upper Permian (Lopingian) in the Khuff Basin.

The prevailing interpretations regarding the paleo-latitude position of the Zagros area during the Permian are quite controversial. It is commonly accepted that during pre-Wordian time Zagros, as a part of Arabian Plate, moved rapidly from 40°S to 25°S (Sharland et al., 2001) and by Wordian time it was located within the tropics (Kobayashi and Ishii, 2003a; Angiolini et al., 2003). More radical interpretations propose a position of the Arabian Plate during the Lopingian as far as at the Equator (Vachard et al., 2005; Gaillot and Vachard, 2007). The data from Zagros in our opinion suggest a more stable position of this part of Arabian Plate during the Middle Permian (Guadalupian). The changes and shifts of biota from non-fusulinid to fusulinid-bearing most probably related to the climate fluctuations rather than to tectonic movement of the Arabian Plate. Starting from Roadian through at least mid-Capitanian, Zagros was located within the temperate climatic belt, i.e. 35–40°S and only by the late Capitanian time could it have been closer to the Equator, still, however, within the tropical/subtropical transition (30–35°S).

Abadeh and Transcaucasia

Both regions were located within the eastern carbonate shelves of the Neo-Tethys Cimmerian terrains (Figure 10) and within a climatic zone that was warmer than Zagros. Artinskian–Kungurian thermal subsidence of the Arabian Plate was coeval with the beginning of Permian marine sedimentation in these regions (Figure 9). The Kungurian (Bolorian) assemblages in Transcaucasia are quite diverse and consist of typical warm-water taxa including the verbeekinid *Misellina*. Similarly, during Kubergandian and Murgabian (early Roadian–early Wordian) the verbeekinids *Armenina*, *Cancellina*, *Pseudodoliolina* and *Presumatrina* were common (Leven, 1998). Nevertheless, the diversity and abundance as well the frequency of occurrences of verbeekinids and other fusulinids are not as great as in typical tropical sections (Skinner and Wilde, 1966; Leven, 1997).

Only 6 to 8 horizons of fusulinids in Transcaucasia and about 12 horizons in Abadeh were reported within the entire Kuberganian and Murgabian (early Roadian to early Wordian), although the carbonate succession there exceeds 300 m (Leven, 1998; Kobayashi and Ishii, 2003b). Among these horizons in Transcaucasia only four contain verbeekinids. Five verbeekinid-bearing horizons occur in Abadeh. In the lower Midian (upper Wordian) of both regions the fusulinid assemblages are *Chusenella*-dominated. Very few and quite rare verbeekinids *Verbeekina*, *Sumatrana* and *Neoschwagerina* schubertellids and ozawainellids were recovered there (Leven, 1998; Kotlyar et al., 1989; Kobayashi and Ishii, 2003b).

The upper Midian (Capitanian), *Chusenella*-dominated assemblage were supplemented with one specimen of advanced *Neoschwagerina* (*N. pinguis*) recovered from the Khachik Formation in Transcaucasia (Kotlyar et al., 1989). *Yabeina* and *Metadoliolina* were reported from the Hambast

section in Abadeh (Baghbani, 1993) from about upper Midian (Capitanian) strata. However, this occurrence has not been confirmed by subsequent studies (Kobayashi and Ishii, 2003b, and personal study of the authors). The present fusulinid data from Abadeh and Transcaucasia suggest that during Roadian–Wordian time the regions were located within the subtropics with annual temperature favorable but marginal for the appearance for verbeekinids. The limited diversity and low frequency of these taxa are evidence that the surface water in both regions was not so high (perhaps 20–25°C) possibly due to permanent upwelling currents that kept surface water temperature low.

Southeast Pamirs

According to the tectonic data the region was located within the west Qiangtang Microcontinent (Hutchison, 1993). Very thick Carboniferous–Sakmarian siliciclastics with cold-water *Conularia* and *Eurydesma* clearly express the position of the region at that time within the Gondwana margins. Post-Sakmarian–pre-Kungurian (pre-Bolorian) pillow lava basalts, the first temperate fusulinids *Monodiexodina* and cool-water Gondwanan conodonts *Vjalovognathus* (Leven, 1967; Kozur, 1978) suggest that the Artinskian rifting of this microcontinent towards the tropics was rather rapid. Because in the mid-Kungurian (Bolorian) Pamirs and surrounding areas of Qiangtang microcontinent were already located within the tropics, fusulinid assemblages of the region were dominated by verbeekinids through the entire Middle Permian (Guadalupian) (Nie and Song, 1983a, b; Leven, 1997). *Chusenella*, *Rugososchwagerina* and *Yangchienia* that are the most common fauna in Zagros are quite rare in the Southeast Pamirs (Leven, 1967). In the composite section of the Southeast Pamirs we recognized over 30 verbeekinid-dominated horizons within the Kungurian–Capitanian, suggesting very warm-water environments for most its duration (Table 3). Volcanoclastic facies developed in Southeast Pamirs during the Upper Permian (Lopingian). Although these facies are not favorable for the fusulinids and corals, the assemblages are typical of diverse warm-water tropical biota (Kotlyar et al., 1983, 1989).

Salt Range, Pakistan

The region belongs to the northern part of Greater India and underwent separation and early rifting phase during the late Paleozoic. The Middle and Late Permian sedimentary development is characterized by two transgressive-regressive (T-R) second-order cycles. In the Salt Range area, these two T-R cycles have been subdivided into five third-order sequences (Baud et al., 1996). The late Paleozoic succession in the Salt Range is quite similar to that in the Zagros area, except that the marine deposits began later in the Wordian Amb Formation. The formation possesses temperate-water *Monodiexodina kattaensis* and *Codonofusiella laxa* in the middle part (Douglass, 1970). It seems that the occurrence of *Monodiexodina kattaensis* in middle Amb Formation is coeval with that of *Monodiexodina kattaensis dalanensis* in Zagros (late Wordian).

Above the Amb Formation, the Wargal Formation is divided into a lower thin and an upper thick part (Mertmann, 2003) that are bounded by sequence boundaries. The lower part of the Wargal Formation contains abundant staffellids and rare *Chusenella* and schubertellids. A single specimen of warm-water verbeekinid *Neoschwagerina margaritae* has been recovered in only one locality (Pakistani-Japanese Research Group, 1985). The lower Wargal with *Neoschwagerina margaritae* corresponds to the Capitanian (upper Midian) Khachik Formation with *Neoschwagerina* in Transcaucasia (Kotlyar et al., 1989) and with *Afghanella schencki* Biozone in Zagros (Figure 3). According to conodonts (Wardlaw and Pogue, 1995) the lower Wargal is Capitanian. Thick upper Wargal and Chidru formations possess *Codonofusiella*, *Reichelina*, *Nanlingella simplex* and several biostratigraphically significant smaller foraminifers (*Colaniella*, *Paradagmarita* etc.) of Lopingian age (Pakistani-Japanese Research Group, 1985) suggesting an age consistent with conodont ages (Wardlaw and Pogue, 1995).

The distribution of fusulinids and other foraminifers in the succession suggest that by late Wordian time the Salt Range area was positioned within the mid-latitude with temperate water conditions similar to that of Zagros, i.e. within the subtropical-tropical transition (40–35°S). The appearance of *Neoschwagerina* in the Capitanian of the Salt Range is coeval with the appearance of verbeekinids *Neoschwagerina* in Transcaucasia, and *Sumatrina* and *Afghanella* in Zagros, and is consistent with the proposed middle Capitanian warming event. The Late Permian (Lopingian) assemblages of the Salt

Range area seem more diverse than those in Zagros, indicating that the former region was located at slightly lower latitude and experienced warmer-water climate than the latter.

In conclusion, it appears clear to us that the proposed model of climate–biota interaction developed on the basis of the Zard-Kuh data represents the initial step towards a better understanding of Middle Permian (Guadalupian) climate in the area. This model requires further consideration and must be tested in other Zagros sections and elsewhere in the Neo-Tethys.

DESCRIPTION OF NEW FUSULINID TAXA

Order *FUSULINIDA* Fursenko, 1958

Family *SCHWAGERINIDAE* Dunbar and Henbest, 1930

Subfamily *MONODIEXODININAE* Kanmera, Ishii and Toriyama, 1976

Genus *Monodiexodina* Sosnina in Kiparisova et al., 1956

Monodiexodina kattaensis dalanensis, new subspecies

Plate 7, Figures 10–19

Holotype: Plate 7, Figure 12, SUI 132123, axial section; sample Z-33, Il-e Beyk section, Dalan Formation, unit 17, 433 m above the base of the section; Zard-Kuh area, Zagros, southwest Iran; Middle Permian (Guadalupian), Midian (upper Wordian–Capitanian).

Synonymy: *Monodiexodina kattaensis* (Schwager, 1887) in Douglass, 1970, G2-G5, his Plate 4, Figures 1–8 (only).

Material examined: 10 axial sections and many paraxial sections.

Etymology: After Dalan Formation where this subspecies has been found.

Type locality: Il-e Beyk section in Zard-Kuh area, Zagros, southwest Iran.

Type level: The nominative species has been described from the Wordian in Salt Range, Pakistan and is also probably found in Oman from Wordian (?). It has been recovered for the first time in Zagros and due to some morphological differences described as a new subspecies. It characterizes a narrow horizon within upper Wordian.

Description: Test medium to large, subcylindrical with bluntly pointed to rounded poles. Coiling is moderate and rather uniform throughout the growth. Mature individuals have 4–7 volutions and are 7–11.4 mm in length and 2–2.9 mm in diameter, giving form ratios of 3.2–4.4. The first volution is 1.3–2.9 mm long and 0.4–0.6 mm wide with form ratios of 1–4.4. The length and diameter of the fourth volution are 5.1–8 mm and 1.3–1.88 mm form ratios of 3.6–4.5. The proloculus is medium to large in size, spherical and commonly distorted in shape; its outside diameter varies from 275–575 microns. The proloculus/final volution diameters ratio is 5–10. Spirotheca is composed of tectum and coarsely alveolar keriotheca, and thickens gradually from third volution. Septa are strongly and regularly fluted from pole to pole. Septal folds are narrow and low and reaching to half as high as chambers but particularly extending to tops of chambers in polar regions. Low cuniculi are observed in two outermost volutions (Plate 7, Figure 14). Tunnel is low and narrow with rather regular path. Chomata are absent or only present on proloculus and first volution. Weak or moderate axial fillings are present in middle and outer volutions.

Comparison: Superficially this subspecies resembles *Monodiexodina kattaensis* (Schwager, 1887) from Salt Range, northeast Pakistan. Douglass (1970), who re-described the species from many locations in the middle Amb Formation of Salt Range and Khisor Range, noted two morphologically separate groups that can be seen as “different and statistically separable species” (Douglass, 1970, p. G2). Particularly they differ in proloculus and overall test size, wall thickness, volution height and tunnel angle (p. G8-9, Figs 5 and 6). One group described from Kattha location in Salt Range

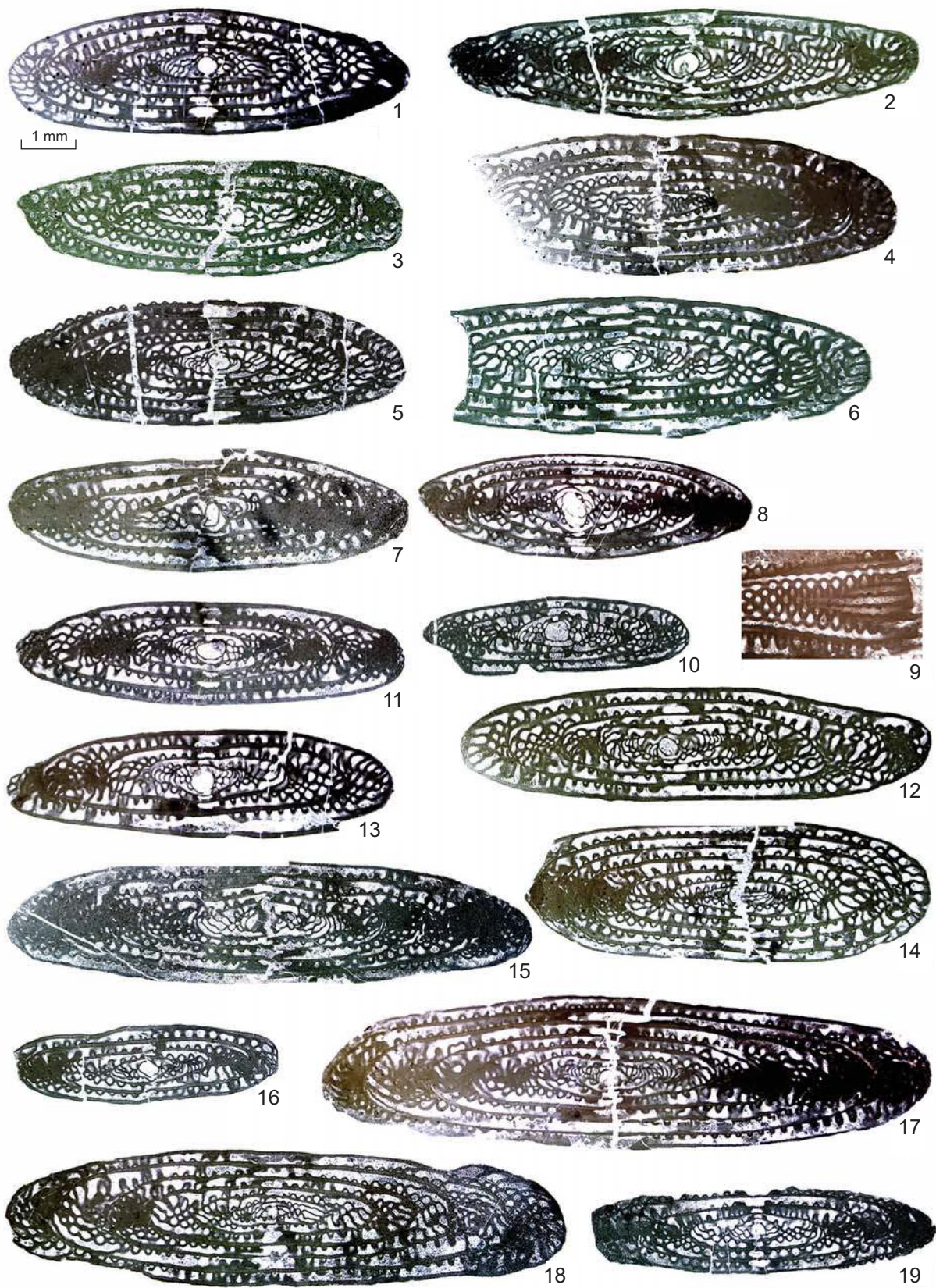


Plate 7: See facing page for caption.

(Douglass, 1970, his Plate 2) is characterized by medium sized test and proloculus, medium wall thickness, relatively tight coiling, wide tunnel and medium to well-developed axial fillings. The Kattha location is the topotype of the species according Schwager (1987) and Dunbar (1933) and therefore there are no doubts the forms from this group resemble the lectotype of the species designated by Douglass (1970). It is also obviously close to the forms described by Dunbar (1933) from Warchha location.

The second group of *Monodiexodina* from Kafirkat location in Khisor Range is characterized by a large test and proloculus, medium coiling, relatively thick wall, narrow tunnel and weakly developed axial fillings. This group closely resembles forms of *Monodiexodina* we recovered in Zagros. Douglass, however, did not separate these two groups and consider these differences as morphological variations because of the same growth curve (the diameter/length, height of the volution and wall thickness). Unfortunately no information has been provided for the geographic distribution of these clines and on the microfacies. At the same time, the forms with large proloculus, greater test and weakly developed axial fillings are described from one Kafirkat location in the Khisor Range, whereas forms with medium size test and proloculus seems widely distributed in the Salt Range (Douglass, 1970, his Plate 4). It is also not clear if the forms with large proloculus and test occur within the population of forms with medium proloculus and *vice versa*. Douglass noted, however, that no correlation of morphology with stratigraphy and/or geography was recognized. *Monodiexodina* from Zagros possesses strong similarities with those described from Kafirkat location and designated here as a new subspecies of the *Monodiexodina kattaensis*. It differs from the nominative subspecies in having twice as large proloculus, generally larger overall test size, thicker wall, more regularly fluted septa both in central and polar ends of the test, narrow tunnel, and weakly developed axial fillings or sometimes no fillings at all. It might be that after additional study of forms from Kafirkat location in Salt Range the status of this subspecies could be raised to species level.

Stratigraphic range: Unit 17, Sample Z-33, Dalan Formation, Middle Permian (Guadalupian), Murgabian (early Roadian–early Wordian).

Geographic occurrence: Il-e Beyk section in Zard-Kuh area, Zagros, southwest Iran.

Monodiexodina hendersoni, new species

Plate 7, Figures 1–9

Holotype: Plate 7, Figure 2, axial section; sample Z-33, Il-e Beyk section, unit 17, 433 m above the base of the section, Zard-Kuh area, Zagros, southwest Iran; Middle Permian, Guadalupian, Murgabian (early Roadian–early Wordian).

Material examined: 11 axial sections and many paraxial sections.

Plate 7 (continued): Fusulinids from Lower Dalan Member, Il-e Beyk Section, Zard-Kuh, Zagros, Iran. The scale of figure 1 applies to all figures.

(1–8) *Monodiexodina hendersoni* sp. nov., (1) Z33-12-1, SUI 1320113; (2) Z33-7-1, SUI 1320114; (3) Z33-24-1, SUI 1320115; (4) Z33-22-1, SUI 1320116; (5) Z33-14-1, SUI 1320117; (6) Z33-4, SUI 1320118; (7) Z33-21, SUI 1320119; (8) Z33-10, SUI 1320120.

(9) *Monodiexodina* sp., showing cuniculi, Z33-7-7, SUI 1320121.

(10–19) *Monodiexodina kattaensis dalanensis* sp. nov., (10) Z33-2, SUI 1320122; (11) Z33-9, SUI 1320123; (12) Z33-5, SUI 1320124; (13) Z33-10, SUI 1320125; (14) Z33-15, SUI 1320126; (15) Z33-23, SUI 1320127; (16) Z33-3, SUI 1320128; (17) Z33-29, SUI 1320129; (18) Z33-11, SUI 1320130; (19) Z33-16, SUI 1320131.

Etymology: Named after Professor Charles Henderson, the former chair of Permian Subcommission of the ISC and well-known Permian conodont worker.

Type locality: Il-e Beyk section in Zard-Kuh area, Zagros, southwest Iran.

Type level: lower Midian (upper Wordian).

Description: Shell medium, short elongate-fusiform with weakly convex median area and lateral slopes and bluntly rounded poles, the expansion of volutions is gradual during the growth. Coiling is tight in early volutions but uniform and gradual in later ones. Mature tests of 5–6 volutions are 6–9 mm long and 1.9–2.7 mm wide, giving form ratios of 2.9–3.8. The first volution is 0.7–1.7 long and 0.5–0.7 mm wide with form ratios of 1–2.4. The length and diameter of the fourth volution are 4.2–6.8 mm and 1.3–2 mm, respectively, with form ratios of 3.1–4.2. The proloculus large in size, spherical, ellipsoidal and often distorted in shape with outside diameter of 337–600 microns averaging 437 microns for 7 specimens. Spirotheca is relatively thin in early two volutions and gradually thickens at the later ones and is composed of tectum and coarsely alveolar keriotheca. The thickness of the spirotheca in the first, fourth and last volutions of 7 specimens are 15–25, 50–100, and 75–100 microns, respectively. Septa are very regularly and intensely fluted throughout the length of the shell. Fluting is extending to half the height of the chambers. Septa are less than twice as thin as the wall in respective volutions. Tunnel is low with a rather irregular path. Chomata are lacking or only recognizable on proloculus. Axial fillings are absent or only present on middle or outer volutions.

Comparison: *Monodiexodina hendersoni* can be distinguished from the comparable *Monodiexodina kattaensis* (Schwager, 1887) from Salt Range, northeast Pakistan, in its short, elongate-fusiform outline in all volutions as opposed to subcylindrical outline on the latter; it has more regularly fluted septa especially in central part of the shell, a larger proloculus and narrow tunnel. The described species possesses strong similarities with *Monodiexodina kattaensis dalanensis* subsp. nov., but differs from it in elongate-fusiform outline in all volutions as opposed to subcylindrical outline throughout the growth in the latter.

Stratigraphic range: Unit 17, Dalan Formation, sample Z-33, Middle Permian, (Guadalupian), Murgabian (early Roadian–early Wordian).

Geographic occurrence: Il-e Beyk section in the Zard-Kuh area, Zagros, southwest Iran.

Genus *RUGOSOSCHWAGERINA* A.D. Miklokho-Maklay, 1959

Rugososchwagerina zagroensis, new species

Plate 4, Figures 5-12

Holotype: Plate 4, Figure 8, axial section; sample Z-55, Il-e Beyk section, Dalan Formation, unit 15, 330 m above the base of the section, Zard-Kuh area, Zagros, southwest Iran.

Material examined: 15 axial sections and 7 paraxial sections.

Etymology: Named after Zagros region.

Type locality: Il-e Beyk section in Zard-Kuh area, Zagros, southwest Iran.

Type level: upper Murgabian–lower Midian (Wordian).

Description: Test is medium in size, inflated fusiform to subglobular with slightly extended and pointed poles. The coiling is straight. First two to four volutions constitute tightly coiled juvenarium, which is followed by sharp inflation into loosely coiled adult stage. Fully grown specimens of 5–7 volutions are 5.9–7.4 mm long and 2.6–3.8 mm wide with form ratios of 1.25–2.5. The first volution is 0.3–1.1 mm long and 0.2–0.4 mm wide, giving form ratios of 1.1–3.4. The length and diameter of fourth volution are 2.1–3.6 mm and 0.8–1.6 mm with form ratios of 1.8–2.9.

Proloculus is spherical, small to medium in size with an outside diameter of 150–250 microns. Spirotheca is composed of tectum and rather coarsely alveolar keriotheca with thickness that varies from thin in juvenarium to abruptly thick in later volutions. The thickness of the spirotheca in the first, fourth and last volutions of 12 specimens are 7–12, 50–80, and 100–130 microns, respectively. Septa are nearly plane or slightly fluted initially, becoming intensely and deeply fluted from pole to pole in loosely outer volutions. Septal folds of outer whorls are high, subsquare to triangular and rather irregular in shape commonly reach tops of chambers. Tunnel is very narrow and low in early volutions and rather narrow with irregular path outwards. Weak chomata are present in the juvenarium and absent in later whorls. Prominent axial fillings along the axis well are developed in tightly coiled volutions; they nearly absent in 2–3 outermost volutions.

Stratigraphic range: Unit 15, sample Z55-Z57, Dalan Formation, Middle Permian (Guadalupian), Murgabian (early Roadian–early Wordian).

Geographic occurrence: Il-e Beyk section in Zard-Kuh area, Zagros, southwest Iran.

CONCLUSIONS

The thick (950 m) Middle–Upper Permian (Guadalupian–Lopingian) carbonate succession of the Dalan Formation has been studied in the Zard-Kuh Mountains of Zagros in Iran. Careful documentation of microfacies throughout the section clarified the environments and particularly the bathymetry of the foraminifera within the succession. Foraminiferal study of 46 samples from the Dalan Formation provided precise chronostratigraphic constraints and taxonomy. Five fusulinid biozones in the Middle Permian (Guadalupian) have been established for the first time in the Zagros.

The Lower Dalan Member has been correlated with Tethyan and Global scales. Particularly, the analogues of Kubergandian (early Roadian), Murgabian (late Roadian–early Wordian) and Midian (late Wordian and Capitanian) stages were recognized. The Kubergandian (early Roadian) age of the basal part of the Dalan Formation was documented for the first time in the region. In the studied material 66 species and 38 genera of foraminifera were recognized, two new species and one subspecies are established and described. Temperate water *Monodiexodina* was recorded for the first time in the area. The model of interaction of biota and climate during the Middle Permian (Guadalupian) in the Zagros region is proposed. The unique position of Zagros, within mid-latitudes where climatic fluctuations and velocity of the climate change and consequently the variations in foraminiferal diversity are most significant, open the opportunity to better understand the Middle–Late Permian (Guadalupian–Lopingian) climate in this and surrounding areas of Neo-Tethys. Three climatically-determined assemblages were distinguished in the Zagros and surrounding areas. The developed model of climate fluctuations and paleogeography in the Neo-Tethys is based on analyses of temporal and spatial distribution of fusulinids.

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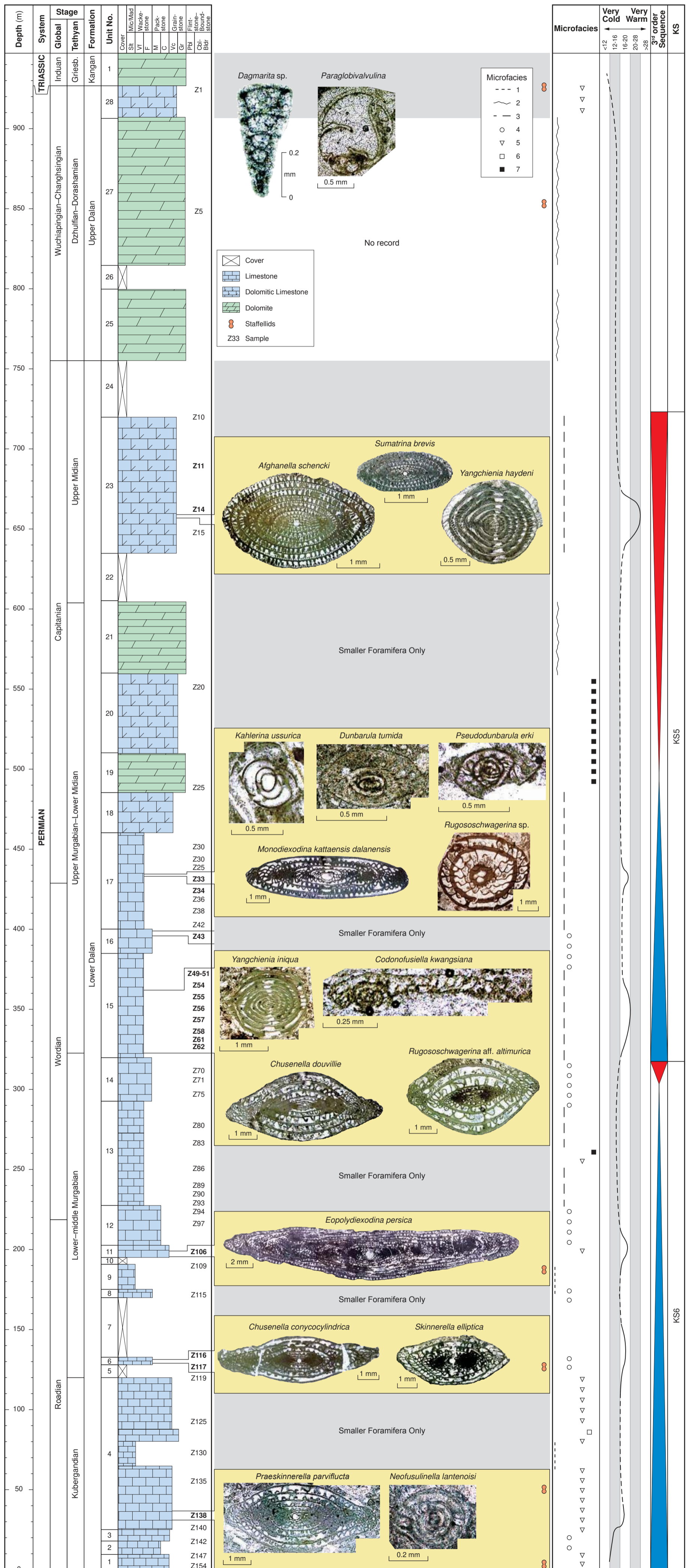


Figure 2: Stratigraphic log of Il-e Beyk section, Zard-Kuh Mountains, Zagros, Iran with some important foraminiferal taxa. The fusulinid-bearing horizons are shown as yellow pattern, whereas successions with smaller foraminifera - as gray pattern. The designated microfacies (1- Dolomudstone, 2-Fenestral dolomitic mudstone, 3-Bioclastic wackestone, 4-Bioclastic wackestone-packstone, 5-Bioclastic packstone-grainstone, 6-Peloidal packstone-grainstone, 7-Ooid dolograins) and interpretations on climatic fluctuations are described in the text.