Foraminiferal-based paleobiogeographic reconstructions in the Carboniferous of Iran and its implications for the Neo-Tethys opening time: a synthesis

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ABSTRACT

The biogeographic distribution of foraminifers and their belonging to either the southern or northern margins of the Paleo-Tethys are used here for paleogeographic reconstructions of Iran during the Carboniferous. Lower Carboniferous foraminiferal assemblages from northern and central Iran show a cosmopolitan character and affinities to both the southern and northern borders of the Paleo-Tethys. Hence, in the Early Carboniferous Iran occupied an intermediate southern latitude position, forming part of Gondwana. This conclusion is consistent with the Late Ordovician to Early Carboniferous drift history of Iran based on paleomagnetic data. In the Late Carboniferous, the foraminiferal affinities of northern and central Iran with the northern part of Paleo-Tethys suggest that Iran separated from Gondwana and moved northwards to a lower latitude. This separation is also evidenced by the Upper Carboniferous coal-bearing sandstones of the Sardar Formation and sandstones with high degree of chemical weathering, which would indicate warm and humid conditions. Considering the composition of foraminiferal fauna along with the evidence of magmatic activities in northwest Iran, it can be inferred that the commencement of the Neo-Tethys opening and continental break-up in Iran occurred sometime in the Late Carboniferous, which contradicts the previous claims that the separation of Iran from Gondwana occurred in Permian and/or Triassic times.

KEYWORDS: Iran, Mississippian, Pennsylvanian, Foraminifera, Paleogeography, Neo-Tethys Opening.

INTRODUCTION

Carboniferous deposits are sporadic and discontinuous in Iran except for Lower Carboniferous strata. The Alborz zone and central Iran have received most of the attention, being subject of stratigraphical and paleontological investigations (Bozorgnia, 1973; Vachard, 1996; Leven et al., 2006; Leven and Gorgij, 2008; Falahatgar et al., 2012, 2015; Zandkarimi et al., 2014, 2017). After the description of the Early Carboniferous Mobarak and Geirud formations by Assereto (1963, 1966), foraminiferal zonations were recognized in several stratigraphic sections of central and eastern Alborz Mountains (Bozorgnia, 1973; Lys et al., 1978; Vachard, 1996; Ueno et al., 1997; Brenckle et al., 2009; Falahatgar et al., 2012, 2015; Zandkarimi et al., 2014, 2017). The Carboniferous deposits of central Iran have been studied in Tabas (Shotori, Shirgesht, and Ozbak-Kuh areas), Posht-e Badam and Yazd blocks and in the Shahreza area. Carboniferous foraminiferal associations of Central Iran have been reported from the Sardar Formation, at the North and South-East of the Tabas town, and from the Gachal Formation, Kalmard area, West of Tabas (Vachard, 1996; Leven et al., 2006; Vachard and Arefifard, 2015). After the description of the Early Carboniferous Mobarak and Geirud formations by Assereto (1963, 1966), foraminiferal zonations were recognized in several stratigraphic sections of central and eastern Alborz Mountains (Bozorgnia, 1973; Lys et al., 1978; Vachard, 1996; Ueno et al., 1997; Brenckle et al., 2009; Falahatgar et al., 2012, 2015; Zandkarimi et al., 2014, 2017). The Carboniferous deposits of central Iran have been studied in Tabas (Shotori, Shirgesht, and Ozbak-Kuh areas), Posht-e Badam and Yazd blocks and in the Shahreza area. Carboniferous foraminiferal associations of Central Iran have been reported from the Sardar Formation, at the North and South-East of the Tabas town, and from the Gachal Formation, Kalmard area, West of Tabas (Vachard, 1996; Leven et al., 2006; Vachard and Arefifard, 2015). After the description of the Early Carboniferous Mobarak and Geirud formations by Assereto (1963, 1966), foraminiferal zonations were recognized in several stratigraphic sections of central and eastern Alborz Mountains (Bozorgnia, 1973; Lys et al., 1978; Vachard, 1996; Ueno et al., 1997; Brenckle et al., 2009; Falahatgar et al., 2012, 2015; Zandkarimi et al., 2014, 2017). The Carboniferous deposits of central Iran have been studied in Tabas (Shotori, Shirgesht, and Ozbak-Kuh areas), Posht-e Badam and Yazd blocks and in the Shahreza area. Carboniferous foraminiferal associations of Central Iran have been reported from the Sardar Formation, at the North and South-East of the Tabas town, and from the Gachal Formation, Kalmard area, West of Tabas (Vachard, 1996; Leven et al., 2006; Vachard and Arefifard, 2015). After the description of the Early Carboniferous Mobarak and Geirud formations by Assereto (1963, 1966), foraminiferal zonations were recognized in several stratigraphic sections of central and eastern Alborz Mountains (Bozorgnia, 1973; Lys et al., 1978; Vachard, 1996; Ueno et al., 1997; Brenckle et al., 2009; Falahatgar et al., 2012, 2015; Zandkarimi et al., 2014, 2017). The Carboniferous deposits of central Iran have been studied in Tabas (Shotori, Shirgesht, and Ozbak-Kuh areas), Posht-e Badam and Yazd blocks and in the Shahreza area. Carboniferous foraminiferal associations of Central Iran have been reported from the Sardar Formation, at the North and South-East of the Tabas town, and from the Gachal Formation, Kalmard area, West of Tabas (Vachard, 1996; Leven et al., 2006; Vachard and Arefifard, 2015). After the description of the Early Carboniferous Mobarak and Geirud formations by Assereto (1963, 1966), foraminiferal zonations were recognized in several stratigraphic sections of central and eastern Alborz Mountains (Bozorgnia, 1973; Lys et al., 1978; Vachard,
zone, poorly preserved upper Pennsylvanian foraminifers have been reported (Gorgij and Leven, 2013).

The paleogeographical position of Iran during the Carboniferous has been discussed by many authors (Meissami et al., 1977; Sengör, 1990; Stampfli, 2000; Kalvoda, 2002; Torsvik and Cocks, 2004; Wendt et al., 2005; Devuyst, 2006; Brenckle et al., 2009; Muttoni et al., 2009; Zandkarimi et al., 2014, 2017; Vachard and Arefifard, 2015). In order to recognize the paleobiogeographic affinity of Iran during Carboniferous times, improved investigations of foraminiferal assemblages have been undertaken with the following results. In the Upper Paleozoic: i) foraminifers were widespread within tropical and subtropical paleolatitudinal belts (Boudagher-Fadel, 2008; Vachard et al., 2010; Davydov, 2014); ii) they were very sensitive to water temperature, and their associations display different compositions in lower latitude tropical-subtropical belts versus intermediate and higher latitudes, i.e. temperate and boreal belts (Beavington-Penney and Racey, 2004; Murray, 2006; Davydov, 2013; Prothero, 2013); iii) foraminifers had a rapid evolution reaching a high taxonomic diversity and iv) they have adapted to abiotic factors such as the paleoenvironmental shift led by tectonics (Kalvoda, 2002). The data for this study comprise author’s own published and unpublished data gathered during years of field work in different parts of Iran and data from literature. Attention is first focused on the distribution of Carboniferous foraminifers in Iran to analyse later their affinity to either warm-water paleoequatorial belts, temperate belts, or cold-water higher latitude belts. Tropical, temperate and boreal belts (Beavington-Penney and Racey, 2004; Murray, 2006; Davydov, 2013; Prothero, 2013) have been both attributed to the southern Paleo-Tethyan domain (Meissami et al., 1977; Vachard, 1996; Ueno, 2006; Davydov and Arefifard, 2007; Huang et al., 2015; Ueno et al., 2015). The northern transitional zone, known as the Arctic paleogeographic realm, subsisted from mid Pennsylvanian to early Sakmarian times. It included foraminifers with low diversity that developed from the northern Urals, in the East, to the Canadian Arctic and Alaska in the West (Rui et al., 1991).

**PALEOBIOGEOGRAPHY**

**Foraminiferal realms during Late Paleozoic**

Traditionally, three major paleobiogeographic realms have been distinguished for the Upper Paleozoic foraminifers: i) tropical/subtropical Paleo-Tethyan realm, represented by highly diversified foraminiferal faunas, ii) the North American realm and iii) the northern Boreal or Uralian-Franklian realm (Lipina, 1973; Reitlinger, 1975; Ross and Ross, 1985; Kalvoda, 2002). In addition, two transitional realms have been reported to the North and South of the Paleo-Tethyan realm (Rui et al., 1991; Leven, 1993; Leven and Okay, 1996) that contain cold foraminiferal faunas which share common features. The southern transitional realm or peri-Gondwanan realm is reported from the Carboniferous to the mid Permian, last Sakmarian and Artinskian up to the Guadalupian, (Leven, 1993; Kalvoda, 2002; Ueno, 2006; Davydov and Arefifard, 2007; Huang et al., 2015; Ueno et al., 2015). The northern transitional zone, known as the Arctic paleogeographic realm, subsisted from mid Pennsylvanian to early Sakmarian times. It included foraminifers with low diversity that developed from the northern Urals, in the East, to the Canadian Arctic and Alaska in the West (Rui et al., 1991).

**Carboniferous foraminiferal assemblages in Iran**

**Alborz zone**

In the Alborz zone, Carboniferous deposits are widespread in the central and eastern parts and are better documented than in other areas of Iran. Foraminiferal faunas are mostly attributed to the Mississippian (Tournaisian-Serpukhovian), with rare early and mid-Pennsylvanian (Bashkirian-Moscovian) records in eastern Alborz (Fig. 2).

Lower Tournaisian foraminifers have been reported only from a few sections, where the Upper Devonian and Lower Carboniferous deposits show stratigraphic continuity (Bozorgnia, 1973). These faunas include species-poor assemblages of earlandiid and septabrunsiid species belonging to biozones MFZ1 to MFZ5 (Bozorgnia, 1973; Vachard, 1996; Ueno et al., 1997; Brenckle et al., 2009; Falahatgar et al., 2015). There are conflicting ideas about the biogeographic affinity of these foraminifers. They have been both attributed to the southern Paleo-Tethyan domain (Meissami et al., 1977; Vachard, 1980; Wendt et al., 2005) and related to northern warm-water Paleo-Tethyan faunas (Kalvoda, 2002; Devuyst, 2006; Brenckle et al., 2009). The lower Tournaisian foraminiferal biozone contains *Earlandia minor* (Rauscher Chernousova, 1948) and *Septabrunsiina Kremlinica* (Lipina, 1948) along with *Archaesphera magna* Suleimanov, 1945, *A.*
minima Suleimanov, 1945, 
Eotuberitina reitlingerae, 

A recent investigation on the Tournaisian in the Kahanag section, central Alborz, revealed that the biozones MFZ1 to MFZ5 do not contain rich species assemblages in this region (Falahatgar et al., 2015). In Alborz, the upper Tournaisian foraminiferal assemblages are more diverse than the lower Tournaisian ones. The MFZ6 to MFZ8 biozones (upper Tournaisian) include Eotextularia diversa (Chernysheva, 1948) (Bozorgnia, 1973) along with Darjella monilis Malakhova, 1963 and Eoforschia moelleri (Malakhova, 1953). Another upper Tournaisian foraminifer reported is Eoparastaffellina rotunda Vdovenko, 1971 (Falahatgar et al., 2015). The main representative species of the Tournaisian of western Europe, North America and the Russian Platform, such as Chernysheinella glomiformis (Lipina, 1948), Chernysheinella multicamerata (Lipina, 1955), and Brunsia sp. Mikhailov, 1935 (Kalvoda, 2002, 2003) are not found in this area. On the other hand,
the Alborz lower Tournaisian foraminifers have close similarity with their counterparts of South China, Turkey and Kazakhstan, which would indicate a peri-Gondwanan affinity (Arefifard, 1997; Falahatgar et al., 2015).

Upper Tournaisian-upper Visean foraminiferal faunas have been reported in several studies (Bozorgnia, 1973; Vachard, 1996; Ueno et al., 1997; Brenckle et al., 2009; Zandkarimi et al., 2014). Eight biozones were recognized, that are correlated with the biozones MFZ8-MFZ14 of Poty et al. (2006), which include the following species: Eoparastaffellina ex gr. rotunda Vdovenko, 1971; 'florigena' Devuyyst, 2006-Lysella cf. gadukensis Bozorgnia, 1973; Eoparastaffellina simplex Vdovenko, 1971-Lapparentidiscus bokanensis Vachard, 1980; Ammarchaediscus Conil and Pirlet, ibid Pirlet and Conil, 1974; Uralodiscus Malakhova, 1973-Glomodiscus Malakhova, 1973; Glomodiscus Malakhova,
1973-Archaediscus Brady, 1873; Poiarkovella Simonova and Zub, 1975 emend. Cõzar 2002 -Mstinia fallax (RAUSER-CHERNOUSOVA and REITLINGER in RAUSER-CHERNOUSOVA et al., 1936); Mstinia bulloides (MIKHAILOV, 1939) emend. DAIN, 1953-Pseudoendothyra MIKHAYLOV, 1939 and Howchinia gibba (HOWCHIN, 1888)-Howchinia bradyana (HOWCHIN, 1888)-Tabisperiodiscus attenuatus (MARFENKOVA, 1978) (Zandkarimi et al., 2014). The foraminiferal assemblages from biozones MFZ8 to MFZ11 reported from the Mobarak Formation in the Valiabad section, have been suggested to have a peri-Gondwanan affinity, whereas those of MZF12 to MZF14 are similar to the assemblages from the northern margin of Paleo-Tethys (Zandkarimi et al., 2014).

The Serpukhovian in central and eastern Alborz is represented by two foraminiferal biozones, Asteroarchaediscus baschkiricus (KRESTOVNIKOV and TEODOROVITCH, 1936)-Globivalvulina sp. SCHUBERT 1921 and Eostaffella pseudostravei (RAUSER-CHERNOUSSOVA and BIELJEV in RAUSER-CHERNOUSSOVA et al., 1936) -E. mirifica BRAZHNIKOV in BRAZHNIKOV and ROTSTOYTEVA, 1967 (Bozorgnia, 1973; Vachard, 1996) which indicate North Paleo-Tethyan elements (Kalvoda, 2002). Recently, Zandkarimi et al. (2017) reported two Serpukhovian biozones in northern Iran, the lower Serpukhovian Biseriella parva CHERNSHEVA, 1948-Climacaminina BRADY, 1873, and the upper Serpukhovian Turrispiroides multivolutus (REITLINGER, 1949)-Brenchklevina ZANNINETTI and ALTNER, 1979-Eostaffellina protvae (RAUSER-CHERNOUSSOVA, 1948). The Serpukhovian-Bashkirian in eastern Alborz comprises three foraminiferal biozones which are the Asteroarchaediscus postrugosus (REITLINGER, 1949)-Eostaffella pseudostravei (RAUSER-CHERNOUSSOVA and BIELJEV, 1936), Pseudoostaffella antiqua DUTKEVICH, 1934 and Profusulinella primitiva GROZDLOVA and LEBEDeva, 1954 (LYS et al., 1978; Vachard, 1996). These biozones suggest southern Laurasian affinity (Kalvoda, 2002).

Gaetani et al. (2009) recognized the fusulinid species Plectostaffella jakhensis REITLINGER, 1971 indicative of early Bashkirian in the Dzodshband Formation in the Toyeh section from eastern Alborz. This fusulinid is also reported from Turkey, Russian Platform, Urals, Donets Basin and central Iran (Leven et al., 2006).

Two Moscovian foraminiferal biozones were reported from eastern Alborz, the Aljutovella tikhonovichi RAUSER-CHERNOUSSOVA in RAUSER-CHERNOUSSOVA et al., 1951 and Fusulinella ex gr. bocki MOELLER, 1878 (LYS et al., 1978; Vachard, 1996) indicative of the northern margin of Paleo-Tethys (Rui et al., 1991, Kalvoda, 2002). Recently, Gaetani et al. (2009) reported fusulinids, e.g. Ozawanella mosquensis RAUSER-CHERNOUSSOVA in RAUSER-CHERNOUSSOVA et al., 1951, Pseudostaffella (P.) paracompressa SAFONOVA in RAUSER-CHERNOUSSOVA et al., 1951, Taitzehoellia cf. prolirbovichii (RAUSER-CHERNOUSSOVA, 1951), Profusulinella prisca (DEPRAT, 1912) and P. convoluta (LEE and CHEN in LEE et al., 1930), from eastern Alborz and referred them to the early Moscovian. These fusulinid faunas are also found in Eurasia, North America, South China, and Turkey and have Paleotethyan affinities (Zhang et al., 2003; Groves et al., 2007; Okuyucu, 2009; Kobayashi, 2011). There is no evidence of Kasimovian deposits in this area.

One fusulinid assemblage Ruchenzevites DAVYDOV, 1986 -Rausertes ROSOVSKAYA, 1950, from the latest Ghzelian, has been reported in the Toyeh Formation (Gaetani et al., 2009). The fusulinids of this age were widespread in the warm water Paleo-Tethyan realm from the Carnic Alps, in the West, to South China, in the East (Leven and Taheri, 2003; Leven et al., 2006).

Central Iran

Carboniferous foraminiferal faunas of central Iran are reported and described from the Tabas, Posht-e Badam and Yazd blocks and from the Shareza area (Baghbani, 1993; Leven and Taheri, 2003; Leven et al., 2006; Leven and Gorgij, 2006a; Leven and Gorgij, 2008; Leven and Gorgij, 2011a, b, c; Vachard and Arefifard, 2015) (Fig. 2).

Lower Carboniferous foraminiferal assemblages have been described from the Gachal Formation in the Posht-e Badam Block. The rich associations of the uppermost Tournaisian-lower Visacean foraminiferal biozones contain Eoparastaffellina ex gr. rotunda VDOVENKO, 1971 (upper MFZ8), Eoparastaffellina ex gr. simplex VDOVENKO, 1971 (lower MFZ8-9), and Eostaffella RAUSER-CHERNOUSSOVA, 1948 along with Lapparentidiscus VACHAR, 1980 (upper MFZ9) (Vachard and Arefifard, 2015). They show a close resemblance with western Europe and southern Urals and have similarities with the coeval foraminiferal fauna from Alborz (Vachard and Arefifard, 2015).

The Visacean-Serpukhovian foraminiferal fauna from the oolitic limestones at the topmost Gachal Formation, in the Padhe section, Posht-e Badam Block, have elements of northern Paleo-Tethyan affinity and contain “Viseidiscus” monstratus (GROZDLOVA and LEBEDeva, 1954), Planoarchaediscus sp. MIKLUKHO-MAKLAY in KIPARISSOVA et al., 1956, Glomodiscus oblongus (CONIL and LYS, 1964), Earlandia sp. PLUMMER, 1930, Eogloboendothyra? sp. VDOVENKO, 1972, Pseudoplanotoendothyra? sp. BRAZHNIKOV and VDOVENKO in BRAZHNIKOV, 1982 and Endothyranopsis sp. CUMMINGS, 1955 (Leven and Gorgij, 2011a).


A diversified association of Moscovian foraminifers in the Tabas and Yazd blocks contains *Aljutovella cafumiganica* Bensh, 1969, *A. priscoidea* (Rauser-Chernousova, 1948), *Putrella sp.* Rauser-Chernousova in Rauser-Chernousova et al., 1951, *P. donetzianna* (Lee, 1936), *P. persica* Leven et al., 2006, *Fusulinella (Moellerites) praebocki* Rauser-Chernousova in Rauser-Chernousova et al., 1951 and *Fusilla typica* Lee and Chen in Lee et al., 1930 (Leven et al., 2006; Leven and Gorgij, 2011b). The Bashkirian-Moscovian foraminiferal associations in the Tabas and Yazd blocks represent typical elements of the eastern European Platform (Leven et al., 2006; Leven and Gorgij, 2011b).

There is no evidence of Kasimovian foraminiferal faunas in central Iran.

Baghbani (1993) reported on Moscovian foraminifer associations from Tang-e Darchaleh section, near Shahrreza town. They contain Endothyra spp. Phillips, 1846, Pseudostaffella sp. Thompson, 1942, Ozawainella mosquensis Rauser-Chernousova in Rauser-Chernousova et al., 1951 and representatives of the Fusulininae subfamily. These foraminifers are assigned to the Ozawainella mosquensis Rauser-Chernousova in Rauser-Chernousova et al., 1951 biozone with typical eastern European biogeographic affinities.

Moscovian fusulinids were also identified in the Asad-Abad section, NE of the Shahrreza town and contain five typical assemblages of the northern Paleo-Tethyan domain (Middle Asia, Donbass, eastern European Platform), such as i) *Pseudostaffella gorskiyi* (Dutkevich, 1934), *Neostaffella ozawai* (Lee and Chen in Lee et al., 1930), *Putrella sp.* Rauser-Chernousova in Rauser-Chernousova et al., 1951 ii) *Neostaffella umbilicata* (Putria and Leontovich, 1948), *Putrella primaris* Leven, 2008 in Leven and Gorgij, 2008 iii) *Beedeina ex gr. samarica* Rauser-Chernousova and Beljaev in Rauser-Chernousova et al., 1940, *B. bona anarakensis* Leven and Davydov in Leven et al., 2006, *Citronites aff. apokensis* (Rauser-Chernousova in Rauser-Chernousova et al., 1951) iv) *Fusulinella (Moellerites) bedakensis* Solovieva, 1986, *F. (Fusulinella) pseudobocki* Lee and Chen in Lee et al., 1950, *F. (Fusulinella.) aff. fluxa* Lee and Chen in Lee et al., 1930, and v) *Beedeina keltmensis* (Rauser-Chernousova, 1953), *Kamaina ex gr. ozawai* (Rauser-Chernousova and Beljaev in Rauser-Chernousova et al., 1936) (Leven and Gorgij, 2008).


**Sabzevar zone**

In this zone there is no evidence of the Mississippian, only the upper part of the Pennsylvanian is represented (Fig. 2). Gorgij and Leven (2013) found poorly determined...

**DISCUSSION**

The paleogeographic reconstruction of Iran for the Late Paleozoic has always been controversial. The absence of Variscan orogeny in Iran and the resemblance of most Paleozoic deposits to their coeval strata in the Arabian Plate led to the idea that Iran had a Gondwanan affinity during the Late Paleozoic. The Late Paleozoic was a period of major tectonic events. By the Early Permian, the supercontinent Pangea had coalesced, the Paleo-Tethys ocean was closed, and Cimmerian terranes including present-day Turkey, Iran, Afghanistan, South Pamir, Karakoram, Tibet, Qiantang, Burma, Thailand and Malaysia broke-off from the northern margin of Gondwana and drifted northward across the Paleo-Tethys as a result of the Neo-Tethys opening to collide finally with the Cimmerian Orogen (Sengör, 1984; Scotese and Langford, 1995; Besse et al., 1998; Metcalfe, 1999; Angiolini et al., 2003; Kent and Muttoni, 2003; Ruban et al., 2007; Muttoni et al., 2009; Berra and Angiolini, 2014).

The taxonomic composition of Carboniferous foraminifers in Iran has been studied since the 1960s by Iranian and European workers. But, there is no consensus on their paleobiogeography. The results of previous studies suggest that these foraminifera were related to either the southern margin of the Paleo-Tethys (Meissami et al., 1977; Vachard, 1980, 1996; Stampfli, 2000; Torsvik and Cocks, 2004; Brenckle et al., 2009; Zandkarimi et al., 2014; Qiao et al., 2016) or the northern margin (Kalvoda, 2002; Devuyst, 2006). According to the paleomagnetic data from the Alborz zone, Iran shows an Apparent Polar Wandering (APW), well-matched with that of West Gondwana (Besse et al., 1998; Muttoni et al., 2009). These data suggest a paleolatitude for Alborz of about 40-45° South in the Early Carboniferous. Considering these data, North Iran was positioned in the northern margin of Gondwana during this period (Angiolini et al., 2007; Brenckle et al., 2009; Bahrammanesh et al., 2011; Falahatgar et al., 2015; Qiao et al., 2016).

Paleontological evidence stands in opposition to the presumed 40-45° South location of North Iran in the Early Carboniferous. The smaller foraminifers and brachiopods reported from the Lower Carboniferous of Alborz are indicative of warm water (Brenckle et al., 2009; Bahrammanesh et al., 2011). Warm water faunas from Iran may be explained by a counterclockwise oceanic current that conducted equatorial warm Paleo-Tethyan waters to the peri-Gondwanan blocks, including Iran at the southern margin of the Paleo-Tethys (Kissling et al., 1999; Brenckle et al., 2009; Bahrammanesh et al., 2011). Additionally, during the Early Carboniferous there were no glacial events to hamper this warm surface current gyres and the dispersion of taxa from the tropics towards intermediate latitudes. Although the climate began to cool in the late Visean because of the onset of the late Visean glacial event (Melvin et al., 2010), warm water and cosmopolitan faunas of this age in Alborz (Bozorgnia, 1973; Zandkarimi et al., 2014) confirm the continuation of the warm surface-current gyres in the southern border of the Paleo-Tethys (Brenckle et al., 2009).

Zandkarimi et al. (2014) and Falahatgar et al. (2015) speculated that Alborz was located in the southern margin of the Paleo-Tethys up to the early Visean, based on the presence of foraminifers with typical elements of peri-Gondwanan affinity. They hypothesized that since the Paleo-Tethys was narrow in the early Visean, the peri-Gondwanan terranes in the southern border of the Paleo-Tethys were easily connected with those of the northern margin. Moreover, these authors noted that the mid Visean foraminiferal assemblages in Alborz were similar to those of the northern margin of Paleo-Tethys and concluded that Alborz rifted from the northern margin of Gondwana and migrated to the North in the early mid Visean. They considered this as the first stage of the Cimmerian terranes assembly.

The Upper Tournaisian-lower Visean foraminifers of Posht-e Badam, central Iran, are similar to those of Alborz (Vachard and Areffifard, 2015). It has also been mentioned that the foraminiferal species identified in the Lower Carboniferous of the Posht-e Badam Block have common features with both the northern and southern margins of the Paleo-Tethys. Vachard and Areffifard (2015) suggested that since Alborz has been attributed to the peri-Gondwanan margin during the late Tournaisian-early Visean by many authors, the Posht-e Badam Block was probably located in the southern margin of the Paleo-Tethys as well.

Bashkirian-Moscovian foraminiferal assemblages have been examined both in North and central Iran, but beyond these regions there are no reports in Iran, possibly due to the lack of deposition or erosion. In the Tang-e Darchaleh section, near the town of Shahreza, Moscovian foraminifers were reported and showed biogeographic affinity with the eastern European platform (Baghbani, 1993). The Bashkirian-Moscovian foraminiferal associations in
North and central Iran reveal great similarities. They also show strong relationship with coeval foraminifers from Turkey, central Asia, Donets, Russian Platform and the Urals located in the northern margin of the Paleo-Tethys during this period (Kalvoda, 2002; Leven et al., 2006; Dzhenchuravea and Okuyucu, 2007).

Vachard (1980, 1996) compared the Carboniferous deposits in the Tabas region, Central Iran, with those of central Afghanistan, and the ones in Alborz strata with the Band-e Bayan sequences in northern Afghanistan. He concluded that there were no similarities between the Carboniferous basins in North and central Iran. Leven et al. (2006) objected to Vachard’s correlations and suggested that there is no faunal evidence to support these comparisons. They argued that Bashkirian-Asselian foraminifers in Iran are not endemic and both central and North Iran belonged to the same basin in the Bashkirian-Moscovian time.

There is no evidence of Kasimovian foraminifers in Iran, may be as a result of a regional regression and subsequent subaerial erosion. The uppermost Gzhelian foraminiferai faunas in Alborz, central Iran and the Sabzevar zone contain typical elements of the northern margin of the Paleo-Tethys and have resemblance to those of the Carnic Alps, Donets Basin, Eastern European Platform, Darvaz and Fergana (Leven and Gorgij, 2006a,b; Gaetani et al., 2009; Leven and Gorgij, 2011a,b,c; Gorgij and Leven, 2013).

Based on the available data on Lower Carboniferous foraminifaera, it is plausible that Iran was located in the southern margin of the Paleotethys and displayed a peri-Gondwanan faunal biogeographic affinity in the Early Carboniferous (Fig. 3). The presence of faunal elements of both northern and southern Paleo-Tethys supports this idea (Bagheri and Stampfli, 2008; Brenckle et al., 2009; Bahrammanesh et al., 2011; Berra and Angiolini, 2014; Vachard and Areffard, 2015). Furthermore, the concurrent occurrences of both faunas may be explained, either by the southerly circulation of the warm-water Paleo-Tethyan current along the northern margin of Gondwana (Brenckle et al., 2009; Bahrammanesh et al., 2011) or by the narrowness of the Paleo-Tethys ocean allowing the connection of the peri-Gondwanan faunas with those of the southern margin of Laurussia (Zandkarimi et al., 2014; Vachard and Areffard, 2015; Falahatgar et al., 2015). The paleogeographic position of Iran as part of Gondwana in the Early Carboniferous is also supported by the strong accordance of paleomagnetic poles of Iran and West Gondwana, during the Ordovician- Early Carboniferous (Muttoni et al., 2009). In fact, based on paleomagnetic data, Iran has a similar drifting history as the Arabian Plate from Late Ordovician to Early Carboniferous (Muttoni et al., 2009). The Ordovician-Carboniferous Gondwana apparent polar wander path shows that the Arabian Plate, as part of Africa, sustained an important plate motion, drifting from a high southern latitude in the Late Ordovician to a subequatorial latitude in the Early Devonian and then moved to intermediate southern latitudes in Late Devonian-Early Carboniferous times (McElhinny et al., 2003).

The faunal assemblages of the Late Carboniferous in Iran are clearly different from those of the peri-Gondwanan realm. They differ both in taxonomic composition as in climatic affinity. The Bashkirian-Moscovian and upper Gzhelian fusulinids in Alborz, central Iran and the Sabzevar zone indicate warm water conditions and are typical of the northern margin of the Paleo-Tethys. This may be linked to the rifting of Iran from the northern margin of Gondwana in early Late Carboniferous and its migration northwards. The movement of Iran toward the North, to a low latitude position with a warm climate is suggested by the occurrence of the Upper Carboniferous coal-bearing sandstones of the Sardar Formation in central Iran (Stöcklin et al., 1965). Coal is one of the most important paleoclimatic indicators of humid climate conditions. These sandstones are rich in quartz and poor in Al₂O₃ indicating humid to semi-humid climate. Moreover, the geochemical analyses of the Sardar Formation sandstones suggested a high degree of chemical weathering, indicative of warm and humid conditions during the deposition of these sandstones (Khanefhbad et al., 2012). Besides, the paleogeographic reconstruction of Iran based on paleomagnetic data suggests a 30°S position for Iran (Muttoni et al., 2009). The whole dataset suggests a warm and humid climate during the Late Carboniferous in central Iran.

Neotethyan rifting started in Carboniferous times along the eastern Gondwana margin from India (Garzanti and Sciuinach, 1997) to Oman (Al-Belushi et al., 1996). The continental breakup and the onset of the oceanic lithosphere formation followed from the Himalayas towards northern Oman in mid-Early Permian time (Garzanti, 1999; Angiolini et al., 2003).

Indications of the early phases of the Neo-Tethys opening during the Carboniferous and rifting of the Cimmerian terranes from northern Gondwana are recorded in the Misho magmatic complex and Ghushchi complex in northwestern Iran (Saccani et al., 2013; Dilek et al., 2014; Moghadam et al., 2014). Using SIMS U-Pb zircon ages, the Misher gabbros are dated at 356.7±3.4Ma and the gabbronorites and granites of the Ghushchi complex yield an age of ~320Ma. These igneous rocks may provide good evidence of the timing of the Neo-Tethys opening in Iran and cast doubts about the previous ideas of the rifting of Neo-Tethys in Iran in the Early Permian (Angiolini et al., 2007; Gaetani et al., 2009; Muttoni et al., 2009).
Proofs about Carboniferous magmatic activities and extensional deformation, related to the Variscan orogeny are increasing in Iran. For instance, an angular unconformity below the Upper Carboniferous(?) - Lower Permian Faraghan Formation in the High Zagros Belt suggests a connection with the Variscan orogeny (Tavakoli-Shirazi et al., 2013). However, the North to North-East trending faults and tilted blocks related to this Variscan unconformity show no signal of compressional deformation. The Ghushchi complex and Khalifan A-type granites in northwestern Iran are thought to be in conjunction with crustal movements in an extensional tectonic setting (Moghadam et al., 2014). Zanchi et al. (2015), according to the radiometric ages of the trondhjemite dikes and stocks that intruded the accretionary wedge of the Anarak metamorphic complex in central Iran, it was proposed that the subduction of the Paleo-Tethys happened during the Late Carboniferous. These authors suggested that the Anarak metamorphic complex developed along the southern Eurasian margin and was part of an allochthonous crustal fragment belonging to the Variscan belt before the Cimmerian collision of Iran.

Therefore, the Neo-Tethys opening and rifting of Iran from the northern margin of Gondwana has probably occurred sometime between the latest Visean to early Late Carboniferous (Bashkirian) (Fig. 4). Evidence for this conclusion are: i) the northern Paleo-Tethyan affinity of the foraminiferal associations in the late Visean-late Sepukhovian in Alborz, ii) the unique similarity between the Bashkirian-Kasimovian and late Gzhelian fusulinid assemblages of Iran to the northern margin of the Paleo-Tethys and iii) the Carboniferous magmatic activities in northwestern Iran and normal faulting and tilted blocks in the High Zagros Belt which, taken together, support extensional deformation related to the Variscan orogeny.
CONCLUSIONS

i) In the Early Carboniferous, foraminiferal associations in North and central Iran had a cosmopolitan character with elements from both the southern and northern margins of Paleo-Tethys. These faunal assemblages confirm the paleoposition of Iran in intermediate southern latitudes (ca. 30°S) and still forming part of Gondwana. This foraminiferal-based paleogeographic reconstruction of Iran is consistent with the results of paleomagnetic data by Muttoni et al. (2009).

ii) In the Late Carboniferous, data from both smaller foraminifer and fusulinid assemblages in North and central Iran reveal the similarity of these faunas with their northern Paleo-Tethys counterparts. This can be inferred as a sign of the commencement of the separation of Iran from the northern margin of Gondwana and its movement towards the North.

iii) The movement of Iran towards the North and its low latitude position in the Gzhelian also is inferred from the occurrences of the coal-bearing sandstones of the Upper Carboniferous Sardar Formation.

iv) The Neo-Tethys opening in Iran occurred during the Late Carboniferous, based on the foraminiferal associations and magmatic activities in North-West Iran. This conclusion contrast with previous ideas on the onset of Neo-Tethys opening between northern Gondwana and the Cimmerian terranes during the Permian/ and or Triassic.

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REFERENCES

Alavi, M., 1991. Tectonic map of the Middle East, Geological Survey of Iran. Tehran, Iran, Scale 1:5 000 000.


REFERENCES
Devuyst, F.-X., 2006. The Tournaisian-Visean boundary in
Deprat, J., 1912. Etude des fusulinides de Chine et d’Indochine
Davydov, V.I., Arefifard, S., 2007. Permian fusulinid fauna of
Davydov, V.I., 2014. Warm water benthic foraminifera document
Davydov, V.I., 2013. Climate fluctuations within the western
Davydov, V.I., Arefifard, S., 2007. Permian fusulinid fauna of
Gondwana affinity from Kalmard Region, East-Central Iran and its significance for the tectonics and paleogeography. Paleontologia Electronica, 10(2), 40pp.
Tournaissian (Early Carboniferous) of the Kahanag section (central Alborz; northern Iran); biostratigraphy with calcareous algae and foraminifers; palaeobiogeographic implications. Revue de Micropaléontologie, 58, 217-237.
Forke, H.C., 1995. The Carboniferous/Permian boundary in the Carnic Alps (Austria): additional observations on correlating fusulinid zones in the stratotype sections of the southern Urals and the Darvaz region with the Schulterkofel section. Permophiles, a Newsletter of Subcommission on Permian Stratigraphy, 26, 13-16.
Forke, H.C., 2002. Biostratigraphic subdivision and correlation of Uppermost Carboniferous/Permian sediments in the Southern Alps: Fusulinoidean and conodont faunas from the Carnic Alps (Austria/Italy), Karavante Mountains (Slovenia), and Southern Urals (Russia). Facies, 47, 201-275.
Grozolidvo, L.P. and Lebedeva, N.S., 1954. Foraminifers from the Lower Carboniferous and Bashkirian stage of the Middle Carboniferous of the Kolvo-Vishera area (in Russian). Trudy Vsesoyuznogo Neftyanogo Nauchno-issledovatel’skogo

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the Russian Platform and the Cis-Ural region (in Russian).


une nouvelle subdivision. Archives des Sciences, Genève, 32, 163-175.


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