of 12 m/sec (*8*). However, unlike small asteroids which can encounter meteoritic dust approaching with negligible relative velocity, Phobos must suffer impacts from particles moving with relative velocities of not less than 0.9 km/sec, nearly 100 times greater than the escape velocity. This general relation between impact and escape velocities will occur for any very small satellite moving deep within the gravitational field of its massive primary. We might then imagine Phobos, and perhaps Deimos as well, as having a surface continuously sputtered clean by meteoritic particles.

Phobos is elongated in the plane of its orbit (Fig. 3). The elongation along the line of sight is of course unknown, but we can infer from Fig. 3 that the ratio of maximum to minimum diameter is at least 1.3, a significant departure from spherical symmetry. This result should not be surprising for a small rigid body, which is unable to adjust its physical surface to a gravitational equipotential surface. It does suggest, however, that Phobos did not form by accretion as it orbited within the planetesimal cloud around primordial Mars, but may have been captured in its present form at some later time. That Phobos may have had its origin within the asteroid belt is not an unreasonable supposition.

Finally, the true anomaly of Phobos was advanced approximately 2 to 3° with respect to its ephemeris position. Uncorrected geometrical distortion in the far-encounter photographs limits the accuracy to which we can measure the areocentric position of Phobos at present. In a later paper we expect to be able to report improved orbital elements of Phobos.

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2. A time separation of only 85 seconds between frames 6F40 and 6F41 provides near-redundancy to optimize detection of the satellite and its shadow.
3. Phobos was 130,900 km from the spacecraft when frame 7F91 was taken. This corresponds to an image scale of 3.5 km per pixel.
4. Observations by G. P. Kuiper give a mean opposition visual magnitude of 11.6 ± 0.1 for Phobos as reported by D. L. Harris [in *Planets and Satellites*, G. P. Kuiper and B. M. Middlehurst, Eds. (Univ. of Chicago Press, Chicago, 1961), p. 289].
5. Based on observed phase coefficients of small asteroids (T. Gehrels, personal communication) I have taken values of 0.02 and 0.04 magnitude/degree as extremes of the phase coefficient of Phobos.
6. By using Kuiper's mean opposition visual magnitude of $+11.6$ and adopting the martian geometric albedo of 0.154, one arrives at a mean radius of 6.5 km for Phobos. This value is typical of many earlier estimates of the size of Phobos.
7. Geometric albedos are taken from D. L. Harris [in *Planets and Satellites*, G. P. Kuiper and B. M. Middlehurst, Eds. (Univ. of Chicago Press, Chicago, 1961), p. 307]. They are all "visual" albedos, corresponding to the *V* spectral band of the UBV system, and are measured at an effective wavelength of 550 to 560 nm. The effective wavelength of the Mariner television camera which took frame 7F91 is approximately 560 nm; therefore the geometric albedo of Phobos may be regarded as the visual value, $p(V)$.
8. This value is based on a mean density of 2.8 g/cm^3, the average for the earth's crust. The escape velocity varies with the square root of the mean density.
9. I thank T. B. Kirby for measurements of the orbital position of Phobos, S. A. Dean for assistance with the hand correction of the photometric data, and B. C. Murray and R. B. Leighton for suggestions. I also thank the project personnel at the Jet Propulsion Laboratory, particularly G. E. Danielson, S. A. Collins, and J. A. Dunne for assistance.

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Paleomagnetism and Gondwanaland

Abstract. *Lower Paleozoic data now available for all the southern continents enable a unique reconstruction of Gondwanaland to be determined from paleomagnetic measurements alone. This reconstruction is corroborated by the computerized fit of the continental shelves and the matching of geological age provinces.*

We have recently completed some paleomagnetic measurements on lower Paleozoic formations from India (*1*) and Australia (*2*). For the first time, lower Paleozoic paleomagnetic data are available for each of the southern continents. These data, together with the upper Paleozoic results, now make it possible to reconstruct Gondwanaland uniquely from paleomagnetic results alone. The purpose of this report is to present such a reconstruction and to show that it is supported by the geological evidence previously used to favor an alternative Gondwanic configuration.

Early paleomagnetic studies of various Mesozoic rock formations from the southern continents (*3, 4*) demonstrated the occurrence of relative movement between these land masses since Mesozoic times (*4*). The African and Austrialian results (*4*) showed that during the Mesozoic era the pole remained stationary with respect to both continents, so that, in effect, only one average Mesozoic pole position was determined for each. A single pole places a continent in latitude and azimuthal orientation, but the longitude remains indeterminate. Thus the configuration of the southern land masses prior to continental drift could not be determined uniquely from the Mesozoic data. However, the relative positions of two or more continents can be determined without ambiguity from paleomagnetic data if they have remained in a fixed position relative to each other during a period in which substantial polar wandering occurred (*5*). Results from Africa (*6*) and South America (*7*) indicate that this condition was satisfied during most of the Paleozoic era, for it has been shown that the polar-wander paths for the two continents are almost coincident for most of the Paleozoic if the South Atlantic is closed (*8*).

Briden has noted that Paleozoic paleomagnetic poles from the Gondwanic continents tend to group about three stable positions that occur in the intervals Cambrian to Lower Devonian, Devonian to Lower Carboniferous, and Upper Carboniferous to Permian, respectively (*9*). These "quasi-static intervals" were separated by short periods of time in the Devonian and Carboniferous, during which the pole moved from one stable position to the next. We may therefore reconstruct the relative locations of the Gondwanic continents during the Paleozoic if the respective paleomagnetic poles corresponding to at least two of these stable positions are determined. Our new results for the lower Paleozoic of India and Australia complete these requirements for four of the five Gondwanic continents. However, the single lower Paleozoic pole for Antarctica (*10*) is sufficient to define its position because of constraints imposed by the adjoining continents.

In Table 1 the paleomagnetic poles that have been determined for the Paleozoic of each of the southern continents have been summarized. In each case the result has been derived through the use of cleaning techniques, so that we can be reasonably sure that secondary components of magnetization have been removed and that the primary component is represented by the result.

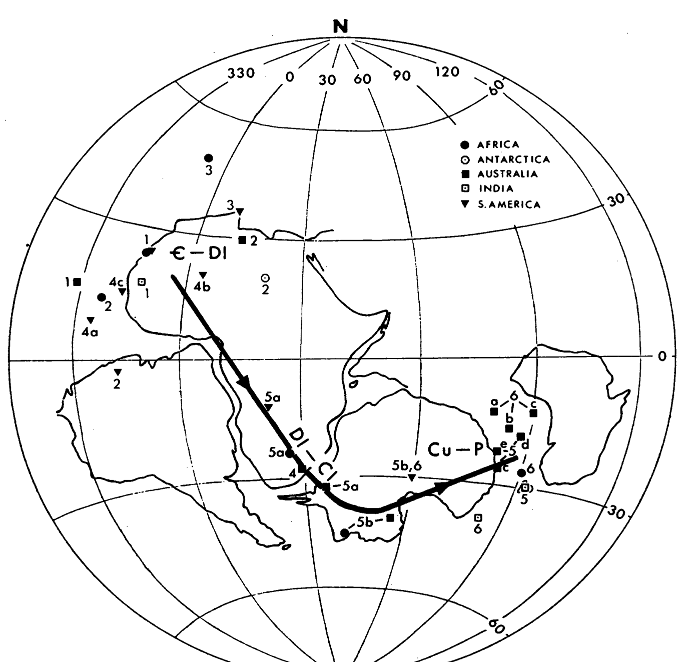
Table 1. Paleozoic paleomagnetic poles for the southern continents: Africa (*6*), South America (*7*), Australia (*2, 13*), India (*1, 21*), and Antarctica (*10*). Pole locations are shown in Fig. 1.

Age	Africa		South America		Australia		India		Antarctica	
	No.	Coordinates	No.	Coordinates	No.	Coordinates	No.	Coordinates	No.	Coordinates
					6c	35°S,128°E				
Permian	6	27°S,89°E	6	65°S,13°W	6b	44°S,132°E	6	21°N,130°E		
					6a	46°S,122°E				
Carboniferous					5e	52°S,138°E	5	32°N,134°E		
Upper	5b	45°S,40°E	5b	65°S,13°W	5d	43°S,135°E				
					5c	53°S,148°E				
					5b	73°S,147°E				
Lower	5a	26°S,26°E	5a	28°S,34°W	5a	84°S,46°E				
Devonian (Lower)			4c	20°N,46°W	4	80°S,20°E				
			4b	9°N,26°W						
			4a	18°N,56°W						
Silurian	3	50°N,11°W	3	17°N,13°W						
Ordovician	2	14°N,24°W	2	3°N,59°W					2	28°S,10°E
Cambrian	1	28°N,15°W	1	23°N,36°W	1	9°S,20°W	1	28°S,32°E		

In Fig. 1 we have produced a reconstruction of Gondwanaland compatible with all these data. Africa has been placed in its present coordinates, and all the other continents have been moved (with their poles) to the positions shown. The thick line is the polar path common to all the Gondwanic continents.

The lower Paleozoic poles form a loose group around northwest Africa, which is consistent with the occurrence of glacial horizons in lower Paleozoic rocks of this region (*11*). Although it is still not clear if real differences exist between poles of various ages within this group, some suggestion of such differences occurs in data from Australia (*2*). The youngest poles in the group are the three Lower Devonian results from South America (Table 1).

A grouping of the poles for the middle Paleozoic then occupies a position around southern Africa and includes a Lower Devonian pole from Australia. This grouping appears to be inconsistent with the presence of South American Lower Devonian poles in the lower Paleozoic group. However, the polar transition between these groups, which has also been found in the paleomagnetic record of Eurasia (*12*), occupies such a short interval of time that the problems of intercontinental correlation arise. Another difficulty is that the most useful sediments for paleomagnetic purposes are red beds, which are often the least fossiliferous. Also, in this case the intercontinental correlation requires an accuracy of about one-third of a geological period, something difficult to maintain during the Paleozoic. The oc-



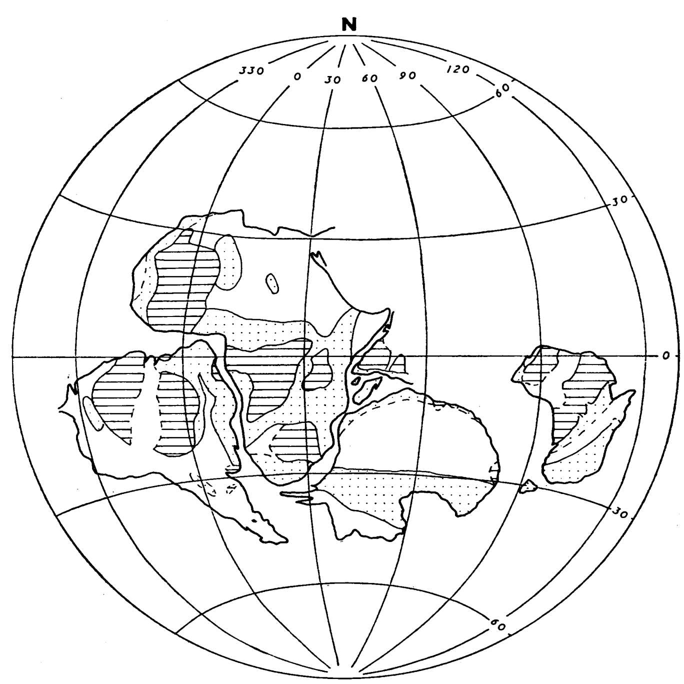


Fig. 1 (left). Reconstruction of Gondwanaland from Paleozoic paleomagnetic results. Equal area meridional projection is employed, with Africa placed in its present coordinates. The common polar-wander path is indicated by the thick line with ages indicated at three positions. The poles are numbered as in Table 1. Fig. 2 (right). Reconstruction of Fig. 1 with the addition of Madagascar and the distribution of two geological age provinces. Striped zones are the ancient cratons with ages of at least 2000 million years, and the stippled regions are the younger metamorphic belts and geosynclines whose ages cluster around 450 to 650 million years and reach a maximum of 1100 million years.

currence of a tillite near the top of the Table Mountain Series in the Cape System of South Africa provides paleoclimatic evidence for the timing of the transition. A possible Lower Devonian age for this tillite is consistent with the polar transition taking place within the Lower Devonian.

The transition that occurs during the mid-Carboniferous (*13*) is represented by two poles (5b, Fig. 1, for both Africa and Australia) occupying positions intermediate between the middle and upper Paleozoic positions. However, Creer (*14*) does not seem to recognize a Carboniferous transition of the same magnitude in the South American data, although this would appear to be a matter of interpretation. It would not be difficult to interpret results from the Piaiu formation (*15*) such that South American pole 5b is replaced by two poles, one lying to the west and one to the east of its position shown in Fig. 1. Such an arrangement would be consistent with the interpretation of African and Australian results (*13*). Finally, the upper Paleozoic poles are all characterized by reverse magnetization, which suggests that they all fall within the Kiaman Magnetic Interval (*16*).

The reconstruction of Fig. 1 is very similar to the one originally proposed by du Toit (*17*), but it has been derived from paleomagnetic results only. The data are now sufficient to make it almost unambiguous, although one possible adjustment might be the narrowing of the gap between Antarctica and Australia when further lower Paleozoic results from Australia become available. In Fig. 2 we have compared our reconstruction with evidence from geological age provinces. The inclusion of Madagascar in this figure to fill the vacant gap between India and Antarctica constitutes the only departure from a recent computer fit of the southern continents (*18*). The paleomagnetic data cannot at present distinguish between these alternatives. The age provinces have been drawn according to zones similarly shown on a different reconstruction by Hurley (*19*). They comprise two main groups: the ancient cratons with an age of at least 2000 million years and their surrounding younger metamorphic belts or geosynclines, whose ages cluster around 450 to 650 million years but reach a maximum of 1100 million years. Recent geochronological information from India shows that the events with ages of 450 to 650 million years, which affected Ceylon, have also affected southernmost India and coastal Andrah Pradesh (*20*) (see Fig. 2). The fit of these geological age provinces across the continental boundaries on our reconstruction is equally as good as, or better than, the fit proposed by Hurley (*19*). We believe, therefore, that these geologic data provide additional support for the paleomagnetically determined reconstruction.

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Pyroxene-Garnet Transformation in Coorara Meteorite

Abstract. *Majorite is a new garnet in a veinlet of the Coorara meteorite. Its chemical composition is compatible with derivation mostly from original pyroxene, not from olivine as originally reported. Silicon is partly in sixfold coordination. Ringwoodite, a spinel of olivine composition, occurs as purple grains set in a matrix of fine-grained garnet. The similar mineralogy and texture of the Coorara and Tenham meteorites suggest a common parent body.*

The mineralogical assemblages in the veinlet of the Coorara meteorite examined by Mason, Nelen, and White (*1*) are extremely complex as a result of high-pressure extraterrestrial transformations followed by extensive alteration, probably terrestrial. The reported discovery of a garnet with olivine composition must be modified, because the composition of the garnet is actually near that of pyroxene and is associated with a spinel of olivine

Table 1. Microprobe analyses. All abundances are given in percent by weight. Analysis for Ni was very uncertain because extensive net veining of a material rich in Fe and Ni caused a secondary fluorescence.

Element	Ringwoodite (%)	Olivine in main body (%)	Majorite (%)	Pyroxene in vein (%)	Pyroxene in main body (%)
Si	17.8	18–19	22–26(24.3*)	26.7	25–26
Ti	0	0	0	0.16	0.2
Al	0	0	0.4–1.6(1.4)	0.00	0.00
Cr	0	0	0.2–0.6(0.45)	0.11	0.1
Fe	18.1–19.9	19.4–22.5	12–14(13.1)	10.2–11.3	10–11
Mn	0.16–0.28	0.2	0	0.4	0.4
Mg	21.7–23.2	18.7–21.5	15–22(16.6)	15.7–17.5	16.5–17.5
Ni	0	0.03 up	0.02–0.05(0.03)	0.07	0.1
Ca	0	0.03	0	0.06	0.6
Na	0	0	0.4–0.6(0.5)	0	0
K	0	0	0	0	0

* Mean of five measurements thought to best represent the composition of specimen checked by x-ray powder diffraction.