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DIVISION OF MINERAL PHYSICS

THE PALAEOLATITUDE OF AUSTRALIA THROUGH PHANEROZOIC TIME

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1. INTRODUCTION

With the acquisition of new palaeomagnetic data and an update/ revision of existing data, considerable detail can now be discerned in the drift history of Australia during the Phanerozoic. The purpose of this report is to present that data in a form directly interpretable in terms of Australia's palaeolatitude. Climatic characteristics are controlled primarily by latitudinal disposition but it is also important to take into account the effects and influences of neighbouring landmasses. For this reason, the palaeolatitude maps presented in the report include also those landmasses juxtaposed to, or lying near the Australian continent.

2. DEFINITION OF APPARENT POLAR WANDER

Apparent polar wander (APW) refers to the motion of the geographic pole relative to a particular landmass - in this case Australia. Conversely, the pole may be regarded as fixed and the continent in relative motion - thus describing a sequence of palaeolatitude figures. The apparent polar wander path (APWP) describes the track that the pole has taken with respect to a continent and contains all of the information required in order to describe a continent's drift history and this remains the commonest way to present palaeomagnetic results. However, the APWP is not immediately visually descriptive in terms of palaeolatitudes. Therefore the path has been calibrated and the grid references of the required calibration points transformed to geographic poles. Thus a chronological sequence of palaeolatitude figures for Australia has been produced.

3. CONTINENTAL RECONSTRUCTION

For the purpose of describing palaeoclimates for a particular continent, the disposition of adjacent continental landmasses must also be known. The presence or absence of oceanic realms is also dependent on continental distribution and the extent of epicontinental seas, which constitute primary controls on precipitation, is largely governed by the interrelationships of continental landmasses. For these reasons, the main Australian platform must be regarded in due context when its palaeolatitude history is considered. The continental reconstruction chosen for this purpose is the most recent and detailed available (Norton and Sclater, 1979) based on the results of sea-floor spreading and independently confirmed from palaeomagnetism (Embleton and McElhinny, 1982). In general terms, the reconstruction favoured is similar to that first proposed by du Toit (1937) and one that has been promoted by Smith and Hallam (1970). The "keystone" to the reconstruction was the position of Madagascar between India and Africa. This was resolved in favour of the du Toit (1937) model by Embleton and McElhinny (1975) and McElhinny et al. (1976). South America and Africa are joined along their opposing Atlantic continental margins and Arabia is rotated to north east Africa to close the Red Sea. Madagascar is reconstructed to the Kenya-Tanzania coast of East Africa and India is oriented so that Kutch is adjacent to Somalia. Australia and Antarctica are reconstructed following a combination of constraints provided by sea-floor spreading, continental edge bathymetry and continental geology (Griffiths, 1974). Antarctica is then fitted into the embayment created between India and Mozambique. It is generally recognised (e.g. Norton and Sclater, 1979) that the Antarctica Peninsula cannot occupy the resultant position created for it by this reconstruction. The Agulhas Plateau for example is overlapped and a number of submerged continental fragments cannot be fitted within the resulting "tight" match. However, West Antarctica comprises several displaced terrains such as Marie Byrd Land, Thurston Island, the Palmer Peninsula, the Ellsworth Mountains and Stonington Island (Hamilton, 1967). We have little idea exactly how these fragments fit into any drift model. To this list of course, we must add New Zealand. The continental fragments which comprise New Zealand have only occupied their present relative positions for part of the Tertiary Period. In recognition of these factors and uncertainties, the palaeolatitude diagrams are presented with southern Patagonia, West Antarctica and New Zealand as dashed outlines. Their morphology has been constrained by Mesozoic and younger tectonic activity. It is also probable that eastern Australia should be regarded in this way. The Phanerozoic geological history is consistent with an accretive model and suturing of exotic continental fragments. The western and north western continental margin of Australia displays a geological history consistent with a major landmass having existed immediately to the west. However, the preferred reconstructed position of India as shown is constrained by sea-floor spreading and its alternative position around Western Australia is no longer regarded tenable. Therefore to overcome the problem, Veevers et al. (1975) suggested that peninsular India may only have represented part of the subcontinent when it was a constituent of Gondwanaland. Thus the idea of greater India was established and is today recognised as a realistic part of the model. A line from the Gulf of Oman to North West Cape approximately defines the extent of greater India. The oceanic realm to the "north" of Australia is now known to have been occupied by a number of continental fragments such as Sikhote Alin, South East Asia, Kolyma, Sino-Korea and the Yangtze Platform (McElhinny et al., 1981).

4. MODELLING APPARENT POLAR WANDER

The basic assumption made for the purpose of interpreting palaeomagnetic data is that the geomagnetic field can be described by the axial geocentric dipole field model and that this holds for the whole of the period under consideration. The arguments used to support the use of the model are firm and based on sound physical principles. It is not necessary to repeat those arguments here. A second important assumption made is that the palaeogeomagnetic field has been time-averaged sufficiently so that the corresponding pole positions may be regarded as palaeomagnetic poles, that is, analogues of palaeogeographic poles of rotation. Hence the palaeomagnetic equator and the palaeogeographic equator coincide as do the palaeomagnetic and palaeogeographic latitudes.

5. THE DATA BANK

Table 1 lists rock formations and rock units studied in Australia together with the palaeomagnetic pole and an estimate of the rock age where known. It is important to distinguish between rock age and the age of magnetisation. Where the age of magnetisation can be shown to be younger than the rock age, it is referred to as an overprint magnetisation. The palaeomagnetic pole positions naturally fall into discrete groups which can be regarded as quasi-static intervals during which the continent remained approximately stationary with respect to the pole. An average for each group, an estimate of precision and an age range for each group are also shown. In general terms, the latitudes are known to within about 10°. The only significant gap in our data bank occurs in the Late Devonian to Late Carboniferous time interval. There are no results available for that age range that can be used with any degree of confidence to describe Australia's drift history. Likewise there is a dearth of data from the other continents comprising Gondwanaland.

6. THE PALAEOLATITUDE OF AUSTRALIA

During the late Precambrian, extensive glacial deposits in South Australia and northern Australia confirm the palaeomagnetic result that the continent lay in high latitudes. By the beginning of the Cambrian Australia had drifted to occupy an equatorial position. Its western margin was adjacent to greater India, its northern margin probably fronted onto Papua New Guinea in much the same way as at present but its Pacific margin was in the process of accreting. During the Cambrian Australia remained equatorial merely changing its azimuthal orientation.

Australia remained essentially equatorial until the beginning of the Devonian Period - see also Figure 2. At about 350 m.y. it began its drift towards the south pole and by the Late Carboniferous occupied polar latitudes. Australia remained in its polar position throughout Permian and Early Triassic times. However, during the Late Triassic and Middle Jurassic there was a relatively brief period (<100 m.y.) when Australia lay between 30°S and 60°S prior to a return to polar latitudes during the Cretaceous Period. At this time the continental reconstruction that had pertained throughout the Palaeozoic and Mesozoic began to change in response to the late Mesozoic phase of sea-floor spreading. At about 100 m.y. ago South America and Africa had split and India had began its northward drift. Madagascar may have moved to occupy a position south of its present position relative to Africa. Australia and Antarctica remained approximately fixed with respect to one another until about 53 m.y. Incipient breakup may have occurred much earlier, for example as early as the breakup between the Lord Howe Rise and the east coast of Australia at 80 m.y. The establishment of a circum-polar current is critical to the evolution of Australia's climatic pattern during the late Mesozoic and early Tertiary. During the Tertiary, Australia drifted northwards in a systematic fashion with the Southern Ocean opening around 53 m.y. During the early phase of opening, cyclonic influences may have penetrated considerably further inland than occurs at present.

The drift history of Australia is known more precisely than that of any other southern hemisphere continent. Continued refinement of our data bank and the acquisition of new information allow us to provide continued up-dates on the drift model. However, the basic pattern as described has remained almost unchanged for about six years. The major addition to our knowledge has been the recognition of the relatively brief lower latitude position of Australia between 200 and 150 m.y. Considerable improvement can also be made to the Siluro-Devonian and Early Carboniferous drift history. Data deficiencies in these time intervals are providing us with goals for investigation during the coming few years.

7. REFERENCES

du Toit, A.L., 1937. Our Wandering Continents. Oliver and Boyd, Edinburgh. 366 pp.

Embleton, B.J.J., 1981. A review of the paleomagnetism of Australia and Antarctica, in Paleoreconstruction of the Continents, Geodynamics Series, Vol.2, 77-92.

Embleton, B.J.J. and McElhinny, M.W., 1975. The palaeoposition of Madagascar: palaeomagnetic evidence from the Isalo Group. Earth Planet. Sci. Letters, 27, 329-341.

Embleton, B.J.J. and McElhinny, M.W., 1982. Marine magnetic anomalies, palaeomagnetism and the drift history of Gondwanaland. Earth Planet. Sci. Letters (in press).

Golby, B.R., 1980. Early Palaeozoic Palaeomagnetism of South East Australia. PhD Thesis, Aust. Nat. Univ., 162 pp.

Griffiths, J., 1974. A revised continental fit of Australia and Antarctica. Nature, 249, 336-338.

Hamilton, W., 1967. Tectonics of Antarctica. Tectonophysics, 4, 555-567.

Klootwijk, C.T., 1980. Early Palaeozoic palaeomagnetism in Australia. Tectonophysics, 64, 249-332.

McElhinny, M.W., Embleton, B.J.J., Daly, L. and Pozzi, J-P., 1976. Paleomagnetic evidence for the location of Madagascar in Gondwanaland. Geology, 4, 455-457.

McElhinny, M.W., Embleton, B.J.J., Ma, X.H. and Zhang, Z.K., 1981. Fragmentation of Asia in the Permian. Nature, 293, 212-216.

Norton, I.O. and Sclater, J.G., 1979. A model for the evolution of the Indian Ocean and the breakup of Gondwanaland. J. Geophys. Res., 84, 6803-6830.

Smith, A.G. and Hallam, A., 1970. The fit of the southern continents. Nature, 225, 139-144.

Van Eysinga, F.W.B., 1975. Geological Time Table, Elsevier Publ. Co., Amsterdam, 3rd edition.

Veevers, J.J., Powell, C.McA. and Johnson, B.D., 1975. Greater India's place in Gondwanaland and in Asia. Earth Planet. Sci. Letters, 27, 383-387.

TABLE 1 PALAEOMAGNETIC DATA BANK FOR THE PHANEROZOIC OF AUSTRALIA

Formation/Rock Unit	Lat.	Long.	A_{95}	Rock Age
Pound Quartzite	60°S	006°E		latest Precambrian
Arumbera Sandstone (lower)	44°S	342°E		latest Precambrian
Arumbera Sandstone (upper)	47°S	337°E		latest Precambrian
Todd River Dolomite	43°S	340°E		Early Cambrian
Late Precambrian-Early Cambrian combined	49°S	345°E	12.5°	600-560 m.y.
Deception Formation	32°S	011°E		late-Middle Cambrian
Illara Sandstone	30°S	011°E		Middle Cambrian
Tempe Formation	36°S	013°E		early-Middle Cambrian
Kangaroo Island	29°S	016°E		late-Early Cambrian
Lake Frome Group	31°S	027°E		Middle Cambrian
Hawker Group	21°S	015°E		Early Cambrian
Billy Creek Formation	37°S	020°E		late-Early Cambrian
Giles Creek Dolomite	36°S	020°E		Middle Cambrian
Middle Cambrian combined	34°S	18°E	5.0°	540-520 m.y.
Hugh River Shale	11°N	037°E		Early-Middle Cambrian
Hudson Formation	18°N	019°E		Middle Cambrian
Shannon Formation	15°N	035°E		early Late Cambrian
Early Late Cambrian combined	15°N	030°E	15.5°	510 m.y.
Delamarian overprint	27°N	072°E	7.5°	500 m.y.
Jinduckin Formation	13°S	025°E		Early Ordovician
Stairway Sandstone	02°N	050°E		Middle Ordovician
Cliefden Caves Limestone	13°N	020°E		Mid-Late Ordovician
Walli Andesite	10°S	006°E		Early Ordovician
Mt Pleasant Andesite	12°S	000°E		Early Ordovician
Malongulli Formation	08°N	025°E		Mid-Late Ordovician
Angulong Tuff	10°N	027°E		Mid-Late Ordovician
Ordovician combined	0°	022°E	15.0°	490-450 m.y.

Rockdale Formation	36°S	029°E		Late Ordovocian
Millambri Formation	46°S	036°E		Late Ordovocian-Early Silurian
Belubula Shale	48°S	024°E		Ludlovian-Early Silurian
Narragnal Limestone	31°S	037°E		mid-Silurian
Mereenie Sandstone	41°S	040°E		Silurian? Devonian
Mt Pleasant Andesite overprint	32°S	039°E		-
Early-Middle Silurian combined	39°S	034°E	7.0°	440-420 m.y.
Canowindra Porphyry	44°S	000°		Mid-Late Silurian
Upper Avoca Shale	35°S	359°E		Late Silurian
Ghost Hill Formation	42°S	351°E		Late Silurian
Mumbil Formation	57°S	345°E		Late Silurian
Mugga Porphyry	63°S	008°E		423 m.y.
Middle-Late Silurian combined	48°S	356°E	12.0°	420-400 m.y.
Dolerite Intrusions	36°S	239°E		Late Silurian-Early Devonian
Cowra Granodiorite	36°S	242°E		Middle Devonian
Cunningham Formation	32°S	269°E		Early-Mid Devonian
Tenandra Formation	66°S	255°E		Late Silurian-Early Devonian
Angulong Tuff overprint	46°S	279°E		-
Mt Pleasant Andesite overprint	48°S	271°E		-
Millambri Formation overprint	38°S	302°E		-
Lower Avoca Shale overprint	46°S	254°E		-
Canomodine Limestone overprint	56°S	258°E		-
Cliefden Caves Limestone overprint	61°S	289°E		-
Ghost Hill Formation overprint	38°S	273°E		-
Belubula Shale overprint	42°S	270°E		-
"Silurian" volcanics	54°S	271°E		Mid-late Silurian
Early-Middle Devonian combined	47°S	267°E	8.0°	390-370 m.y.
Ross River overprint	60°S	068°E		-
Bowning Group	64°S	045°E		Early Devonian
Mulga Downs	54°S	096°E		Late Devonian
House Top Granite	67°S	094°E		375 m.y.
Middle-Late Devonian combined	63°S	077°E	14.0°	370-350 m.y.

Main Glacial Stage	53°S	148°E		Late Carboniferous
Rock Creek Conglomerate	52°S	138°E		Late Carboniferous
Currabubula Formation	43°S	135°E		Late Carboniferous
Permo-Carb. Volcanics	44°S	132°E		Permo-Carboniferous
Upper Marine Latites	46°S	136°E		248 m.y.
Late Carboniferous-Late Permian combined	48°S	137°E	6.0°	290-240 m.y.
Patonga Claystone	30°S	147°E	8.0°	(230 m.y.) Early Triassic
Garrawilla Volcanics	46°S	175°E		193 m.y.
Victorian Basalt	47°S	186°E		190 m.y.
Jurassic Intrusives	51°S	186°E		185-170 m.y.
Tasmanian Dolerite	51°S	175°E		167 m.y.
Kangaroo Island basalt	39°S	183°E		170 m.y.
Barrenjoey dyke	53°S	182°E		-
Minchinbury dyke	56°S	179°E		-
Colleroy dyke	53°S	180°E		-
Late Triassic-early Mid Jurassic combined	48°S	180°E	5.0°	200-160 m.y.
Springfield Basin overprint	32°S	170°E		-
Hornsby Breccia	29°S	166°E		<Early Jurassic
Gosses Bluff Impact Structure	13°S	164°E		133 m.y.
Mid Jurassic-Late Jurassic	25°S	167°E	16.0°	150-130 m.y.
Bunbury Basalt	49°S	161°E		100 m.y.
Cygnet Alkaline Complex	53°S	158°E		100 m.y.
Mount Dromedary Intrusion	56°S	153°E		100 m.y.
Middle Cretaceous combined	53°S	158°E	6.5°	100 m.y.
Lower Deccan Trap (reversed)	51°S	108°E		65 m.y.
Lower Deccan Trap (reversed)	50°S	113°E		65 m.y.
Upper Deccan Trap (normal)	54°S	111°E		65 m.y.
Upper Deccan Trap (normal)	50°S	114°E		65 m.y.
Indian transformed and combined	51°S	112°E	3.0°	65m.y.

Early Tertiary	66°S	127°E	10.0°	60-40 m.y.
Mid to Late Tertiary	75°S	099°E	8.0°	34-20 m.y.
Late Tertiary	87°S	086°E	2.0°	4.5-0 m.y.

Notes to Table

The latitude (Lat) and longitude (Long) are given with respect to the present coordinates of Australia. A_{95} is the semi-angle of the cone of confidence calculated at the 95% probability level. The 65 m.y. pole is based on data for India since none are available for Australia; India is well documented and the results have been transformed to Australia's coordinates.

The table has been compiled with data listed in Klootwijk (1980), Dolby (1980) and Embleton (1981).

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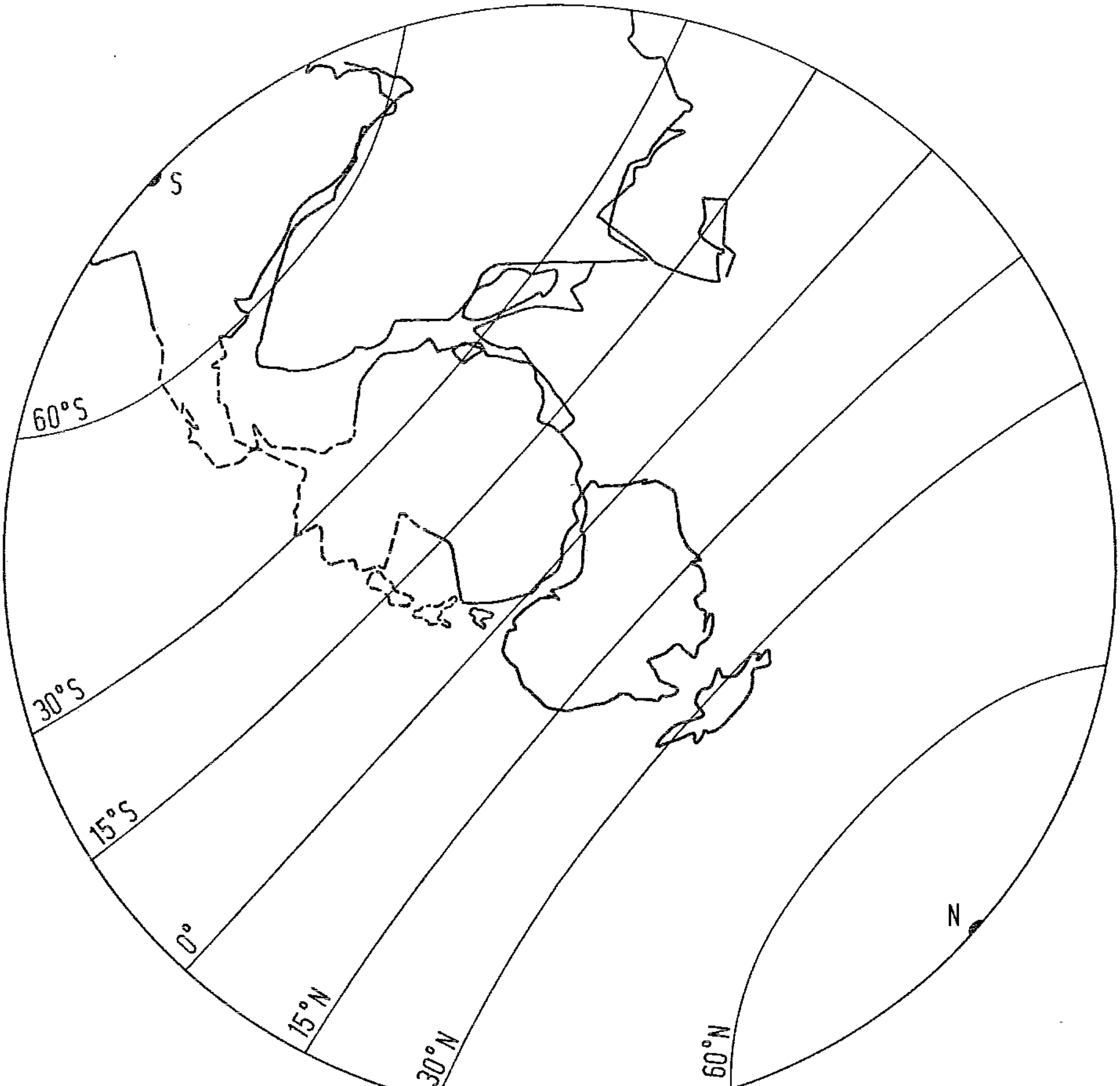

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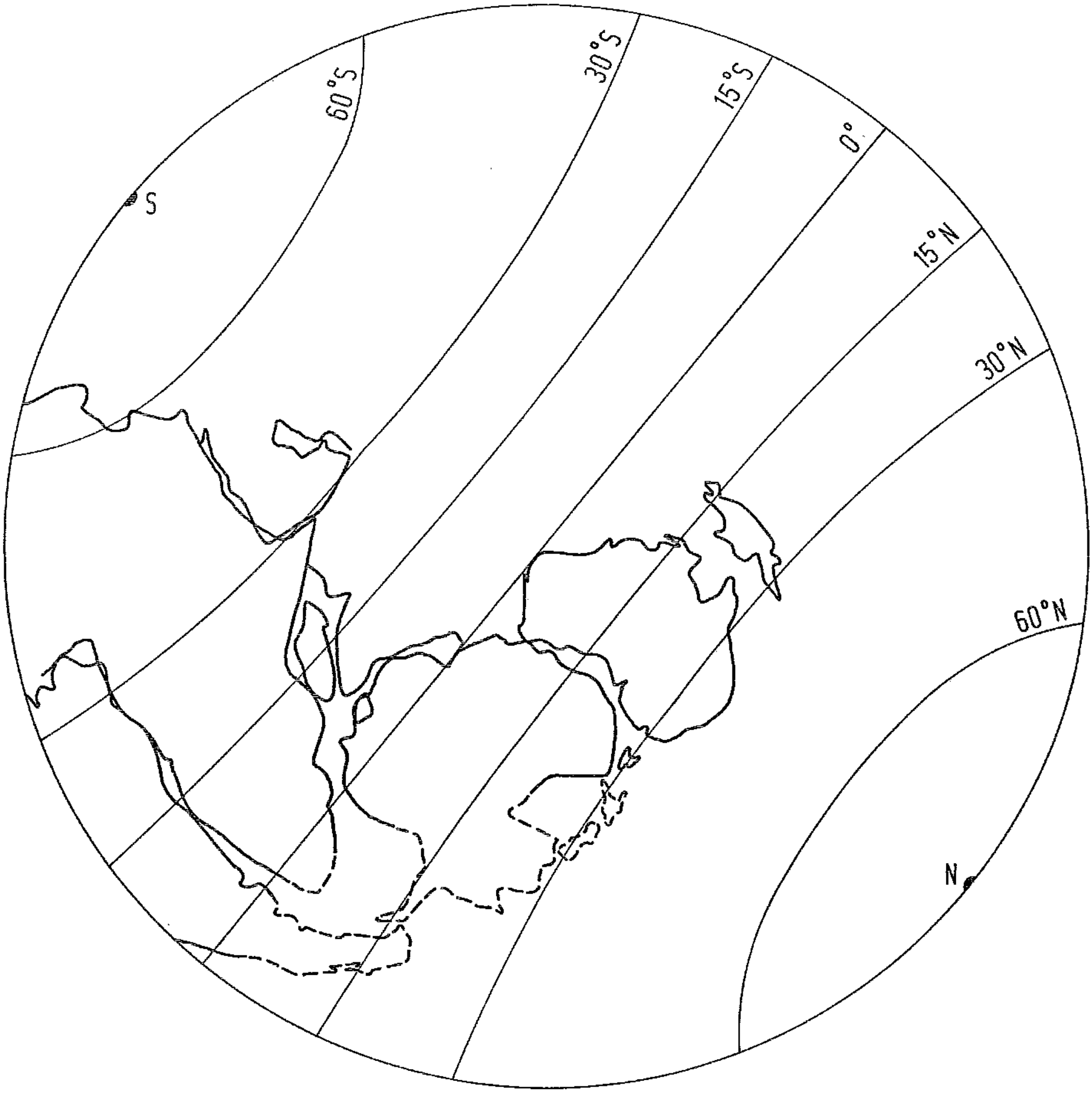

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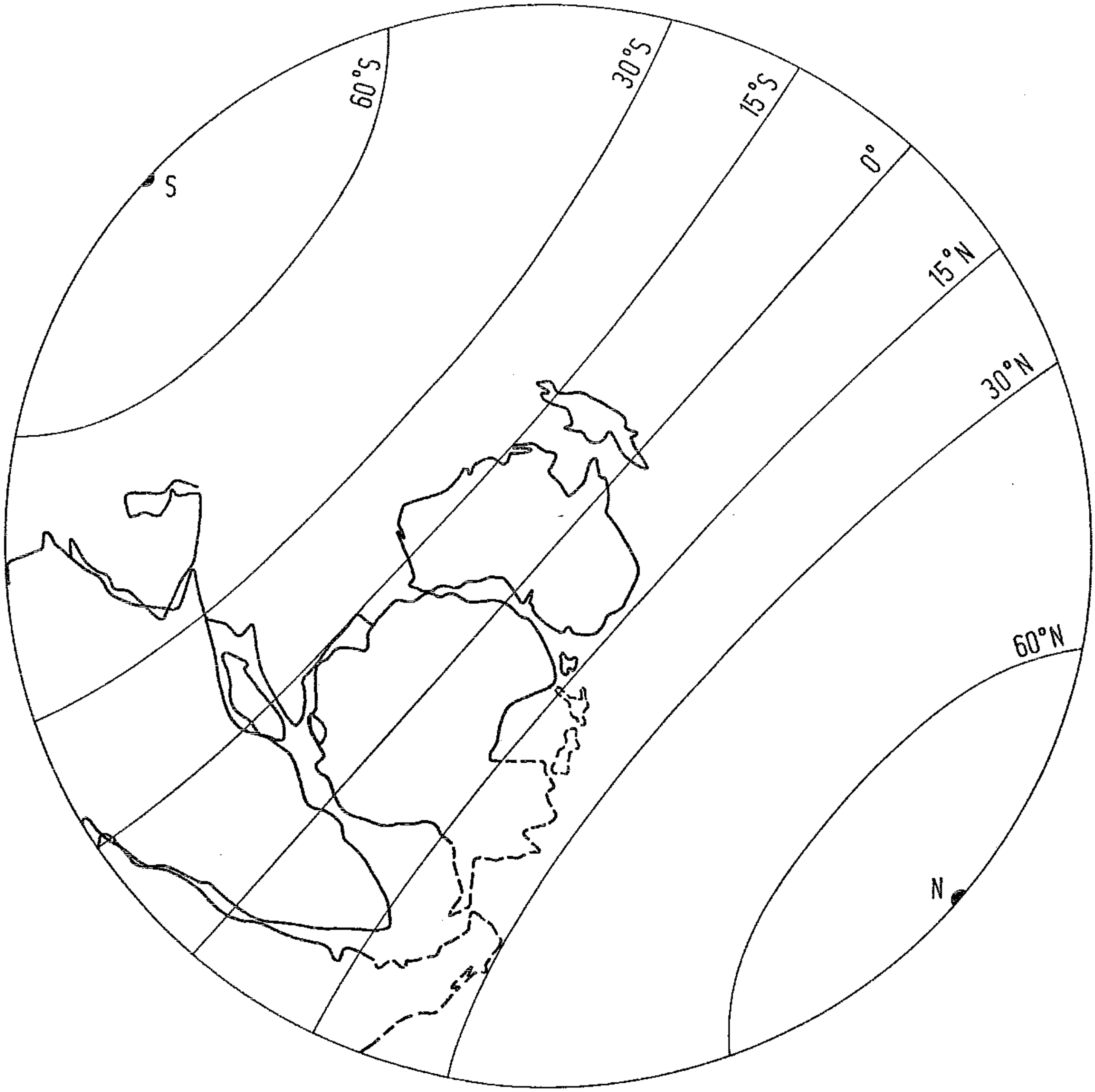

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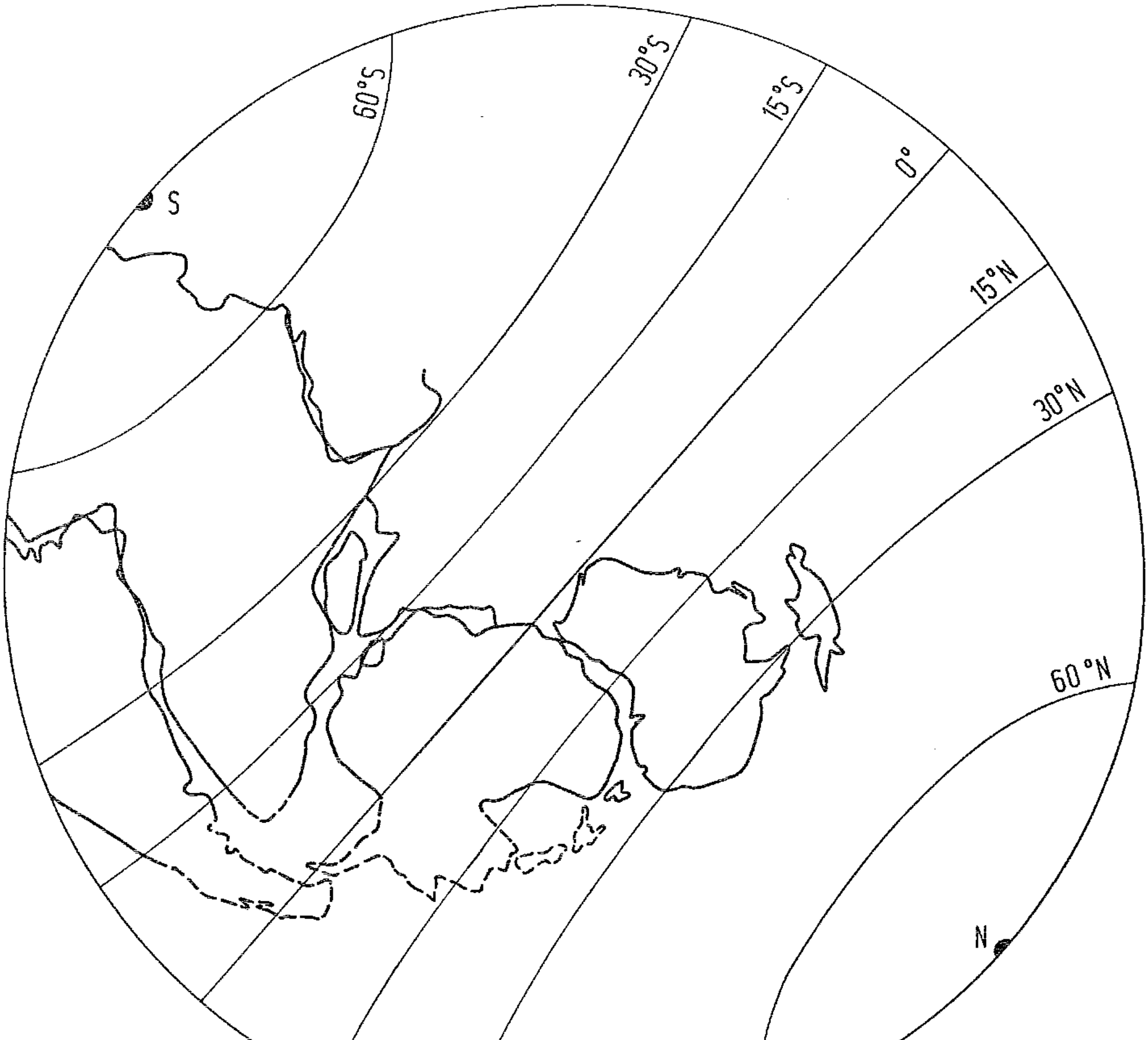

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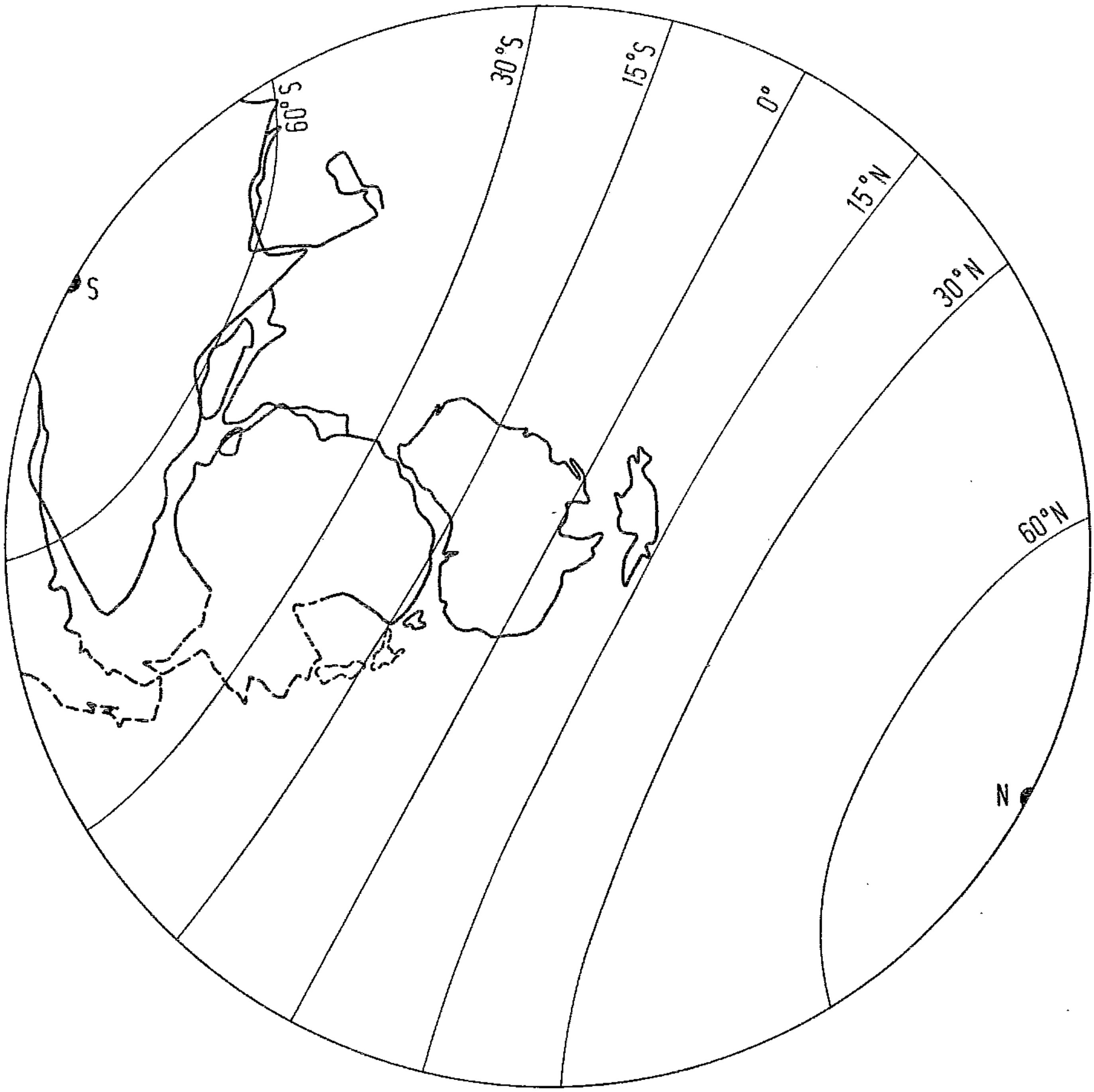

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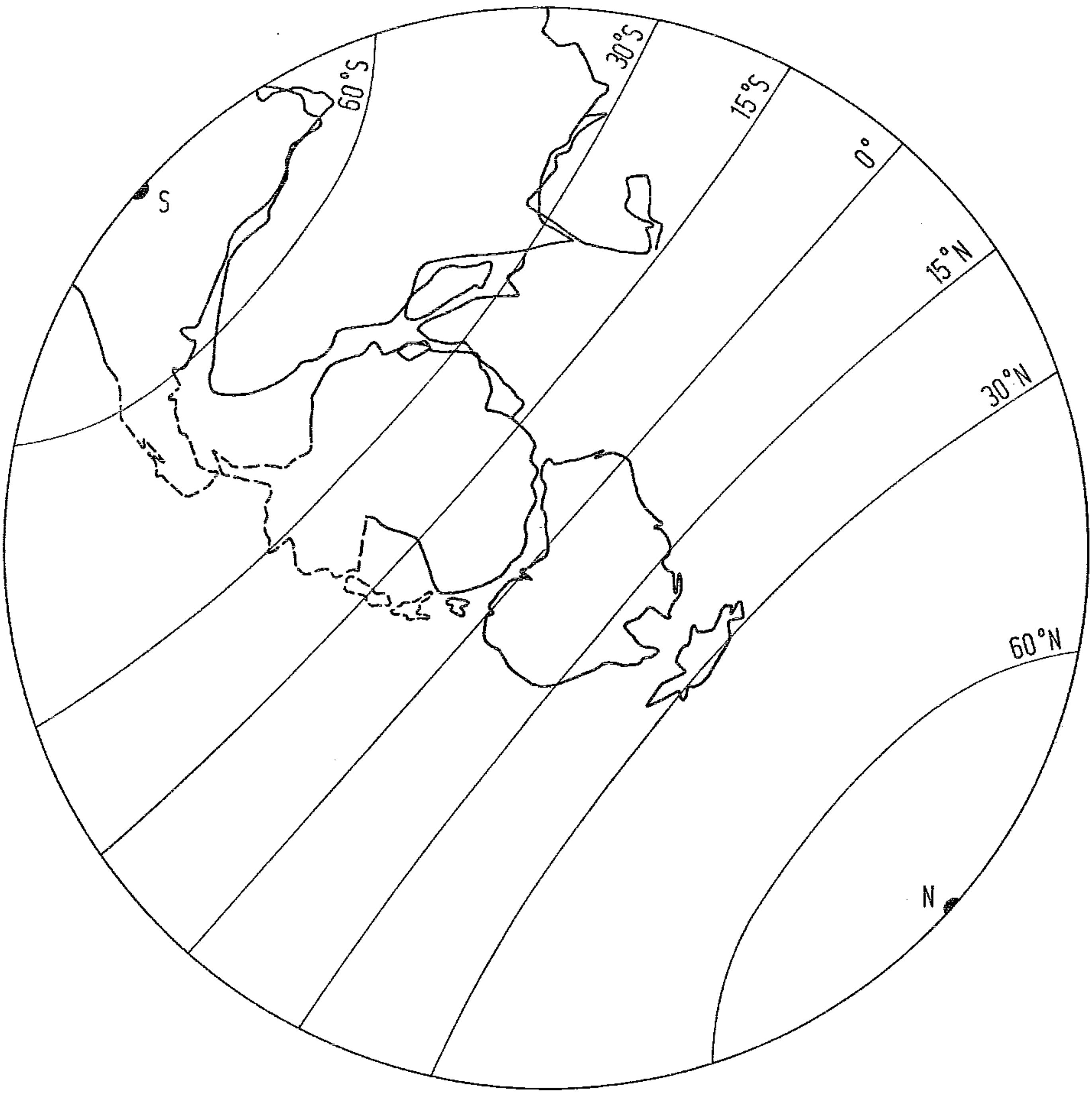

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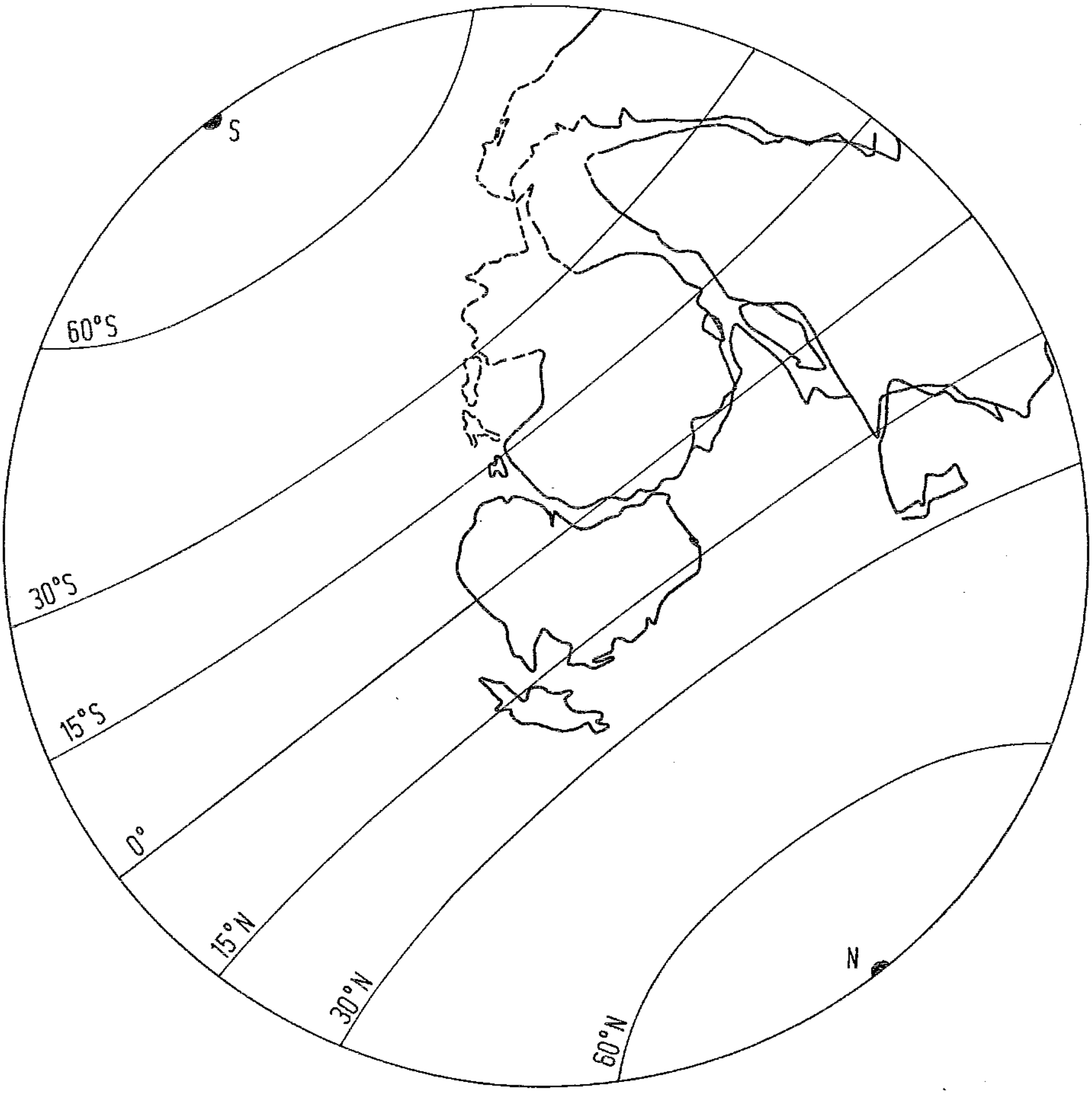

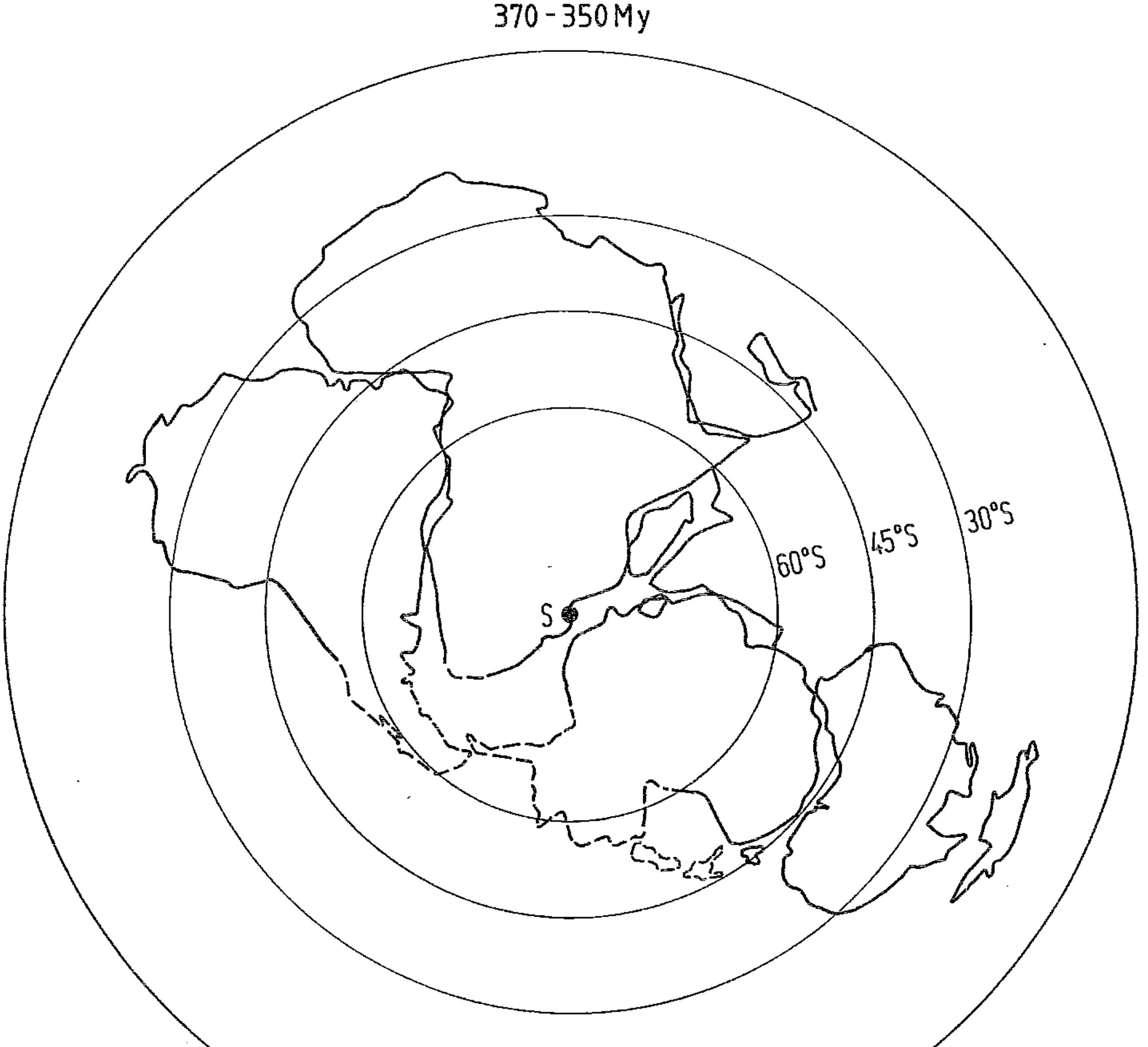
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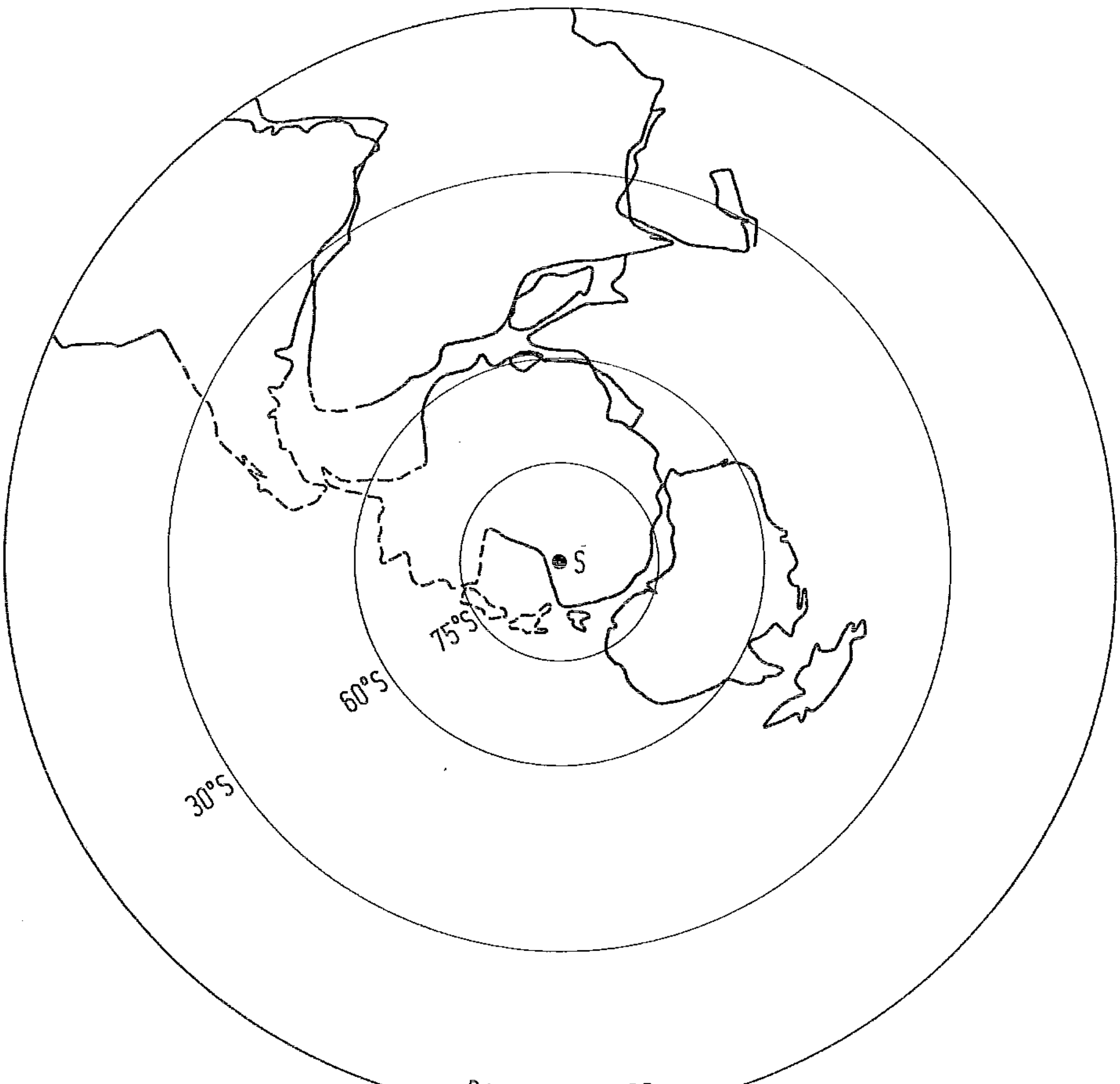

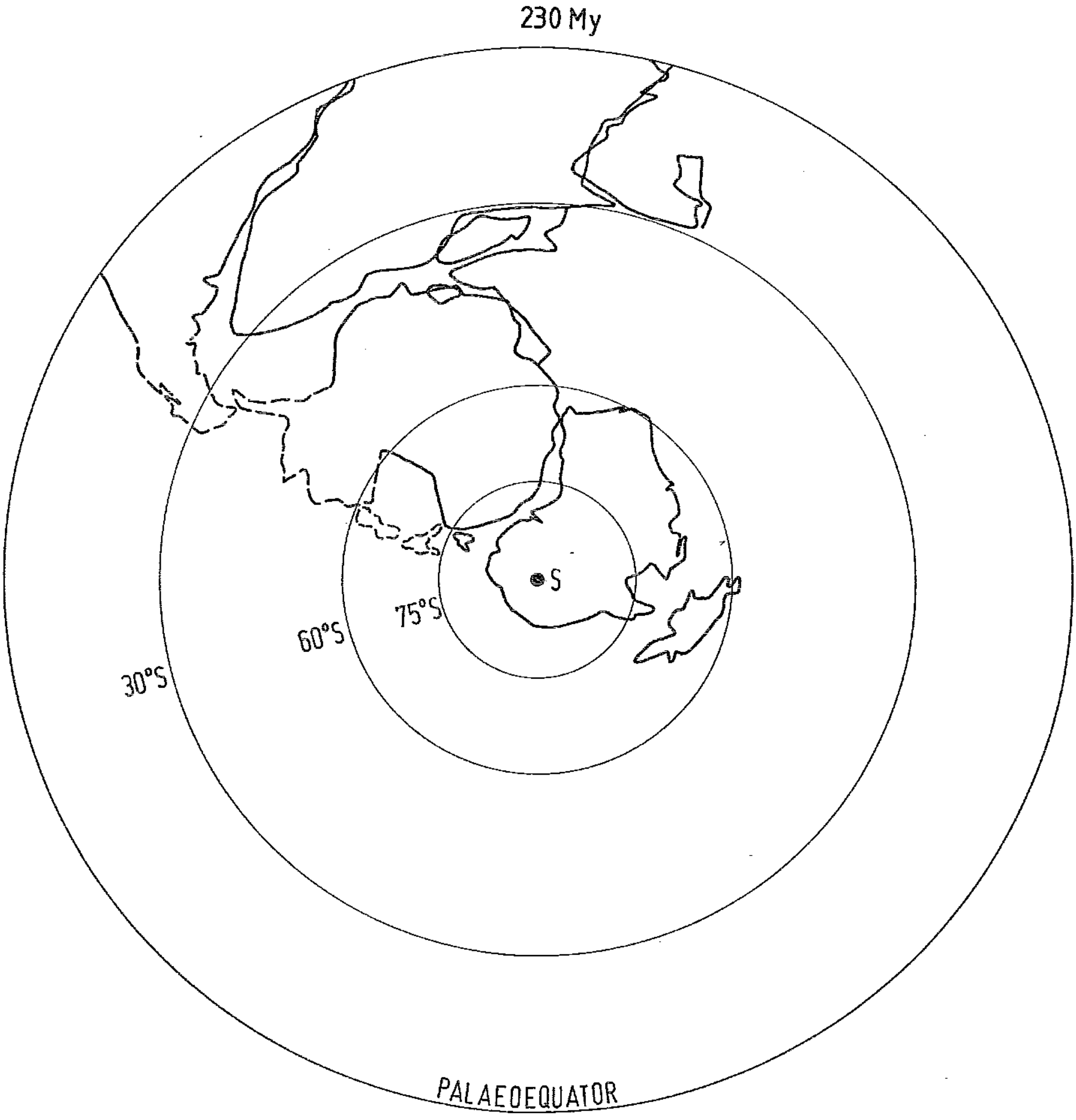
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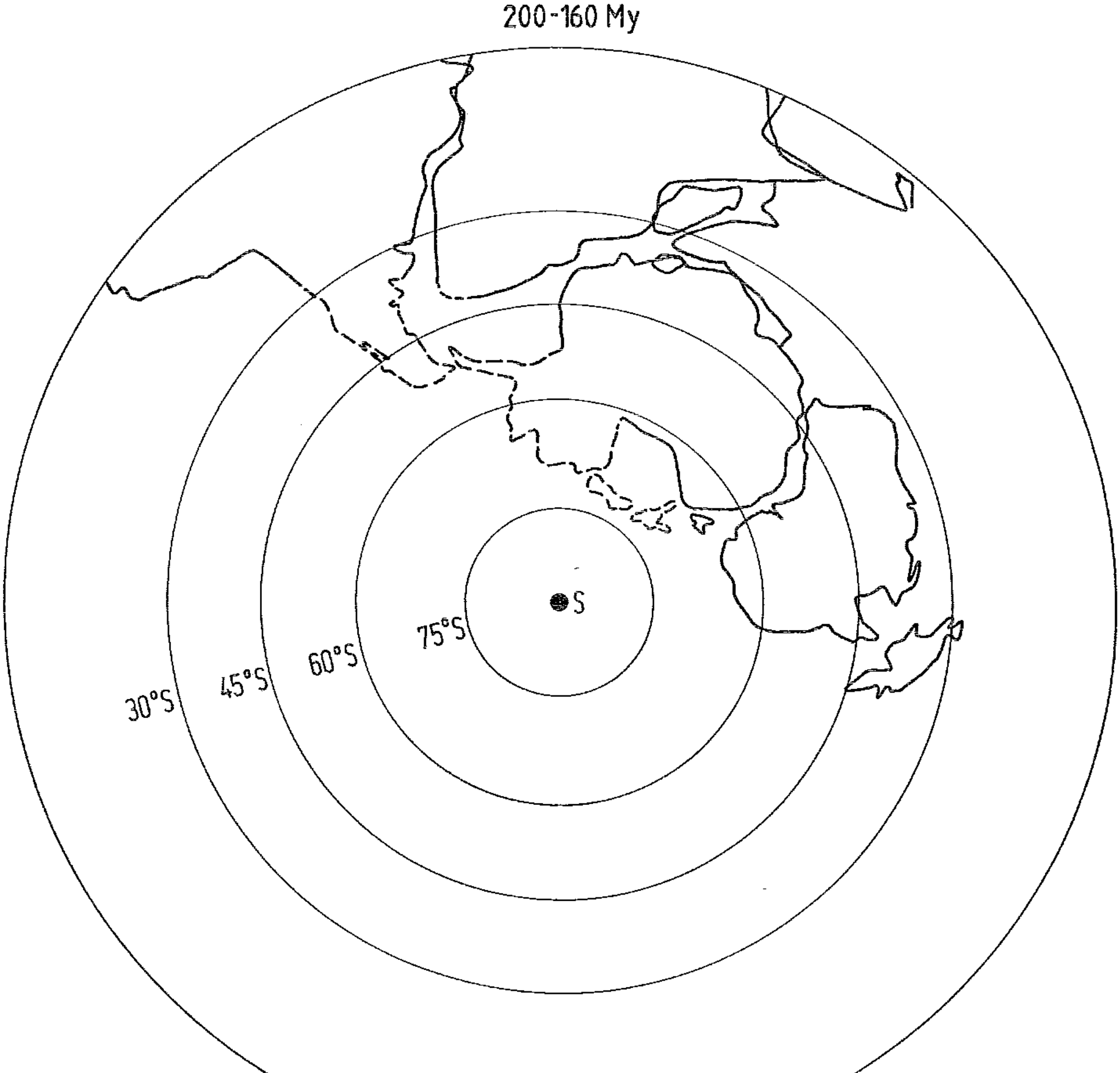
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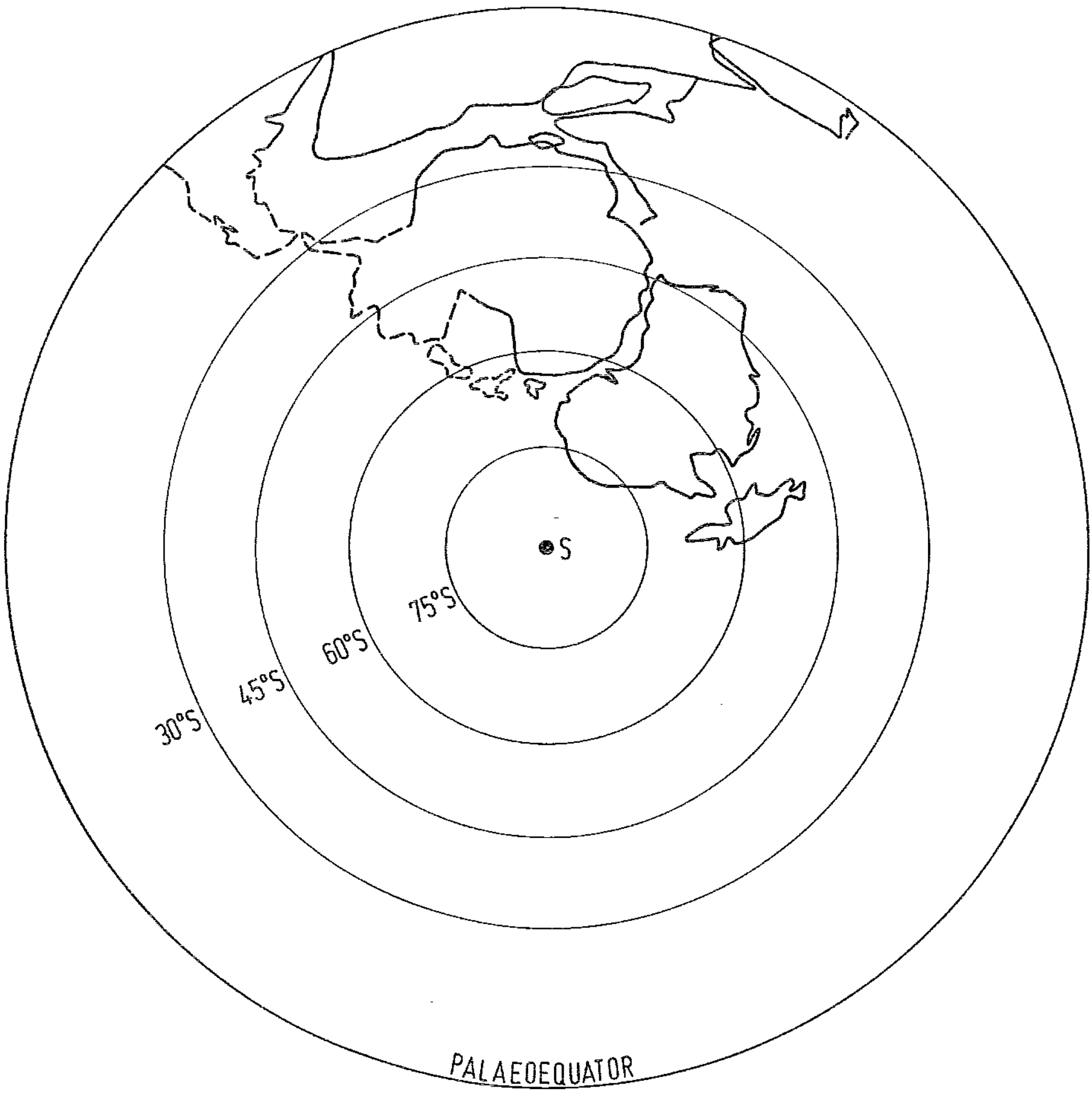

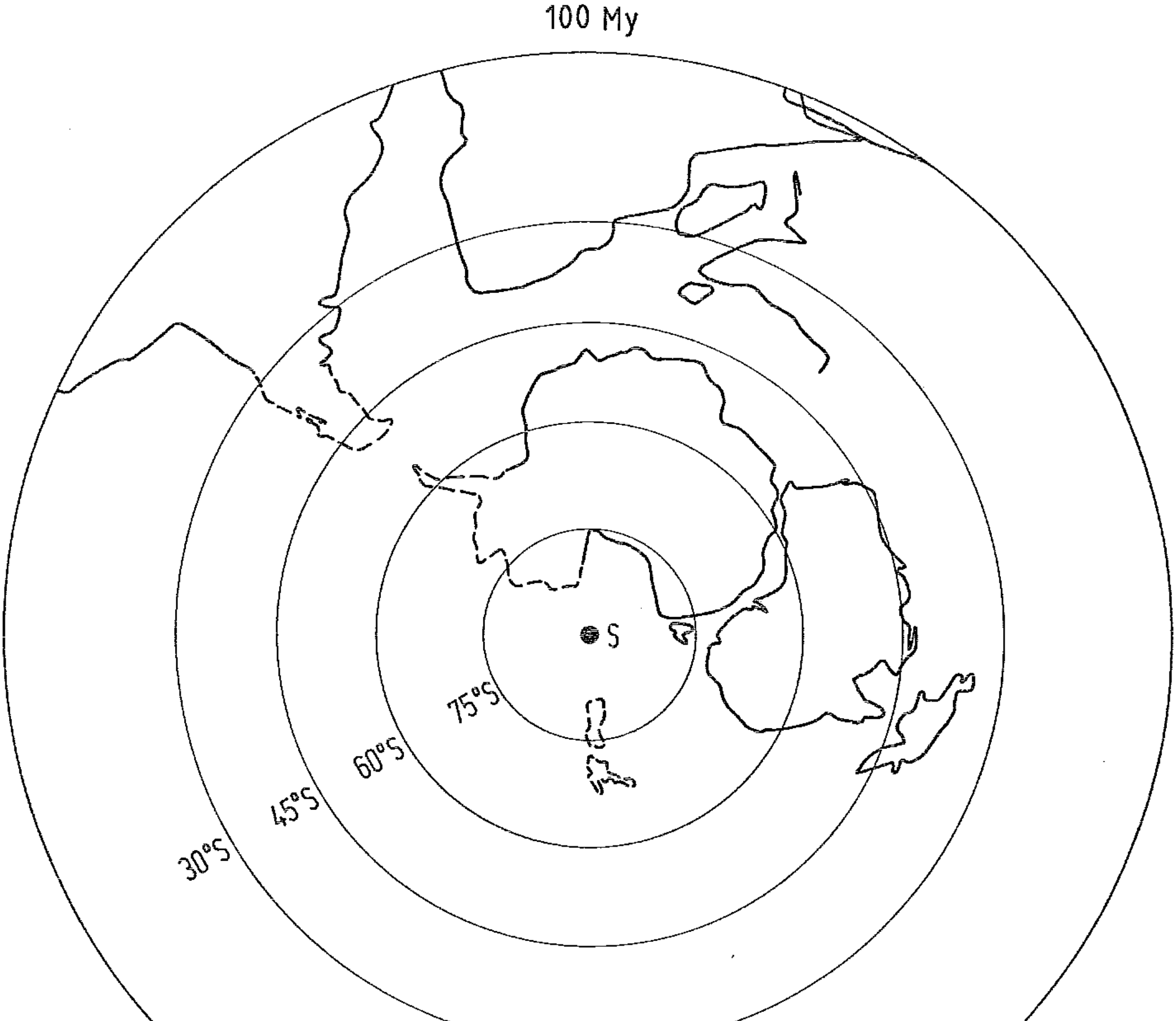
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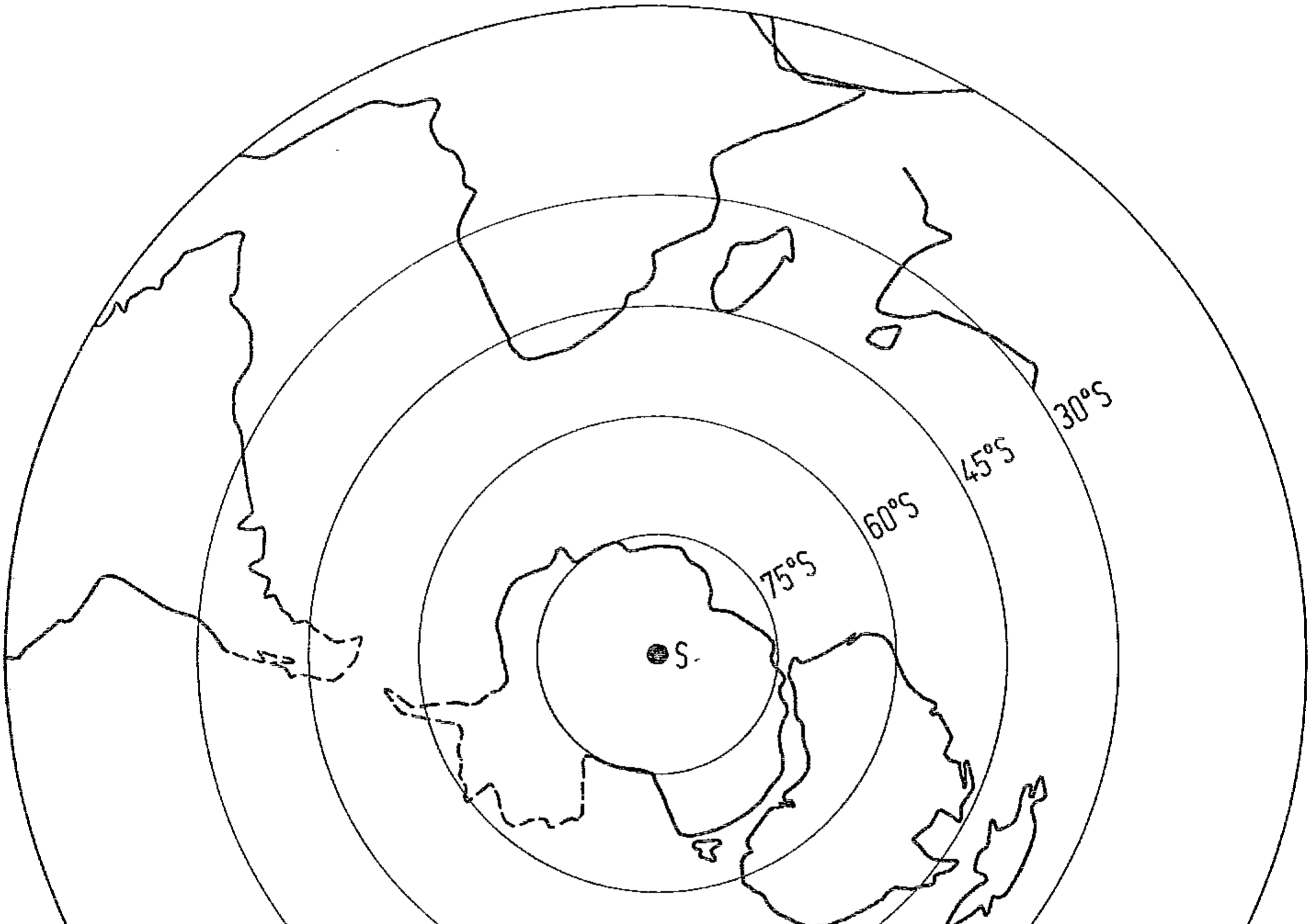

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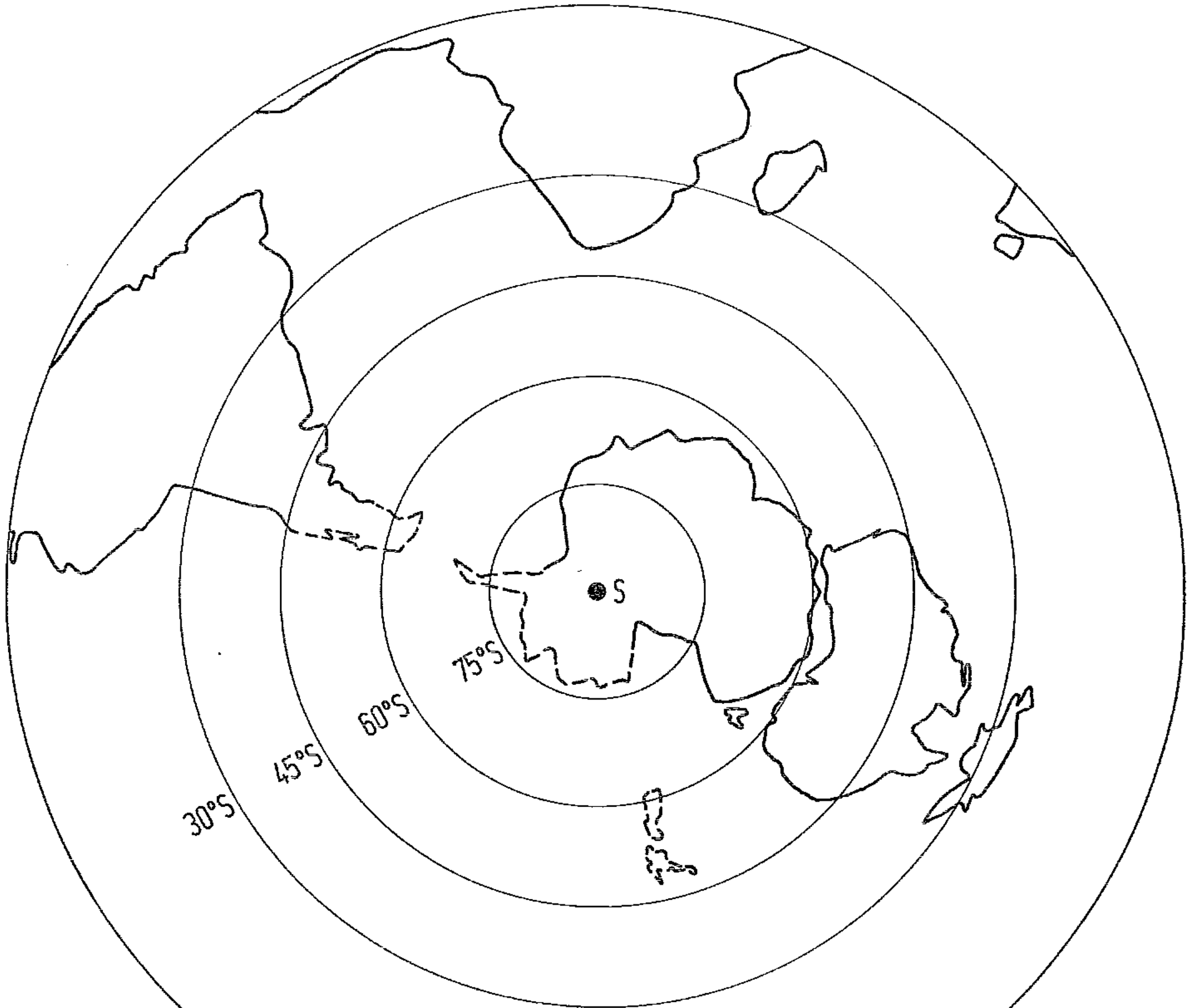

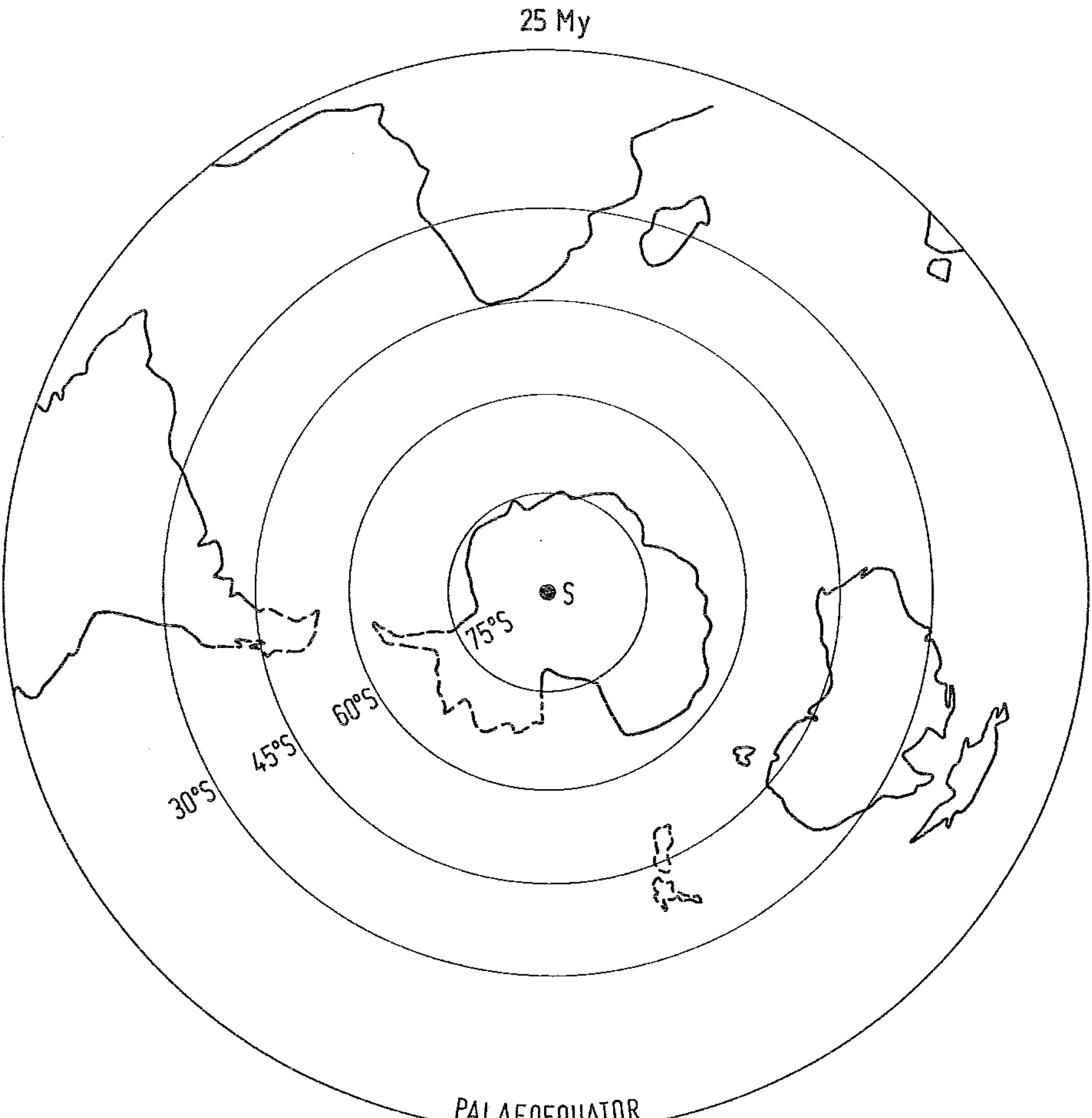
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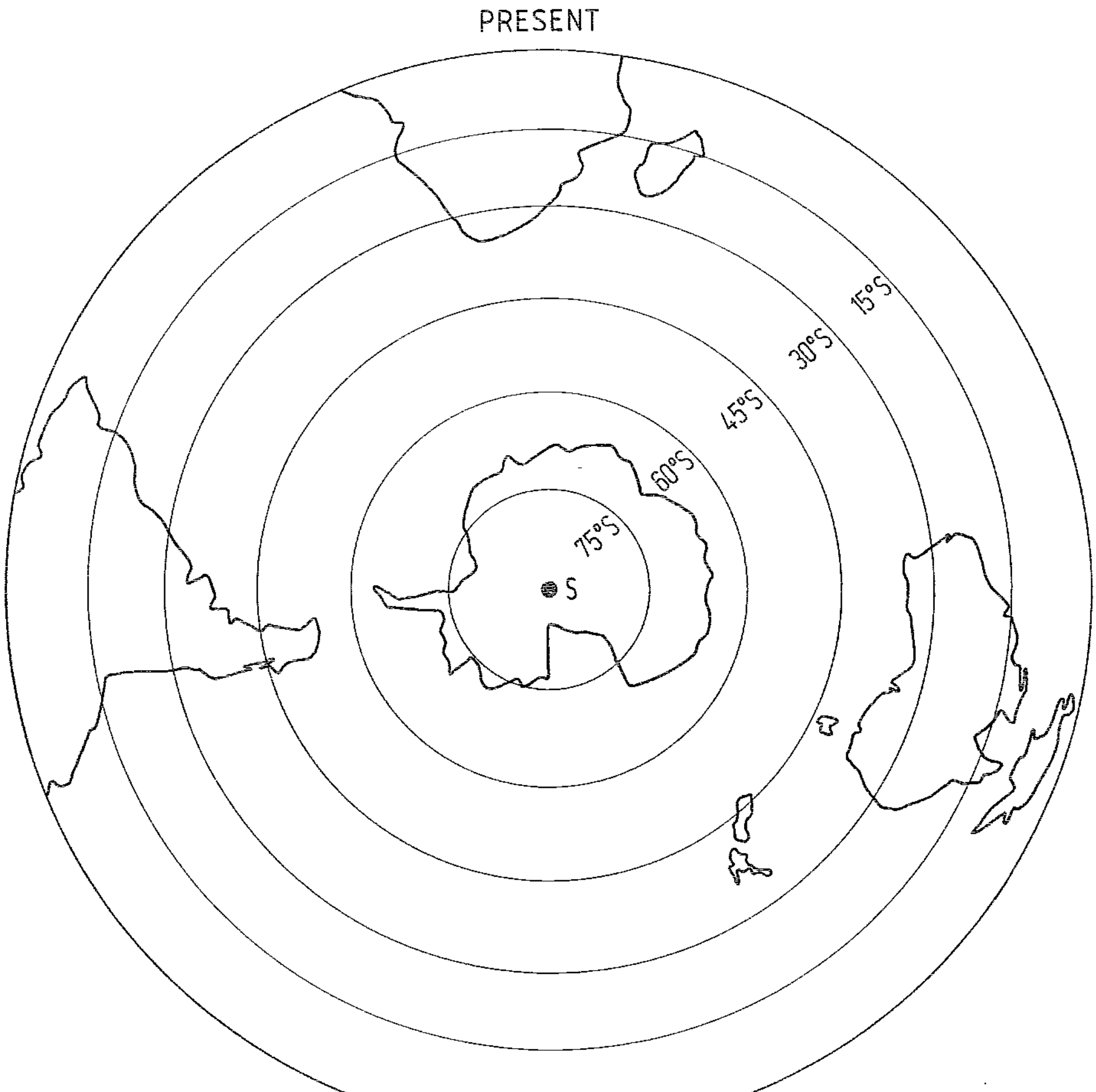
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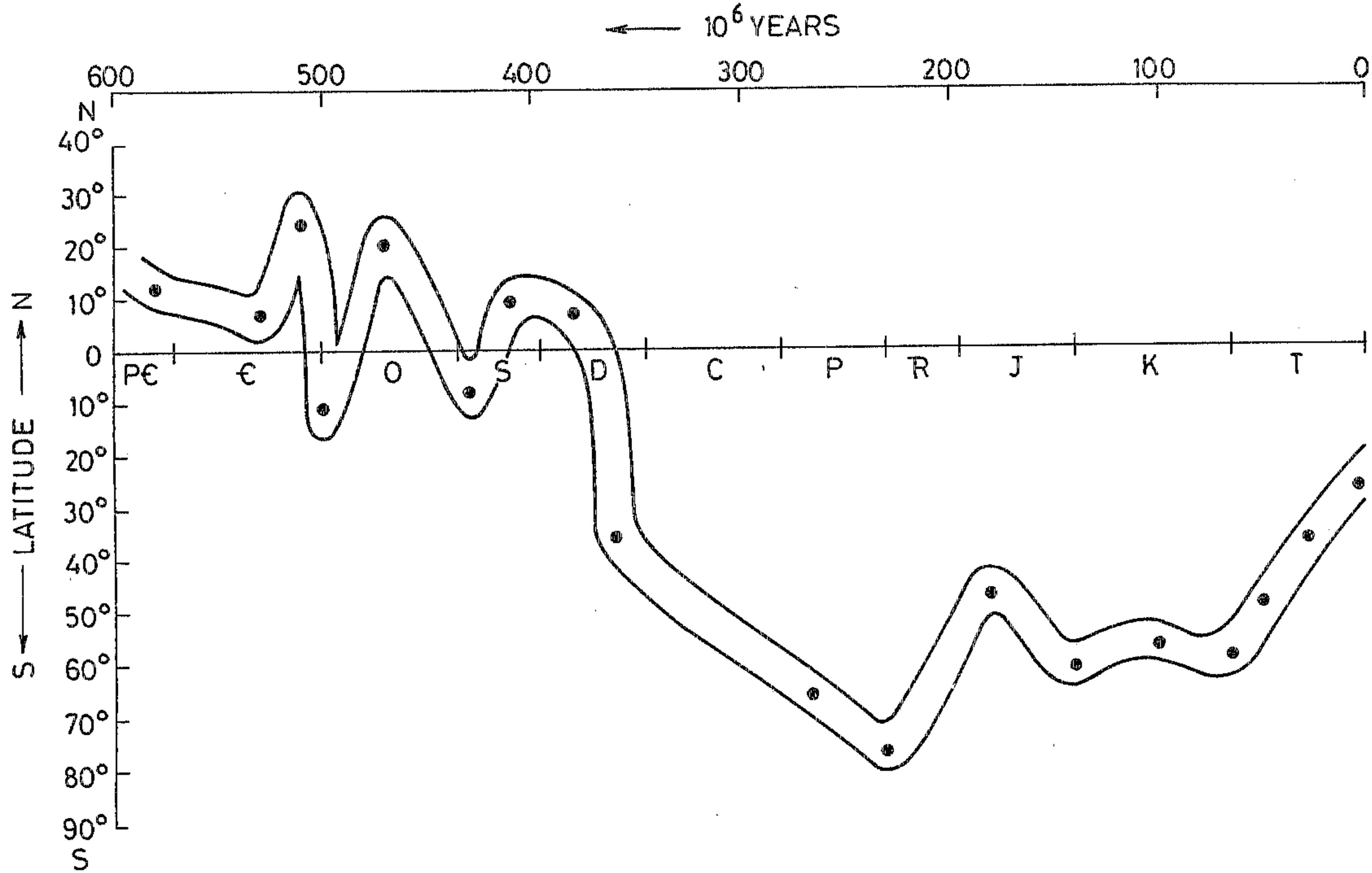
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