

Tethyan oceanic currents and climate gradients 300 m.y. ago

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ABSTRACT

We reconstruct the oceanic circulation pattern of the Tethys Ocean 300 m.y. ago by placing Late Carboniferous–Early Permian climate-sensitive biotic associations from Gondwana and Laurasia on a Pangea paleogeography constrained by selected paleomagnetic data. Warm-climate fossils and facies from Iran, located at that time along the Gondwanan margin of Arabia, are compatible with the existence in the Tethys Ocean of a warm subtropical surface current gyre, whereas cold surface currents swept the glaciated Gondwanan margin at higher southern latitudes, redistributing cold biota toward the tropics. This Tethyan surface current system and the associated narrow zonal barrier show similarities to recent glacial climate patterns. When placed on a large-scale paleogeographic reconstruction of Pangea of the B type, it neatly explains the otherwise problematic observation that the Carboniferous–Permian biota of Iran and northern Arabia is dominated by warm Euramerican and/or Russian taxa that are strikingly different from typical cold Gondwanan associations.

Keywords: Carboniferous–Permian, biotic distribution, Pangea B configuration, paleocurrents, Gondwanan glaciation, paleogeography.

INTRODUCTION

Reconstructing past oceanic circulation patterns, latitudinal thermal gradients, and the history of Earth's climate in general requires placing climate-sensitive biotic associations on paleogeographic reconstructions; these require a paleogeographic grid constructed independently of climate, and paleomagnetism is the best method (Irving, 2005). Here we apply a biogeographic-paleomagnetic approach to reconstruct the climate gradients and the general features of the oceanic circulation pattern of the Tethys Ocean during the extensive glaciation that affected Gondwana 300 m.y. ago, and look for analogies with circulation patterns typical of the last glacial maximum (ca. 18 ka). We first reconstruct the general paleogeography of Pangea by using paleomagnetic data, and subsequently focus on the biogeography of the Gondwanan margin facing the Tethys Ocean, and specifically on Iran, the locus of extensive field work carried out in the recent years by some of us. Paleontological-biogeographic data from Iran are summarized and compared to coeval data from adjacent Gondwanan terranes located at higher southern latitudes as well as to Boreal bioprovinces from Laurasia.

PALEOGEOGRAPHY OF IRAN WITHIN PANGEA

During the Late Triassic, several Gondwanan terranes, including Iran, broke off the eastern Gondwanan margin to collide with the Eurasian active margin. This process of accretion resulted in one of the most conspicuous mountain chains of the Phanerozoic, the Cimmerian orogen (Şengör, 1979). Iran is composed of several blocks, e.g., northern Iran—Alborz, central Iran—Lut, and Sanandaj-Sirjan (Fig. 1). Northern and central Iran shared a common geological evolution for most of the Paleozoic; they are characterized by a substantial continuity of Paleozoic sedimentary rocks and a uniform distribution of biota (Berberian and King, 1981; Leven and Gorgij, 2006). According to recent data,

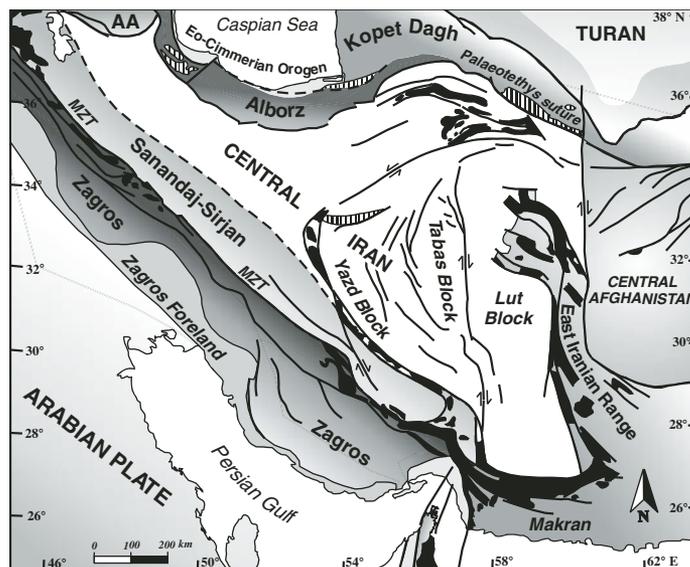


Figure 1. Tectonic scheme of Iran. Black: Mesozoic ophiolites along Main Zagros thrust (MZT) and around central Iran. Hachures indicate ophiolites and metamorphic rocks related to Cimmerian orogeny. AA—Astar-Adzerbaijan block.

the metamorphic Sanandaj-Sirjan zone shows an affinity to central Iran (Rachidnejad-Omran et al., 2002), whereas the Zagros belt is part of Arabia (Fig. 1). Northern and central Iran have been considered to be located along the Arabian margin during the Paleozoic (Stöcklin, 1974) on the basis of several lines of evidence: (1) their pre-Paleozoic basement was affected by the Pan-African orogeny; (2) Precambrian–Cambrian sedimentary rocks are continuous between Arabia and northern and central Iran; and (3) Variscan deformation is lacking.

We place Iran in a broad paleogeographic context by reconstructing the configuration of Pangea using selected Late Carboniferous–Early Permian paleomagnetic data (ca. 315–285 Ma; mean ca. 300 Ma) from stable Africa and Europe (GSA Data Repository Table DR1 and Fig. DR1¹). Africa is internally treated as three plates (northwest, northeast, and South Africa) with parts of Adria tectonically coherent with northwest Africa (Muttoni et al., 2003). Northwest Africa and Adria are reconstructed using a paleomagnetic pole placed (within error resolution) at 239.2°E, 33.3°N ($N = 4$, $K = 418$; $A_{95} = 4.5^\circ$) obtained by averaging poles from northwest Africa and Adria. Internal Gondwana plates are reconstructed using

¹GSA Data Repository item 2007267, Figure DR1 (Late Carboniferous–Early Permian paleomagnetic poles), Figure DR2 (stratigraphic log of Pennsylvanian–Early Permian succession of northern Iran with list of taxa), Table DR1 (paleomagnetic poles), and Table DR2 (data matrix of brachiopod genera for statistical analysis), is available online at www.geosociety.org/pubs/ft2007.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Euler poles of Lottes and Rowley (1990). Eurasia is reconstructed using a paleomagnetic pole placed (within error resolution) at 169.3°E, 41.8°N (N = 12, K = 151; $A_{95} = 3.5^\circ$) obtained by averaging poles from Europe. Internal Laurasia plates are reconstructed using Euler poles of Bullard et al. (1965). These data support a configuration of Pangea of the B type similar to that introduced by Irving (1977) and confirmed by subsequent analyses (Muttoni et al., 1996, 2003; Torcq et al., 1997; Irving, 2005; but see Torsvik and Van der Voo, 2002), where Africa is placed south of Asia and South America is south of Europe (Fig. 2). Pangea B continued to exist well into the Early Permian and transformed into a more classical Wegenerian type of Pangea by the Late Permian–Early Triassic by means of ≥ 3000 km of dextral motion of Laurasia relative to Gondwana taking place essentially along the Variscan suture (Muttoni et al., 2003).

Paleomagnetic data from volcanic rocks from northern Iran, albeit sparse, point to a paleolatitude of $\sim 50^\circ \pm 5^\circ$ during the Late Devonian (Wensink et al., 1978) and of $\sim 12^\circ \pm 3^\circ$ during the middle Permian (Besse et al., 1998); these values are broadly compatible with a Southern Hemisphere location of Iran adjacent to the Arabian margin (Fig. 2), in agreement with alternative paleogeographic reconstructions from the literature (e.g., Torsvik and Cocks, 2004).

BIOTIC DISTRIBUTION PATTERN

Within the paleogeographic framework outlined above, the paleontological affinities and differences described herein are used to define the spatial distribution of bioprovinces in order to gauge large-scale paleoclimate. Angiolini and Stephenson (2007) showed that the Lower Permian (Asselian–Sakmarian) brachiopod assemblages of northern Iran [*Neochonetes* (*Neochonetes*) sp., *Costispinifera* sp., *Reticulatia uralica*, *Calliprotonia* sp., *Juresania dorudensis*, *Linoproductus dorotheevi*, *Cancrinella cancriniformis*, *Acosarina* aff. *juresanensis*, and *Larispirifer fantinestinii*; fossils and stratigraphic log in Fig. DR2 (see footnote 1)] are substantially different from the coeval cold and poorly diversified assemblages of Gondwana (Western Australia, India, Oman) and its peripheral (Perigondwanan) regions (Karakoram, central Afghanistan, and Sibumasu with Thailand and Baoshan; Angiolini et al., 2005) (Fig. 2).

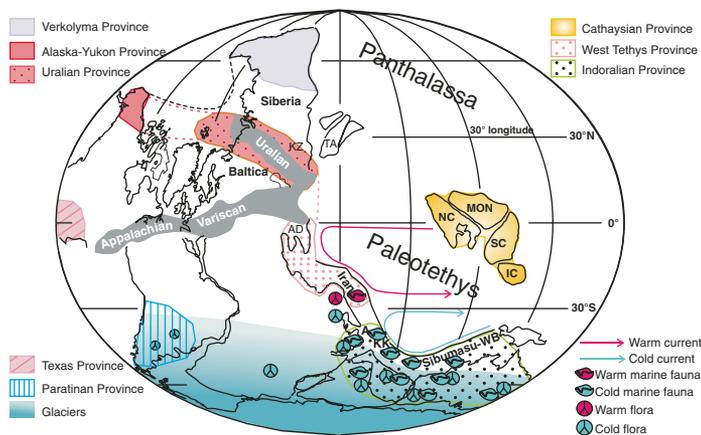


Figure 2. Distribution of bioprovinces and oceanic circulation pattern plotted on a Pangea B configuration of 300 m.y. ago. Bioprovinces distribution modified from Shi (1998). Cool to warm Verkolyma, Alaska-Yukon, and Uralian Provinces are part of Boreal Realm; warm Texas, West Tethys, and Cathaysian Provinces are part of Tethyan Realm; cold Indoralian and Paratitan Provinces are part of Gondwanan Realm. Extension of glaciers and distributions of cold marine faunas are modified from Angiolini et al. (2005). Distribution of Appalachian, Variscan, and Uralian thrust belts is from Matte (2001) (modified). KZ—Kazakhstan, TA—Tarim, NC—north China, MON—Mongolia, SC—south China, IC—Indochina, WB—west Burma, KK—Karakoram, A—central Afghanistan, AD—Adria.

Instead, Iranian brachiopods show similarities to coeval biota from the warm Boreal Realm (Shi, 1998) of the Urals, Russian Platform, Yukon Territory, and Carnic Alps (Angiolini and Stephenson, 2007). The same holds true for the Carboniferous; recently collected (and under study) Mississippian brachiopods from northern and central Iran mostly consist of species typical of the Russian Platform.

We substantiate these observations by means of multivariate analysis. A data matrix of 71 brachiopod genera of Early Permian (Asselian–early Sakmarian) age from 10 geographic operational units (OGUs) from the Gondwanan Realm, including Iran and additional Perigondwanan regions, and the Boreal Realm, has been compiled from personal data and the published literature (Table DR2). Statistical analysis was performed by using PAST software (Hammer et al., 2001). Pre-processing manipulation of the original data matrix led to removal of outliers, such as genera exclusive of one OGU as well as genera common to all OGUs. The secondary matrix was then processed in Q mode by multiple classification (cluster analyses) and ordination techniques (principal coordinate analyses, nonmetric multidimensional scaling). Cluster analysis (CA) of the derived data matrix was carried out by flexible unweighted pair-group arithmetic averaging based on the Jaccard coefficient of community. Ordination methods, which do not force OGUs into groups but provide information if natural clusters exist, was then applied to test the groups identified by CA. Principal coordinates analysis and nonmetric multidimensional scaling have been run on the same data set, showing natural grouping of the faunal stations in the scatter plots, which roughly correspond to those obtained by CA. The Procrustes rotation applied to the two different ordinations of the same data set showed that they are closely fitted, the stress values being close to zero.

As a general conclusion of multivariate analysis we find that Lower Permian brachiopods of Iran are best grouped with warm taxa from the Urals and Yukon rather than with cold taxa from Gondwana-Perigondwana (Western Australia, eastern Australia, central Afghanistan, Karakoram, India, Baoshan, Thailand) (Fig. 3).

Fossil groups other than brachiopods seem to confirm these findings. For example, Leven and Gorgij (2006) showed that Pennsylvanian–Lower Permian fusulinid assemblages of northern and central Iran are similar to those of eastern Europe and the northern Paleotethys (Carnic Alps, Uzbekistan, Tajikistan). The distribution of Pennsylvanian fusulinids along the western and southern shore of the Paleotethys is restricted to low latitudes, whereas no fusulinids have been found at higher southern latitudes (Villa and Wahlman, 2006). Webster et al. (2003) also showed that Mississippian crinoids from northern and central Iran are very similar to those of Europe and North America. On land, the palynomorph assemblage of northern Iran (Angiolini and Stephenson, 2007) is dominated by monosaccate pollen with very few spores; this assemblage is most unlike those recorded from the Asselian–Sakmarian *Granulatisporites confluens* biozone (ubiquitous in the cold Gondwana region), which is characterized by the eponymous taxon as well as the fern spores *Microbaculispora* and *Horriditriletes*, and the colpate pollen *Cycadopites cymbatus*.

Paleontological evidence from this study and the literature from both the marine and terrestrial realms thus seem to suggest that during the Carboniferous–Permian, northern and central Iran had a clear Eurasian affinity rather than a Gondwanan affinity, in apparent contradiction with geological data.

SURFACE OCEAN CIRCULATION PATTERN AND PALEOCLIMATE

The unsuspected strong affinity of the Iranian biota with Boreal taxa is consistent with the proposed Pangea B configuration in which the Urals are placed to the north of the western Tethys Gulf, thus potentially allowing a direct genetic flux from the Boreal Realm (Russia–North America) to the western Tethys (Fig. 2). These warm Boreal taxa did not colonize

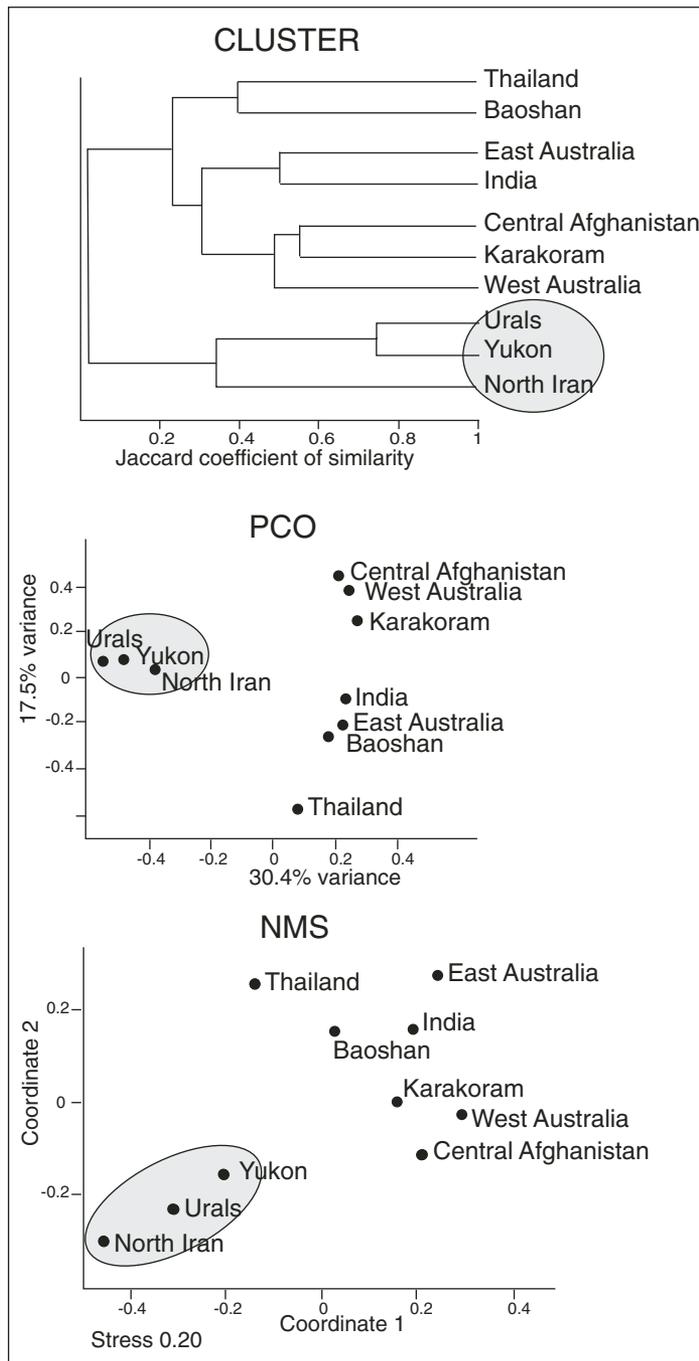


Figure 3. Cluster dendrogram, principal coordinate (PCO), and nonmetric multidimensional scaling (NMS) scatter plots based on Jaccard coefficient of similarity applied to 39 brachiopod genera from 10 faunal stations. Brachiopod data are in GSA Data Repository (see footnote 1). Output of PAST software (Hammer et al., 2001). For location of the faunal station see Figure 2. Baoshan and Thailand are part of Sibumasu.

Gondwanan and Perigondwanan regions to the south of Iran (i.e., central Arabia, central Afghanistan, Karakoram, Baoshan, Thailand), probably because of the effects of the Southern Hemisphere glaciation. In Pennsylvanian–Early Permian time, an extensive glaciation affected much of Gondwana (e.g., Stephenson et al., 2007), leaving a consistent record of glacial deposits and cold biota at high to intermediate southern latitudes in, e.g., central Afghanistan, Karakoram, Baoshan, and Thailand (Fig. 2)

(Angiolini et al., 2005). Consequently, the warm belt, compressed from the south by the thermal effects of the Gondwanan glaciation, was presumably restricted to very low latitudes, where it benefited from a westward-flowing equatorial current (Kutzbach et al., 1990; Kiessling et al., 1999), which, upon reaching the continental shelves of the western Tethys Gulf, deflected southeastward, bringing heat and moisture and Boreal (Uralian) taxa toward the northern corner of Arabia, where Iran was located. Kiessling et al. (1999) proposed a similar pattern of surface currents for the Asselian, albeit using a different paleogeographic reconstruction.

Our paleobiogeographic data not only indicate a compressed warm belt, but also a sharp climatic gradient. Marine faunal distribution shows a sharp boundary between warm and cold assemblages, with transitional faunas and/or zones developed only subsequently (Shi, 1998). On land, Carboniferous–Permian palynomorph assemblages of cold climate occur as far north as central Arabia (Stephenson and Filatoff, 2000), while approximately coeval warmer climate assemblages occur only a few hundred kilometers to the north (Owens and Turner, 1995) (Fig. 2). Facies evidence is also consistent with a narrow warm climatic belt. Glacial sediments deposited during the major and latest episode of the Gondwanan glaciation of Pennsylvanian–Early Permian age occur in central Arabia (Melvin and Sprague, 2006), whereas no coeval glacial deposits have been recorded immediately to the north, as well as in northern and central Iran, where warm-water indicators such as coral bioherms, fusulinid limestones, and oncoidal limestones are present. Oncolite deposition at the Carboniferous–Permian transition is widespread in North America, Europe, Russia, and south China (Shi and Chen, 2006), suggesting the development of shallow-water carbonate platforms in tropical settings during a major sea-level drop caused by the last phase of the late Paleozoic glaciation.

RECENT ANALOGS

Our findings can be reconciled with climate model simulations for the last glacial maximum and Cooperative Holocene Mapping Project (COHMAP) reconstructions (Ruddiman, 2001, and references therein) that indicate the presence of a clockwise spiral of cold air moving off and around the Northern Hemisphere ice sheets, causing glacial cooling in the North Atlantic Ocean and sea ice to reach farther south than it does today. The warm waters of the Gulf Stream were compressed southward and deflected eastward such that they could not penetrate northeastward and bring heat and mild climate to Scandinavia as they do today. Similarly, Permian–Carboniferous ice sheets may have promoted a counterclockwise spiral of cold air at high-moderate latitudes in the Southern Hemisphere, thus compressing northward and deflecting eastward the warm current gyre and preventing it from penetrating southeastward toward the eastern Gondwanan margin (Fig. 2).

The contraction of the warm belt and the expansion of the polar region have modern analogs in the Cenozoic global coolings (Crame and Rosen, 2002), when the near-equatorial biome has contracted ~40%–50% in size. The principal effect of these global temperature drops within the tropical region was not so much a reduction in temperature, but one in area (Ruddiman, 2001; Crame and Rosen, 2002). Similarly, during the Permian–Carboniferous glaciation, the warm belt was narrow and confined to the West Tethys and Cathaysian Provinces (Fig. 2). In addition, the steep climate gradient observed in the reconstructions of the last glacial maximum between the tropics and higher latitudes is similar to that recorded for late Paleozoic time between the western Tethys Gulf and the cold eastern Gondwanan margin.

CONCLUSIONS

We have shown that the distribution of climate-sensitive fossils and bioprovinces placed on a paleomagnetically constrained paleogeographic reconstruction of Pangea of the B type can be used to gauge large-scale climate conditions at the beginning of the Permian. Earth's climate

300 m.y. ago was characterized by a narrow near-equatorial current gyre sweeping the western Tethys Gulf down to Iran. Similar to recent glacial analogs, this compressed warm current gyre was sharply bounded to the south by an extended southern latitude cold belt, caused by the thermal effects of the Gondwanan glaciation. A steep thermal gradient between is recorded by marine faunal distribution and, on land, by palynomorphs. We believe that this integrated paleobiogeographical-paleomagnetic approach is a fundamental prerequisite for modeling of climate and oceanic circulation at global scale in the geological past.

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