Stratigraphy and Geological Correlation, Vol. 10, No. 6, 2002, pp. 586–602. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 10, No. 6, 2002, pp. 62–81.

Climate during Permian–Triassic Biosphere Reorganizations, Article 1: Climate of the Early Permian

N. M. Chumakov and M. A. Zharkov

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia

Received September 19, 2000

Abstract—The Permian was marked by transition from the glacioera to the thermoera, the last one in the geological history. This global climatic reorganization followed the significant paleogeographic changes related to Pangea formation and preceded the major reorganization in the Earth's biota that occurred in the terminal Permian–initial Triassic. Climatic changes served as a coupling process in this chain of events. The analysis of climatic history makes it possible to estimate the role of climate in the cardinal reorganization of the Late Paleozoic biosphere. The compiled one lithological–paleogeographic and two paleoclimatic maps allowed reconstruction of the Early Permian climatic zonation. In the initial Permian, glaciations developed in high and middle latitudes of the Southern Hemisphere and resembled the Pleistocene glacial maximum. Later on, the ice shield gradually decreased and in the late Sakmarian–initial Artinskian, it approached the shape of a polar cap. Separate glaciation centers were preserved only in Antarctica until the end of the Permian. These climatic changes were not unidirectional and showed different-scale oscillations. The Permian climate was strongly influenced by the Pangea supercontinent. The asymmetric position of continental blocks relative to the equator determined by an asymmetry in climatic zoning. It was particularly well manifested at the beginning of the Permian, when the glacial belt in the past continental southern hemisphere extended from the pole to 40°–30°S. Correspondingly, other climatic belts in the southern hemisphere were reduced except for the arid one. To the contrary, the glacial belt was missing in the oceanic northern hemisphere, where most developed were semiarid and temperate belts. By the end of the Early Permian, the asymmetry in position of climatic belts slightly decreased. Arid and semiarid climatic belts were widely developed in both hemispheres. The growing aridity of the Pangea supercontinent was caused by its huge dimension, orographic barriers, and successive regression of epicontinental seas and strengthened by the global postglacial warming.

Key words: Early Permian, glacial, cool–temperate, temperate, semiarid, arid, and equatorial climatic belts, climatic asymmetry, glaciations, oscillations.

INTRODUCTION

The Permian–Triassic interval of the geological history was characterized by three peculiar features, which make it an attractive object for the study of biosphere reorganizations. First, the geographic reorganization that resulted in the formation of principally new configuration of oceans and single Gondwana supercontinent stretched from the South Pole to almost the Northern Pole terminated by its beginning. Second, this interval was marked by major climatic reorganizations: by transition from the Gondwana glacial era (glacioera) to the Siberian ice-free era (thermoera) and by successive aridity growth in Pangea due to its huge dimension, occurrence of mountains isolating it from the ocean, regression of epicontinental seas, and general planetary warming.[1] Third, the largest Phanerozoic biotic crisis that started in the mid-Late Permian, was particularly strong near the Permian–Triassic boundary and resulted in the replacement of the "Paleozoic evolutionary fauna" by the Recent one (Sepkowski, 1990).

Thus, the geographic reorganization was followed by climatic and biotic ones. Their integral consequences were very significant. They imply that the entire biosphere was completely transformed during the Permian–Early Triassic from the "cool" (glacial) to the "warm" (ice-free) one. The climate served as a coupling agent in this reorganization. The analyzed dynamics climatic of history, first of all, the revealed climatic zoning makes it possible to estimate the role of climate in this biosphere reorganization and to elucidate relationships between its main events.

In addition, the Permian–Triassic is the closest interval of geological history most suitable for investigations of transition from the glacial climate of the "cool biosphere" to the ice-free climate of the "warm biosphere." The study of climatic changes during the Permian–Early Triassic and their consequences have therefore a great scientific and prognostic significance for the assessment of similar changes, which can occur in the future. The preceding, older transition from the

[1] This ice-free era is frequently termed the "Mesozoic Era," but this is not quite correct because it spanned, in addition to the Mesozoic, the early Cenozoic Era.

cool to warm state of biosphere occurred in the terminal Ordovician, and it is a substantially more complicated task to study this phenomenon because of many reasons.

Paleogeographic, biotic, partly sedimentological, and climatic events of the Permian have recently been discussed in several summarizing works (Embry *et al.*, 1994; Deynoux *et al.*, 1994; Scholle *et al.*, 1995; Martini, 1997; Ziegler *et al.*, 1998; Rees *et al.*, 1999; Zharkov and Chumakov, 2001). In this paper therefore, we pay particular attention to evolution of the climatic zoning, which has not been considered at all or is characterized very briefly in these works. Our interpretations are based on paleoclimatic reconstructions that reflect typical intervals of the Permian–initial Triassic climatic history. They were compiled using the technique described earlier (Chumakov *et al.*, 1995), maps of sedimentation settings (Zharkov and Chumakov, 2001), paleogeographic data (Dobruskina, 1982, 1994; Meyen, 1987; Durante, 1995; Grunt, 1995; Ignat'ev and Naugol'nykh, 2001; Grunt and Shi, 1997; Wnuk, 1996; Shi and Grunt, 2000), and aforementioned and other paleoclimatic, paleobiogeographic, and geological materials available in publications. Difficulties in the global correlation of Permian and Lower Triassic deposits are well known. We used correlation schemes proposed for the International project "Pangea" (Ross and Ross, 1995). There are several other schemes slightly different from the latter (Kotlyar, 1997; Jin *et al.*, 1997; Kozur, 1998; Leonova, 1999; and others). Existing uncertainties in correlation determine conditional character of age interpretations of proposed paleoclimatic reconstructions and considered events, though do not influence their essence and succession.

In this paper, we discuss climatic zoning and climatic history of the Early Permian Epoch, while the next one will be dedicated to the same aspects of the Late Permian–Early Triassic (Induan) and to general problems of climatic evolution during the Permian–initial Triassic, its causes, and probable consequences.

CLIMATIC ZONING IN THE EARLY PERMIAN

The Early Permian climatic zoning was largely inherited from the Late Carboniferous one, but the trend of climatic changes was opposite in many respects. The tendency of cooling was gradually replaced by warming, and aridity of Pangea increased by the end of the Permian. Both processes cardinally changed the climatic zoning of the planet.

To reconstruct the Early Permian climatic zoning, we compiled, in addition to previously published lithological–paleogeographic map for the late Sakmarian–early Artinskian time (Zharkov and Chumakov, 2001), a similar map for the Asselian Age (Fig. 1) and two paleoclimatic maps for the late Asselian–early Sakmarian and late Sakmarian–early Asselian intervals (Figs. 2, 3). When compiling them, we used materials published in a series of works (Bhattacharya, 1991; Collinson and Miller, 1991; Cole and McLachlan, 1991; Geslin, 1998; Heckel, 1980; Isbell and Collinson, 1991; Peterson, 1980; Rall, 1996; Stevens, 1991a, 1991b; Tsubone *et al.*, 1991; Wartiti *et al.*, 1990; Wopfner, 1991), in addition to others mentioned in the text. The lithological–paleogeographic map demonstrates the sedimentation zoning at the moment of widest development of glaciation and complete formation of the collision orogenic system in central Pangea.

Below, we consider successively climatic belts of both hemispheres from high to low latitudes.

The southern glacial belt of high and middle latitudes. Glaciations of southern Pangea represent most remarkable climatic events of the initial Permian. They were responsible for formation of the sublatitudinal glacial belt (Fig. 1—SG; Figs. 2, 3—G). The development history of this belt is intricate. Most complete glacial sections discussed below demonstrate repeated alternation of continental and glaciomarine sediments with interglacial deposits. This implies a succession of different-rank glacial and interglacial phases and relevant episodes of the belt expansion and reduction accompanied by glacioeustatic sea-level fluctuations and glacioisostatic changes in the continent topography. Even dating and correlation of major (glacial and interglacial) periods is sometimes very difficult because of a limited amount of organic remains in glacial sections, endemic character of fauna and flora, and great facies variability of sediments. This explains discrepancy of age estimates and errors in spatial distribution of separate glacial episodes. Glaciations began in the mid-Carboniferous (Lopez-Gamundi, 1997), and the belt was evidently widest in the terminal Late Carboniferous–initial Early Permian.[2] As many researchers believe now, the Early Permian glaciers were most widespread in the Asselian–Sakmarian time (Visser, 1990, 1994, 1996, 1997; Visser *et al.*, 1997; Frakes *et al.*, 1992; Eyles and Young, 1994; Crowell, 1995; Dickins, 1996; Eyles *et al.*, 1998; and others). Glaciation of that time spread over high and middle latitudes of South America, Africa (including Arabia and Madagascar), India, Tibet, and Australia. Its influence is also recorded in the Malacca–Burma block. Antarctica that surrounded the South Pole was probably entirely covered by ice. The glacial belt was sometimes about 45°–60° wide (Figs. 1, 2). Ice shields and mountainous glaciers left numerous marks of glacial exaration (striated glacial bed with characteristic structures, trough valleys, fiords), different tillites, fluvioglacial, lacustrine–glacial, and glaciomarine sediments in these continental areas. Glaciomarine sediments are particularly widespread, because they were rapidly buried in vast

[2] The width of glacial belts and the total ice volume on the Earth are not strictly proportional. Judging from the eustatic and oxygen-isotope curves, as well as from mathematical modeling and calculated paleotemperatures (Gonzalez-Bonorino and Eyles, 1995), the total ice volume was maximal at the beginning of the Middle Carboniferous.

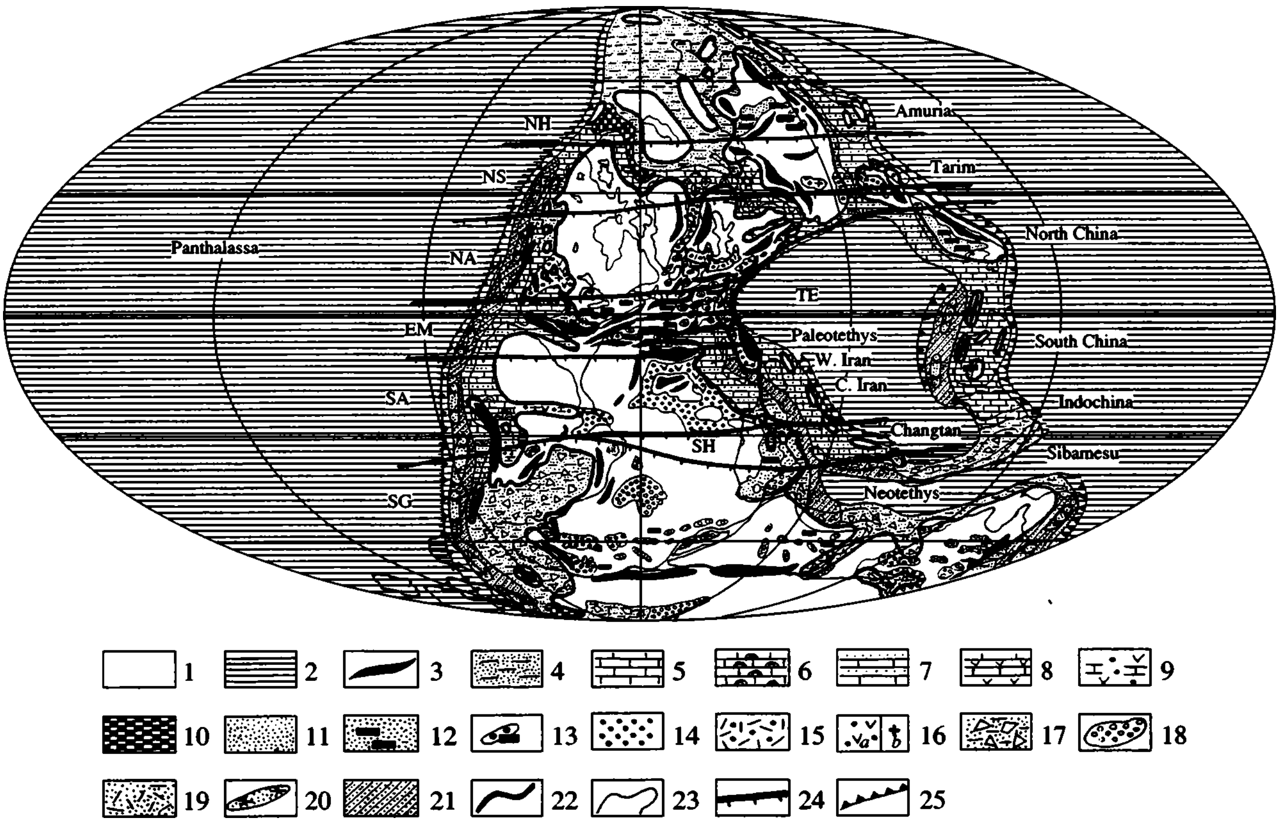

Fig. 1. Lithologic–paleogeographic map for the Asselian–early Sakmarian period of the Early Permian: (1) land; (2) oceans; (3) mountains; (4) shelf seas with terrigenous sedimentation; (5) carbonate platforms; (6) carbonate reefal deposits; (7) shelf seas with terrigenous–carbonate sedimentation; (8) evaporite–carbonate platforms; (9) inner sulfate–carbonate and sebkha basins that accumulated terrigenous red beds; (10) anoxic (black shale) basins; (11) epicontinental and coastal alluvial and alluvial–lacustrine basins in humid zones; (12) coal-bearing basins; (13) red bed terrigenous coal-bearing basins; (14) epicontinental and coastal alluvial, eolian, and lacustrine basins with red beds in arid zones; (15) basins of volcanogenic–terrigenous continental sedimentation; (16-a) epicontinental and coastal alluvial, lacustrine, sebkha, and saliferous basins with terrigenous red beds and gypsum-bearing strata; (16-b) saliferous basins; (17) glaciomarine and glacial deposits; (18) continental glacial deposits; (19) epicontinental basins with gray terrigenous and volcanogenic sediments; (20) terrigenous–volcanogenic complexes of island arcs; (21) turbidite troughs; (22) past coastal lines; (23) modern coastal lines, boundaries of sedimentary basins and lithologic–paleogeographic zones; (24) boundaries of sedimentation belts; (25) subduction zones. Letter symbols: (SG) southern glacial; (SH) southern humid, coal-bearing; (SA) southern arid; (EM) equatorial mountainous; (TE) tropical–equatorial; (NA) northern arid evaporite; (NS) northern semi-arid; (NH) northern humid, coal-bearing; (W. Iran) western Iran; (C. Iran) central Iran.

sedimentation basins in contrast to continental glacial deposits. Glaciomarine sediments accumulated under the influence of shelf glaciers, thawing waters, and icebergs. They were reworked to a different extent by the underwater colluvial processes. In the late Sakmarian–initial Artinskian, glaciers retreated everywhere and the glacial belt became narrower. Its northern boundary was located near the Antarctic Circle (Fig. 3). This interpretation is based on regional correlation and on faunal, palynological, and isotopic data obtained for the Dwyka Group of South Africa (Visser, 1990, 1997; Stollhofen *et al.*, 2000), several Upper Paleozoic glacial successions of Australia (Dickins, 1996; Eyles *et al.*, 1998; and others), and for the Itarare Group of South America (Franca, 1994; Santos *et al.*, 1996).

In the initial Early Permian, the Karroo, Kalahari, and Karasburg basins of South Africa accumulated a thick sequence of glacial deposits—the upper part of the Dwyka Group (up to 700 m thick).[3] Along periphery of the basins and on separating uplifts, the group is composed of continental glacial sediments, and mainly glaciomarine sediments are characteristic of central and southwestern parts of basins. Glaciers advanced in the basins probably twice (in the Asselian and Sakmarian) and subsequently retreated (in the terminal Asselian–initial Sakmarian and at the beginning of the Artinskian Age). The last signs of ice rafting are recorded in South Africa at the base of the Ecca Group and in the lower part of the Prince Albert Formation that is likely of the Artinskian age (Visser, 1994). The low degree of terrigenous material weathering in overlying deposits allows some authors to assume that some glaciation centers

[3] Hereinafter, we follow the stratigraphic scheme elaborated for South Africa by Visser (1990, 1997).

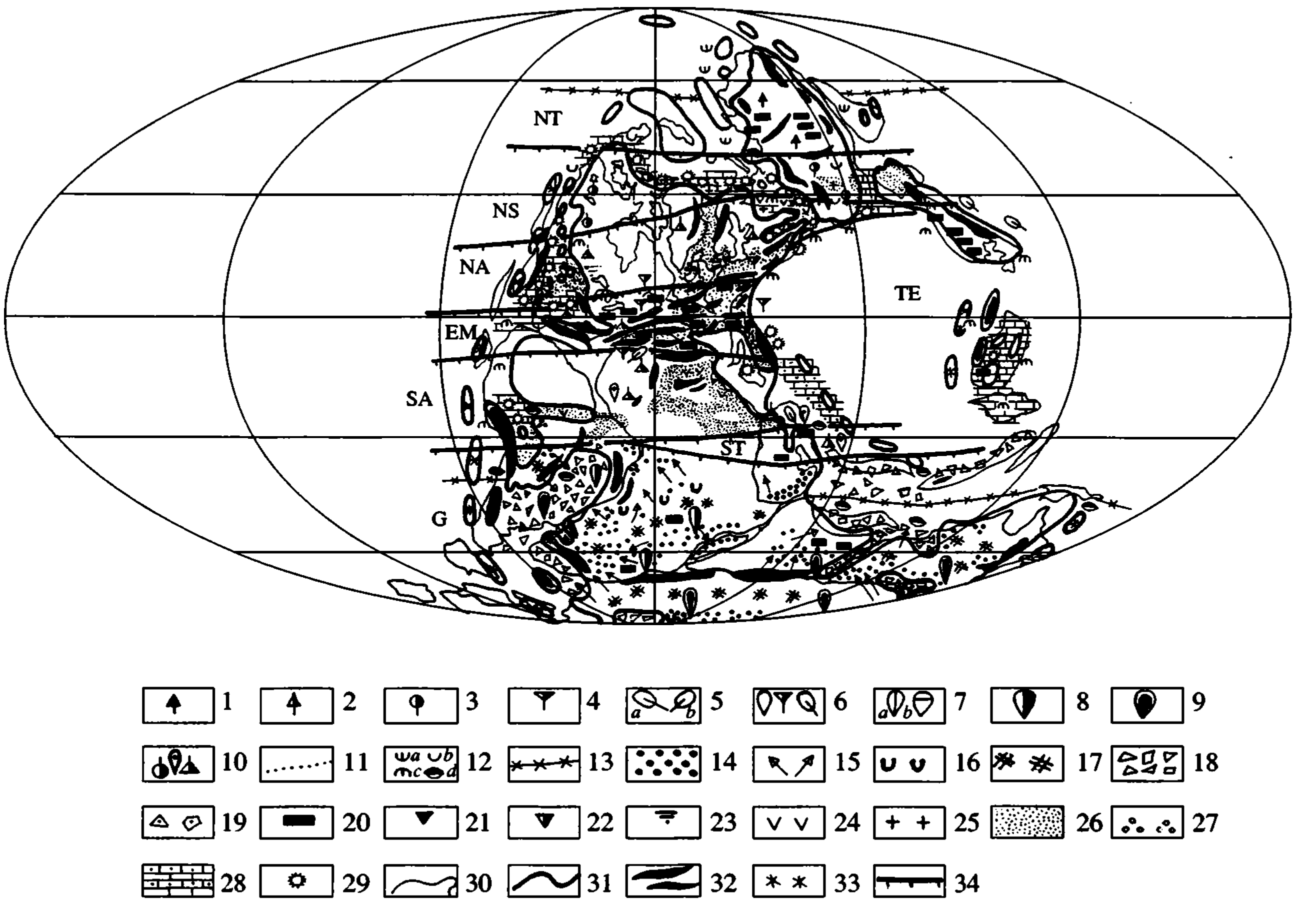

Fig. 2. Climatic zoning of the Asselian–early Sakmarian time with paleontological climatic indicators: (1) cold-resistant North Siberian vegetation, (2) moderately cold-resistant Siberian vegetation, (3) thermophilic Subangarida vegetation, (4) thermophilic Euramerian vegetation and also vegetation similar to the Euramerian one in the Arabian and Burma–Malacca regions, (5) thermo- and hygrophilic vegetation of the Cathaysian type in (a) North and (b) South Chinese floral regions, (6) thermophilic vegetation of the Southern Hemisphere (Gondwanan vegetation with elements of the Euramerian and/or Cathaysian floras in Africa), (7) moderately thermophilic vegetation of the Gondwanan Kingdom in (a) Australian–American and (b) Argentinean–Brazilian regions, (8) moderately cold-resistant vegetation of the Gondwanan Kingdom (*Glossopteris* floral region), (9) cold-resistant vegetation of the Gondwanan Kingdom (*Gangamopteris* floral region), (10) main localities of palynoflora in corresponding phytochores, (11) boundaries of some phytochores, (12) assemblages of shelf invertebrate fauna (after Grunt, 1995; Grunt and Shi, 1997) of (a) high-boreal, (b) low-boreal, (c) tropical (paleoequatorial), and (d) notal types, (13) northern and southern distribution boundaries of Early Permian conodonts (after Wardlaw, 1995); (14–29) lithological indicators: (14) mainly continental glacial and interglacial deposits, (15) directions of glacier movements, (16) fossil trough valleys, (17) glaciation centers, (18) mainly marine and glaciomarine deposits, (19) assumed glacial deposits, (20) coals; (21) bauxites, laterites, (22) humid soils, (23) carbonate, red, and variegated (partly gleyed) soils and calcretes, (24) gypsum and anhydrite, (25) stone, potassium, and other salts, (26) arid red beds, (27) eolian deposits, (28) carbonate platforms, (29) reefs (after Kiessling *et al.*, 1999); (30–33) some geographic elements: (30) modern shore lines, (31) past shore lines, (32) mountains, (33) volcanic chains; (34) boundaries of climatic belts. Letter symbols for climatic belts: (G) glacial, (SCT) southern cool-temperate, (NT, ST) northern and southern temperate, (NS, SS) northern and southern semiarid, (NA, SA) northern and southern arid, (EM) equatorial mountainous, (TE) tropical–equatorial.

could exist longer, up to the Kungurian Age (Visser and Young, 1990; Visser, 1994). The influence of different glaciation centers changed with time. In the Asselian Age, sedimentation was mainly affected by ice shields located in the northeast (Transvaal, Botswana, and Namibia), but later on, most influential were glaciation centers located in Antarctica, east and southeast of the South African Republic (Visser, 1997; Visser *et al.*, 1997). Simultaneously, glaciers advancing in the west–northwestern direction along trough valleys from the Namibian glaciation centers crossed ancient rises of western Namibia to reach the eastern flank of the Parana basin in South America. This is evident from preserved pre-glacial topography, glacial bed structures, and boulder orientations in tillites (Martin, 1981; Santos *et al.*, 1996). Marginal parts of the Parana basin accumulated tillites, fluvioglacial and lacustrine–glacial deposits; ice-rafted deposits are present in the central basin parts.

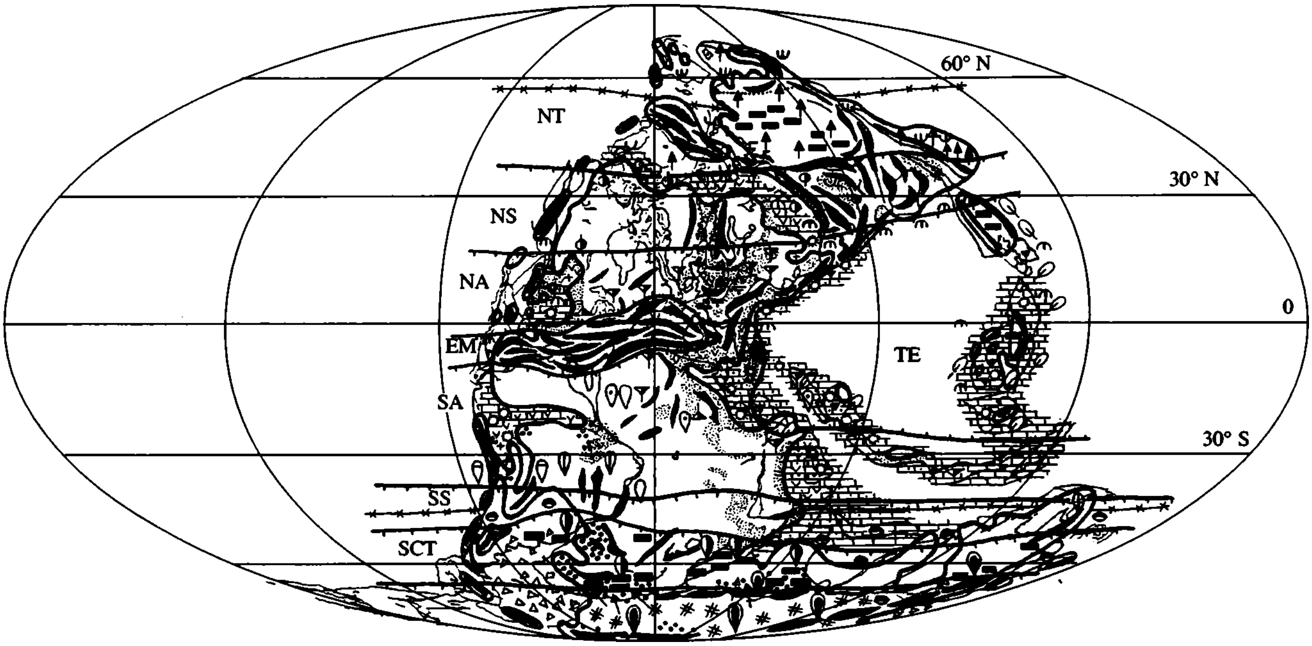

Fig. 3. Climatic zoning of the late Sakmarian–early Artinskian time (symbols as in Fig. 2).

During the Asselian–Sakmarian maximum, glaciers of Africa reached Gabon (Hambrey, 1981), Zair (Cahen and Lepersonne, 1981), and the southern Arabian Peninsula (Levell *et al.*, 1988; Alsharhan and Nairn, 1995; Stephenson, 1999). Thus, the northern boundary of the glacial belt in Africa was located near the paleolatitudes of 30°–40°S.

In Australia, the Lower Permian glacial deposits are preserved in numerous sedimentary basins distributed from the eastern coast of the continent and Tasmania in the south to the Jose Bonaparte Bay in the north (Lindsay, 1997). According to many researchers, Permian glaciations in Australia began in the Sakmarian and lasted, decreasing discretely during the Artinskian and Kungurian ages, at lest until the end of the epoch (Eyles *et al.*, 1998) and further, in the Kazanian (Crowell and Frakes, 1971; Frakes 1979), and even Tatarian time (Herbert, 1981; Veevers *et al.*, 1994). Other researchers suggest that glaciation in Australia was of the Asselian–early Sakmarian age, and that ice covers did not exist after this period (Dickins, 1996; Lindsay, 1997). In opinion of Dickins, the period from that glaciation to the Kazanian Age corresponded to fourfold alternation of cooling and warming phases. Cooling episodes are evident from dropstones (evidence of iceberg or seasonal ice rafting) and glendonites, while warm periods left behind kaolin, bauxites, and Tethyan invertebrates in deposits (Dickins, 1996). The contrasting character of these indicators and abundance of ice-rafted dropstones in Artinskian and Kungurian strata (Spry and Banks, 1962; Eyles *et al.*, 1998) cast doubt on the conclusion that glaciations terminated in Australia before the late Sakmarian time.

During the periods of maximum glaciation, ice shields and mountainous glaciers evidently covered the greatest part of Australia (Crowell and Frakes, 1971; Frakes, 1979) and probably advanced to the northern coast of the continent. Most significant glaciation centers were in the western, central, and southern parts of Australia (Lindsay, 1997) and in the Great Artesian Basin (Frakes, 1979). A thick ice sheet covered mountains along the eastern coast of the continent. Structures of glacial beds and tillites imply that glaciers advanced into the southern coastal area of Australia from the southeast, i.e., from Antarctica (Lindsay, 1997; Bourman and Alley, 1999). Antarctica supplied southeastern Australia mainly with the ice-rafted material. The glacial material was partly transported also from local mountainous centers (Eyles *et al.*, 1998). From northwestern and northern Australia, glaciers apparently advanced into sea basins of the Himalayas, Tibet, and, probably, the Malacca–Burma block, transporting the coarse ice-rafted material in these areas (Lindsay, 1997; Wopfer and Gasshyap, 1997).

In Australia, short climatic oscillations of different ranks complicated the main glacial periods, which lasted as long as several millions of years. For instance, four to five thick glacial members separated by interglacial deposits are registered in the Asselian Lyons Formation of glaciomarine sediments on West Australia (Condon, 1967; Dickins, 1985). Every glacial member consists of four to six smaller glacial submembers also separated by interglacial deposits (Condon, 1967). The average duration of episodes corresponding to glacial and interglacial members and submembers did not exceed 1.00–1.25 and 0.18–0.46 m.y, respectively (Chumakov, 1985; Veevers and Powell, 1987). Some researchers report on signs of glaciation events in sections of southeastern Australia, which resemble the Pleistocene Heinrich events (Eyles *et al.*, 1997). Glacial oscillations are registered also in the Tillite Wynyard Formation of Tasmania that is composed of nine tillite members separated by sediments with marine fossils (Spry and Banks, 1962).

In South America, the Upper Permian glacial deposits are known from several basins southward of 10°S (in modern coordinates). The largest Parana Basin in southern Brazil is as large as 1200 × 1200 km. The Itarare Group corresponds to Upper Paleozoic glacial deposits of the basin, which are up to 1400 m thick. The largest upper part of the sequence (locally as thick as 1200 m) is referred to the Lower Permian. Viewpoints on its stratigraphic range are different. At present, some researchers believe that it spans the Asselian–Sakmarian (Santos *et al.*, 1996; Stephenson, 1999) or Asselian–Artinskian (Franca, 1994) interval, while others suggest that uppermost beds are of the Kungurian age. Like the Lower Permian glacial sections in other continents, the Itarare Group demonstrates the repeated (at least sevenfold; Rocha-Campos *et al.*, 1999) alternation of continental and glaciomarine facies deposited during glacial and interglacial episodes; the latter were frequently responsible for the coal accumulation. South America hosted several centers of Permian glaciation. As was noted, glaciers advanced from the southeast, i.e., from South Africa, into the eastern Parana Basin and from the Asuncion uplift into its western areas (Franca, 1994). The occurrence of Permian glacial deposits in the northeastern part of the Brazil Rondonia State implies that glaciation centers also existed north of the Parana Basin (Rocha-Campos, 1981). Into the Sergipe-Alagoas trough (the San Francisku River mouth area), the glacier penetrated from the Kongo River basin of equatorial Africa, probably moving via Gabon (Santos *et al.*, 1996; Visser, 1997). As is evident from distribution of Permian deposits in South America, the glacier reached the paleolatitude of 30°S.

Signs of Permian glaciations are also rather abundant in southern Asia. They are recorded in northeastern and northwestern India (Radjustan), northern Pakistan, in the Himalayas (from Pakistan in the west to Assam in the east, Hambrey *et al.*, 1981), in many sections of the Tibet from the Karakorum Ridge in the west to the Saluin River in the east and from Lhasa in the south to foothills of the Kuen Lun Mountains in the north (Metcalfe, 1994). In the Hindustan Peninsula, glacial deposits are preserved in numerous grabens at the base of Sakmarian–Artinskian Talchir Formation (Chandra, 1992). These sections predominantly consist of continental facies: tillites, boulder conglomerates, and other glacial sediments. Locally, the sections are crowned with glaciomarine sediments. In many places, the Talchir Formation overlies the glacier bed with peculiar indications of glacial exaration. The striation on the bed and orientation of elongated rock fragments point, with rare exceptions, to the general northeastern movement of glaciers during the Permian (Ahmad, 1981), when they advanced toward the Himalayas where mainly glaciomarine deposits occur. In the eastern Hindustan Peninsula, orientation of striation implies that glaciers moved from Antarctica adjoining the peninsula in the south. All these data and replacement of continental glacial deposits in the Himalayas and Tibet with glaciomarine ones indicate, contrary to the widespread opinion that only local ice domes existed in the peninsula, the northeastward movement of glaciers from Antarctica, via India, into an epicontinental sea located in the marginal part of Gondwana.

The Upper Paleozoic glacial deposits are known in the Transantarctic Mountains, along periphery of the Ronne Glacier, and in the western Queen Mod Land in the Atlantic segment of Antarctica (Hambrey *et al.*, 1981). In the Transantarctic Mountains, glacial deposits are 300 to 1000 m thick and fill in several sedimentary basins. They are represented here by continental and glaciomarine facies. According to palynological data, their stratigraphic range corresponds to the Carboniferous–Early Permian. The occurrence patterns of glacial sequences and directions of glaciers responsible for their accumulation (Isbell *et al.*, 1997) allow an assumption that some of the basins originated in response to glacial erosion (Isbell and Cueno, 1996). The contemporary ice cover is an obstacle for the detailed reconstruction of Late Paleozoic glaciations in Antarctica. Nevertheless, the fact that glaciers from this continent reached South Africa, India, and South Australia in the Early Permian time implies two conclusions: first, the Antarctic continent experienced strong glaciation at that time, and second, the glaciation lasted here until the Artinskian Age at least, because Antarctic glaciers still reached South Africa in the west (Visser, 1997) and India in the east (Ahmad, 1981; Chandra, 1992) at the beginning of this age. Antarctic icebergs continued to transport intermittently coarse detrital material to southeastern Australia until the Kungurian Age (Eyles *et al.*, 1998) or even until the end of the Late Permian epoch (Veevers *et al.*, 1994).

Despite the prevalence of glacial settings in the climatic belt under consideration, its marginal periglacial and even central (during interglacials) zones hosted vegetation and bogs, which accumulated peat subsequently transformed into coal seams. The interglacial floras and coals are known in southeastern Australia and South America. It is assumed that the peat accumulated after glacioeustatic transgressions in coastal bogs and river floodplains during the postglacial isostatic emergence of the region (Santos *et al.*, 1996; Bustin, 1997) or glacioeustatic sea-level falls (Michaelson and Henderson, 2000). The interglacial climate was sufficiently cool, as it is evident from the cold-resistant affinity of the primary vegetation and from occurrence of solifluction, ice wedges, and impressions of ice crystals in coal-bearing rocks, which reveal admixture of fresh feldspar grains and enclose coarse ice-rafted material (Bustin, 1997; Martini, 1997; Eyles *et al.*, 1998; Michaelson and Henderson, 2000).

Vegetation of interglacial periods and that of periglacial margins of the belt was very impoverished. The initial Permian in Australia (Retallack, 1980) and South America (Guerra-Sommer *et al.*, 1999) was a time of wide development of herbaceous "tundra" and shrub pteridosperms (*Botrychiopsis*). Later on, this flora was supplemented by and then replaced with the dwarfish arboreal vegetation of the "taiga" affinity. The latter consisted mainly of probably deciduous *Gangamopteris* that could grow in permafrost areas (Retallack, 1980). This vegetation is known under the name "*Gangamopteris* floral assemblage" (*Gangamopteris* florula according to Retallack, 1980; *Gangamopteris* region after Wnuk, 1996). In Australia, Antarctica, Africa, and India, the impoverished flora (Cúneo, 1996) consisted of cold-resistant plants locally associated with tillites (Chandra, 1992) and permafrost signs (Retallack, 1980). In India, *Gangamopteris* remains occur in association with conchostracan and small insects (Chandra, 1992), and in Antarctica, interglacial deposits enclose remains and fucoids of freshwater crayfish. Judging from habitat conditions of modern crayfishes, some researchers believe that temperature in rivers and lakes of Antarctica could be as high as +10–+20°C during the Permian interglacial summers (Babcock *et al.*, 1998).

Sufficiently warm summer seasons of interglacial phases is also inferred from finds of fossilized stumps up to 1m in diameter in the Transantarctic Mountains. These remains probably belong to *Glossopteris* and partly occur in their life-time position. They have wide (up to 14 mm) summer–spring growth rings. Numerous cell layers in every ring point to favorable conditions for these trees during their vegetative period that lasted, as is roughly estimated, 48 days (Francis *et al.*, 1994). According to palynological assemblages, the enclosing rocks are of the late Early Permian age. The area with wood remains was situated at that time at the paleolatitudes of 80°–85°, where the dark polar period lasted at least 140–165 days. It can be assumed therefore that the interglacial summer season in high latitudes of the Southern Hemisphere was mostly unfavorable for arboreal vegetation because of low temperatures. Periglacial conditions remained also for some time after the glacier retreat. They were appropriate for development of the *Gangamopteris* assemblage, ice rafting, bog formation, and peat accumulation (Chandra, 1992; Isbell *et al.*, 1997; Smith *et al.*, 1998). During the glacier retreating and permafrost degradation, the *Gangamopteris* floral assemblage gave place to the more thermophilic *Glossopteris* flora, which completely substituted the *Gangamopteris* flora in Australia only by the end of the Late Permian. The period when the *Glossopteris* assemblage became prevalent can be considered as a time of eventual degradation of the Early Permian glacial belt in Gondwana. In South America, particularly, in Patagonia, vegetation was more diverse and thermophilic since the beginning of the Early Permian (Cúneo, 1996) despite the proximity of the glacial belt and penetration of South African glaciers into the Parana Basin located slightly westward (Santos *et al.*, 1996). This anomaly was probably related to the insular position of Patagonia, otherwise this flora can be of a younger age. Some researchers argue that the Patagonia block was separated from West Gondwana and situated during the Permian within lower latitudes than it is now believed (Cúneo, 1996). In Brazil, the Lower Permian flora resembled in composition the *Glossopteris* assemblage (Wnuk, 1996), although *Gangamopteris* forms prevailed locally in this region as well (Rocha-Campos and Santos, 1981).

Sea basins adjacent to glaciation regions and flood areas of interglacial glacioeustatic transgressions were populated by peculiar cold-resistant *Eurydesma* fauna, as it is frequently termed. This fauna was widespread in Australia, South Africa, India, Himalayas, Tibet, and southern Afghanistan (Termier *et al.*, 1973). It is also known in South America (Amos and Lopez Gamundi, 1981; Santos *et al.*, 1996). Some representatives of the *Eurydesma* fauna occur in the southern Pamirs (Grunt and Novikov, 1994). The *Eurydesma* fauna represented an impoverished variant of the Notal (Gondwanan, Australian) fauna (Runnegar, 1984). It was lacking fusulinids, reef-forming brachiopods, Rugosa, conodonts, and other thermophilic groups and was frequently associated with glaciomarine sediments and glendonites.[4] Bipolar forms represented significant components of this biota (Runnegar, 1984; Shi and Grunt, 2000).

The southern cold–temperate humid belt. In the terminal Sakmarian–initial Artinskian, when the Gondwanan glacial zone became significantly narrower and retreated toward the Antarctic Circle, a narrow (10°–15°) belt with prevalent temperate to cool climatic conditions formed immediately north of the glacial zone (Fig. 3, SCT). Numerous Lower Permian coal deposits of Australia, India, South Africa, and South America are situated in this belt. Relatively small local glaciation centers occurred sometimes within this belt, and tongues of Antarctic glaciers simultaneously reached the belt from the south. As was mentioned, the terminal Sakmarian–initial Artinskian glacial episodes are recorded in South Africa (Visser, 1997). The formation centers of local glaciers coincided with elevated areas. The glaciers moved mainly in the northwestern direction to the Parana Basin leaving behind mostly glaciomarine sequences. During glacial episodes, Antarctic glaciers reached eastern India (Ahmad, 1981; Chandra,

[4] The Notal biota of the Permian time was of a low generic diversity in general. For instance, the number of its brachiopod genera was six to eight times lower than in the tropical biota. Even in eastern Australia, the generic diversity of Permian brachiopods and bivalves decreased twice in the north–south direction with parallel decline of Rugosa abundance until the extinction.

1992). Small glaciation centers could probably appear in mountains of eastern Australia. The adjacent Sidney Basin received, in addition, a large amount of the ice-rafted material from Antarctica (Eyles *et al.*, 1997).

Nevertheless, climate in the belt under consideration was temperate to cool and humid despite some glacial episodes. This is evident from a wide distribution of the early *Glossopteris* floral assemblage reviling a notable percentage of *Gangamopteris* forms. Judging from the leaf accumulation, stem dimensions, wood and root structures, and abundant coal seams, this vegetation can be classed with the boggy deciduous forests with fern and horsetail underbrush (Retallack, 1980; Chandra, 1992). In the more arid areas, conifers represented subordinate components. The *Glossopteris* forests were populated by amphibians, reptilians, and large neuropterous insects (Chandra, 1992).

The proximity of the glacial belts determined to a significant extent the climate in adjacent sea basins. They accumulated locally ice-rafted sediments and were populated by the Notal fauna of the *Eurydesma* type. Seas of western Australia and Himalayan India near the northern boundary of the belt were populated by more thermophilic fauna (Indian province of the Gondwanan paleogeographic region according to Runnegar, 1984).

The southern temperate humid belt of middle latitudes. The available data indicate that climate of the Asselian–initial Sakmarian period was locally temperate and humid in the low middle latitudes (30°–40°S) of the Southern Hemisphere (Fig. 1, SH; Fig. 2, ST). This was characteristic of relatively limited areas, which did not form a continuous latitudinal belt. Indications of such a climate are known only from the central part of the Arabian block, where terrigenous sequences enclose thin coal seams (Alsharhan and Nairn, 1995) and yield the Cathaysian palynological assemblage that show admixture of Euramerian and Gondwanan taxa (Utting and Piasecki, 1995). Coals and composition of palynological spectra point to a sufficiently humid and warm climate of the territory in question located on the leeward monsoon-influenced margin of Pangea. Westward, this narrow band of the temperate humid climate is not traceable, because the gypsum-bearing red beds and eolian deposits are distributed close to the development area of glacial deposits in South America (Figs. 1, 2). Accordingly, we may assume that the temperate humid belt was missing here, and the glacial belt immediately contacted in the north with the arid one.

The northern temperate humid belt of middle and high latitudes. In the Early Permian, the entire northern part of Pangea, from the Arctic coast to paleolatitudes of 35°–40°N, was occupied by a wide belt of arboreal vegetation that was of Siberian phytogeographic type and gave rise to an intense coal accumulation (Fig. 1, NH; Figs. 2, 3, NT). Preponderant arboreal taxa of the belt were cordaites whose pycnoxilic wood had distinct growth rings indicative of the temperate climatic conditions. Some researchers compare that Siberian phytogeographic region with contemporary Boreal forests and conditionally apply term "Cordaitean taiga" to its vegetation (Durante, 1995). The Amuria continent of formerly amalgamated Primor'e, Transbaikal region, and Mongolia was evidently located within the same belt north of Siberia proper. This is evident from a wide development of the Siberian flora in that continent (Durante, 1995) and from remains of highly boreal fauna (Grunt, 1995). Remains of Siberian-type flora are also known from the Sakmarian deposits of the Canadian Arctic Archipelago (Wnuk, 1996). Thus, the northern temperate belt extended into the western part of Pangea.

The Siberian segment of Pangea extended far to the north in the Early Permian time (75°N according to Scotese and Langford, 1995; 80°N according to Ziegler *et al.*, 1997, 1998; about 68°N according to Parfenov *et al.*, 1999). If these data are correct, a presumable width of the northern temperate belt could be as wide as 35°–45°. According to Durante (1995), floral assemblages of a uniform Siberian composition occur up to the Okhotsk massif that was located near the northernmost boundary of Pangea. Nevertheless, some researchers tend to distinguish the South and less diverse North Siberian floras (Wnuk, 1992). Sea basins adjacent to the northern part of the belt lacked fusulinids (Leven, 1993) and conodonts (Wardlaw, 1995). Taking into consideration the aforementioned facts and a large width of the belt, we may assume that climate within the belt was variable and noticeably cooler in its northern areas. There are some indications of ice-rafted or glacial deposits in the Lower Permian sections of Siberia (Bobin, 1940; Andrianov, 1966), although their origin is debatable (Vikhert, 1957; and others) and unproven so far (Chumakov, 1994). Using these data, it is impossible do define the northern glacial belt, and only local glaciers, if there were any, could sporadically develop during the Early Permian in northern Siberia, where the temperate cool climate dominated.

Shelf seas of the belt under consideration were populated by the highly boreal invertebrate fauna (Grunt, 1995) that was of a low diversity and lacked colonial corals, fusulinids, and other thermophilic forms, though it shows presence of bipolar taxa (Ustritskii, 1993; Shi and Grunt, 2000; and others). Only areas near the southern boundary of the belt, in its western part, hosted more thermophilic low-boreal assemblages (Grunt, 1995).

The southern temperate semiarid belt of middle latitudes. In the terminal Sakmarian–initial Artinskian, a narrow semiarid belt 5°–15° wide appeared between the paleolatitudes of 40°–45° and 50°–55°S, where land areas were formerly ice-covered and begun to accumulate terrigenous, usually slightly calcareous red beds (Fig. 3, SS).[5] Significant amid them were alluvial

[5] Considering arid zones of the past, we call them "semiarid" following the definition and classification accepted in maps published by UNESCO (Shantz, 1958).

and lacustrine, sediments and fan deposits of seasonal flows. Sedimentation settings favorable for coal accumulation were missing. These features suggest that climate in the belt was arid in general, with short humid seasons responsible for appearance of branching and wandering short-term flows, and lakes. Proportions of alluvial and lacustrine facies in sections are variable, implying annual and secular moisture variations. The temperature was probably moderate. This can be inferred from the belt proximity to glaciation centers that episodically formed in the neighboring temperate cold belt and also from the occurrence of ice-rafted deposits in the Parana Basin (Santos *et al.*, 1996). This conclusion is also supported by terrestrial *Glossopteris* flora found in land areas (Wnuk, 1996), by wide development of Notal fauna in shelf seas (Grunt, 1995), where conodonts were scarce or completely absent (Wardlaw, 1995), and by the intermediate position of the belt between the temperate cold and typical warm arid ones (Fig. 3).

The northern warm semiarid belt of low latitudes. In distinction from its southern counterpart, the northern semiarid belt of middle and low paleolatitudes was sufficiently wide (15°–20°). During the Asselian Age, it was situated between 40°–45° and 15°–30°N (Figs. 1, 2, NS), while in the terminal Sakmarian–initial Artinskian it slightly widened southward, particularly in the Eurasian segment (Fig. 3). Later on, in the Kungurian Age, the belt shifted slightly northward. Land areas of the belt accumulated terrigenous, frequently calcareous alluvial–lacustrine sediments. Their sequences along coasts of lakes and epicontinental or shelf seas enclose sebkha deposits and caliche. In southern Kazakhstan, they host continental sulfate–sodium salts pointing to alternation of warm humid and cold arid seasons. As Zherebtsova (1977) estimated, the salts' formation temperatures were 20 to 30 and –5 to –15°C during warm and cold seasons, respectively. Such a wide temperature range suggests that climatic conditions within the belt could fluctuate from temperate cool to subtropical. More definite are some seasonal characteristics of the climate: the monsoon-type moistening and large seasonal variations of temperature typical of the continental climate.

Cool winter temperatures, as those indicated above, are now untypical of the same low latitudes and conflict with paleobotanical data characterizing the belt. In the Early Permian, vegetation of the belt was of the cordaites–conifers–pteridosperm type and included elements of tropical and Siberian floras usually associated with coal-free red beds. Proportions between tropical and Siberian forms in the flora were variable. Abundance of the latter increased in the Early Permian (Durante, 1995) that may be indicative of some cooling. In general, composition of this "Subangarida" flora implies the warm arid climate (Meyen, 1987; Durante, 1995) and open landscapes. This conclusion well agrees with the aforementioned properties of continental deposits and with composition of marine sediments in inner and marginal epicontinental seas of the belt. In the eastern Russian platform, southern Barents Sea, and northern Canadian Arctic Archipelago, sea basins hosted gypsum-bearing evaporite carbonate platforms, very spacious sometimes and fringed by reefal buildups. Sections in the southwestern Barents Sea (the Ottar basin and others) enclose salt-bearing deposits (Breivik *et al.*, 1995; Stemmerik and Worsley, 1995). The basins were mainly populated by moderately thermophilic fauna of the low-boreal type, and only the East European sea hosted the Mediterranean fauna (Grunt, 1995). The reef-building *Paleoaplisina* forms characteristic of northern areas of the belt (Beauchamp, 1995; Stemmerik and Worsley, 1995; Keissling *et al.*, 1999) could dwell, according to recent data, in moderately warm waters and were distributed mostly between the paleolatitudes of 25 and 45°N. Only in the western North American coast, they reached 15°N with the help, as is thought, of the cold anticyclonic Panthalassa coastal current (Keissling *et al.*, 1999). This assumption is well consistent with the southward advance of the Subangarida flora in this region (Utting and Piasecki, 1995). All these features are used to outline the northern semiarid belt in the North American segment of Pangea. In the south of the Eurasian belt segment, main reef-building organisms were represented by algae.

The northern arid belt of low latitudes. The southern part of the Laurasian segment of Pangea was occupied by a vast arid belt (Figs. 2, 3, NA).[6] During the Asselian Age, this belt extended from the paleolatitude 15°N almost up to equator in the west and from 25°–30° to the Paleotethys coast in the east. In the terminal Sakmarian–initial Artinskian, the northern arid belt of Pangea was located between equator and 15°–20°N. During this period, it widened southward and joined the southern arid belt along the eastern margin of the supercontinent (Fig. 3). In the terminal Permian, the belt again slightly widened northward. In the east, along the Paleotethys coast, the belt was narrower and probably pinched out (Figs. 2, 3). Land areas of the belt accumulated terrigenous, commonly gypsum-bearing sebkha and eolian (dunes) red beds. In the southwestern Moscow syneclise, Dnieper–Donets depression, and in western North America (Denver and Julesburg depressions, Supui Basin), saliferous sequences formed. In the Kungurian Age, areas and rates of salt accumulation in the northern arid belt significantly increased. Saliferous deposits accumulated in the Anadarko, Kansas, Julesburg, Williston, West Texas, and North Mexican, western North American, Central and East European basins (Zharkov, 1978). The initial thickness of the Kungurian saliferous sequence in the central part of the North Caspian depression (southern part of the East European basin) is estimated to be 4–5 km.

[6] We combined in this case the arid proper and extra-arid zones, because the available geological data do not permit their discrimination in line with classification used in maps published by UNESCO (Shantz, 1958).

The belt in question was characterized by the thermophilic xerophilous Euramerian vegetation that was relatively impoverished and largely composed of conifers (Meyen, 1987; Wnuk, 1995). The spores–pollen spectra from the belt commonly show presence of pollen of dessert and semidesert plants (Utting and Paiasecki, 1995). The climate aridity is also evident from sedimentation patterns in adjacent shelf seas, which hosted during the early Permian the accumulation settings of coastal gypsum-bearing sebkha deposits and spacious carbonate or evaporite–carbonate platforms (Zharkov and Chumakov, 2001). Remains of tropical fauna imply that sea basins were warm-water in general (Grunt, 1995).

The southern arid belt of low and middle latitudes. In the Southern Hemisphere, the arid belt represented a zone of development of terrigenous red beds, frequent gypsum-bearing sebkha sequences and eolian dunes. It was slightly wider that the arid belt of Northern Hemisphere and mainly occupied the low latitudes (between the paleolatitudes of 10° and 30°N; Figs. 1, 2, SA). As was already noted, it bordered the glacial belt in the west and the temperate one in the east. When glaciers retreated in the terminal Sakmarian–initial Artinskian period, the southern arid belt considerably widened toward the middle latitudes to be located between the paleolatitudes of 0°–15° and 40°–45°S. In South America, it included the vast saliferous Peruvian–Bolivian and evaporite Amazonian basins. The eastern part of the belt was occupied by the spacious Arabian and North Italian zones of evaporite–terrigenous–carbonate sedimentation (Zharkov and Chumakov, 2001). Thus, the southern arid belt became almost twice wider than its northern counterpart and was located farther from the equator (Fig. 3).

The plant and relevant palynological assemblages of the initial Permian, which are known from the belt, are of a mixed composition: the Euroamerian–Cathaysian in the north and Euramerian–Gondwanan in the south (Broutin *et al.*, 1990; Wnuk, 1996). After the belt expansion, its phytobiogeographic features became rather intricate that was quite natural for the belt of huge dimensions. The northern part of the belt (North Africa) was populated by the Euramerian flora that mixed southerly (Central Africa) with the Gondwanan flora and slightly easterly (Turkey) with the Gondwanan and Cathaysian floras (Meyen, 1987; Broutin *et al.*, 1990; Wnuk, 1996). The last type of floras probably indicates some humidity growth in the eastern peri-oceanic part of Central Pangea. The southern part of the belt under consideration belonged almost entirely to the Gondwanan floral kingdom. This segment of the belt corresponds to the extended area with dispersed remains of the so-called Australian–African–American flora (Wnuk, 1996) that included arboreal ferns and lycopods, in addition to *Glossopteris* forms, and presumably was of the thermophilic type. Localities of this flora are known near areas of gypsum-bearing sebkha and dune sand accumulation sites. This suggests that its development was connected with oases. The so-called "Argentinean–Brazilian desert flora" reflects cooler conditions. (Wnuk, 1996). It grew in the extreme southwest of the southern arid belt near the saliferous and gypsum-bearing basins along the boundary with the temperate semiarid belt. Some coniferous remains were found in this flora from eolian sands. Thus, the southern arid belt of Pangea shows a certain climatic differentiation from the warm climate in the north to the temperate warm or even temperate one in the south.

The eastern continuation of the southern arid belt is traceable in the southern part of the Tethys, where microcontinents of the southeastern part of the Kimmerian arc host red beds and remains of the Euroamerian and Australian–African–American floras (the Burma–Malacca and New Guinea blocks, respectively; Wnuk, 1996). Shelf and inner seas adjacent to the belt were characterized by development of coastal gypsum-bearing sebkhas (Zharkov and Chumakov, 2001). Biogeography of marine basins was as intricate as in continental areas. The tropical (paleoequatorial) fauna was characteristic of the Andean zone along the western margin of the belt, whereas the Notal (Gondwanan according to Grunt, 1995, and Grunt and Shi, 1997) vegetation was distributed easterly, in the Amazonian basin and near the Arabian block.

The equatorial belt of mountainous climate. The huge belt of Hercynian mountains formed as a result of collision between Laurasia and Gondwana and crossing Pangea almost from ocean to ocean was located in the central part of supercontinent between the northern and southern arid belts. In the Early Permian, it mainly occupied southern, near-equatorial paleolatitudes (5–10°S). Narrow sea gulfs still existed in the belt at the beginning of the Permian (Autunian or early Wolfcampian periods). The Val-Verde sea trough that accumulated terrigenous deep-water sediments, partly turbidites (Oriel *et al.*, 1967), stretched along the northern front of the Wichita-Marathon orogenic belt. Northward, the Eastern shelf corresponded to a shallow sea basin, which accumulated clayey and carbonate sediments, whereas coal-bearing and fluvial terrigenous deposits were characteristic of its eastern coastal margins (Oriel *et al.*, 1967). The area south of the Wichita-Marathon orogenic belt was occupied by a fore-arc sea that stretched probably to southern Arkansas and northern Louisiana separating the continental blocks of South and North America (Wickman *et al.*, 1976; Frazier and Schwimmer, 1987). In the eastern margin of the mountainous belt, the sea entered North Africa spreading over the northern part of the Mauab-Ramzes Basin (southern Tunisia), where thick sandy–clayey and carbonate sediments are deposited (Hoffmann-Rothe, 1966; Vysotskii *et al.*, 1973). During the Asselian Age, the area northwest of the belt was occupied by a spacious alluvial–lacustrine boggy plain that was populated by freshwater ostracodes, fishes, and amphibians, and where peat subsequently metamorphosed to coal accumulated. The occurrence of brachiopods suggests episodic sea invasions or a partial salinization of waters in the plain. In dry seasons, the plain accumulated, particularly in its southern part, alluvial red beds (Berryhill, 1967).

Piedmonts and numerous intermontane depressions in central and eastern parts of the mountainous belt represented deposition sites of volcanogenic, alluvial–lacustrine, gray-colored deposits and red beds. In the Autun depression of France, the Asselian (Autunian) deposits are represented by gray to black calcareous and bituminous shales intercalated with fluvial, partly variegated beds and volcanic ash layers, which yield the characteristic flora in association with freshwater algae whose accumulations are transformed into sapropel coals. These deposits accumulated under conditions of the hot and humid climate (Cassins *et al.*, 1995; Châteauneuf and Farjanel, 1989). Similar humid environments prevailed in the Pyrenees and southeastern France, where coal-bearing sequences are present. Intermontane depressions in the Iberian plate accumulated alluvial–lacustrine red beds alternating with gray to black terrigenous sediments and volcanics. Almost all depressions here bear coals (Cassins *et al.*, 1995). In the Southern Alps of Italy, the Upper Permian deposits fill in several deep grabens (Orobic, Val-Trompia, Tione, Bolzano, and others basins). They are represented by volcanogenic, fluvial, and lacustrine rock complexes accumulated under conditions of the warm and temperate semiarid climate with alternating warm and dry periods (Cassins *et al.*, 1995). Similar sedimentation environments were also characteristic of deposition sites of continental coal-bearing red beds in southern areas of the mountainous belt, namely in the Tiddas, Argana, Ourica, Chougrane, Haouz, Oued-Zfe, and other intermontane basins of northwestern African (Conrel *et al.*, 1991; Wartiti *et al.*, 19990).

Thus, it can be stated that the local climate in piedmonts and intermontane depressions was very variable at the beginning of the Early Permian and depended on orographic peculiarities of the belt. Coal-bearing deposits frequent in depressions point to alternation of predominant warm and humid climatic phases with semiarid periods. The Autunian red beds could accumulate in areas protected from rains by mountains. Alternation of semiarid and humid climate likely was typical of the eastern and western margins of the belt. The vertical climatic zoning of mountainous forests, meadows, and steppes, like that in modern equatorial and tropical belts, was characteristic of mountains. The Euramerian flora from Autunian deposits includes the Gondwanan and abundant thermo- and hygrophilic equatorial Cathaysian elements (Broutin *et al.*, 1990; Wnuk, 1996). Later on, during the late Sakmarian–Artinskian time, remaining sea basins closed in response to the general uplift of the orogenic system, and the mountainous belt of Central Pangea that probably resembled the Himalayas terminated its formation (Scotese and Langford, 1995). Simultaneously, climate changed to semiarid and arid. Piedmonts and intermontane depressions mostly accumulated red beds frequently enclosing horizons of carbonate, partly gleyed soil, caliche, and gypsum (Mader, 1992; Cassins *et al.*, 1995). It can be assumed that climatic zoning in the region approached that of the intracontinental arid type (Zharkov and Chumakov, 2001).

The tropical–equatorial hot humid belt. This belt was spread over the Paleotethys, its coasts, Cathaysian microcontinents, and the northern part of the Cimmerian arc that bordered the ocean in the east and south (Figs. 1, 2, 3, TE). In its widest eastern part, the belt extended almost from 30°N to 30°S occupying all tropical and subtropical paleolatitudes. From the formal standpoint, this isometric region can be termed the belt conditionally, but in essence, its vast territory with sufficiently uniform climatic, sedimentation, and biogeographic environments did not differ from other climatic belts, because its main characteristics were also determined by the latitudinal geographic position and orography. The belt included the eastern insular and coastal humid zones of the tropical (northern and southern) and equatorial belts, which were closer to each other than to western continental segments of all three belts.

Abundant signs of hot and humid climate are observable on land areas of the former tropical–equatorial belt, e.g., coals, bauxites (Zharkov and Chumakov, 2001), and diverse remains of Cathaysian vegetation (Wnuk, 1996). The latter included typical plants of humid tropics: arboreal *Lepidodendron* and Equisetales, and also *Gigantopteris* representing probably lianas or climbers (Ziegler, 1990). The Cathaysian phytochore was not uniform, and this is quite natural in view of its tremendous width and predominant archipelago-type land patterns. Three floral regions of different latitudinal positions are recognized now within the Cathaysian arc: the North and South Chinese regions corresponding to opposite margins of the arc and the intermediate narrow Ksu-Huan-Yu region (Wnuk, 1996). This phytogeographic differentiation likely developed during the Early Permian (Wang *et al.*, 1998) has reflected both the isolated insular character of floras and their different latitudinal positions within the belt. This is suggested by the fact that the low-latitude South Chinese paleofloral region (South China and Indochina microcontinents) stretched in the latitudinal direction far westward up to Central Iran and northeastern Arabia, which were remote from the Cathaysian arc farther than the Cathaysian blocks from each other. This assumption is supported by some paleobotanical data implying the increasing humidity of the Permian climate within the Cathaysian arc in the north–south direction (Zo, 1999). The western part of the belt under consideration, where different phytochores joined, hosted the mixed Euroamerian, Gondwanan, and South Cathaysian floras (Broutin *et al.*, 1990; Wnuk, 1996).

Spacious carbonate platforms with reefal buildups and diverse Tethyan fauna were characteristic of seas adjacent to the belt in question (Leven, 1993; Grunt, 1995; Grunt and Shi, 1997). Noteworthy were carbonate platforms and reefs widespread during the Asselian in the low and, partly, middle paleolatitudes of the Northern Hemisphere (up to 45° and 40°N), but missing south of 27°S (Figs. 1, 2) and 15°S (Kiessling *et al.*, 1999) in the Southern Hemisphere. Thus, the latitudinal distribution range of carbonate platforms and reefs in the latter was 2–2.5 times narrower than in the Northern Hemisphere during the Asselian glacial maximum and than in the Southern Hemisphere during the later period of the Early Permian (Figs. 2, 3). This indicates that influence of the glacial belt was noticeable up to the southern part of the tropical–equatorial belt. It could be responsible for some general cooling in the region and/or for penetration of cold and slightly turbid waters here.

PECULIARITIES OF THE EARLY PERMIAN CLIMATE

As one can see from previous sections, the Early Permian climate was highly variable and dynamic. We will characterize only its main peculiarities and changes that occurred throughout this epoch.

Global warming. The retreat of glaciers from middle latitudes toward higher ones in the late Sakmarian–early Artinskian time, when the warm arid belt and evaporite–carbonate platforms spread over former glaciation areas, indicate a rapid planetary warming. The reduction of glaciated areas and development of glacioeustatic transgressions decreased the planetary albedo and resulted in warming that accelerated up to the moment when glaciers entirely retreated to high latitudes. After this event, warming decelerated. Small glaciation centers, which sometimes grew in size due to different-rank climatic oscillations, were preserved in southern high latitudes up to the terminal Early Permian. The probable causes responsible for the warming will be discussed in out next paper. Now, we want just to note that, judging from the discussed materials, changes in the Pangea latitudinal position and in proportions between land and sea areas could hardly represent the main factors, because they were insignificant. According to paleomagnetic data (Scotese and Langford, 1995; Ziegler *et al.*, 1997, 1998), the northward displacement of supercontinent during the Early Permian corresponded to several degrees only, as is estimated. The subsequent rise of Pangea and reduction of epicontinental seas should cause the global cooling. The late Artinskian–Kungurian time was probably the warmest period in the entire Early Permian. Nevertheless, abundant indications of the iceberg and ice rafting in southeastern Australia suggest that cool climate in southern polar latitudes lasted up to the end of this epoch.

Global aridity growth. Global climatic changes of the Early Permian time have not been limited by warming. Since its formation time, semiarid and arid climatic environments were characteristic of low latitudes of Pangea. Factors responsible for this were the huge dimensions of supercontinent and emergence of large Hercynian mountainous belts and ranges, many of which extended along continental margins, particularly in the Laurasian segment. Both factors hindered the moisture transfer from oceans into internal areas of the supercontinent. The aridity of Pangea strengthened with time during the Early Permian, as it is reflected in extension and migration of arid and semiarid belts into the middle latitudes. The aridity grew in the equatorial mountainous part of central Pangea as well. Undoubtedly, one of factors responsible for this was global warming that increased evaporation, particularly in low and middle latitudes, where moisture was insufficient. The period of maximal extension of arid belts coincided probably with accumulation time of Kungurian salts and sulfates. The successive regression of inner seas of Pangea and relevant reduction of moisture sources could represent another cause of the arid climate advance. It can also be assumed that the retreat of large ice shields into high southern latitudes in the late Sakmarian–early Artinskian time resulted in reduction and retreat of corresponding annual stable high-pressure zones. This was evidently accompanied by enlargement of adjacent low-latitude Hadley cell and by migration toward poles of high-pressure areas characteristic of tropics and determining development of arid and semiarid belts.

The monsoon role. The existence of spacious Pangea land blocks predetermined an importance of seasonal areas with high and low air pressure and relevant influence of monsoons on the climate formation in both hemispheres (Parrish, 1995). This influence should be most significant in the Southern Hemisphere, where the compact block of the Gondwana land was almost 1.5 times larger in size and across (along 30°) than the present-day Eurasia. The Laurasian segment of Pangea was lesser only slightly. The humid monsoon climate was most distinct in areas adjacent to the Paleotethys ocean. The proximity of the warm ocean located in tropical and equatorial latitudes to huge blocks of the leeward land should stimulate development of monsoons and enhanced their influence. Taking into consideration this fact and mathematical models, some researchers termed these atmospheric events as megamonsoons (Kutzbach and Gallimore, 1989). However, on the way to Laurasia, these monsoons met mountainous belts and marginal ranges fringing the continent in the south, southeast, and northeast. As a result, monsoons connected with the lower troposphere lost the bulk of transported moisture on the leeward slopes of mountains. Therefore, climate in areas protected from rains and in tropical latitudes of Laurasia was arid (Figs. 2, 3). Indications of the intermittent summer moistening observable in deposits of the northerly semiarid belt allow however a suggestion that highly weakened monsoons reached episodically the internal areas of Laurasia. Signs of humid seasons are locally registered also along the southern margin of Pangea. Nevertheless, the year-round high-pressure maximum over the glacial belt probably prevented, especially during the Asselian–early Sakmarian period, from a deep penetration of monsoons into its internal areas. Later on, monsoons could be kept away by tropical and high-latitude high-pressure zones, which existed in northern Gondwana and southern polar area, respectively.

Dynamics of climatic changes. An important feature of Early Permian climatic changes was their high dynamics. Two factors could be responsible for this: the general rapid warming and frequent different-rank oscillations that complicated the warming trend. The rate of global warming was highest during the Sakmarian Age, when glaciation in middle south latitudes terminated. A significant part of the territory that became free of ice was immediately occupied by the arid and semiarid belts (central South America, southern Arabia, Figs. 1, 2, 3). Further reduction of the glacial belt was more gradual. At the end of the Artinskian Age, this belt probably became extinct as a single whole, although glaciation centers that produced abundant icebergs repeatedly renewed in the Southern Polar zone during the Kungurian Age and even later (Eyles *et al.*, 1998).

Oscillations enhanced these dynamic climatic changes, particularly during glaciations. High expansion and even higher degradation (termination) rates of ice covers are well exemplified by Pleistocene glaciations. The available data show that similar short-period oscillations were characteristic of Early Permian glaciations as well (Chumakov, 1985; Dickins, 1985; Eyles *et al.*, 1998). As was noted, glacial oscillations recorded in most complete sections of Permian glacial deposits were of three ranks: with periods of hundred thousands, several millions, and several tens of million years (Chumakov, 1985; Veevers and Powell, 1987). High-amplitude climatic oscillations are also inferable from coal seams occurring sometimes amid glacial deposits (South America, southeastern Australia). They suggest that the glacial climate gave place to the temperate cool one and vice versa. Amplitudes of climatic oscillations within the ice-free areas were naturally less contrast than in glacial belts. They were probably manifested as moisture variations (Miller *et al.*, 1996; and others).

Asymmetry in the climatic zoning. Throughout the entire Early Permian, the Southern Hemisphere was colder that the Northern one. This is evident from the fact that all significant glaciations occurred only in the Southern Hemisphere. In this connection, succession of climatic belts was different in both hemispheres, and corresponding belts were of different width, remote from the equator for a different distance, and showed difference in many other parameters (radiation, seasonal barometric patterns, atmospheric precipitation, wind activity, and others). The asymmetry was particularly well manifested during the Asselian–Sakmarian glaciation (Figs. 1, 2). By the end of the Early Permian, it noticeably decreased (Fig. 3). Main causes responsible for the climatic asymmetry were different dimensions of land blocks and their asymmetric latitudinal position relative to the equator and poles (Chumakov, 1994). In the Early Permian, Gondwana located between paleolatitudes of 5° and 90°S was 1.6 times larger than Laurasia, and a half of its territory was located in high and middle latitudes. Laurasia was situated between the equator and 75°N at that time, and 67% of its territory corresponded to low latitudes. When glaciation zone decreased, distribution of land blocks remained almost unchanged, and climatic asymmetry substantially lessened with time. This suggests that asymmetric position of land masses results in strong climatic asymmetry only during glaciations.

Rearrangement of climatic zoning. The Early Permian climatic changes substantially rearranged the climatic zoning. Transformations were strongest in the Southern Hemisphere, where the glacial belt considerably (by 2.5 times and more) narrowed in the late Sakmarian–early Artinskian time and disappeared at the end of the Early Permian. In the Asselian–early Sakmarian time, the glacial belt bordered immediately the tropical arid belt in western Gondwana and the significantly reduced temperate belt in the east (Fig. 2). Reduction of the glacial belt was accompanied by formation of the semiarid and temperate cool belts between the arid and glacial belts. The temperate cool belt gradually expanding southward replaced the glacial belt at the end of the Early Permian. Simultaneously, semiarid and arid belts of both hemispheres became wider, and aridity increased as well in the equatorial mountainous humid belt. As a consequence, the planetary climatic zoning was drastically transformed.

Evolution of global climate. The climatic zoning is a most distinct reflection of the global climate, and we can confidently speak therefore about the substantial changes in the global climate during the Early Permian. In general, this period can be classed with the glacial epoch, because glaciers developed, although episodically, to the end of the epoch at least in the Southern Hemisphere. By the extent and character of glaciation, three stages in evolution of the Early Permian glacial climate can be distinguished. The Asselian–early Sakmarian climate was similar, in the extent of glaciation, to the Pleistocene one. In these cases, ice shields spread over high and middle latitudes of both hemispheres. Accordingly, it was the *climate of the glacial maximum*, as we can term it. In the popular literature, such glaciations are frequently called "great glaciations." Climate of the terminal Sakmarian–initial Artinskian time can be termed as the *climate of polar cups*, because glacial sheets were mainly confined to high latitudes. Climate of this type exists now and has existed in the Oligocene and in the second half of the Eocene, when first ice covers appeared in Antarctica. At the end of the early Permian, the cold temperate climate became prevalent in polar areas of both hemispheres. The southern polar cap degraded with preservation of small glaciation centers (most likely, episodic ones). This time can be considered as a terminal stage of the Gondwanan Glacioera and corresponding global climate as the *climate of cold polar areas.*

ACKNOWLEDGMENTS

We express our sincere gratitude to V.G. Ganelin, A.V. Goman'kov, M.V. Durante, P.K. Link, S.V. Naugil'nykh, and, particularly, E.Ja. Leven for their comments and valuable recommendations when we worked on the manuscript. The work was supported by the Russian Foundation for Basic Research, project nos. 99-05-64073 and 99-05-65004.

Reviewers A.S. Alekseev and E.Ja. Leven

REFERENCES

Ahmad, N., Late Palaeozoic Talchir Tillites of Peninsular India, *Earth's Pre-Pleistocene Glacial Record*, Hambrey, M.J., Harland, W.B., Chumakov, N.M., *et al.*, Eds., Cambridge: Cambridge Univ., 1981, pp. 326–330.

Alsharhan, A.S. and Nairn, A.E.M., Stratigraphy and Sedimentology of the Permian in the Arabian Basin and Adjacent Areas: a Critical Review, *The Permian of Northern Pangea. V. 2*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, pp. 187–214.

Amos, A.J. and Lopez Gamundi, O., Late Palaeozoic Sauce Grande Formation of Eastern Argentina, *Earth's Pre-Pleistocene Glacial Record*, Hambrey, M.J., Harland, W.B., Chumakov, N.M., *et al.*, Eds., Cambridge: Cambridge Univ., 1981, pp. 872–877.

Andrianov, V.N., *Verkhnepaleozoiskie otlozheniya Zapadnogo Verkhoyan'ya* (Upper Paleozoic Deposits in the Western Verkhoyansk region), Moscow: Nauka, 1966.

Babcock, L.E., Miller, M.F., Isbell, J.L., *et al.*, Paleozoic–Mesozoic Crayfish From Antarctica—Earliest Evidence of Fresh-Water Decapod Crustaceans, *Geology*, 1998, vol. 26, no. 6, pp. 539–542.

Beauchamp, B., Permian History of Arctic North America, *The Permian of Northern Pangea*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, pp. 3–22.

Berryhill, H.L., Jr., Allegheny Region, *Paleotectonic Investigations of the Permian System in the United States*, McKee, E.D., Oriel, S.S., *et al.*, Eds., *Geol. Surv. Prof. Pap.*, 1967, no. 513, pp. 1–7.

Bhattacharya, A., Evidences of Sandur Deposits, the Barakar Formation (Lower Permian) in the Ramgarh Coalfield, India, *Gondwana Seven*, Ulbrich, H. and Rocha-Campos, A.C., Eds., Inst. Geociencias-USP, 1991, pp. 365–377.

Bobin, E.S., The Yudoma–Allakh–Yun Waterdivide, *Tr. Tresta "Zolotorazvedka" Inst. NIGRIZoloto*, 1940, no. 13, pp. 31–53.

Bourman, R.P. and Alley, N., Permian Glaciated Bedrock Surfaces and Associated Sediments on Kangaroo Island, South Australia: Implications for Local Gondwanan Icemass Dynamics, *Australian J. Earth Sci.*, 1999, vol. 45, no. 4, pp. 523–531.

Breivik, A.J., Gudlaugsson, S.T., and Faleide, J.I., Ottar Basin, SW Barents Sea: a Major Upper Palaeozoic Rift Basin Containing Large Volumes of Deeply Buried Salt, *Basin Res.*, 1995, vol. 7, no. 4, pp. 299–312.

Broutin, J., Doubinger, J., Hamet, M.O., and Lang, J., Palynologie comparee du Permien nigerien (Afrique occidentale) et Peritethysien. Implications stratigraphiques et phytogeographiques, *Rev. Palaeobot. Palynol.*, 1990, vol. 66, pp. 243–261.

Bustin, R.M., Cold-Temperate Peats and Coals: Their Sedimentology and Composition, *Late Glacial and Postglacial Environmental Changes. Quaternary, Carboniferous–Permian and Proterozoic*, Martini, I.P., Ed., New York: Oxford. Univ., 1997, pp. 294–310.

Cahen, L. and Lepersonne, J., Late Palaeozoic Tillites of the Congo Basin in Zaire, *Earth's Pre-Pleistocene Glacial Record*, Hambrey, M.J., Harland, W.B., Chumakov, N.M., *et al.*, Eds., Cambridge: Cambridge Univ., 1981, pp. 43–47.

Cassinis, G., Toutin-Morin, N., and Virgili, C., A General Outline of the Permian Continental Basins in Southwestern Europe, *The Permian of Northern Pangea*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, pp. 137–157.

Chandra, S., Changing Patterns of the Permian Gondwana Vegetation, *Palaeobotanist*, 1992, vol. 40, pp. 73–100.

Châteauneuf, J.J. and Farjanel, G., Syntése géologique des bassins permiens français, *Bull. Rech. Geol. Min. (Orlans)*, 1989, Mem. 128, pp. 1–288.

Chumakov, N.M., Glacial Events of the Past and Their Geological Significance, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1985, vol. 51, pp. 319–346.

Chumakov, N.M., Evidence of Late Permian Glaciation in the Kolyma River Basin: A Repercussion of the Gondwana Glaciation in Northeast Asia? *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 5, pp. 130–150.

Chumakov, N.M., Zharkov, M.A., German, A.B., *et al.*, Climatic Belts of the Mid-Cretaceous Time, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 42–63.

Cole, D.I. and McLachlan, I.R., Oil Potential of the Permian Whitehill Sale Formation in the Main Karoo Basin, South Africa, *Gondwana Seven*, Ulbrich, H. and Rocha-Campos, A.C., Eds., Inst. Geociencias-USP, 1991, pp. 379–390.

Collinson, J.W. and Miller, M.F., Comparison on Lower Permian Post-Glacial Black Shale Sequences in the Ellsnorth and Transantarctic Mountains, Antarctica, *Gondwana Seven*, Ulbrich, H. and Rocha-Campos, A.C., Eds., Inst. Geociencias-USP, 1991, pp. 217–231.

Condon, M.A., The Geology of the Carnarvon Basin, W. Australia. Stratigraphy, Part 2, Permian, *Bull. Geol. Aust., Bur. Mineral Res.*, 1967, vol. 77, p. 191.

Conrel, L., Destencq, C., Essamond, R., *et al.*, Coal Occurrence Related to Sedimentary Dynamics: Three African Examples, *J. Afr. Earth Sci.*, 1991, vol. 12, pp. 159–169.

Crowell, J.C., The Ending of the Late Paleozoic Ice Age during the Permian Period, *The Permian of Northern Pangea*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, pp. 62–74.

Crowell, J.C. and Frakes, L.A., Late Paleozoic Glaciation, IV. Australia, *Bull. Geol. Soc. Am.*, 1971, vol. 82, pp. 2515–2540.

Cúneo, N.R., Permian Phytogeography in Gondwana, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1996, vol. 125, pp. 75–104.

Dickins, J.M., Late Palaeozoic Glaciation, *BMR J. Austral. Geol. Geophys.*, 1985, vol. 9, pp. 163–169.

Dickins, J.M., Problems of Late Palaeozoic Glaciation in Australia and Subsequent Climate in the Permian, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1996, vol. 125, pp. 185–197.

Dobruskina, I.A., *Triasovye flory Evrazii* (Triassic Floras of Eurasia), Moscow: Nauka, 1982.

Dobruskina, I.A., *Triassic Floras of Eurasia*, Vienna: Springer, 1994, p. 422.

Durante, M.V., Reconstruction of Late Paleozoic Climatic Changes in Angaraland according to Phytogeographic Data, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 2, pp. 25–37.

Earth's Glacial Record, Deynoux, M., Miller, J.M.G., Domack, E.W., *et al.*, Eds., Cambridge: Cambridge Univ., 1994.

Earth's Pre-Pleistocene Glacial Record, Hambrey, M.J., Harland, W.B., Chumakov, N.M., *et al.*, Eds., Cambridge: Cambridge Univ., 1981.

Pangea: Global Environments and Resources, Embry, A.F., Beauchamp, B., and Glass, D.J., Eds., *Mem. Can. Soc. Petrol. Geol.*, 1994, no. 17.

Eyles, N. and Young, G.M., Geodynamic Controls on Glaciation in Earth History, *Earth's Glacial Record*, Deynoux, M., Miller, J.M.G., Domack, E.W., Eyles, N., Fairchild, I.J., and Young, G.M., Eds., Cambridge: Cambridge Univ., 1994, pp. 1–28.

Eyles, N., Eyles, C.H., and Gostin, V.A., Iceberg Rafting and Scouring in the Permian Shoalhaven Group of New South Wales, Australia: Evidence of Heinrich-like Events?, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1997, vol. 136, pp. 1–17.

Eyles, C.H., Eyles, N., and Gostin, V.A., Facies and Allostratigraphy of Highlatitude Glacially Influenced Marine Strata of the Early Permian southern Sydney Basin, *Sedimentology*, 1998, vol. 45, no. 1, pp. 121–161.

Frakes, L.A., *Climates Throughout Geologic Time*, Amsterdam: Elsevier, 1979, p. 310.

Frakes, L.A., Francis, J.E., and Syrtus, J.I., *Climate Modes of the Phanerozoic*, Cambridge: Cambridge Univ., 1992.

Franca, A.B., Itarare Group: Gondwanan Carboniferous–Permian of the Parana Basin, Brazil, *Earth's Glacial Record*, Deynoux, M., Miller, J.M.G., and Domack, E.W., Eds., Cambridge: Cambridge Univ., 1994, pp. 70–82.

Francis, J.E., Woolfe, K.J., Arnott, M.J., and Barret, P.J., Permian Climates of the Southern Margins of Pangea: Evidence From Fossil Wood in Annarctica, *Mem. Can. Soc. Petrol. Geol.*, 1994, no. 17, pp. 275–282.

Frazier, W.J. and Schwimmer, D.R., *Regional Stratigraphy of North America*, New York: Plenum, 1987.

Geslin, J.K., Distal Ancestral Rocky Mountains Tectonism: Evolution of the Pennsylvanian–Permian Oquirrh-Wood River Basin, Southern Idaho, *GSA Bull.*, 1998, vol. 110, no. 5, pp. 644–663.

González-Bororino, G. and Eyles, N., Inverse Relation Between Ice Extent and the Late Paleozoic Glacial Record of Gondwana, *Geology*, 1995, vol. 23, no. 11, pp. 1015–1018.

Grunt, T.A., Biogeography of Permian Sea Basins, *Paleontol. Zh.*, 1995, no. 4, pp. 10–25.

Grunt, T.A. and Novikov, V.P., Biostratigraphy and Biogeography of the Early Permian in the Southeastern Pamirs, *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 4, pp. 28–37.

Grunt, T.A. and Shi, G.R., A Hierarchical Framework of Permian Global Marine Biogeography, *Proc. 30th Intern. Geol. Congress*, 1997, vol. 12, pp. 2–17.

Guerra-Sommer, M., Cazzulo-Klepzig, M., and Mendonca Filho, J.G., Vegetation Changes, Parana Basin, Permian, South Brazil, *Abstracts XIV ICCP Conf.*, 1999, p. 49.

Hambrey, M.J., Late Palaeozoic Karoo Tillites in Gabon, *Earth's Pre-Pleistocene Glacial Record*, Hambrey, M.J., Harland, W.B., Chumakov, N.M., *et al.*, Eds., Cambridge: Cambridge Univ., 1981, pp. 41–42.

Heckel, P.H., Paleogeography of Eustatic Model for Deposition of Midcontinent Upper Pennsylvanian Cyclothems, *Paleozoic Paleogeography of West-Central United States*, Fouch, T.D. and Magathan, E.R., Eds., Rocky Mountain Sec. SEPM, 1980, pp. 197–215.

Hoffman-Rothe, J., Luz stratigraphic and tektonic des paléozoikums des algerischen Ostsahara, *Geol. Rundschau*, 1966, vol. 55, no. 3, pp. 185–201.

Ignat'ev, I.A. and Naugol'nykh, S.V., The Early Kazanian "Soyana River Flora": Its Place among Coeval Floras and in Phytogeographic Zones of the Angaraland, *Stratigr. Geol. Korrelyatsiya*, vol. 9, no. 3, pp. 58–75.

Isbell, J.L. and Collinson, J.W., Sedimentological Significance of Fluvial Cycles in the Permian of the Central Transantarctic Mountains, Antarctica, *Gondwana Seven*, Ulbrich, H. and Rocha-Campos, A.C., Eds., Inst. Geociencias-USP, 1991, pp. 189–197.

Isbell, J.L. and Cúneo, N.R., Depositional Framework of Permian Coal-Bearing Strata, Southern Victoria Land, Antarctica, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1996, vol. 125, pp. 217–238.

Isbell, J.L., Seegers, G.M., and Gelhar, G.A., Upper Paleozoic Glacial and Postglacial Deposits, Central Transantarctic Mountains, Antarctica, *Late Glacial and Postglacial Environmental Changes. Quaternary, Carboniferous–Permian and Proterozoic*, Martini, P., Ed., Oxford: Oxford. Univ., 1997, pp. 230–242.

Jin, Y., Wardlaw, B.R., Glenister, B.F., and Kotlyar, G.V., Permian Chronostratigraphic Subdivisions, *Episodes*, 1997, vol. 20, no. 1, pp. 10–15.

Kiessling, W., Flügel, E., and Golonka, J., Paleoreef Maps: Evaluation of a Comprehensive Database on Phanerozoic Reefs, *Bull. Am. Assoc. Petrol. Geol.*, 1999, vol. 83, no. 10, pp. 1552–1587.

Kotlyar, G.V., Correlative Reference Levels of the Permian, *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 2, pp. 35–50.

Kozur, H.W., Some Aspects of the Permian–Triassic Boundary (PTB) and of the Possible Causes for the Biotic Crisis Around This Boundary, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1998, vol. 143, pp. 227–272.

Kutzbach, J.E. and Gallimore, R.G., Pangea Climates: Megamonsoons of the Megacontinent, *J. Geophys. Res.*, 1989, vol. 94, pp. 3341–3357.

Leonova, T.B., Permian Ammonoids: Systematics and Evolution, *Doctoral (Geol.–Min.) Dissertation*, Moscow: Paleontol. Inst. Ross. Acad. Sci., 1999, p. 40.

Levell, B.K., Braakman, J.H., and Rutlen, K.W., Oil-Bearing Sediments of Gondwana Glaciation in Oman, *Bull. Am. Assoc. Petrol. Geologists*, 1988, vol. 72, pp. 775–796.

Leven, E., Early Permian Fusulinids from the Central Pamir, *Riv. It. Paleont. Stratigr.*, 1993, vol. 99, no. 2, pp. 151–198.

Lindsay, J.F., Permian Postglacial Environments of the Australian Plate, *Late Glacial and Postglacial Environmental Changes*, Martini, I.P., Ed., New York: Oxford Univ., 1997, pp. 213–229.

Lopez-Gamundi, O.R., Glacial–Postglacial Transition in the Late Paleozoic Basins of Southern South America, *Late Glacial and Postglacial Environmental Changes*, Martini, I.P., Ed., New York: Oxford Univ., 1997, pp. 147–168.

Mader, D., *Evolution of Palaeoecology and Triassic Fluvial Basin in Europe. Vol. 1. Western and Eastern Europe. V. 2. Southeastern Europe and Index*, Stuttgart: Gustav Fischer, 1992.

Martin, H., The Late Palaeozoic Dwyka Group of the South Kalahari Basin in Namibia and Botswana and the Subglacial Valleys of the Kaokoveld in Namibia, *Earth's Pre-Pleistocene Glacial Record*, Hambrey, M.J., Harland., W.B., Chumakov, N.M., *et al.*, Eds., Cambridge: Cambridge Univ., 1981, pp. 61–66.

Martini, I.P., *Late Glacial and Postglacial Environmental Changes. Quaternary, Carboniferous-Permian and Proterozoic*, Oxford. Univ., 1997.

Meyen, S.V., *Osnovy paleobotaniki* (Fundamentals of Paleobotany), Moscow: Nedra, 1987.

Metcalfe, I., Late Palaeozoic and Mesozoic Palaeogeography of Eastern Pangea and Tethys, *Mem. Can. Soc. Petrol. Geol., Calgary*, 1994, no. 17, pp. 97–111.

Michaelsen, P. and Henderson, R.A., Facies, Relationships and Cyclicity of High-Latitude, Late Permian Coal Measures, Bowen Basin, Australia, *Intern. J. of Coal Geol.*, 2000, vol. 44, pp. 19–48.

Miller, K.B., McCahon, T.J., and West, R.R., Lower Permian (Wolfcampian) Paleosol-Bearing Cycles of the US Midcontinent: Evidence of Climatic Cyclicity, *J. Sedimentol. Res.*, 1996, vol. 66, pp. 71–84.

Oriel, S.S., Myers, D.A., and Crosby, E.J., West Texas Permian Basin Region, *Paleotectonic Investigations of the Permian System in the United States*, McKee, E.D., Oriel, S.S., *et al.*, Eds., Washington: US Govern. Printing Office, 1967, pp. 21–60.

Parfenov, L.M., and Nokleberg, U.J., Monger, J.U.H., *et al.*, Development of Terrane Collages in the Northern Circum-Pacific Orogenic Belts, *Geol. Geofiz.*, 1999, vol. 40, no. 11, pp. 1563–1574.

Parrish, J.T., Geologic Evidence of Permian Climate, *The Permian of Northern Pangea, Vol. 1: Paleogeography, Paleoclimates, Stratigraphy*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, pp. 53–61.

Peterson, J.A., Permian Paleogeography and Sedimentary Provinces, West Central United States, *Paleozoic Paleogeography of West-Central United States*, Fouch, T.D. and Magathan, E.R., Eds., Rocky Mountain Sec. SEPM, 1980, pp. 271–292.

Rall, E.P., Influence of Highstands and Lowstands on Virgil and Wolfcam Paleogeography in the Denver Embayment, Eastern Colorado, *Paleozoic Systems of the Rocky Mountain Region Colorado*, Longman, M.W. and Sonnenfeld, M.D., Eds., Littleton: Rocky Mountain Sec. SEPM, 1996, pp. 321–334.

Rees, P., Mc, A., Gibbs, M.T., Kutzbach, J.E., and Behling, P.J., Permian Climates: Evaluating Model Predictions Using Global Paleobotanical Data, *Geology*, 1999, vol. 27, no. 10, pp. 891–894.

Retallack, G.J., Late Carboniferous to Middle Triassic Megafossil Floras From Sidney Basin, *Bull. Geol. Surv. New S. Wales*, 1980, no. 26, pp. 385–430.

Rocha-Campos, A.C., Late Paleozoic Tillites of the Sergipe–Alagoas Basin, Rondonia and Mato Grosso, Brazil, *Earth's Pre-Pleistocene Glacial Record*, Hambrey, M.J., Harland, B., Chumakov, N.M., *et al.*, Eds., Cambridge: Cambridge Univ., 1981, pp. 838–841.

Rocha-Campos, A.C. and Dos Santos, P.R., The Itarare Subgroup, Aquidauana Group and San Gregorio Formation, Parana Basin, Southeastern South America, *Earth's Pre-Pleistocene Glacial Record*, Hambrey, M.J., Harland, B., Chumakov, N.M., *et al.*, Eds., Cambridge: Cambridge Univ., 1981, pp. 842–852.

Rocha-Campos, A.C., Lima Filho, F.P., and Canuto, J.R., Cycles in Piaui Formation, Parnaiba Basin, and Itarare Subgroup, Parana Basin, Brazil, *Abstracts XIV ICCP Conf.*, 1999, p. 124.

Ross, C.A. and Ross, R.P., Permian Sequence Stratigraphy, *The Permian of Northern Pangea. V. 1*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, pp. 98–123.

Runnegar, B., The Permian of Gondwana, *27-oi Mezhdunar. Geol. kongress. Doklady. T. 1* (Proc. 27th Intern. Geol. Congress, Vol.1), Moscow: Nauka, 1984, pp. 147–158.

Santos, P.R., Rocha-Campos, A.C., and Canuto, J.R., Patterns of Late Palaeozoic Deglaciation in the Parana Basin, Brazil, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1996, vol. 125, pp. 165–184.

Scotese, C.R. and Langford, R.P., Pangea and Paleogeography of the Permian, *The Permian of Northern Pangea. V. 1*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, pp. 3–19.

Sepkoski, J.J., Jr., Evolutionary Faunas, *Paleobiology. A Synthesis*, Briggs, D.E.G. and Crowther, P.R., Eds., London: Blackwell, 1990, pp. 37–41.

Shantts, G., History and Problems of Arid Lands Reclamation, *Budushchee aridnykh zemel'* (Future of Arid Lands), Moscow: Inostr. Lit., 1958, pp. 13–33.

Shi, G.R. and Grunt, T.A., Permian Gondwana–Boreal Antitropicality with Special Reference to Brachiopod Faunas, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, vol. 155, no. 2, pp. 239–263.

Smith, N.D., Barrett, P.J., and Woolfe, K.J., Clacier-Fed (?) Sandstone Sheets in the Weller Coal Measures (Permian), Allan Hills, Antarctica, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1998, vol. 141, pp. 35–51.

Stemmerik, L. and Worsley, D., Permian History of the Barents Shelf Area, *The Permian of Northern Pangea, Vol. 2: Sedimentary basins and economic resources*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, pp. 81–97.

Stephenson, M.H., Correlation of Permo-Carboniferous Palynological Assemblages From Arabia, *Program with Abstracts XIV ICCP*, Calgary Univ., 1999, p. 140.

Stevens, C.H., Summary of Paleozoic Paleogeography of Western United States, *Paleozoic Paleogeography of the Western United States—II* Cooper, J.D. and Stevens, C.H., Eds., Pacific Sec. SEPM, 1991a, pp. 1–11.

Stevens, C.H., Permian Paleogeography of the Western United States, *Paleozoic Paleogeography of the Western*

United States—II, Cooper, J.D. and Stevens, C.H., Eds., Pacific Sec. SEPM, 1991b, pp. 149–166.

Stollhofen, H., Stanistreet, I.G., Bangert, B., and Grill, H., Tuffs, Tectonism, and Glacially Related Sea-Level Changes, Carboniferous–Permian, Southern Namibia, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2000, vol. 161, nos. 1–2, pp. 127–150.

Termier, G., Termier, H., Maren, Ph., *et al.*, Donnees nouvelles sur la transgression glacoi-euststique permo-carbonifere (Gzhelien–Sakmarien) en Afghanistan central, *Compt. Rend. Acad. Sci. Ser. D*, 1973, vol. 276, pp. 943–947.

The Geology of Tasmania, Spry, A. and Banks, M.R., Eds., *J. Geol. Soc. Austral.*, 1962, vol. 9, pp. 107–362.

The Permian of Northern Pangea, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995.

Tsubone, K., Apoluceno, A.F., and Neto, I.R., Brazil. Tectonics and Sedimentation of the Solimoes Basin, Northern Brazil, *Gondwana Seven*, Ulbrich, H. and Rocha-Campos, A.C., Eds., Sao-Paulo: Inst. Geociencias-USP, 1991, pp. 119–128.

Ustritskii, V.I., The Paleozoic Boreal Biogeographic region, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 2, pp. 67–77.

Utting, J. and Piasecki, S., Palynology of the Permian of Northern Continents: a Review, *The Permian of Northern Pangea. V. 1*, Schnolle, P.A., Peryt, T.M., and Ulmer-Schnolle, D.S., Eds., Berlin: Springer, 1995, pp. 237–261.

Veevers, J.J. and Powell, C.McA., Late Paleozoic Glacial Episodes in Gondwanaland Reflected in Transgressive–Regressive Depositional Sequences in Euramerica, *Bull. Geol. Soc. Am.*, 1987, vol. 98, pp. 475–487.

Veevers, J.J., Powell, C.McA., Collinson, J.W., and Lopez-Gamundi, O.R., Synthesis, *Permian–Triassic Pangean Foldbelts along the Panthalassan Margin of Gondwanaland*, Veevers, J.J. and Powell, C.McA., Eds., *Mem. Geol. Soc. Am.*, 1994, vol. 184, pp. 331–354.

Vikhert, A.V., Climatic regime in the Verkhoyansk Basin during the Permian and Triassic, *Izv. Vost. Fil. Akad. Nauk SSSR*, 1957, no. 1, pp. 24–50.

Visser, J.N.J., The Age of the Late Palaeozoic Glacigene Deposits in Southern Africa *S. Afr. J. Geol.*, 1990, vol. 93, no. 2, pp. 366–375.

Visser, J.N.J., A Permian Argillaceous Syn- to Post-Glacial Foreland Sequence in the Karoo Basin, South Africa, *Earth's Glacial Record*, Deynoux, M., Miller, J.M.G., and Domack, E.W., Eds., Cambridge: Cambridge Univ., 1994, pp. 193–203.

Visser, J.N.J., Controls on Early Permian Shelf Deglaciation in the Karoo Basin of South Africa, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1996, vol. 125, pp. 129–139.

Visser, J.N.J., A Review of the Permo-Carboniferous Glaciation in Africa, *Late Glacial and Postglacial Environmental Changes*, Martini, I.P., Ed., New York: Oxford Univ., 1997, pp. 169–191.

Visser, J.N.J. and Young, G.M., Major Element Geochemistry and Paleoclimatology of the Permo-Carboniferous Glacigene Dwyka Formation and Post-Glacial Mudrocks in Southern Africa, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1990, vol. 81, pp. 49–57.

Visser, J.N.J., Niekert van, B.N., and van der Merwe, S.W., Sediment Transport of the Late Paleozoic Glacial Dwyka Group in the Southwestern Karoo Basin, *S. Afr. J. Geol.*, 1997, vol. 100, no. 3, pp. 223–236.

Geologiya i poleznye iskopaemye Afriki (Geology and Mineral Reserves of Africa), Vysotskii, I.V., Kats, Ya.G., Leonov, G.P., *et al.*, Eds., Moscow: Nedra, 1973.

Wang, J., Liu, H., Shen, G., and Zhang, H., Notes on the Island Distribution Pattern of the Permian Cathaysian Flora in China: An Example of the Application of the Equilibrium Theory of Island Biogeography in Palaeobiogeography, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1998, vol. 142, pp. 23–31.

Wardlaw, B.R., Permian Conodonts, *The Permian of Northern Pangea*, Scholle, P.A., Peryt, T.M., and Ulmer-Scholle, D.S., Eds., Berlin: Springer, 1995, vol. 1, pp. 186–195.

Wartiti, M.El., Broutin, J., Freytet, P., *et al.*, Continental Deposits in Permian Basins of the Mesetian Morocco, Geodynamic History, *J. Afr. Earth Sci.*, 1990, vol. 10, no. 1/2, pp. 361–368.

Wickham, J., Roeder, D., and Briggs, G., Plate Tectonics Models for the Ouachita Foldbelt, *Geology*, 1976, vol. 4, no. 3, pp. 173–176.

Wnuk, C., The Development of Floristic Provinciality during the Middle and Late Paleozoic, *Rev. Palaeobotany, Palynology*, 1996, vol. 90, pp. 5–40.

Wopfner, H. and Casshyap, S.M., Transition from Freezing to Subtropical Climates in the Permo-Carboniferous of Afro-Arabia and India, *Late Glacial and Postglacial Environmental Changes*, Martini, I.P., Ed., New York: Oxford. Univ., 1997, pp. 192–212.

Wopfner, H., Permo-Triassic Sedimentary Basins in Australia and East Africa and Their Relationship to Gondwanic Stress Pattern, *Gondwana Seven*, Ulbrich, H. and Rocha-Campos, A.C., Eds., Sao Paolo: Inst. Geociencias-USP, 1991, pp. 133–146.

Zharkov, M.A. and Chumakov, N.M., Paleogeography and Sedimentation Settings during Permian–Triassic Reorganizations in Biosphere, *Stratigr. Geol. Korrelyatsiya*, 2001, vol. 9, no. 4, pp. 29–54.

Zharkov, M.A., *Istoriya paleozoiskogo solenakopleniya* (History of Paleozoic Salt Accumulation), Novosibirsk: Nauka, 1978.

Zherebtsova, I.K., *K voprosu o kontinental'nom galogeneze* (To the Problem of Continental Halidegenesis), Yanshin, A.L. and Zharkov, M.A., Eds., Novosibirsk: Nauka, 1977, pp. 124–128.

Ziegler, A.M., Gibbs, M.T., and Hulver, M.L., A Mini Atlas of Oceanic Water Masses in the Permian Period, *Proc. R. Soc. Victoria*, 1998, vol. 110, no. 1/2, pp. 323–343.

Ziegler, A.M., Hulver, M.L., and Rowley, D.B., Permian World Topography and Climate, *Late Glacial and Postglacial Environmental Changes. Quaternary, Carboniferous-Permian and Proterozoic*, Martini, P., Ed., New York: Oxford. Univ., 1997, pp. 111–146.

Ziegler, A.M., Phytogeographic Patterns and Continental Configurations during the Permian Period, *Paleozoic Paleogeography and Biogeography*, McKerrow, W.S. and Scotese, C.R., Eds., *J. Geol. Soc.* (London), 1990, Mem. 12, pp. 363–379.

Zo Wang, *Gigantonoclea*—An Enigmatic Permian Plant From North China *Paleontol.*, 1999, vol. 42, pp. 329–373.