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PALEOZOIC PALEOGEOGRAPHY AND BIOGEOGRAPHY

A. J. Boucot

Department of Zoology. Oregon State University. Corvallis, Oregon 97331-2914, U.S.A.

RESUMEN

El presente trabajo representa un intento de conciliar los datos que proporcionan sedimentos paleozoicos sensibles a las condiciones paleoclimáticas (tales como carbones, evaporitas y bauxitas), con datos contemporáneos de naturaleza paleobiogeográfica. Como resultado se obtienen algunas reconstrucciones, muy distintas de otras propuestas basadas en el magnetismo residual, que están en mayor consonancia con los conocimientos paleobiogeográficos de que se dispone.

Palabras clave: Paleogeografía, Paleobiogeografía, Paleozoico.

ABSTRACT

An attempt is now being made to reconcile the data of Paleozoic climatically sensitive sediments, such as evaporites, coals, and bauxites, with the contemporary biogeographic data. This attempt results in some new paleogeographic reconstructions that are very different from those based on the data of remanent magnetism, and are more consistent with the available biogeographic data.

Key words: Paleogeography, Paleobiogeography, Paleozoic.

INTRODUCTION

It is self evident that a good understanding of Paleozoic biogeography rests in no small part on the possession of reliable paleogeography. It is also obvious that the biogeography and the paleogeography must be internally consistent, i.e., the distributions of the organisms must be consistent with the paleogeography. The paleogeographies must be ones that are consistent with varied mechanisms that will permit reproductive communication between areas with similar biotas, and that will separate areas with distinctly different biotas, excluding from consideration differences due to environmental distinctions. With these sentences in mind it is clear that Paleozoic paleogeographic questions must be addressed adequately before considering the purely biogeographic.

Anyone who has taken the trouble to compare and contrast the numerous Paleozoic paleogeographies published in the past twenty years, time interval by time interval, will have been impressed with the truly major distinctions that characterize them. There is clearly no agreement, particularly for the older Paleozoic, about such matters as which Hemisphere some of the continents and major land masses should be placed in; does Cambrian North America or Silurian North America, for example, belong in the Northern or the Southern Hemisphere; does Siberia belong in the Northern or Southern Hemisphere? These are not trivial questions. Can we hope to eventually resolve such strong differences in interpretation? In my opinion we will be able to eventually resolve these strong differences in interpretation. But, their resolution will require that varied classes of information, physical and biological, be integrated in a manner that is acceptable to all concerned. Such a resolution will clearly require that all concerned parties give ground on many points. What am I talking about? How did this refractory problem develop in the first place? We really are concerned here with time sequences of maps for the Paleozoic developed in largest parts by specialists using different classes of information. Specialists have tended, when problems arose, to rely on their own specific class of information, while largely ignoring information provided by apparently conflicting specialties. The geophysicist has tended to rely largely on geophysically generated information, the lithologist on lithological data, and the biogeographer on paleontological data. There has not been enough effort to integrate *all* classes of information, physical and biological, into a pleasing synthesis. Let us consider the matter further.

During the past few decades most earth scientists have been greatly impressed with the plate tectonic approach to interpreting the past positions of the continents and ocean basins. Those using this approach have reached a very high level of agreement in the Cenozoic, as well as in the younger Mesozoic. Overall, the level of agreement for the older Mesozoic has been fairly good, although not as high as for the Cenozoic. Much of this agreement, it is fair to say most of it, has been based on largely geophysical data derived from sea floor spreading interpretations. Data useful for sea floor spreading interpretations is readily available in the Cenozoic, much less so for the Cretaceous, and

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essentially absent for the older Mesozoic. For the older Mesozoic a combination of land based geophysical determinations based on the information of remanent magnetism preserved in properly dated rocks, with assumptions based on extrapolating sea floor spreading directions and rates from the oldest available data projected still further back into the past has been used. Such an approach has then been further extrapolated back into the Paleozoic. For the Permian the results of such geophysically based extrapolations have been in moderate agreement with those achieved from lithological and paleontological data. However, for the pre-Permian the level of agreement between the geophysical and nongeophysical data has broken down badly. Even for the Permian and younger intervals there are a significant number of serious questions, such as the position of Peninsular India, northeastern Iran (the so-called Lut Block), and for many parts of central and eastern Asia, plus Siberia, that are truly contentious. In view of the structurally complex histories characterizing much of Asia this is not surprising. In more detail it is also clear that real agreement about the changing geography of the Mediterranean region in the Permian to older Cenozoic can still be a subject of strong differences of interpretation. Still, from a global perspective whether or not various parts of what we now call the Italian Peninsula or the Iberian Peninsula were here or there previously is relatively minor when contrasted with such questions as trying to decide whether Devonian North America should be placed in the Northern or Southern Hemispheres, or whether it should straddle both. The largely geophysically based paleogeographies have not met with very ready acceptance by many of those working with lithological and paleontological data.

Those earth scientists primarily concerned with using lithological data have concerned themselves most with what one might term climatically sensitive sediments. Such things as tillites, evaporites, bauxites, coals, carbonate rocks, eolian deposits, and the like come to mind here. Attempts to use lithological data have been of several sorts. Some specialists, such as Bardossy in his global syntheses of bauxites (1982) have tried to use bauxite distribution data through time for deciding about what might be the best paleogeographies compatible with his data. Zharkov (1981) has behaved similarly with regard to Paleozoic evaporite occurrences. Meyerhoff and Teichert (1971, 1976) have tried to combine the data provided by coals and evaporites in their work leading to conclusions inconsistent with the plate tectonic interpretations. Strakhov, in a lengthy series of papers and books (1967 is an excellent example), has tried to synthesize varied classes of lithological data in a non-plate tectonic context. It is fair to say, just as with the largely geophysically based paleogeographies, that the lithologically based paleogeographies for the Paleozoic have not met with acceptance owing to their inability to explain much of the geophysical and paleontological data.

The paleogeographies based largely on paleontological information, biogeographical type interpretations, have provided still a third set of paleogeographies. These paleontologically based paleogeographies have been largely consistent with the paleontological data, but have essentially ignored the evidence for remanent magnetism derived from Paleozoic rocks, and have not paid enough attention to the lithological data. In particular, they have failed to recognize that the potentially key information provided by the bauxites should be taken full advantage of. By this I am referring to the conclusion reached by most students of bauxites, Bardossy (1982) is a good example, that bauxites form in tropical-subtropical humid regions. These bauxite producing regions need not be everwet. There is very limited information suggesting the formation of bauxites under warm temperate conditions, and none for temperate to cool temperate conditions that appears to stand up very well, or to indicate that a significant part of the bauxite record reflects temperate conditions as contrasted with tropical and subtropical conditions. This being the case it is clear that well dated occurrences of Paleozoic bauxites deserve special attention. In this connection a Spanish reader will be very concerned about the alleged Devonian bauxite from Leon (Font-Altaba and Closas, 1960) that was subsequently rejected as Tertiary by Bardossy and Fontbote (1977).

The evidence provided by marine evaporites, and lithological evidence of their former presence such as cauliflower cherts (quartz pseudomorphs after cauliflower-appearing anhydrite nodules) or solution breccias, particularly those with widespread distribution patterns, have been considered for some time as evidence for the location of former arid localities that might have belonged to arid belts of a particular time interval. Zharkov's (1981) work is an excellent example. However, the overall distribution through time of evaporites, time interval by time interval, can raise some problems owing to the apparently major changes in arid belt width(s), both wider and narrower, and location.

The pattern of coal distribution through time poses still another set of problems. For some time it has been obvious that the presence of coals, deposits large enough to be economic or not, has indicated humid conditions during the past, i.e., conditions incompatible with aridity. Admittedly, there are a few arid region situations where local «oases» have permitted the local accumulation of peats that have the potential for eventually forming coal deposits, but this is exceptional, just as is the reverse situation where an orographically generated rain shadow permits the accumulation and preservation of evaporites in an otherwise overall humid region (the Tertiary evaporites of the Rhine Graben come to mind here). Gore (1983, Fig. 1.1 and endpapers) has provided an excellent data base for the earth scientist by plotting up the modern distribution of swamps, peats, mires, and the like on a global basis. Gore's work makes it very clear that there are tropical-subtropical humid belt peats and swamps today, separated from higher latitude peats and swamps, north and south, by the two arid belts, north and south. The important exception to this overall latitudinally oriented relationship occurs along the western margins of

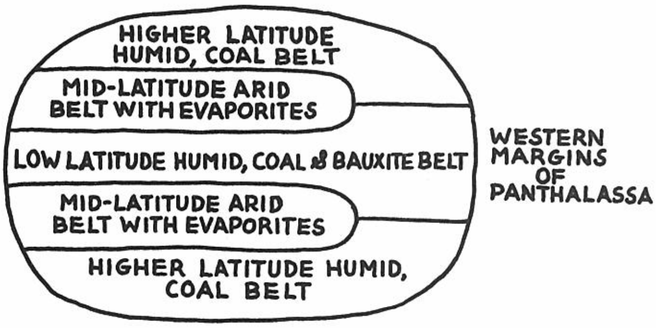

Figure 1. Hypothetical distribution of the climatic belts and associated climatically sensitive sediments during a non-glacial interval, with a moderately high global climatic gradient.

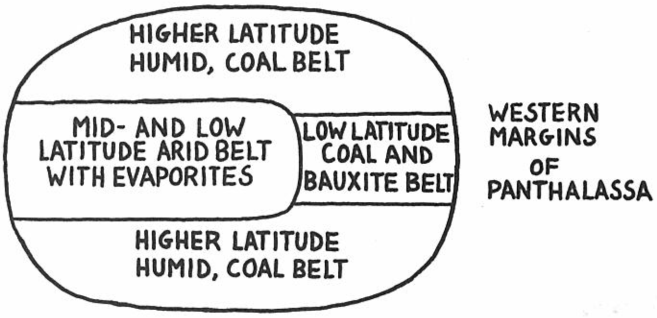

Figure 2. Hypothetical distribution of the climatic belts and associated climatically sensitive sediments during a non-glacial interval, with a very low global climatic gradient.

the Pacific and to a lesser degree the western margins of the Atlantic. Along these western ocean margins the two arid belts to not penetrate to the shoreline owing to the moisture provided from the adjacent oceans, which is enough to provide coastal and inland swamps and peats in some abundance. One needs to recognize here that these coastal and inland swamps and peats may extend, into what would normally be the arid belt, for a considerable distance in the *absence* of topographic barriers. Thus, one can envisage a trifid coal distribution pattern, with one branch being low latitude, equatorial, tropical-subtropical, and two being higher latitude and separated from the equatorial belt by mid-latitude arid belts, *except* for the western margins of any ocean where the three belts will be joined together north-south owing to the inability of arid conditions to approach the western ocean shore region. Many of the Carboniferous and younger karst bauxites are associated with coals, lignite in the case of the younger bauxites, although this is not the case with most of the lateritic bauxites owing to their commonly occurring in topographically higher preservational position inimical for the preservation of coals; this relationship helps to positively identify tropical-subtropical coals.

PALEOZOIC BAUXITE DISTRIBUTION PATTERNS AND THEIR SIGNIFICANCE

Once it is concluded that the presence of bauxite signifies tropical-subtropical humid conditions one has a most valuable tool for locating the Paleozoic low-latitude equatorial region as contrasted with mid-and higher latitudes. Chronologically speaking one begins with Early Cambrian bauxite in southern Siberia, the eastern Sayan and the Kuznetsk Alatau (Bardossy, 1982), none known yet from the Middle or Late Cambrian, from southeastern Kazakhstan for the Ordovician (Aleksandrov, 1974; Murzaliev, 1984; Dolgopolv, 1975), none known yet from the Silurian or Early Devonian, from the Altai-Sayan, central Urals, northern Urals, Polar Urals, Salair and Tien Shan for the Middle Devonian (Bardossy, 1982; Tkachenko et al., 1980; Ushatinskiy and Borovskiy, 1980; Kharin, 1969; Sukharina, 1974; Abdullayev, 1969), from Morocco (Bardossy and Aleva, 1990), Pakistan (Stauffer, 1969), the Urals (Bardossy, 1982), Kazakhstan (Bardossy, 1982), and Timan (Bardossy and Aleva, 1990) for the Late Devonian, widespread in South China (Bardossy, 1982), Tarim (Liu Changling, 1987), Tien Shan (Abdullayev, 1969), Taimyr (Bardossy, 1982), Kazakhstan (Bent and Skorina, 1973), Siberia (Tsykin, 1989), Poland (Bardossy, 1982), and northern Russia (Bardossy, 1982) for the Mississippian, from widespread localities in North China (Bardossy, 1982), Tarim (Liu Changling, 1987), South China (Bardossy, 1982), many locales in former Soviet Central Asia (Bardossy, 1982), Scotland (Bracewell, 1962), France (Vetter, 1964; Bardossy and Aleva, 1990), Poland (Gorzynski, 1968), Missouri (Bardossy, 1982), and Pennsylvania (Patterson et al., 1986) for the Pennsylvanian, from North China (Zhang *et al.*, 1987), South China (Bardossy, 1982) and Korea (Odokii, 1978) for the Early Permian, from Afghanistan (Beer *et al.*, 1972), Cambodia (Bardossy, 1982), China (Bardossy, 1982), Iran (Bardossy, 1982), Maly Caucasus (Beer *et al.*, 1978), southern central Asia, the Altai Sayan, trans-Baikal, pre-Amur and Far East (Odokii, 1978), Turkey (Bardossy, 1982), Vietnam (Bardossy, 1982), Greece (Bardossy, 1982) and eastern Australia (Loughnan, 1975) for the Middle and Late Permian.

The above Paleozoic bauxite occurrences resolve themselves into two basic patterns: 1) for the older Paleozoic, Early Cambrian through Middle Devonian one sees a central Asian plus Uralian Devonian distribution. 2) for the later Paleozoic there is a basic East Asian to north European pattern, plus a post-Early Permian Mediterranean presence. The Early Paleozoic occurrences may be interpreted as a central Asian and Uralian tropical belt consistent with placing most of Eurasia within the Southern Hemisphere. The Mississippian pattern is consistent with an East Asian tropical-subtropical humid belt incorporating China and northern Europe. The Pennsylvanian pattern is also consistent with an East Asian tropical-subtropical humid belt incorporating China joining with a European through central United

States tropical-subtropical belt. The Permian pattern is consistent with an East Asian tropical-subtropical humid belt incorporating China and points to the south, plus a Mediterranean tropical-subtropical humid belt, with the East Asian area partly changing in a westerly direction into arid conditions exemplified by widespread evaporites over much of Europe and western North America after the Early Permian. Phytogeographically the Cathaysian Realm of southern Asia corresponds to this humid, tropical-subtropical bauxite region, and westerly also to the Euramerian Province. Evaporites occur to either side when one moves westerly enough to be removed from the influence of Panthalassic moisture on eastern Asia.`

CLIMATICALLY SENSITIVE SEDIMENT TRENDS AND ANOMALIES

Any Paleozic paleogeography must comprehend and be consistent with a number of Paleozoic climatically sensitive sediment distribution trends and anomalies. For example, during the interval Cambrian through earlier Middle Devonian, Eifelian, North America is characterized by scattered evaporite deposits that are consistent with relatively arid conditions. Australia during the Cambrian-Devonian interval, and the Siberian Platform *sensu strictu* (between the Lena and the Yenissei) are characterized by similar evaporites, which continue on through the Mississippian for part of the Siberian Platform, but are replaced by coals in Australia, i.e., a major change to humid conditions for the latter. Beginning in the later Middle Devonian, Givetian, the coal-evaporite, humid-arid boundary in North America progressively moves in a southerly direction from Arctic Canada until by the Pennsylvanian this boundary has moved to a position well south of the scattered more southerly Pennsylvanian coal-producing states of the U.S. (Alabama, Arkansas, Texas, New Mexico), and in the Old World adjacent to a position between the Moroccan, Algerian, Egyptian Pennsylvanian coals and the more southerly North African evaporites in Algeria and Libya. Also notable in the Pennsylvanian is the incoming on the northern fringe of North America and Europe of a second evaporite belt, presumably a Northern Hemisphere arid belt, in Arctic North America and Arctic Europe. To the east one finds Permian and Pennsylvanian, as well as Mississippian coals and bauxites widely distributed in China, as well as in northern Siberia. As mentioned earlier, bauxites are also present in the Cambrian through Devonian interval in Kazakhstan and in the Urals during the Devonian, indicating the presence of tropical-subtropical, humid conditions.

SYNTHESIZING THE AVAILABLE BIOGEOGRAPHIC AND CLIMATICALLY SENSITIVE SEDIMENT DATA

For some time (Boucot, 1988, 1990; Boucot and Gray, 1979, 1980, 1983, 1987) an attempt has been made to synthesize the data of Paleozoic paleobiogeography with that of climatically sensitive sediments. However, it is only during the past two years that a concerted effort has been made (Boucot, Chen Xu, Scotese, in prep.) to gather a comprehensive sample of the climatically sensitive sediment data, and to then plot it on varied geographic base maps. The most novel part of this new paleogeographic synthesis is as follows: 1) placement of the southeastern Kazakhstan-Mongolian-Inner Mongolian-Heilongjiang belt of central to east central Asia in an equatorial, tropical-subtropical position, owing to its Cambro-Devonian bauxites, together with the Uralian bauxites of the Devonian; 2) placement of the Siberian Platform in a Northern Hemisphere Arid Belt position, while at the same time placing North America in a Southern Hemisphere Arid Belt position; 3) placement of the Pennsylvanian coals of North America, Europe and the northern fringe of Africa, in a tropical-subtropical position; 4) placement of the Chinese Carboniferous and Permian coals and co-occurring bauxites into a tropical-subtropical position, adjacent to Panthallassa, the great ocean of the Paleozoic, while placing the adjoining Carboniferous and Permian coals of Siberia *sensu lato* in a North Temperate position, with the moisture for both being derived from adjacent Panthalassa, and a gradation in western Asia into increasingly arid conditions that explain the evaporites of western Asia and Europe.

BIOGEOGRAPHIC CONSEQUENCES OF THE NEW PALEOGEOGRAPHIES

The new paleogeographies place the bulk of the Cambrian through earlier Middle Devonian, Eifelian, continental areas in the Southern Hemisphere, except for the Siberian Platform, which is placed in a Northern Hemisphere Arid Belt position. This new, earlier Paleozoic paleogeography helps considerably in explaining the curious biogeographic anomaly posed by the region from southeastern Kazakhstan (the Lake Balkhash region) through Mongolia, Inner Mongolia and Heilongjiang. In this area during much of the earlier Paleozoic one finds a «mixture» of endemic genera, Old World genera, New World genera and Tasman genera.

PALEOZOIC BIOGEOGRAPHIC COMMENTS

In view of the papers by Boucot and Gray cited two paragraphs above, with the many figures illustrating possible Paleozoic biogeographies and schematic paleogeographies, based largely on paleontological data, it would be redundant to review this evidence yet again, time interval-by-time interval. But it is appropriate to comment on new Paleozoic biogeographic interpretations made possible by the newly compiled lithologic data discussed above.

For the Ordovician Kaljo and Klaamann (1973) emphasized the generic-level similarities of coral faunas from the North American and Siberian Platforms. There are some coral taxa, however, restricted to the respective platforms, and the same is true for the brachiopods. Taken together, however, it is clear that these two platform faunas have more in common with each other than with Ordovician faunas elsewhere. The new geography, placing the Siberian Platform in a Northern Hemisphere Arid Belt position, and North America in a southern Hemisphere Arid Belt position, with westerly directed, equatorial and lower latitude oceanic surface currents in between makes it entirely reasonable to view these currents as the mechanism whereby the more teleplanic larvae were distributed to both of these platforms.

As with the Ordovician, Kaljo and Klaamann (1973) emphasize the overall Silurian similarities existing in their coral faunas between the Siberian and North American Platforms. The Siberian Platform brachiopods, almost entirely of pre-mid Wenlockian age, are also very similar generically to those of the North American Platform, and probably should be assigned to the American rather than the European Province of the North Atlantic Region. This being the case a similar oceanic surface current explanation for maintaining reproductive communication can be used as for the Ordovician.

Hou Hong-fei and Boucot (1990) discussed the biogeographic anomaly in the southeastern Kazakhstan-Mongolian-Heilongjiang region at some length for the Devonian, and proposed that it be recognized as the Balkhash-Mongolia-Okhotsk Region of the Old World Realm. The explanation lies in the fact that placing this region in an equatorial region, owing to its bauxites, permits one to have oceanic surface current gyres from the Tasman Region and the Eastern Americas Realm feed more teleplanic larvae into this low latiude region where they mixed with local endemics where they were swept in a westerly direction by an equatorial, westerly directed surface current, as well as more cosmopolitan Old World Realm taxa. A similar explanation can be used for the curious generic «mixtures» encountered in certain older parts of the Paleozoic in this part of the world.

Also for the Devonian, and particularly in view of Young's (1981) emphasis on the high level endemicity of its vertebrates, it is now appropriate to consider the Siberian Platform as an Early Devonian endemic area that might be ranked somewhere between the provincial and regional level, although our ignorance of its brachiopods precludes certainty on this last point, as does our need for a more in depth analysis globally of earlier Devonian trilobite endemism.

For the Mississippian it is important to point out that a flora with Angaran affinities (Spicer and Thomas, 1987) has been recognized in the Brooks Range of Northern Alaska, which provides a tie to similar Siberian floras, suggesting that parts of both Siberia and Alaska had reached North Temperate latitudes this early. Mamet (1992) has recognized North American, Arctic and Tethyan algal floras for the Carboniferous that go a long way towards integrating Carboniferous relations with those of the Permian, i.e., the relative lack of biogeographic attention directed towards the Carboniferous is now beginning to be fixed.

For the Permian Dutro and Saldukas (1973) have emphasized that there is an Arctic very low diversity biogeographic unit, their «Arctic Permian marine Fauna», termed the «Boreal Realm» by Boucot and Gray (1979). Dutro and Saldukas (1973) did not cite the bulk of the very similar Soviet conclusions regarding Arctic Permian low diversity, but these exist (Dagis and Ustritskiy, 1973, for example).

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