

Short Communication

REVISED PALAEOMAGNETIC DATA FOR THE AUSTRALIAN MESOZOIC AND A SYNTHESIS OF LATE PALAEOZOIC—MESOZOIC RESULTS FOR GONDWANALAND

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ABSTRACT

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Revised palaeomagnetic data for the Mesozoic of Australia confirm the unity of Gondwanaland until the mid-Jurassic. By combining palaeomagnetic poles from all the Gondwana continents, an apparent polar shift is recognized for the late Palaeozoic, Triassic and Jurassic.

INTRODUCTION

New palaeomagnetic results from South Australia, Victoria and New South Wales (Schmidt, 1976a,b) have provided the key to solving the apparent inconsistency that has existed between Mesozoic palaeomagnetic results for Australia and the rest of the Gondwanaland continents. Several workers (Irving and Robertson, 1969; Creer et al., 1969) have explicitly noted the discrepancy in the palaeomagnetic directions when Australia is considered in the context of the super-continent Gondwanaland prior to break-up. In a recent review of Australian palaeomagnetism covering the Phanerozoic, McElhinny and Embleton (1974) reconsidered the problem within the framework of the new global tectonics and the concept of plate movements, but they concluded that Mesozoic palaeomagnetic results for Australia, ‘. . .continue to remain enigmatic’.

It would seem that, from some time in the Late Carboniferous (represented by results from the Main Glacial Stage, the Rocky Creek Conglomerate and the Currabubulla Formation (Irving, 1966)) until mid-Cretaceous times (represented by results from the Cygnet alkaline complex (Robertson and Hastie, 1962) and the Mt. Dromedary igneous complex (Robertson,

1963)), there was little or no apparent polar wander relative to Australia (Irving et al., 1963). Apparent polar wander during the Cainozoic (McElhinny et al., 1974) is consistent with the northward movement of Australia relative to Antarctica, as deduced from analyses of marine magnetic anomalies measured in the Southern Ocean by Le Pichon and Heirtzler (1968) and Weissel and Hayes (1971).

THE PROBLEM

Pole positions for the Triassic, Jurassic and Cretaceous periods, considered analogues of the fossil axes of rotation by McElhinny and Embleton (1974), plot in a region just south of Tasmania. When Australia is reconstructed to its pre-drift position within Gondwanaland, whether by following the classical reconstructions (Du Toit, 1937; King, 1958), or by matching the geometry of the continental margins (Sproll and Dietz, 1969; Smith and Hallam, 1970), the palaeomagnetic data are clearly anomalous. Palaeomagnetic pole positions for the Triassic and Jurassic periods for South America, Africa, India, Antarctica, Arabia (McElhinny, 1973) and Madagascar (Embleton and McElhinny, 1975) plot in a group consistently further east than the pole positions for Australia for the same time interval. Co-latitudes calculated from inclinations of magnetization from basalt cores collected off the west and northwest shelf of Western Australia on leg 27 of the Deep Sea Drilling Project (McElhinny, 1974) yielded two pole loci, one supporting the Gondwanaland group of poles and the other supporting the Australian group.

Much attention has in the past been focused on the difference between the Jurassic Ferrar Dolerite pole of Antarctica (Bull et al., 1962) and the Tasmanian Dolerite pole for Australia (Irving, 1963). Although none of the other Australian poles fitted with Gondwanaland, the problem has been conveniently formulated by comparing those two pole positions. They were obtained from studies of a rock type so similar in age and composition that the rocks are considered derivatives of the same geochemical source region (McDougall, 1961, 1963; Compston et al., 1968). The Tasmanian Dolerite pole at $160^{\circ}\text{E}, 51^{\circ}\text{S}$ is, in fact, one of the Australian Mesozoic poles that lies closest to the majority group for Gondwanaland (e.g. the Ferrar Dolerite pole on Australian coordinates (and pre-drift) lies at $183^{\circ}\text{E}, 44^{\circ}\text{S}$).

Palaeoclimatic evidence obtained from geological indicators (Brown et al., 1968) also conflicts with the palaeolatitude determinations based on the palaeomagnetic data. The magnetic results obtained by Embleton (1973) appeared to place Australia in anomalously high latitudes during the Mesozoic.

THE PROJECT

All earlier results pertinent to the problem had been obtained from investigations of igneous and sedimentary rock units restricted in outcrop to Tas-

mania and the eastern seaboard of New South Wales. This region is known to have suffered a complex tectonic history (Brown et al., 1968; Oversby, 1971) and its Palaeozoic palaeomagnetic data have been interpreted within the framework of plate tectonics (Embleton et al., 1974). Although the geological evidence appeared lacking, it was initially considered that the Mesozoic problem might also be resolved tectonically, and an investigation of the late Palaeozoic and Mesozoic sediments of the Perth Basin and the Bunbury basalt was begun. It was soon discovered that the post-Mesozoic laterization had remagnetized most of the sediments (Schmidt and Embleton, 1976) and the only useful results regarding the original problem were obtained from the Bunbury basalt (Schmidt, 1976a). Wellman (1971), using the K–Ar technique, has dated samples of the Western Australian Bunbury basalt as Cretaceous and other igneous bodies in South Australia and Victoria as Jurassic. Amongst these, the Kangaroo Island basalt (South Australia), dykes from near Bendigo (Victoria) and basalts from western Victoria were chosen for study. The sequence of Jurassic lavas known as the Garrawilla Volcanics (Bean, 1974) was sampled in New South Wales with the intention of covering more than one polarity interval.

In view of the discrepancy in the results between the Tasmanian Dolerite and the Ferrar Dolerite of Antarctica, a new collection of the Tasmanian Dolerite was made to test its stability of magnetization to thermal and alternating magnetic field treatment. Irving (1963) argued that cleaning was unnecessary on the basis that: (1) random directions were obtained from an Early Tertiary dolerite breccia, indicating a pre-Early Tertiary age for the stable magnetization; (2) a detailed laboratory study by Stott (1963) of the Red Hill dyke, which belongs to the Tasmanian Dolerite intrusive complex, revealed no significant change in direction after progressive alternating field treatment to 75 mT (750 oersteds); and (3) a convincing baked contact test was obtained by Stott (1963) from one of the sites in the dyke. Curiously, the Red Hill dyke pole position ($187^{\circ}\text{E}, 48^{\circ}\text{S}$) agrees well with the Ferrar Dolerite pole (see earlier).

Three Jurassic igneous stocks (the Gibraltar microsyenite, the Prospect dolerite and Gingenbullen dolerite) were studied by Boesen et al. (1961). Specimens from the original collection were complemented with a new collection of samples from the Gingenbullen dolerite and the Gibraltar microsyenite and treated in higher alternating fields than those used previously. It was worthwhile testing for the presence of high coercive force secondary magnetizations.

THE SOLUTION

The results of this investigation have shown that the pole positions for the Jurassic period for Australia need no longer be considered anomalous when compared with the relevant Mesozoic poles for Gondwanaland (Fig. 1). On the other hand, results from the 100 m.y. Bunbury basalt have verified the

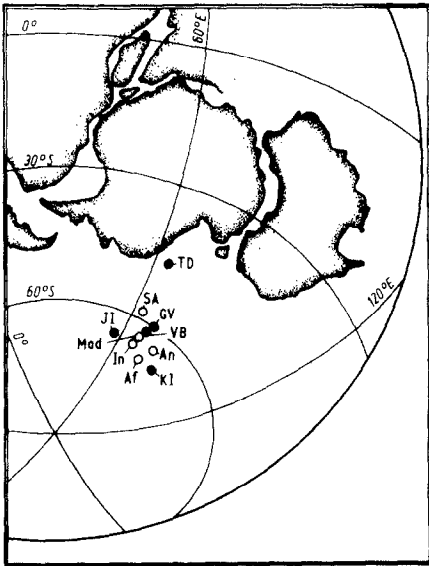


Fig. 1. Pole positions for Australian Triassic–Jurassic rock units (full circles) plotted on the background of the Smith and Hallam (1970) geometrical reconstruction of Gondwanaland. Mean Triassic–Jurassic palaeomagnetic poles (open circles) are shown, for comparison, for Africa (Af), South America (SA), India (In), Antarctica (An) and Madagascar (Mad). The data on which the mean poles are based are referenced in the notes to Table II and the Australian data are listed in Table I. A linear polar projection centred at $25^{\circ}\text{E}, 30^{\circ}\text{S}$ is used: grid lines are shown relative to Africa.

existing Cretaceous pole position (Robertson and Hastie, 1962) from a study of the Cygnet alkaline complex, also dated at approximately 100 m.y. by Evernden and Richards (1962). The pole positions are listed in Table I. None of the lava sequences sampled covered a polarity reversal of the geomagnetic field.

Further cleaning of the Gibraltar microsyenite, the Prospect dolerite and the Gingenbullen dolerite has removed a component of magnetization, possibly acquired during the Cretaceous/Tertiary, with a slightly steeper inclination than the Jurassic field. These data have been combined with new results from the Glenrowan intrusive suite (Schmidt, 1976b) (sampled in north-central New South Wales): the new pole position for these igneous stocks now plots further east (Table I and Fig. 1).

The results (Irving, 1963; Robertson, 1963) from the original investigations of the Narrabeen chocolate shale, the Brisbane Tuff and the Noosa Heads Complex are quite compatible with the drift scheme described below. The Narrabeen chocolate shale and the Brisbane Tuff are Early and Middle Triassic in age and acquired their magnetization during the apparent shift of the pole from its late Palaeozoic position near Tasmania to its Late Triassic/Early to Middle Jurassic position in the vicinity of New Zealand. The Noosa

TABLE I

Summary of Mesozoic palaeomagnetic data for Australia

| Rock unit | Mean site coordinates | | Age | Sites (samples) | Pole coordinates | | A ₉₅ (°) | References |
|-------------------------------------|-----------------------|-------------|-----------------|--------------------|------------------|---------------|------------------------|---------------------------------|
| | lat. (°S) | long. (°E) | | | lat. (°S) | long. (°E) | | |
| Narrabeen chocolate shale (NS) | 33.9 | 150.9 | Tr1 | 4 (32) | 49 | 160 | 14 | Irving, 1963 |
| Brisbane Tuff (BT) | 27.8 | 153 | Trm | 6 (12) | 57 | 143 | 11 | Robertson and Hastie, 1962 |
| Garrawilla Volcanics * (GV) | 31.3 | 149.7 | Tru-J1 | 14 (36) | 46 | 175 | 10 | Schmidt, 1976b |
| W. Victoria basalts (VB) | 37.4 | 141.4 | J1 | 6 (36) | 47 | 186 | 4 | Schmidt, 1976a |
| <i>Jurassic intrusives</i> ** (J11) | | | <i>J</i> | 3 (28) | 48 | 147 | 10 | McElhinny and Embleton, 1974 |
| Jurassic intrusives *** (J12) | | | <i>J</i> | 6 (35) | 51 | 186 | 11 | Schmidt, 1976b |
| <i>Tasmanian Dolerite</i> (TD1) | 41.3—43.3 | 146.3—148.1 | <i>Jm</i> (167) | 51 (132) | 51 | 160 | 6 | Irving, 1963 |
| Tasmanian Dolerite (TD2) | 40.8—43.1 | 146.3—148.2 | <i>Jm</i> (167) | 33 (69) | 52 | 156 | 7 | Schmidt, 1976b |
| Bendigo Dykes (BD) | 37 | 141.4 | <i>Jm</i> (150) | 4 (26) | (47) | 135 | 39) | Schmidt, 1976a |
| Kangaroo Is. basalt (KI) | 35.6 | 137.5 | <i>Jm</i> (170) | 2 (20) | 39 | 183 | 11 | Schmidt, 1976a |
| Noosa Heads Complex (NH) | 26.4 | 153.1 | <i>Ju</i> (140) | 4 (10) | (36) | 132 | 24) | Robertson and Hastie, 1962 |
| Bunbury basalt (BB) | 33.8 | 115.6 | <i>K</i> (100) | 5 (54) | 49 | 161 | 10 | Schmidt, 1976a |
| Cygnets alkaline complex (C) | 43.2 | 147.1 | <i>K</i> (98) | 15 (45) | 50 | 158 | 10 | Robertson and Hastie, 1962 |
| Mt. Dromedary igneous complex (MD) | 36 | 150 | <i>K</i> (93) | 22 (55) | 56 | 138 | 9 | Robertson, 1963 |

A₉₅ = semi-angle of the cone of confidence calculated at the 95% probability level (Fisher, 1953).

* Also includes results from the Noombi extrusives.

** Includes results from the Gibraltar microsyenite (site coordinates 34.5°S, 150.4°E), the Prospect dolerite (site coordinates 33.8°S, 150.8°E) and the Gingenbullen dolerite (site coordinates 34.4°S, 150.3°E) reported by Boesen et al. (1961).

*** Includes results from the Gibraltar microsyenite, the Prospect dolerite, the Gingenbullen dolerite and the Glenrowan intrusives (site coordinates 31.1°S, 149.9°E).

Entries in italics indicate superseded results.

Entries bracketed are based on scattered directions ($A_{95} > 20^\circ$) and have not been used to compile Figs. 1 and 2.

Heads Complex is Late Jurassic in age and was therefore magnetized at some time after the initial rifting which heralded the fragmentation of Gondwanaland.

The pole position for the Tasmanian Dolerite (Irving, 1963) remains practically unchanged (Table I). The angular difference between it and the mean Ferrar Dolerite pole is 20° whereas the combined semi-angles of the cones of confidence (for $P = 0.05$ (Fisher, 1953)) is only 15° . The amount of secular variation of the geomagnetic field covered by the separate studies remains uncertain. Small regional differences in the cooling rates and non-synchronicity of intrusion would explain the apparent discrepancy in the palaeomagnetic data (we note here the difference between the poles for the Tasmanian Dolerite and the Red Hill dyke). We conclude that the regional studies of the dolerite, of which four have been carried out in Antarctica and one in Tasmania, are best considered as discrete records of the Jurassic field. For the purpose of averaging secular variation equal weight can be attributed to each.

APPARENT POLAR WANDER

Details of the Smith and Hallam (1970) reconstruction of Gondwanaland, recently verified by palaeomagnetic studies of late Palaeozoic and Mesozoic rock formations from Africa and Madagascar (Embleton and McElhinny, 1975; McElhinny and Embleton, 1976), are also valid until the Early to Middle Jurassic of entire Gondwanaland including Australia. We are now in a position to compare all of the palaeomagnetic data for Gondwanaland for this period of time, confident that the Smith-Hallam reconstruction is as realistic a model as is currently available. There are 73 palaeomagnetic pole positions available from rock units covering the Late Carboniferous to Middle Jurassic of Gondwanaland. Following an hypothesis proposed by Daly and Pozzi (1976), we have divided them into groups covering intervals of time broadly corresponding to Permo-Carboniferous, Permo-Triassic and Triassic—Jurassic. This division is also convenient from the point of view of sampling density: ages of rock units are frequently ascribed to time ranges covering Period boundaries. Mean Gondwanaland pole positions (with source listings) for the Permo-Carboniferous, Permo-Triassic and Triassic—Jurassic are given in Table II. In Fig. 2 they are plotted on a Smith-Hallam reconstruction of Gondwanaland. Now that a large volume of data is available, significant differences between successive pole positions covering the late Palaeozoic and Mesozoic can be clearly seen (Table II).

The apparent polar wander curve for Gondwanaland reached the region close to Tasmania by the Late Carboniferous. The south pole remained there only until the Late Permian or Early Triassic. The pole position for the Late Permian Milton monzonite (Robertson, 1964), once considered anomalous at $170^\circ\text{E}, 32^\circ\text{S}$, may well indicate that the south pole had already commenced its apparent shift toward the Jurassic group, a timing similar to that of the polar shift relative to South America (Embleton, 1970). This will be

TABLE II
Mean palaeomagnetic pole positions for Gondwanaland and Australia for the Late Carboniferous to Middle Jurassic

| Time span | Rotated to Africa | | Angular differ-ences (degrees) | Rotated to Australia | | Australian pole position | |
|---------------------|----------------------|-----------------------|--------------------------------|----------------------|-----------------------|--------------------------|-----------------------|
| | lat. ($^{\circ}$ S) | long. ($^{\circ}$ E) | | lat. ($^{\circ}$ S) | long. ($^{\circ}$ E) | lat. ($^{\circ}$ S) | long. ($^{\circ}$ E) |
| Permo-Carboniferous | 35.9 | 63.0 | 4.5 | 53.0 | 138.7 | 48.1 | 137.8 |
| Permo-Triassic | 52.7 | 79.1 | 5.2 | 42.6 | 164.9 | 46.8 | 153.6 |
| Triassic-Jurassic | 64.6 | 72.0 | 2.8 | 44.6 | 182.0 | 47.0 | 176.3 |

The analysis for Gondwanaland has been carried out using the following pole positions (identified by Geophys. J. R. Astron. Soc. (Irving, 1960, 1965; Irving and Stott, 1963; McElhinny, 1968a,b, 1969, 1970, 1972a,b) pole list numbers or for the more recently reported poles, the actual references).

Permo-Carboniferous: Africa (8/91-92, Daly and Pozzi, 1976), South America (12/116, 117, 123, 124, 14/309, 332, 333, 345, 346), Australia (8/103, 104, 105, McElhinny and Embleton, 1974), Madagascar (McElhinny and Embleton, 1976; Razafindrazaka et al., 1976).

Permo-Triassic: Africa (8/73, 14/303), South America (11/49, 56, 60, 61, 13/42, 14/286, 291, 306), Australia (7/33, 34, 39, 8/80), India (11/57, 14/301, 302), Madagascar (McElhinny and Embleton, 1976; Razafindrazaka et al., 1976).

Triassic-Jurassic: Africa (6/40-43, 8/59, 63, 67, 72, 10/77, 12/93, 13/35, 36, 40, 14/248, 249, 250, 288, 290, 693, Daly and Pozzi, 1976), South America (11/46, 12/102, 14/241, 274), Australia (Schmidt, 1976a,b), India (11/43, 45), Madagascar (14/269), Antarctica (2/26, 27, 6/36, 10/70, 14/239).

The Australian pole positions are based on the data given in Table I.

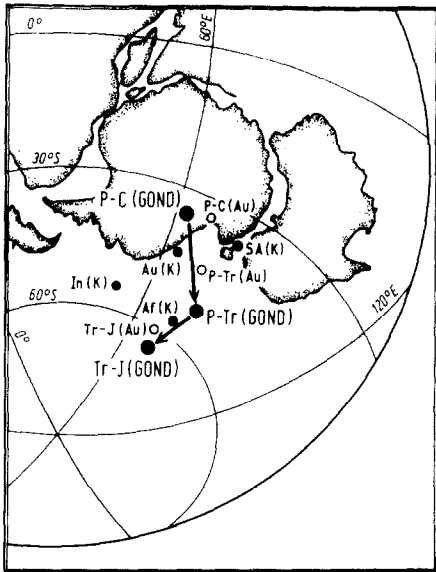


Fig. 2. The late Palaeozoic–Mesozoic apparent polar shift for Gondwanaland. Mean Gondwanaland poles (large full circles) are shown for the Permo-Carboniferous, Permo-Triassic and Triassic–Jurassic periods: the Australian data (open circles) for the same time intervals are also shown. The data on which the mean poles are based are referenced in the notes to Table II. Late Jurassic/mid-Cretaceous poles (small full circles) are plotted for each continent: Africa (Af) $77^{\circ}\text{E}, 58^{\circ}\text{S}$, South America (SA) $34^{\circ}\text{E}, 79^{\circ}\text{S}$, India (In) $113^{\circ}\text{E}, 20^{\circ}\text{S}$ and Australia (Au) $152^{\circ}\text{E}, 53^{\circ}\text{S}$. The analysis is based on the following poles (see Irving, 1960, 1965; Irving and Stott, 1963; McElhinny, 1968b, 1972a, b, 1976): Africa (7/21, 9/40, 13/32, 14/224, 225, 226), South America (6/35, 12/60, 14/215, 231, Pacca and Hiodo, 1975), India (9/39, 12/59, 13/30) and Australia (Table I). A linear polar projection centred at $25^{\circ}\text{E}, 30^{\circ}\text{S}$ is used: grid lines are shown relative to Africa.

verified by further work on selected Triassic formations; work is in progress with a collection from the Springfield Basin, South Australia. By the end of the Jurassic, Gondwanaland had begun to fragment; the scatter in the Late Jurassic–Early Cretaceous pole positions, plotted in Fig. 2 for each continent, clearly reflects this event. It would now appear that Australia and Antarctica rifted from the southeast coast of Africa during the Late Jurassic or Early Cretaceous and drifted as a unit until their final separation in the Cainozoic.

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