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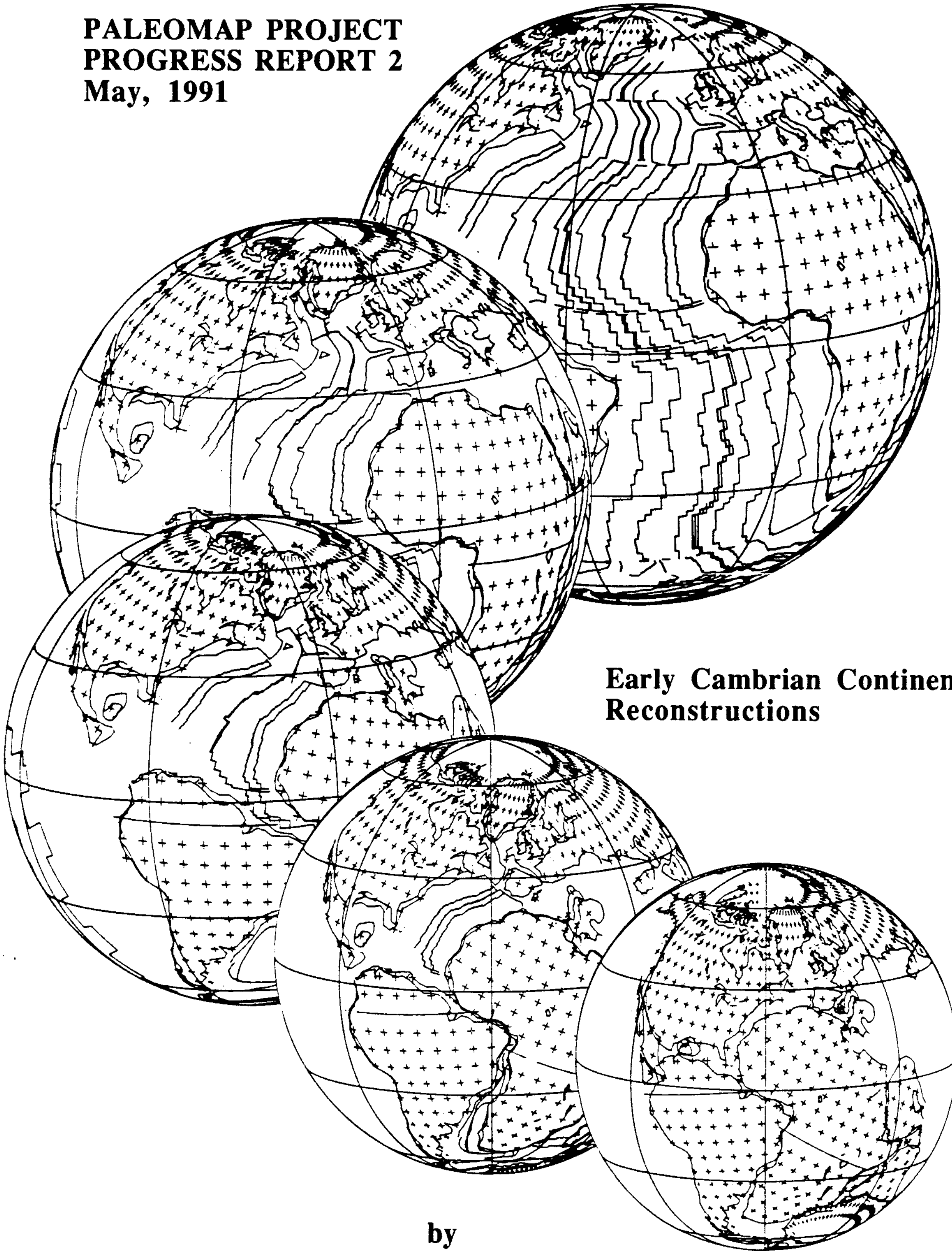
PALEOMAP PROJECT
PROGRESS REPORT 2
May, 1991



Early Cambrian Continental Reconstructions

by

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EARLY CAMBRIAN CONTINENTAL RECONSTRUCTIONS

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ABSTRACT : Climatically-related sedimentary facies and faunal distributions have been combined with palaeomagnetic data to make provisional reconstructions of the Early Cambrian world. Laurentia, Baltica and Siberia appear to have formed a continental group which rifted apart from each other prior to 600Ma. The consolidation of much of Gondwana probably occurred (in the Pan-African Orogeny) well before the Cambrian, though the assembly of several east Asian terranes is still speculative. The archaeocyathan reefs of Siberia, southern Europe and Morocco, with their bigotinid trilobite fauna, suggests that these areas were adjacent to each other and at low latitudes. Avalonia has close faunal links with western Gondwana, but lacks bigotinids and archaeocyathans and may have been situated off west Africa and Florida. During the Early Cambrian, there was a northward migration of Laurentia towards the Equator as its separation from Baltica and Siberia increased, and a southward movement of Gondwana.

There is some debate as to whether, in the Late Precambrian, two large continental assemblages are more probable than just one. Many geologists (Morel & Irving

1978; Bond et al. 1984; Piper 1983, 1987) consider that the majority of the major continents were fused to form a single Late Precambrian "Pangea". But, before exploring Late Precambrian continental distributions, a necessary first stage is to determine the situation in the Early Cambrian, where biostratigraphy can now recognise several fine time divisions, and where biogeography is available to assist the sedimentological and palaeomagnetic evidence. This is the aim of the present paper.

By the Early Cambrian, it is clear that Laurentia, Baltica and Siberia had separated from each other (Fig.1). Not only do these continents exhibit several Late Precambrian (c.600Ma) rifted margins (McKerrow et al. 1991 and references therein), but the evidence of their separation can be seen in faunal distinctions and latitudinal indicators which we discuss here. By contrast, the Pan-African Orogeny (750-550Ma) suggests that amalgamation of some Gondwana continents occurred in the Late Precambrian, largely preceding the time when Laurentia, Baltica and Siberia started to rift from each other.

Our current ideas on the Cambrian arrangement of Gondwana have developed from several papers in the Palaeozoic Palaeogeography and Biogeography Memoir (McKerrow & Scotese 1990), notably the contribution by Burrett et al. (1990) who provide a reconstruction based on palaeontological and palaeomagnetic data, which agrees well with additional palaeogeographic evidence presented by others in the same memoir.

The Antrim Volcanics of NW Australia (Veevers, 1984, p.281-2) indicate that some rifting in eastern Gondwana had developed before the end of the Early Cambrian (?515Ma), but this is a distinctly later event than the (c.600Ma) initiation of rifting between Laurentia, Siberia and Baltica. If the continental assemblage around Australia was like that envisaged by Burrett et al. (1990), these volcanics may have been related to the separation of Tibet (or some other part of east Asia) from NW Australia.

Problems of correlation.

The Early Cambrian presents a challenge to stratigraphy: fossils are scarce, many of the commoner forms are facies controlled and provincial, and biostratigraphers studying this interval are few in number. Archaeocyathan sponges provide the backbone of Early Cambrian biostratigraphy (Rozanov & Sokolov 1984; Spizharski et al. 1986), but they are restricted to carbonate platforms. Their evolution has been worked out on the Siberian Platform to provide the four stages widely used for archaeocyathan assemblages elsewhere (Table 1). In the Tommotian Stage, a lack of archaeocyathans beyond Siberia has stimulated research into small skeletal fossils for biostratigraphy (see Brasier 1989b), but the taxa may be long-ranging and facies-controlled. An integrated approach, employing first appearances of small skeletal fossils and assemblages, sequences stratigraphy and chemostratigraphy, holds out some hope of unravelling the sequence of events across the Precambrian-Cambrian boundary interval.

At the time of writing, neither the base nor the top of the Early Cambrian has been agreed internationally. Popular usage takes the Precambrian-Cambrian boundary as the base of the Tommotian Stage in Siberia, but this horizon (Table 1) is arguably slightly younger than the locally defined base to the Cambrian in the Chinese stratotype (Brasier et al. 1990) and much younger than in Newfoundland (Landing et al. 1989). In addition, there is no general agreement on a series of chronostratigraphic intervals for the Early Cambrian. For the present, we have followed the Siberian stage nomenclature, but have taken a low, Avalonian, marker for the base of the Cambrian (Table 1). This horizon may have an age of around 530Ma (Cowie & Harland 1989, p.196; Compston & Williams 1990).

TABLE 1 ABOUT HERE

In this paper we present world reconstructions for the latest Vendian/Nemakit-Daldynian (Fig.1), the Tommotian (Fig.2) and the Toyonian (Fig. 3). Fig. 2 shows some facies distributions for the early Atdabanian as well as the Tommotian; and Fig. 3 illustrates the facies and faunas for all the later part of the Early Cambrian.

FIG.1 ABOUT HERE

Use of latitude-related facies.

Certain Palaeozoic lithologies are often deposited under particular, restricted climatic regimes, which, when they occur over large areas, can be used to orientate continents with respect to latitude with almost as much precision as palaeomagnetism (Ziegler et al. 1984; Scotese & Barrett 1990; Witzke 1990).

In the Early Cambrian, archaeocyathans formed reef-like assemblages, which appear to have developed in warm shallow seas with similar climates to those where modern coral reefs are developed (Rowland & Gangloff 1988). Our reconstructions (Figs. 2, 3) suggest that these were, like modern coral reefs, dominantly within 30° of the Equator (Zhuravlev 1986).

Salt, gypsum and other evaporites are present on several continents, at times from the Late Precambrian to the Middle Cambrian. In the reconstructions presented here such deposits do not occur within 10° of the Equator (in the tropical rain belt) nor more than 35° N or S (where the temperate rain belts occur), with the one exception of North China, which was situated between 30° and 40°N in the later part of the Early Cambrian (Fig. 3). The area of Toyonian evaporites in North China may have been on the lee side (Fig. 2) of the northern prong of Gondwana, with a dry climate similar to southern Argentina at the present day, where deserts occur between 35° and 45° S. Thus, if these reconstructions are correct, climatic belts in the Early Cambrian appear to have had a similar latitude distribution to those at the present day.

Major phosphate deposits associated with cherts and black shales have often been considered to be associated with sites of oceanic upwelling. However, the climatic and environmental controls on phosphorite deposition are complex and have still not been completely resolved (Cook & Shergold 1986, p.384; Parrish et al. 1986, p.290). In Fig. 2, general lines of atmospheric circulation for a northern winter (from

Parrish et al. 1986, Fig.22.2) have been added to our world map; many of the phosphorites plotted (Figs. 2, 3) do not appear to lie close to predicted areas of upwelling, nor can upwelling easily explain the development of phosphates far from cratonic margins. but their distribution does appear to be confined to low latitudes. They have not been employed in the construction of our maps.

FIG.2 ABOUT HERE

We have found no securely dated record of Early Cambrian tillites. The Luoquan glaciation of North China and the Hangerqok glaciation of Xinjiang (Harland, 1983; 1989) may be of latest Precambrian or Early Cambrian age. In view of the latitudes indicated by other evidence for both North and South China in the Early Cambrian, we consider a Precambrian age more probable.

Faunal realms

The assignment of archaeocyathans into a western North American province and an Afro-Siberian-Antarctic province (Zhuravlev 1986) suggests that Laurentia may have been relatively isolated from other continents which straddled the Equator. Our reconstructions (Figs. 1 to 3) therefore show Siberia close to Gondwana, with Laurentia further to the west.

The benthic trilobites of cratonic sequences were already divided into olenellid and redlichiid realms by the Atdabanian, very shortly after their first appearance. Olenellids were present in Laurentia and Baltica, both situated in the southern hemisphere, while redlichiids covered the northern parts of Gondwana, mainly north of the equator (Fig.3). Distinct successions of olenellids appeared in Laurentia and Baltica, with Holmia providing a tenuous link between them. Occurrences in Laurentia of the small Baltic shelly fossils Platysolenites, Mobergella and Volborthella (Brasier 1989b) confirm the existence of this link. The faunal differences between Laurentia and Baltica may be related to climate and latitude rather than to any great geographical isolation (Conway Morris & Rushton 1988).

Trilobites typical of the redlichiid realm of Gondwana occur with some olenellids in parts of the transitional bigotinid realm of Morocco, southern Europe and Siberia, which thus forms a region of overlap between the two major realms (Pillola 1990; Brasier 1989b, pp.139-154; Burrett & Richardson 1980). The bigotinids of Siberia support the archaeocyathan distributions in suggesting proximity between Siberia and western Gondwana (Fig.3).

FIG.3 ABOUT HERE

Our reconstructions agree well with the trilobite distributions, with a single exception: we can see no way of modifying the suggested disposition of the Early Cambrian continents to place the olenellids in South America near the similar forms in Laurentia (this is discussed more fully below).

Although some local forms are still present on most continents, many benthic trilobites (e.g. Fallotaspis) were widely distributed, and most oceans were crossed by some taxa. These observations suggest that, during the Atdabanian and Botomian, the oceans separating Laurentia, Baltica, Siberia and western Gondwana were narrow enough for some, but not all, of the pelagic spat of benthic trilobites to be able to cross freely. It has been suggested (McKerrow & Cocks 1986) that the spat of most modern and Palaeozoic marine benthic invertebrates may have a modal transportation range of around 1,000km. So we suspect that Laurentia, Siberia, Baltica and Gondwana may have been separated by oceans which were around this width during the Atdabanian and Botomian (when some faunal distinctions were developed) and perhaps slightly less in the Tommotian, before biomineralised trilobites appeared.

Palaeomagnetic evidence

Though the palaeoclimatic and biogeographic data were the primary constraints used to orient Laurentia, Gondwana, Baltica and Siberia, the positions shown here (Figs 1 to 3) are consistent with the palaeomagnetic data for the latest Precambrian and Cambrian.

Our latest Vendian location of Laurentia agrees with palaeomagnetic results from the Caborca sequence of Sonora, Mexico (Barr & Kirschvink 1983) and the Buckingham dykes of Quebec (Dankers & Lapointe 1981). During the Early Cambrian, the Laurentian apparent polar wander path includes palaeomagnetic results from the Colorado intrusives (French et al. 1977), the McClure Mountain alkali complex, Colorado (Lynnes & Van der Voo 1984) and the Sept-Isles intrusion, Quebec (Tanczyk et al. 1987). The latest Early Cambrian position of Laurentia (Fig. 3) is consistent with the orientation predicted by palaeomagnetic results from the Lamotte Sandstone (Van der Voo et al. 1976) and the somewhat younger (Tremadoc) St. George Group of western Newfoundland (Deutsch & Prasad 1987).

Unfortunately, the palaeomagnetic results from Gondwana, Baltica and Siberia are not as numerous or as well dated as those from Laurentia. The position of Gondwana in Fig.3 is similar to the orientation predicted by palaeomagnetic results from the Todd River Formation (Kirschvink 1978), the Bhander red beds (Klootwijk 1973; McElhinny et al. 1978), and surprisingly, an older pole from the Cambrian red beds of Bolivia (Creer 1970). The position of Baltica during the Early Cambrian is based on the recent work of Torsvik & Trench (1991). This "inverted" position is similar to the orientation suggested by the earlier results from the Nexo Sandstone of Denmark (Prasad & Sharma 1978) and the Fen-Tinguaites intrusive of Norway (Piper 1988). Our location of Siberia is consistent with the Cambrian orientation shown by Khramov & Rodionov (1980) and Khramov et al. (1981).

EVIDENCE USED IN CONSTRAINING THE POSITIONS OF CONTINENTS

a) Siberia

In the Palaeozoic, the continent of Siberia was bounded by what are now the northern Urals, the Altai-Sayan mountain belt, the South Mongolian arc and the Verkoyansk Fold Belt. Throughout most of the Palaeozoic, Siberia was oriented 180° from its present alignment, so that the modern Arctic coast faced south, and the South Mongolian arc faced north (Scotese & McKerrow 1990).

Vendian gypsum and Tommotian salt deposits are present in the Interior Province of Siberia (Khomentovsky 1986), which indicate that the region now north of Lake Baikal was around 10° to 35° from the Equator at these times. The presence, throughout the Early Cambrian, of archaeocyathan reefs in regions now more to the north (Debrenne et al. 1990; Zhuravlev 1986) indicates that interior areas of Siberia further from Lake Baikal were consistently in warm climates. We show (Figs 1 to 3) Siberia with a latitude of between 5° and 35° S.

The distribution of the trilobite bigotinid realm (Fig. 3), which occurs in Siberia, southern Europe and north-west Africa (Pillola 1990), suggests Siberia was adjacent to the western parts of Gondwana.

<u>b) Kazakhstan</u>

Kazakhstan was shown as a distinct, coherent continent in most of our previous reconstructions (e.g. Scotese & McKerrow 1990), but it has been omitted from our present maps, for it is an amalgum of assorted continental and oceanic material. It consists of fragments of Vendian and Early Palaeozoic arcs and some terranes of older continental crust with a cover of Vendian and Palaeozoic platform sediments (Nalivkin 1973; Brasier, 1989a, p.56). Many of these terranes are separated by ophiolites. Some of the arcs may have extended out from Siberia (in the manner of the present Aleutians) others are associated with older crust and may be more analogous with the Malay Peninsula.

Different platform faunas from different parts of Kazakhstan show affinities, individually, with Siberia, China, Baltica and southern Europe during the Early Palaeozoic (Cook & Taylor 1989; Cocks & Fortey 1990;

Bergstrom 1990). In the platform sequence of Maly Karatau in southern Kazakhstan, some Early Cambrian monoplacophorans, hyoliths and tommotiids include taxa comparable with faunas from South China and Tarim (Cook & Taylor 1989), as well as from Siberia (Brasier 1989a, pp.56, 64-5), while Botomian-Toyonian archaeocyathans have Afro-European affinities (Zhuravlev 1986). These diverse faunal affinities suggest that they occur in different terranes which were close to, or derived from, a variety of other continents. Some areas were at low latitudes in the Early Cambrian, as archaeocyathans are present in the Kavatan Range (Nalivkin 1973) and at Kuruktag (Zhuravlev 1986). The distributions of the different Kazakhstan terranes cannot be plotted with any certainty at present, and are therefore omitted from our reconstructions.

c) Laurentia

During the Cambrian, Scotland, north-western Ireland, Greenland and the Chukotsk Peninsula of the north-eastern USSR were attached to North America to form Laurentia. The continent of Barentsia (which probably included Svalbard and most the the crust now below the Barents Sea) may have been attached to Laurentia on the margin of NE Greenland (Scotese & McKerrow 1990). During the Early Cambrian (as for most of the Palaeozoic) all of Laurentia had warm water carbonates (Witzke 1990), with archaeocyathan reefs particularly strongly developed from the late Atdbanian in the Western Cordillera (Zhuravlev 1986; Debrenne et al. 1990). The relatively late (Botomian/Toyonian) arrival of warm water carbonates and archaeocyathans along the Atlantic margin of

Fish...

Laurentia (Zhuravlev 1986) may reflect a relatively more southerly latitude for this margin (Kirschvink in press). We thus show Laurentia moving across the Equator during the Early Cambrian, with its Cordilleran margin at lower latitudes than its southward facing Atlantic margin (as in Scotese & McKerrow 1990).

Trilobite genera of the olenellid realm in Laurentia (Fallotaspis, Nevadella, Judomia, Olenellus) are largely distinct from the members of the same family (Schmidfiellus, Holmia, Kjerulfia) represented in Baltica (Brasier 1989), which was probably situated in a cooler climatic belt to the south of Laurentia.

d) Baltica

The presence of Vendian carbonates of aragonitic origin in Norway (Tucker 1983) suggests that Baltica was at moderately low latitudes at this time. In contrast, the dominance of clastics and the absence of archaeocyathan reefs, oolitic limestones, dolomites and evaporites are compatible with movement into a temperate latitude by the Cambrian. As Laurentia remained close to the equator throughout the Cambrian, many of the faunal differences across the widening Iapetus Ocean between Baltica and Laurentia may thus be related in part to latitude (Conway Morris & Rushton 1988). However, some trilobites and many small shelly fossils are present in both Baltica and Laurentia (Brasier 1989b) and the separation of the two continents may not have been very great.

e) Avalonia

Avalonia extends from the Ardennes through England, Wales, southern Ireland and the Avalon Peninsula of eastern Newfoundland to coastal New England. Cocks & Fortey (1982; 1990) have shown that it rifted away from Gondwana before the Middle Ordovician. The time of rifting is not clear, but it was probably long after the Early Cambrian and may have been as late as the Tremadoc (McKerrow et al. 1991). Thus Avalonia, with its widespread Vendian volcanic rocks, may have bordered western Gondwana during the Vendian and the Cambrian.

The Cambrian trilobite faunas of Avalonia are most similar to those of western Gondwana; they also have many aspects in common with Baltica and Siberia (Brasier, 1989b) which we show nearby (Figs. 2, 3). Unlike Morocco, Avalonia had no archaeocyathans or bigotinid trilobites and a dominance of clastic sediments which suggest that it lay futher south on the west Gondwana margin. Episodes of algal and skeletal biomicrite deposition with fenestral fabrics and acicular carbonate cements do not, however, suggest a very high latitudinal position. In our maps we tentatively show Avalonia off Mauritania, Senegal and Florida. Clastic sequences, partly of probable Cambrian age, occur in Mauritania and Senegal (Deynoux et al. 1985), which are similar to the Lower Palaeozoic clastic sequence in the subsurface of Florida, where the oldest fossiliferous rocks are of Early Ordovician age (Rodgers 1970, pp.198-9).

f) Africa

Atdabanian and Botomian archaeocyathan reefs are present in Morocco (Debrenne & Debrenne 1978; Debrenne et al. 1989) and Atdabanian archaeocyathans also occur in Israel (Zhuravlev 1986), indicating that northern Africa lay at low latitudes. Clastics in Libya (Klitzsch 1981) and Algeria (Legrand et al. 1985) must also have been deposited at similar low latitudes, whereas the clastic sequences in Mauritania and Senegal (Deynoux et al. 1985) presumably lay further south: perhaps at 40° to 50°S in the Tommotian (Fig. 2).

The Nama Group of Namibia contains Vendian clastics plus dolomites, oolitic limestones and Cloudina reefs (Germs 1983), whereas such carbonates are absent from the Early Cambrian Fish River Subgroup. Taken with the constraints for positioning the rest of Gondwana, this suggests that south-west Africa was not at very high latitudes (near the South Pole) during the Early Cambrian.

g) S.America

There are no recorded archaeocyathans or evaporites in South America, but there is little doubt that the South American craton was fully attached to Africa in the Cambrian, and that its position is thus controlled by the position of Africa.

However, the carbonate sequence with Olenellus near San Juan in the Precordillera of NW Argentina (Borrello 1971) needs explanation. Not only the faunas, but the Early Palaeozoic strata, are very similar to those in the Northern Appalachians (Ramos et al. 1986; Acenolaza & Durand 1986). Our reconstructions place these warm water facies at around 75°S (Fig.3), which seems improbable if they are, indeed, an integral part of Gondwana. The sequence at San Juan is bounded by melanges. It thus lies in a terrane which is certainly suspect, and may be exotic. Either the same sequence of facies developed in two widely separated parts of the world (one of which was at a high latitude), or the Argentinian sequence lies on a far-travelled terrane. This problem was addressed by Acenolaza & Durand (1986), but we find it difficult to accept their conclusion that, in the Early Cambrian, the Atlantic margin of Laurentia must have been adjacent to the Pacific margin of South America. The transfer of a part of the Appalachian orogen to South America raises many complex problems, but, in the light of the evidence available to us, it is a hypothesis which must be investigated further.

h) Southern Europe.

Archaeocyathans are present in Spain, Sardinia, Normandy and the south of France (Brasier & Cowie 1989, p.111; Debrenne et al. 1990), and there is also a record in eastern Germany (Zhuravlev 1986); these parts of southern and western Europe were thus likely to have been in low latitudes during the Early Cambrian.

The presence of both redlichiid and bigotinid trilobites in southern and western Europe (Pillola 1990) indicates affinities intermediate between Morocco and China, so much of southern Europe was probably adjacent to the present north African coast, where archaeocyathans also occurred (as in Morocco and Israel).

The clastic facies seen in Normandy, Brittany and central Iberia (Robardet et al. 1990), together with the clastics recorded in Yugoslavia and Libya, may relate to the deposition of sediments in the equatorial rain belt. Not only do oolites and archaeocyathans occur with the clastic sediments in many of these areas, but the constraints for positioning Gondwana all suggest a tropical setting for these regions. It is possible that Bohemia and adjacent parts of Europe south of the Rheic Ocean, protruded north as a peninsula from the African part of Gondwana (Young, 1990).

i) Turkey to India

Most of the extensive evaporite deposits of Oman, Iran, Pakistan and India are now thought to be close to the Precambrian-Cambrian boundary in age (Husseini & Husseini 1990) and correlated with early to mid Meishucunian (i.e. Nemakit-Daldynian) strata in China (Brasier et al. 1990). This region appears to have seen a major change in climate from torrid and dry in the Nemakit-Daldynian to warm and wet in the Tommotian and Atdabanian (Luo et al. 1984; Brasier, 1989a). We show this region ranging from 10° to 25°N in our latest Vendian map (Fig.1) when evapoites were present, but nearer the Equator in our later maps (Figs. 2, 3), where a wet climate would be expected. Central Iran, north of the Zagros suture, has a closely comparable Palaeozoic development to southern Iran and Arabia on the south of the suture, and the two regions were probably adjacent at this time (Husseini & Husseini 1990; Z.R.Beydoun, pers.comm. 1990).

There is a younger, possibly Toyonian, salt deposit in the Salt Range of Pakistan (e.g. Husseini & Husseini 1990; Brasier & Gao, in press), which may reflect southward movement, to around 10° or 15°S, by the end of the Early Cambrian.

Hickman

i) SE Asia and Australasia.

There is still no generally accepted reconstruction for the Palaeozoic assembly of the eastern Gondwana continents now forming south-east Asia, Australasia and Antarctica; a wide selection has been proposed (e.g. McKerrow & Scotese 1990, pp. 6, 98, 108, 165, 192, 249-253, 294, 354-5, 370, 401). The reconstructions used here follow Burrett et al. (1990 p.165), who have examined the relevant faunal, sedimentological and palaeomagnetic data.

The whole area is within the redlichiid trilobite realm, but other shallow water benthos show regional differences within this region. Burrett et al. (1990) suggest that the close faunal affinities in many benthic groups of the Shan-Thai terrane and Australia suggest proximity in the Cambrian and Ordovician, and that North China was also contiguous. They use palaeomagnetic evidence to suggest that North China was situated off the present north Australian coast and that Shan-Thai lay near NW Australia. By contrast, South China has many Lower Cambrian facies in common with northern Pakistan and the Himalaya of India, so that Burrett et al. (1990) conclude that South China was adjacent to this part of Gondwana. If South China is indeed a single block, the evidence of the relatively deep water agnostid facies (Brasier & Gao, in press) and of very deep water isograptid facies (Cocks & Fortey 1990) along the present SE margin suggests that this region faced outwards from Gondwana, and not inwards as shown by Scotese & McKerrow (1990). In South China, the presence of Botomian archaeocyathans (Debrenne et al. 1990) and the palaeomagnetic data are indicative of very low latitudes (Burrett et al. 1990), compatible with a position north of Pakistan.

The presence of evaporites (Brasier & Gao, in press) from the late Canglangpuan (= late Botomian) to the Xuzhuangian (Middle Cambrian) indicates that both South and North China had moved well north of the equatorial region before the end of the Early Cambrian. Similar development of Ordian (=late Toyonian) evaporites in the Amadeus Basin of Australia (Veevers 1984, p.284) suggest that South China, North China and northern Australia were in comparable latitudes. Early Atdabanian archaeocyathan reefs in South Australia indicate very low latitudes (Debrenne et al. 1990; Rowland & Gangloff 1988).

For these reasons we accept the reassembly positions of of Burrett et al. (1990) for Turkey, Iran, Afghanistan, South China, South and North Tibet, Qaidam, Indo-China, Tarim, Malaysia, Burma, and N. China. We have, however, slightly adjusted their overall orientation to fit with our evidence from climatically-related facies from over the whole of Gondwana.

CONCLUSIONS

Laurentia, Baltica and Siberia rifted apart prior to 600Ma, but still formed a distinct grouping, separate from Gondwana, with Baltica, lacking archaeocyathan reefs, at higher latitudes. Laurentia appears to have moved northwards across the equator during the Early Cambrian, permitting the migration of archaeocyathans from the Cordilleran to the Appalachian margin.

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The bigotinid trilobite realm of Siberia, southern Europe and north Africa is taken to indicate that these regions were adjacent. Laurentia and Baltica, lay further away from Gondwana; they initially lacked redlichiids and bigotinids, and even their olenellids faunas were largely distinct. Laurentia and Baltica do, however, share a similar suite of small shelly fossils as well as a few trilobite genera, so they were probably not very widely separated from each other or from western Gondwana. Avalonia shows faunal affinites with west Africa to which it was probably attached; the dominance of clastic facies are more like those of Mauritania,Senegal and Florida than the carbonate facies of Morocco.

Kazakhstan is thought to be an amalgam of terranes, including arcs and fragments of continental crust with platform faunas showing affinities with several different continents.

The presence of olenellid trilobites in a carbonate sequence in north-west Argentina is anamolous; it occurs in a small suspect terrain which might be exotic.

This contribution has been prepared using a combination of available faunal, facies and palaeomagnetic evidence. We would stress also that it is only by consideration of all types of data from all major landmasses that a reliable world picture can be established.

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Fig.2. Tommotian continental distributions showing Tommotian and early Atdabanian archaeocyathan, evaporite and phosphorite occurrences. The atmospheric circulation for the northern winter (Parrish et al. 1986, Fig. 22.2) is indicated.

A = archaeocyathans; data from Zhuravlev 1986.

E = evaporites; data from Khomentovsky 1986.

P = phosphorites; data from Brasier 1989a, pp.42-55; Cook & Shergold 1986.

Fig.3. Toyonian continental distributions showing occurrences of archaeocyathans, evaporites and phosphorites from the late Atdabanian to the Toyonian. The olenellid trilobite realm is indicated by vertical shading, the redlichiid realm by horizontal shading, and the intermediate bigotinid realm by cross-hatched shading (after Pillola 1990). The area of the Cambrian terrane with olenellids near San Juan in NW Argentina has been exaggerated for clarity.

A = archaeocyathans; data from Zhuravlev 1986.

E = evaporites; data from Khomentovsky 1986; Brasier 1989a; Veevers 1984.

P = phosphorites; data from Cook & Shergold 1986; Brasier 1989a.

TABLE 1

Correlation of Early Cambrian chronostratigraphic units.

<table>
<tr><th>SIBERIAN SERIES</th><th>SIBERIAN STAGES</th><th>CHINESE STAGES</th><th>AVALON ZONES</th></tr>
<tr><td rowspan="4">Lenian</td><td rowspan="2">Toyonian</td><td>Maozhuangian</td><td rowspan="3">Protolenus</td></tr>
<tr><td>Longwangmiaoian</td></tr>
<tr><td rowspan="2">Botomian</td><td>Canglangpuan</td></tr>
<tr><td rowspan="3">V
Qiongzhusian
IV</td><td rowspan="2">Callavia</td></tr>
<tr><td rowspan="4">Aldanian</td><td rowspan="3">Atdabanian</td></tr>
<tr><td rowspan="2">Camenella baltica</td></tr>
<tr><td rowspan="5">III
Meishucunian
II
I</td></tr>
<tr><td>Tommotian</td><td>Sunnaginia imbricata</td></tr>
<tr><td rowspan="3">--</td><td rowspan="3">Nemakit-Daldynian</td><td>Watsonella crosbyi</td></tr>
<tr><td>Rusophycus avalonensis</td></tr>
<tr><td>Phycodes pedum</td></tr>
</table>

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Fig 1.

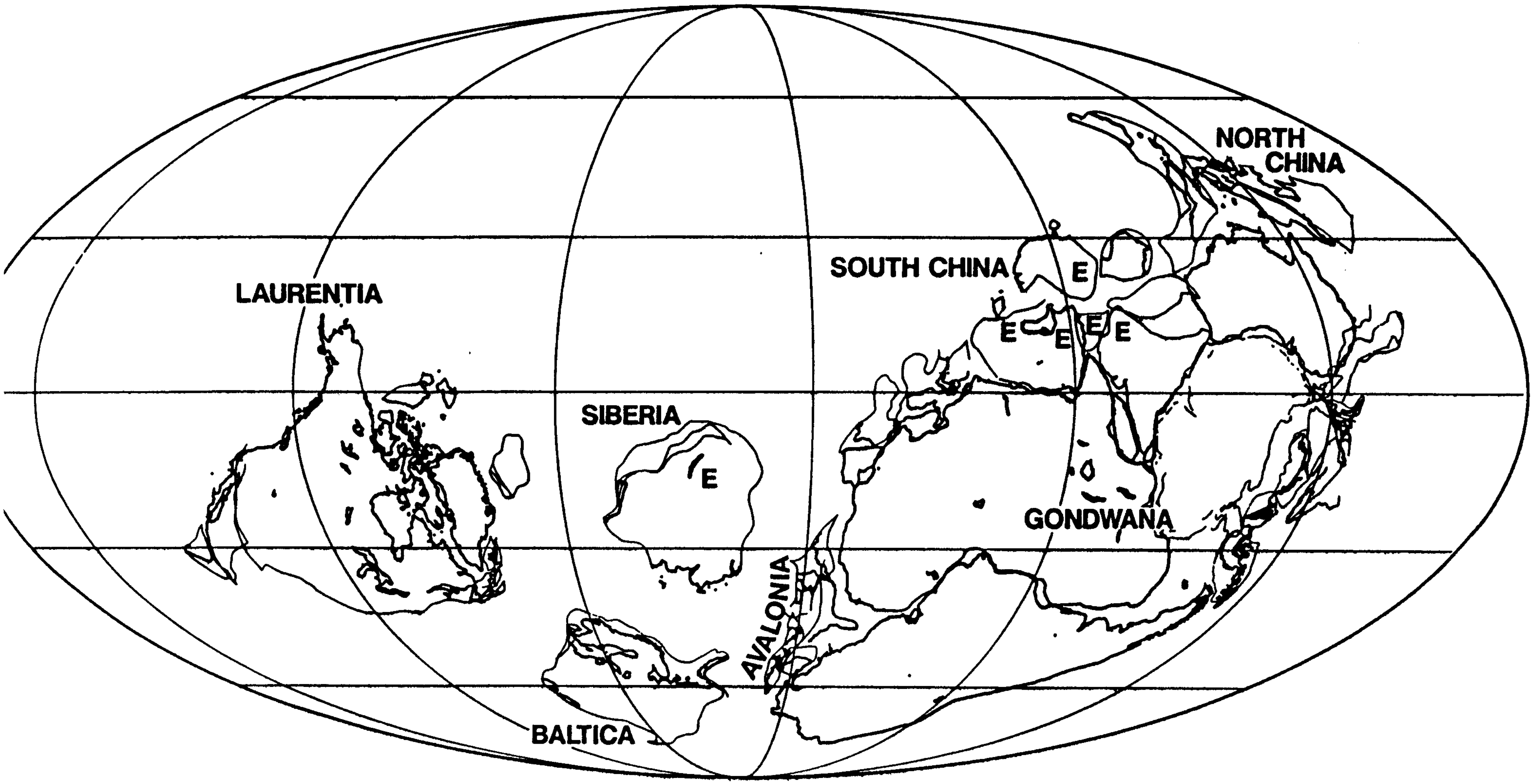

Figure 1 McKerrow et al.

McKerrow et al
Fig 2.

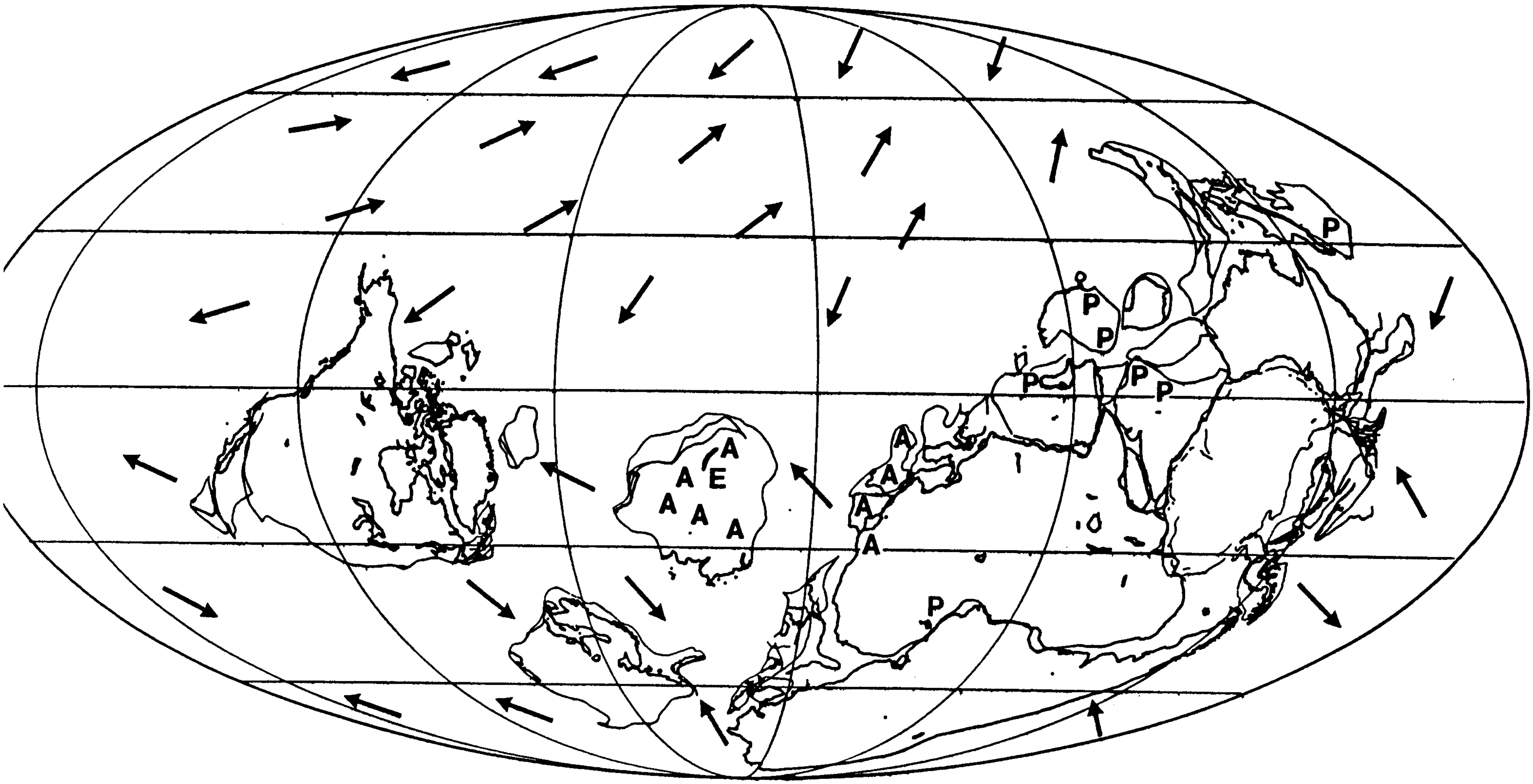

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Fig 3.

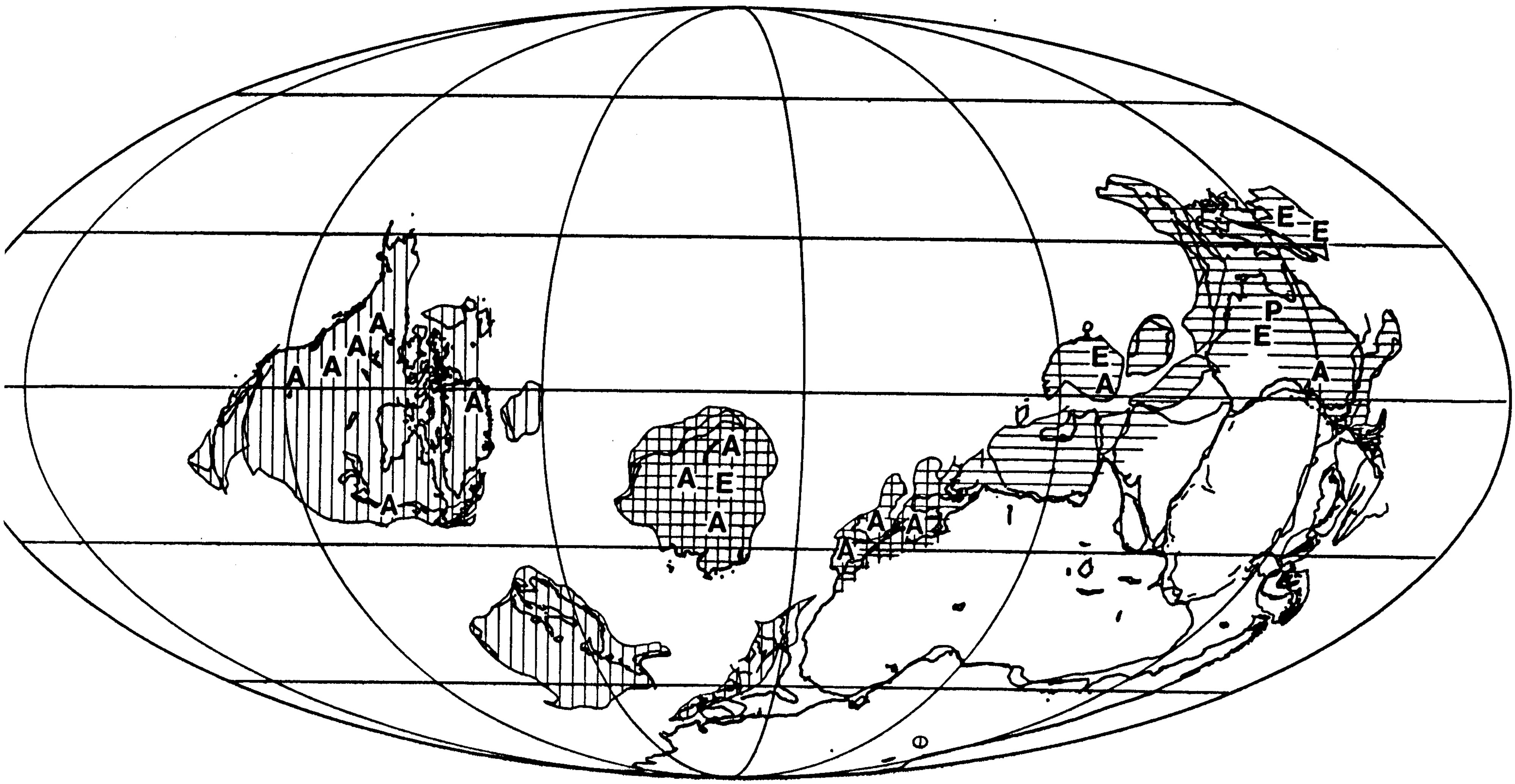

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FIGURE CAPTIONS

Fig.1. Reconstruction of the world in the latest Vendian and the Nemakit-Daldynian.

E = evaporites; data from Khomentovsky 1986; Husseini & Husseini 1990; Brasier 1989a.