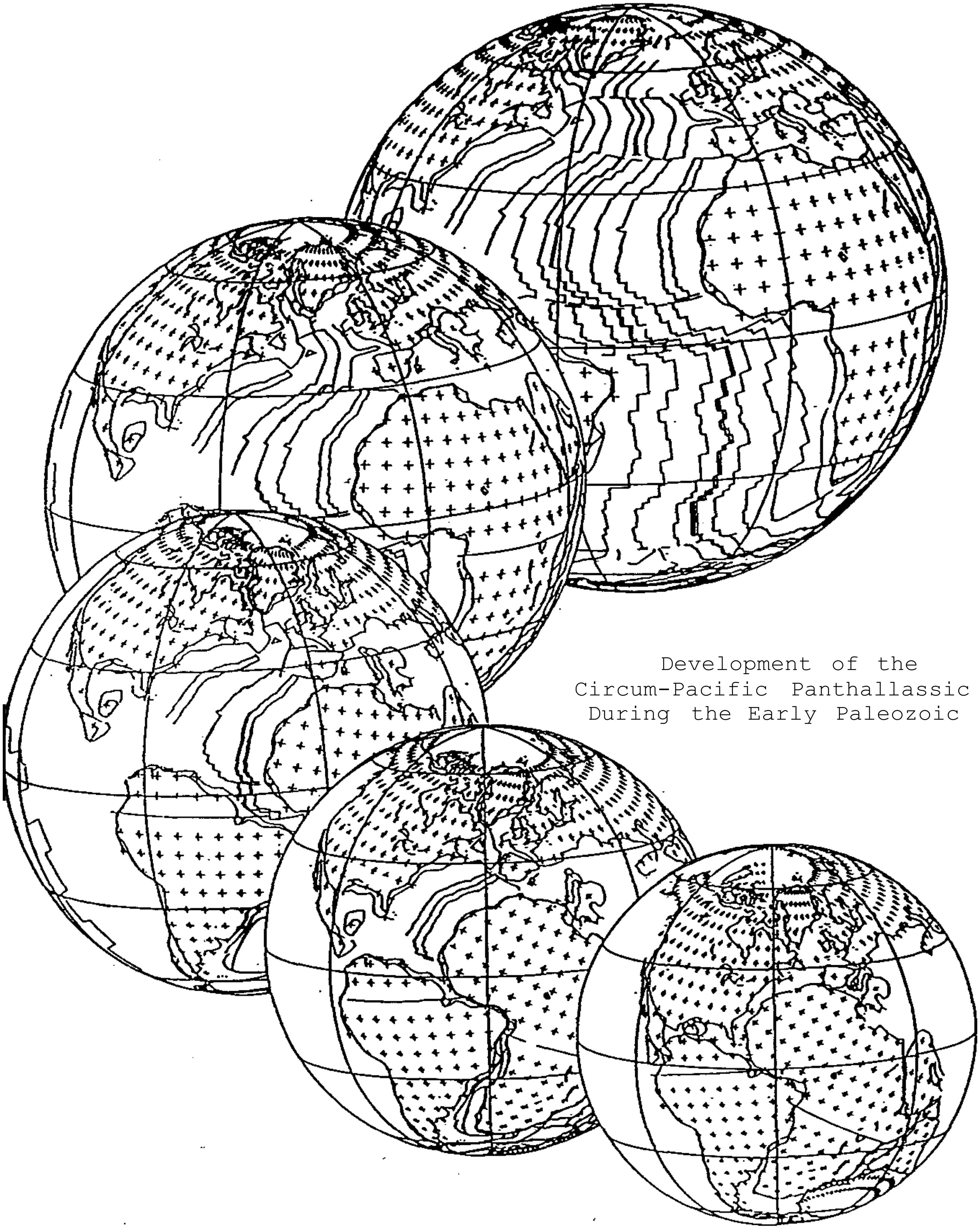
PALEOCEANOGRAPHIC MAPPING PROJECT
PROGRESS REPORT NO. 10-0386



Development of the Circum-Pacific Panthallassic Ocean During the Early Paleozoic

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University of Texas Institute for Geophysics Technical Report No. 57

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· Texas 78T51

Abstract. Though the Pacific plate is less than 200 million years old, the Circum-Pacific ocean basin (Panthallassic ocean basin) has probably been in existence since Precambrian times. During the Early Paleozoic the Tasman. trans Antarctic, arid southern Andean margins of the Panthallassic ocean basin appear to have been the site of active subduction. This convergent system may have continued north into Southeast Asia, northern China, and southern Siberia. Continental reconstructions for the Late cambrian, Late Ordovician, Late Silurian, and Late Devonian times are presented from a "Panthallassic" point-of-view. Paleomagnetic, biogeographic, and paleoclimatic evidence supporting three different Late Devonian reconstructions is reviewed.

Introduction

Panthallassa, the 'universal sea', was the name given by the ancient Greeks to describe the vast oceanic expanse surrrounding the known world. In Wegner's scheme, Panthallassa became the primordial ocean, just as Pangea was the primordial continent. Our present understanding of Paleozoic plate motions, however, requires us to abandon the concept of Pangea as the primordial continent for we now know that Pangea did not exist during the Paleozoic. Pangea formed as a result of continental collisions that began in the Middle Paleozoic, continued through the Late Paleozoic, but· were not completed until the Early jurassic.

Panthatlassa, whose:modern descendant is the Pacific Ocean, certainly existed before Pangea, and may justifiably be called 'primordial'. As far back as we can see into the Paleozoic, the Circum-Pacific region appears to have been a large ocean basin bordered by a rim of continents. We do not have a clear picture, however, of the exact geometry of this ocean basin or the plates that composed it, for less attention has been given to Panthallassa, than has been given to Pangea.

This is due, in part, to the fact that there is no extensive oceanic crust of Paleozoic age, and it has been difficult to rigorously estimate both the width of oceans and the nature of oceanic plate boundaries during the Paleozoic. Indeed, the life histories of Paleozoic oceans have often been summarized by the simple epitagh, ·· It was born. during rifting, and was consumed through continental collision... This ignorance arises both from the lack of direct evidence and from the fact that the tools that are required to resolve the pattern of Paleozoic plate evolution have not yet been sufficiently developed.

Ideally, these tools would include: I) a complete paleomagnetic record for the major continental cratons. 2) a geologic data base comprising the age and distribution of subduction-related and rift-related volcanics and tectonism. 3) a comprehensive biogeographic data base, 4) a global summary of climatically sensitive lithofacies, and finally, 5) a understanding of the forces that drive the plates that would allow us to predict plate motions given the changing geometry of plate boundaries.

At present. though the Early Paleozoic paleomagnetic record for North America, Siberia, and Gondwana is relatively complete (Scotese et al., 1979), there are still large gaps in the apparent polar wander paths of Baltica. China, and Southeast Asia. Biogeographic data, though useful, are often inComplete and anecdotal. The geologic and paleoclimatic databases have not been compiled, and though we have an increasingly accurate picture of the history of plate motions. we still do not understand the complex interplay of forces that drive .the plates.

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Paleozoic plate evolution is not completely unconstrained. This paper summaries what we do .know. and highlights the existing areas of uncertainty and controversy. ·However. rather than present this information from the usual perspective of a."Pangea centered" world, the figures and discussion will be given from a "Panthallassic" point-of-view.

Defining the Hltent of the Circum-Pacific Panthallassa

From a plate tectonic perspective, most oceans are defined by the lithospheric plates that carry them. In the case of Panthallassa, however, the oceanic plates comprising this ocean basin have been completely subducted, so an alternate tact must be taken. We choose to define the Panthallassic ocean basin by the continents that formed its perimeter. These continents, in most cases, are the same as those that border the modern Pacific Ocean. ProCeeding clockwise, they include North America. the Gondwanan continents of South America, Antarctica, and Australia; probably Southeast Asia and the two Chinese cratons. and completing the circuit, Siberia, which lay adjacent to North America.

As illustrated in Figures 1 - 6, during the Early Paleozoic the Panthallassic Ocean was relatively constant in siZe. Spanning 200 degrees of longitude, it was over 20,000 km wide and covered nearly twice the area of the modern Pacific Ocean. Though Panthallassa remained relatively constant in siZe. its orientation with respect to the geographic pole changed gradually during the Paleozoic. During the Early Paleozoic, the Panthallassic Ocean <:overed the entire northern hemisphere. Through the Middle Paleozoic this hemispherical cap rotated southward, eventually occupying a meridionial orientation similar to the orientation or the modern Pacific Ocean.

cambrian and Ordovician Configuration of Panthallassa(Filzures I and 2)

Figures 1 and 2 illustrate the relative positions or the rontinents during the Late cambrian and Late Ordovician, respectively. The reconstructions have been rotated so that the Panthallassic Ocean occupies the center or the map projection.

The position of Gondwana during the cambrian and Ordovician is fairly well constrained by paleomagnetic and paleoclimatic data. Both lines of evidence indicate that the South Pole was in the vicinity or North Africa during the Late Cambrian, and moved steadily southward during the Ordovician (Scotese, 1984).

The best paleomagnetic data for this interval is from northwest Africa, South America, and Australia (Hallwood. 1974; Thompson and Clark, 1982). Paleomagnetic determinations place the South pole at approximately 40 N, 13 E. during the Late cambrian and at 30 N, 5 E during the Late Ordovician. (Pole positions in African coordinates). These results from Gondwana-proper, are confirmed by recent paleomagnetic results from western France (Armorica) that indicate this areas were located at near polar latitudes during the Late Ordovician. (450 ma; Perroud and Vander Voo. 1985).

During the Cambrian and Ordovician, carbonates and evaporites occur throughout a broad belt that stretched from northern India, across Australia and Antarctica, and into southernmost South America (Ronov et al., 1984). In Australia, an east to west progression of evaporite basins can be seen as the continent appears to bave rotated across the equator from the dry north subtropics to the dry south subtropics. Probably the most signincant paleoclimatic iodicat however, are the Late Ordovican tillites that occur throughout the northern half of Gondwana. from the Sahara (Biju-Duval et at.. 1981) north to southcentral Europe (Dore. 1981: Hamaumi, 1981; · Robardet. 1981), and eastwards to Arabia (McClure. 1978).

Extensive carbonate piatforms covering much of North America, Siberia. and the South China platform confirm paleomagnetic evidence that indicates that these continents occupied equatorial latitudes during the Cambrian and Ordovician (Vander Voo, 1986; Lin et at. 1984). North China and Southeast. Asia have been placed adjacent to northeastern Australia, though the exact position of these areas is not well constrained. Ordovican paleomagnetic data from the North China platform places it at latitudes of 10-30 degrees. However. because the polarity of this magnetic signature is not known. it is not clear whether North China lay north or south of the equator. The northern position of the North China craton that we have chosen. is consistent with our interpretation that the Chilian-Shan mobile belt may be a continuation of the Trans-Antarctic -Tasman subduction zone. Similarly, following the reconstruction of Audley-Charles (1983), we prefer to keep parts of Southeast Asia adjacent to northern Australia during the Early Paleozoic, despite the fact that paleolatitudes or 45 degrees have been determined from Ordovician limestones or the Malay peninsula (Haile, I 980).

Silurian and Devonian Configuration of Panthallassa (Figures 3- 6)

Figures 3 through 6 illustrate the changing configuration of the Panthallassic ocean basin during the Late Silurian and Late Devonian. Because ofthe uncertainty in the orientation or Gondwana, three alternate

Late Devonian reconstructions are presented (Figures 4, 5, 6). In all of these reconstructions. the extent Of Panthallassa is approximately the same;

The uncertainty in the position of Gondwana is due to the fact that Siluro-Devonian paleOmagnetic poles for Gondwana are widely scattered (Scotese et at., 1985) and that the better established paleomagnetic · directions make paleolatitudinal predictions that do not agree with available biogeographic and paleoclimatic evidence (Heckel and Witzke, 1979; Barrett, 1985). The South Pole, which was in the vicinity of North Mrica during the Late Ordovician, had moved to a position adjacent to the southeastern coast of Africa by the end of the Carboniferous . Though the end points of this apparent polar wander path path are well established, controversy continues to rage regarding the timing and trajectory of this transition.

Three independent lines of evidence may be used to constrain the orientation of Gondwana during the Middle Paleozoic: 1) paleomagnetism, 2) biogeographic affinities, and 3) the distribution of climatically sensitive lithofacies. Unfortunately, for the Middle Paleozoic, these criteria are not in agreement. In each of the reconstructions shown in figures 4 through 6, one of these lines of evidence has been given precedence.

The position of Gondwana shown in Figure 4 is the orientation that has the best paleomagnetic support (Hurley et aL. 1985). A paleomagnetic pole from an undated Morroccan intrusive. truncated by Famenian red beds (Hailwood, 1974) when combined with a recent results from Late Devonian rocks of the Canning Basin (Hurley et al., 1985) and preliminary results from the Table Mountain Group, South Mrica (Bachtadse and Vander Voo, 1984), indicates that during the Late Devonian the South Pole was located in equatorial Mrica (3S, l5B: Mrican coordinates).

This paleomagnetic pole places the northern margin of Gondwana at latitudes of 45 - 60 degrees south during the Late Devonian. This paleolatitudinal prediction is significant because by the Harty Devonian, carbonates had reappearred along the northern margins of Gondwana, and by the Middle Devonian reefs were also present. When compared with the Mesozoic and Cenozoic distribution of carbonates and reefs, we find that carbonates rarely occur at such high latitudes. Only 7r. of Mesozoic and Cenozoic carbonate localities occur above latiutudes of 4'5 degrees; less than l r. occurr above latitudes of '55 degrees (Ziegler et at.. 1984).

Even more problematic is the occurrence or biostromes and carbonate buildups at these high latitudes. Due to the decrease in lation and the increasing degree of seasonality, Mesozoic and Cenozoic reef building organisms do not range beyond 3'5 degrees .I):6ID the equator (Ziegler et at.. 1984; johannes et al., 1983). Evidence of isolated carbonate buildups and coral wackestones along the northern margin of Gondwana during the early Middle Devonian (Wendt, 1985; Oliver, 1980), and the extensive occurence or reefs. stromatoporoids, and receptaculids (Heckel and WitZke, 1979) during Late Devonian. argues against a high latitudinal position for this margin.

Another important aspect of the orientation of Gondwana shown in Figure 4 is that it requires a wide seaway separating Gondwana from North America and Europe. Strong Harty Devonian biogeographic affinities between Gondwana and North America (Eastern Americas Realm) and between Europe and Gondwana (Old World Realm) argue against a wide oceanic barrier (Boucot et al.• 1969; Barrett, 198'5).

The orientation of Gondwana shown in Figure '5 best fits the distribution of limatically sensitive lithofacies data (Scotese and Barrett, 198'5; caputo,i and Crowell, 1985). In this reconstruction the South Pole does not lie along the trans"Mrican apparent polar wander path. but rather. is located In ·central Argentina (22 S, lOE, Mrican coordinates). This configuration brings the wide carbonate platform that bordered the northern and northeastern . margin of Gondwana Into tropical latitudes. Probable Devonian tillites described from Brazil (Rocha campos, 198la,b) are positioned at latitudes of 60 degrees south.

The biogeographic data within Gondwana also matches this orientation. The low diversity, cold-water Malvinokaffric Realm occurs at high temperate and circum-polar latitudes on this reconstruction, and the high diversity Old World and Americas Realm faunas are located at low latitudes. A problem arises. however, because this orientation of Gondwana. as in the case of the orientation shown in Figure 4, does not permit a match between equivalent faunal realms in Gondwana and Laurussia (North America and Europe). This problem may be resolved if North America and Europe are positioned slightly further south. At the moment the Late Devonian position of North America. The paleomagnetic results from the Late Devonian red beds of the catskill mountains (Kent and Opdyke, 1978; Van der Voo et al., 1979), which previously have been used to orient North America (Scotese et al., 1979; 1984, 1985) are now thought to represent a Late Paleozoic remagnetization (Vander Voo, 1986). The position of North America shown on the Late Devonian reconstructions (Figure 4 and 5) is an Interpolation between control points In the Early Devonian and Early carboniferous, and therefore, may be in error.

The paleomagnetic support for the orientation of Gondwana shown in Figure 5 is equivocal. There are sever'al paleomagnetic poles that plot in the vicinity of south-central Argentina, however they have been regarded by most authors as unreliable due to the fact that they are based on results ·from tectonically unstable areas (Tasman Orogen). A recent result from Middle Devonian volcanics of the Tasman orogenic belt (Comerong volcanics, New South Wales; Schmidt et al., 1986), however. confirms these earlier determinations. and places the South Pole in the vicinity of east-central Argentina (3'1 S, 2 E. African coOrdinates). The agreement between, these paleomagnetic poles, and an estimation of the position of the geographic pole calculated; from the distribution of paleoclimatic ata (Scotese and Barrett. 198S). suggests that the earlier paleomagnetic results from the Tasman orogenic belt may be more accurate than previously thought.

Th position of Gondwana shown in the final figure is based on questionable paleomagnetic pole from Moroccan red beds (Kent et al., 1984) and a reasonably reliable pole from eastern Australia (Mulga Downs; Embleton, 1977). The Moroccan pole, as in the case of the Catskill red beds, is now thought to be a secondary remagnetization. This reassembly produces a "premature" Pangea-like configuration that best explains the disjunct distribution or biogeographic data. but is only fair agreement with the paleoclimatic indicators.

Summary and Conclusions

In this review, I have attempted to present a framework from which we can begin to consider the evolution of the Circum-Pacific region from a plate tectonic perspective. By mapping the positions of the continents that bordered Panthaliassa, we can get a rough idea of the changing shape and size of this ocean basin during the Early and Middle Paleozoic. It is clear, . hOwever, that the size and shape of the Pantballassic ocean basin ultimately.

must have been controlled by the changing geometry of the plate boundaries within it. andalona its perimeter. In order to understand the Harty and - Middle Paleozoic plate tectonic development oC Panthallassa, several important questions remain to be answered: 1) W.llem were the Harty PaleOzoic margins of Panthallassa? 2) When did these margins form?, and 3) Wbal is the evidence for subduction along these margins? At present we can only begin to answer these questions.

The most unusual aspect of the Panthallassic/Pacific ocean basin is·its size and stability through Phanerozoic history. For approximately the past billion years there has been an ocean basin, roughly twice the size of the modern Pacific, bounded by a ring of subduction zones. The apparent stability of this configuration may be telling us something important about the dynamics of the plate tectonic process. To maintain an ocean basin of this extent,there must have been delicate balance between the forces of subduction and the forces of sea floor spreading. How was this equilibrium maintained? What special plate geometries were required? At present we can only speculate, however, by carefully building an accurate model of plate evolution during the past 600 million years we may be able to recognize the broader patterns of plate evolution and arrive at a new understanding of the processes that drive the plate tectonic system.

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References

Audley-Charles, M.G., Reconstruction of eastern Gondwanaland, Nature. 306, -48-)0,.1983.

Bachtadse, V., and R. Vander Voo, Paleomagnetic results from the Lower Devonian part of the Table Mountain Group, South Africa (abs.) , EOS, Trans. AGU 65, 863, 198-4.

Barrett, S.F., Early Devonian continental positions and climate: a framework for paleophytogeography, in Geological Factors and the Evolution of Plants, B. Tiffany, ed., Yale Univ. Press, New Haven, 198).

Biju-Duval, B., M. Deynoux, P. Rognon, Late Ordovician tillites of the Central Sahara, in Earth's pre-Pleistocene Glacial Record, M.j. Hambrey and W.B. Harland, eds., pp. 99-107, Cambridge University Press, London, 1981.

Boucot, A.J., j.G. johnson, and j.A. Talent, Early Devonian brachiopod zoogeography, Geol. Soc. A mer. Soec. Pap., 119, 197 pp., 1969.

Caputo, M.V., and j.C. Crowell, Migration of glacial centers across Gondwana during the Paleozoic Era, Geol. Soc. A mer. BulL 96. 1020-1036, 1985.

Dore, F., The Late Ordovician tillites in Normandy (Armoricain Massif), in Earth's pre-Pleistocene Glacial Record, M.J. Hambrey and W.B. Harland, eds., pp. 99-107, Cambridge University Press, London, 1981.

Embleton, B.j.J, A Late Devonian paleomagnetic pole for the Mulga Downs group, western New South Wales, I. and Proc. Roy. Soc. New South Wales, 110, 25-27, 1977.

Haile, N.S., Paleomagnetic evidence from Ordovician and Silurian rocks of northwest peninsular Malaysia, Earth PLanet. Sci. Lett.. -48, 233-236, 1980.

fL

Lin, J.-L., M. Fuller, W. Y. Chang, Position of the South China block on the cambrian world map Cabs.), BOS, Trans. AGU. *64,* 320, 1983.

McClure, H.A., Early Paleozoic glaciation in Arabia, Palaeogeog .. Pa1aeocJjm .. Pa!aeoecol , 25, 315-326, 1978.

Oliver, W.A., Corals in the Malvinokaffric Realm, Munster. Forscb. Geol. Pataont.. $2, 13-27, 1980.

Perroud, H., and R. Vander Voo, Paleomagnetism of the late Ordovician Thouars massif, Vendee province, France, I. Geopb.ys. Res. 90, *4611-4625,* 1985.

Robardet. M., Late Ordovician tillites in the Iberian peninsula, in Earth's ore-Pleistocene Glacial Record, M.j. Hambrey and W.B. Harland, eds., pp. 99-107, Cambridge University Press, London, 1981.

Rocha-Campos, A.C., Late Devonian Curua formation, Amazon Basin, Brazil, in Earth's pre- Pleistocene Glacial Record, M.J. Hambrey and W .B. Harland, eds., pp. 99-107, cambridge University Press, London, 198la.

— — — — — — Middle-Late Devonian cabecas formation, Parnaiba basin. Brazil, in Earth's ore-Pleistocene Glacial Record, M.J. Hambrey and W.B. Harland, eds., pp. 99-107, cambridge University Press, London, 198lb.

Ronov. A., V. Khain, and K. Seslavinsky, Atlas of Lithological-Paleogeographical Maps of the World, Late Precambrian and Paleozoic COntinents. pp. 1-70, Leningrad, 1984.

Schmidt, P.W., B.j.J. Embleton, T.j. Cudahy, and C.McA. Powell, Prefolding and premegakinking magnetizations from the Devonian Comerong volcanics, New South Wales, Australia, and their bearing on the Gondwana pole path, Tectonics, *5,* 135-150,1986.

Scotese, C.R., Paleozoic paleomagnetism and the assembly of Pangea, in

Reconstruction (rom Paleozoic Pa!eomunetism. R. Van dec Voo, c.R. · Scotese, and N. Bonhommet; eds., Geodynam. Series, 12, 1-10, 1984.

·Scotese, C.R., R.ICBambach, C. Barton, R. Van dec Voo, and A.M. Ziegler, Paleozoic Basemaps, J, Geology, 87, 217-277,' 1979.

Scotese, C.R., and S.F. Barrett, Paleoclimatic constraints on the motion of Gondwana during the Paleozoic (absJ. Sixth Gondwana Symposium, 19-23 August, 1985, Ohio State University, Misc. Pub. #231, lnstit, Polar Studies, Columbus, Ohio, 1985.

Scotese. C.R., R. Vander Voo, and S.F. Barrett, Silurian and Devonian base maps, Phil. Trans. R. Soc. Lond. B 309, *57c77*, 1985.

Thompson, R., and R.M. Qark. A robust least-squares Gondwanan apparent polar wander path and the question of paleomagnetic assessment of Gondwanan reconstructions. *Barth* Planet Sci. Lett.. '57, 152-158, 1982.

Van dec Voo, R., Paleomagnetism of Continental North America: the craton, its margins, and the Appalachian Belt, in Geoohysical Framework of the Continental United States, L.C. Palciser and W.D. Mooney, eds., Geol. Soc. A mer. Mem. (in press), 1986.

Vander Voo, R., A.N. French, Rll. French, A paleomagnetic pole position from the folded Upper Devonian Catskill red beds, and its tectonic implications, Geology, 7, 345-348, 1979.

Wegner. A., The Origin of the Continents and Oceans, john Biram, trans. 1929, Dover, New York, 1966.

Wendt, j., Distribution of the continental margin of northwestern Gondwana: Late Devonian of the eastern Anti-Atlas (Morocco), GeOlogy. 13. 815-818, 1985.

Ziegler, A.M., M.L. Hulver, A.L. Lottes, and W.F. Schmachtenberg, · Uniformitarianism and Paleoclimates: Inferences from the distribution of carbonate rocks, in Fossils and Oimates. P.J. Bencbley, ed., john Wiley and sons. Chichester. p. 3-2l. I 984.

Figure captions

Figure 1. Late cambrian reconstruction centered on the Panthallassic Ocean. 'Thick black line is position of subduction zone from evidence of subduction related volcanics and plutonism (solid triangles) and probable island arc· volcanics (open triangles) of HarJy and Middle Paleozoic age. Areas outside of subduction zone boundary represent terranes accretted after the HarJy Paleozoic. Present-day geographic areas are labelled.

Figure 2. Late Ordovician reconstruction centered on the Panthallassic Ocean.. For explanation of features refer to Figure 1.

Figure 3. Late Silurian reconstruction centered on the Panthallassic Ocean. For explanation of features refer to Figure 1.

Figure 4. Late Devonian reconstruction centered on the Panthallassic Ocean. Gondwana is oriented on the basis of as recently determined Late Devonian pole (Hurley et at., 1985). For explanation of features refer to Figure 1.

Figure 5. Late Devonian reconstruction centered on the Panthallassic Ocean. Gondwana is oriented on the basis of paleoclimatic indicators (Scotese and Barrett, 1985). For explanation of features refer to Figure 1.

Figure 6. Late Devonian reconstru tion centered on the Panthallassic Ocean. The orientation of Gondwana is consistent with biogeographic data that indicates the ocean between Gondwana and North America was nearly closed. For explanation of features refer to Figure L

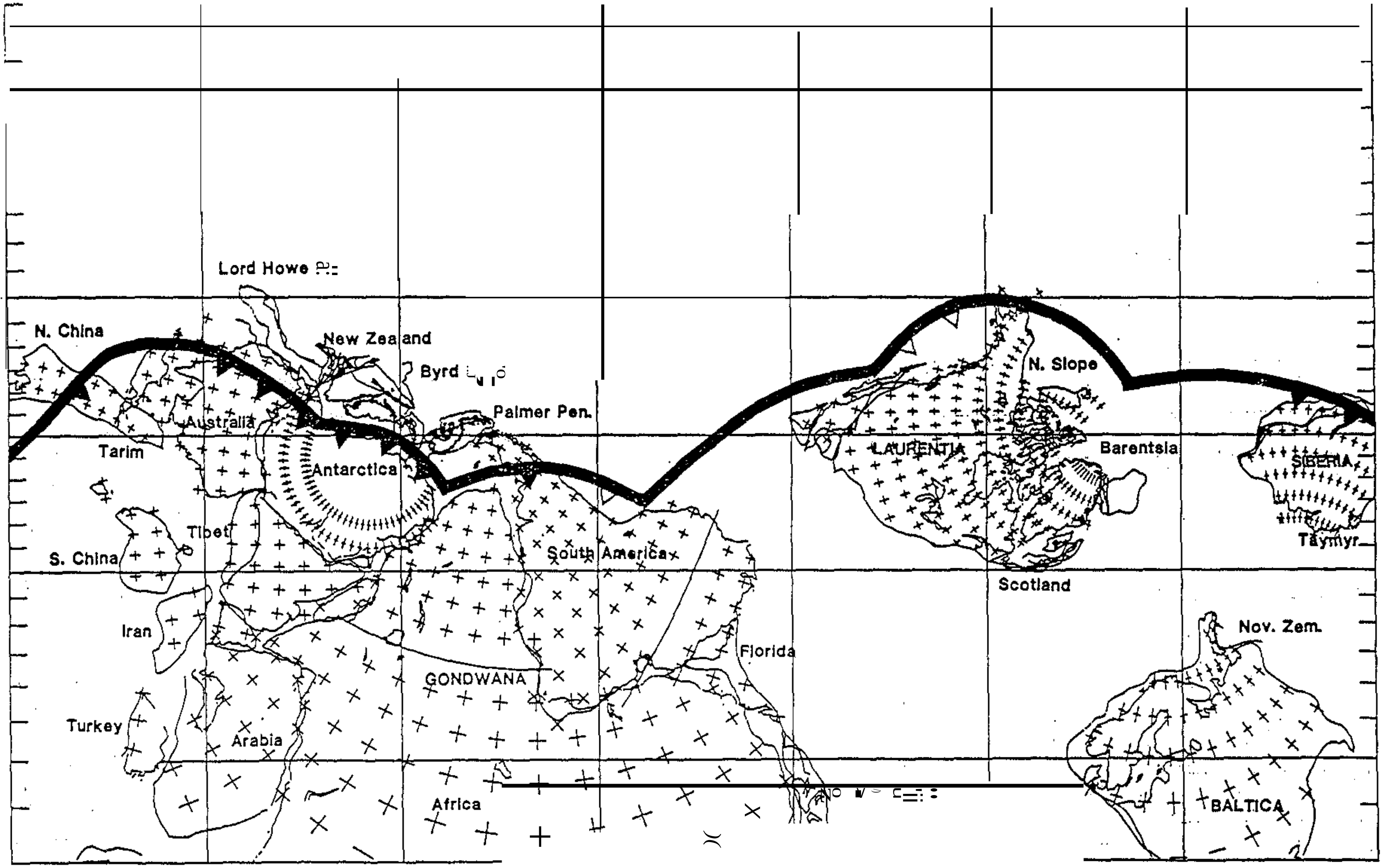
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Fig 1

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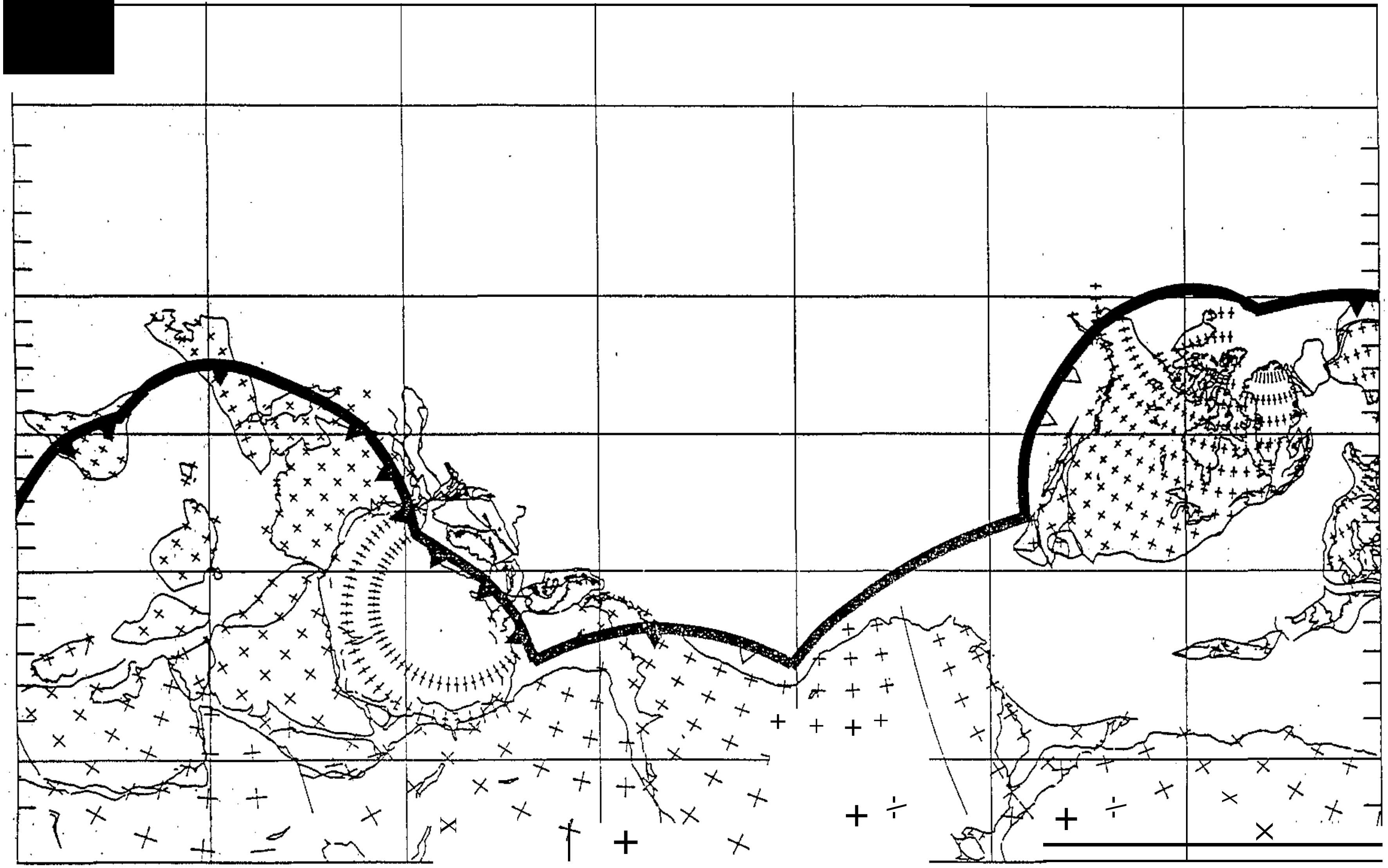

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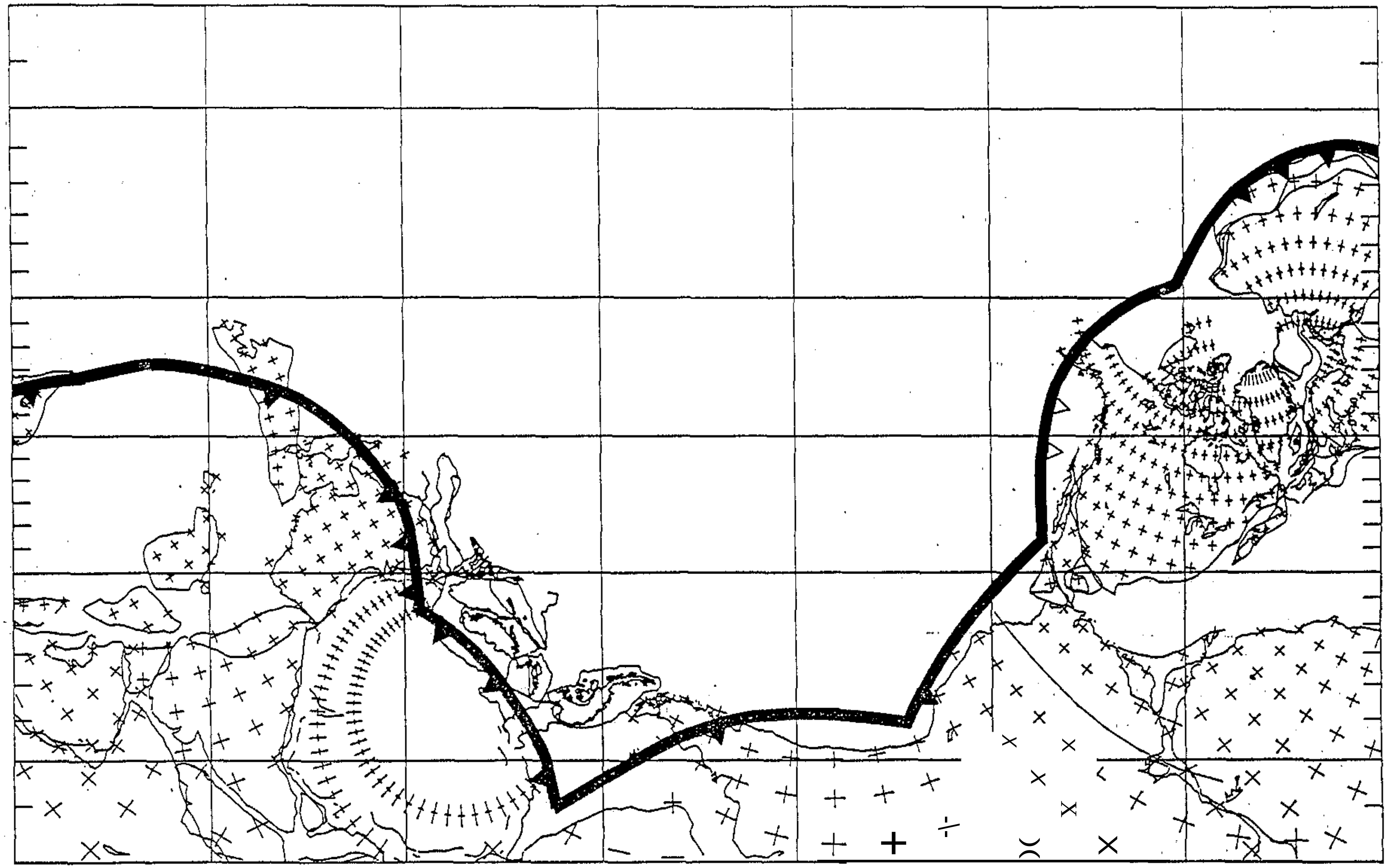

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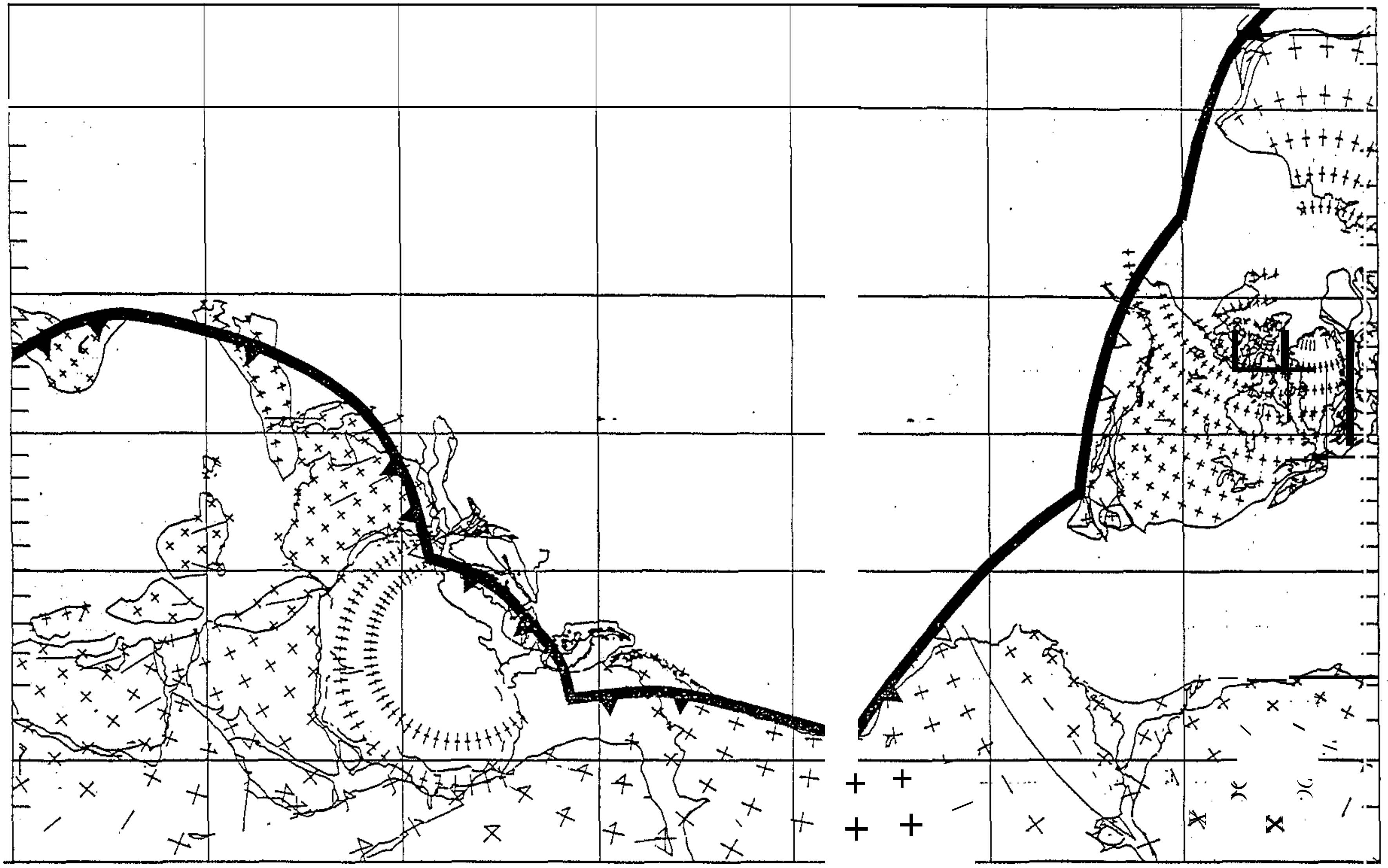

Fig 4

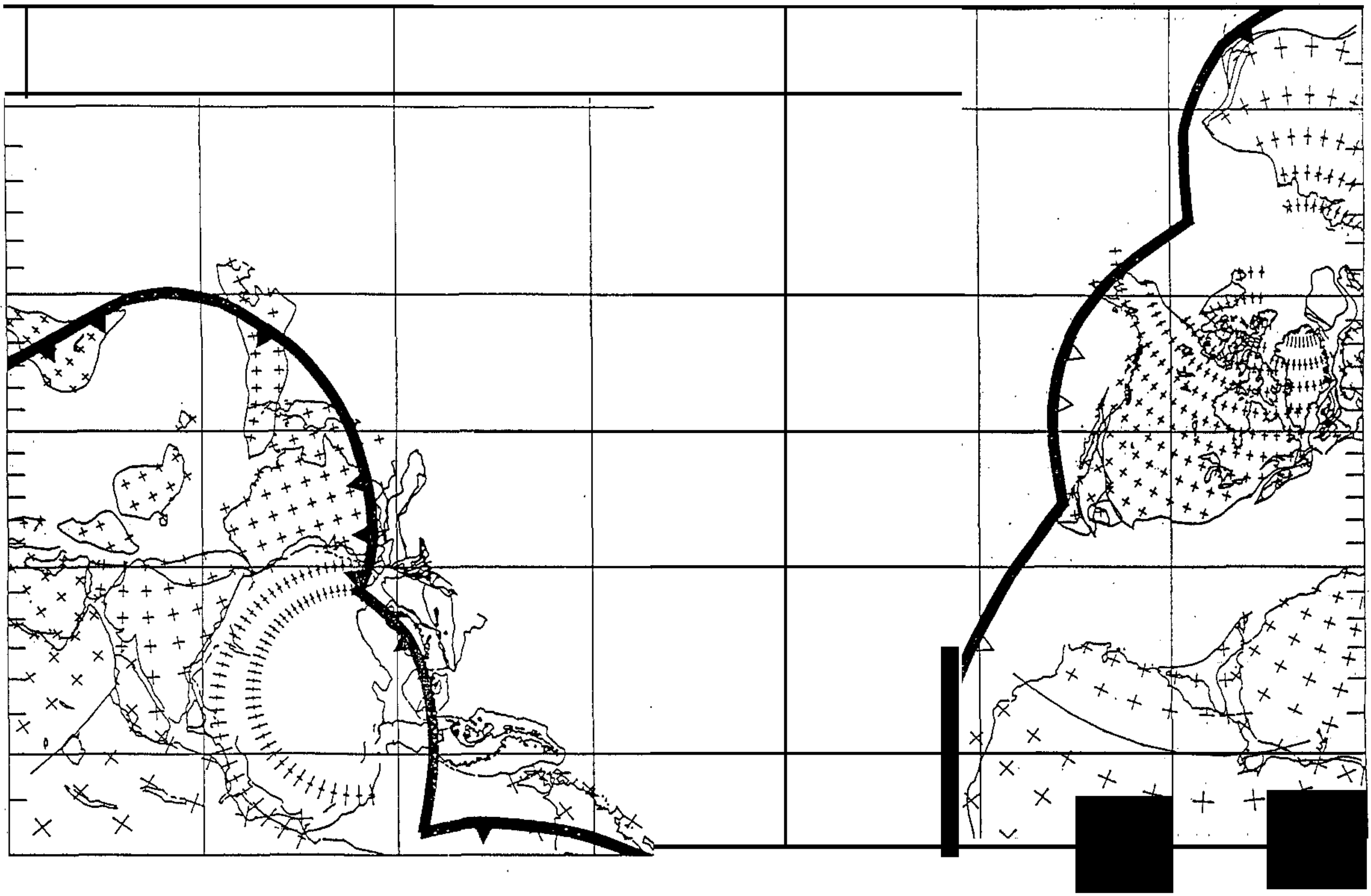

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Figure 5

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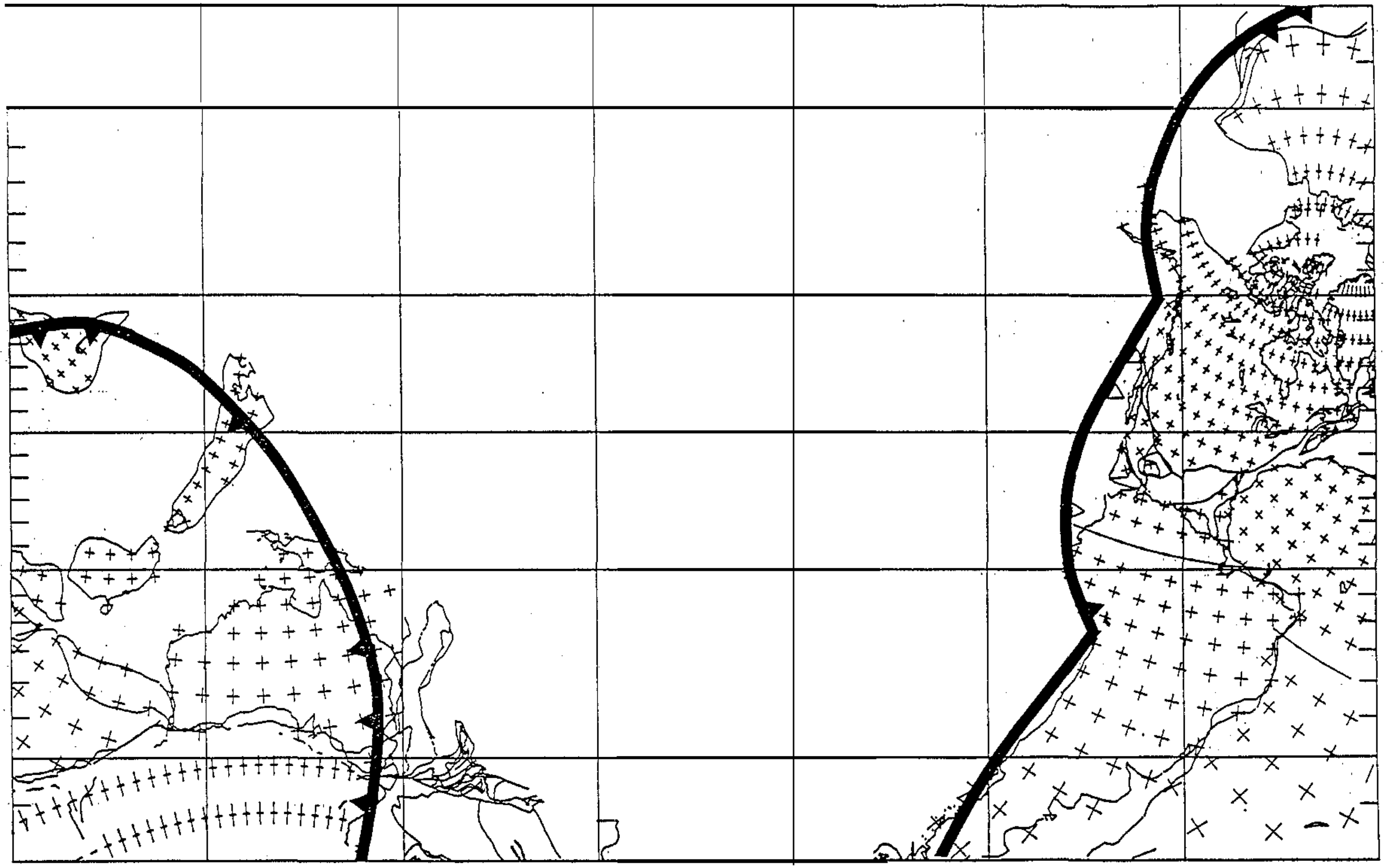

Figure