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Palaeomagnetic and Radiometric Evidence for the Age of the Lower Boundary of the Kiaman Magnetic Interval in South America

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Summary

Palaeomagnetic and radiometric studies of samples collected from the Paganzo succession of north-west Argentina date the base of the Kiaman Magnetic Interval at 295 My. A more exact correlation of the Paganzo sequence with the geological time scale is deduced from the palaeomagnetic and radiometric results.

1. Introduction

Irving & Parry (1963) placed the lower limit of the Kiaman Magnetic Interval at the Paterson reversal, and the upper limit at the Illawarra reversal, on the evidence of their results from New South Wales. Combining these results with others from 41 rock units from several continents, Irving (1966) concluded that the lower boundary of the Kiaman Magnetic Interval lies in the middle of the Upper Carboniferous, and the upper boundary falls in the Upper Permian. Palaeomagnetic results from red beds in North America, which span the boundaries of the Kiaman Magnetic Interval, confirm the conclusions from the Australian results (McMahon & Strangway 1968). Russian work summarized by Khramov (1967) places the lower and upper limits of the Kiaman Magnetic Interval in the Moscovian stage of the Carboniferous and the Tartarian stage of the Permian respectively. Reverse polarities of palaeomagnetic directions belonging to the Kiaman Magnetic Interval have been reported from South America (Creer, Embleton & Valencio 1969); from Africa (McElhinny *et al.* 1968); from India (Wensink 1968) and from Europe (e.g. Zijderveld 1967). However, results from these continents did not extend across the boundaries of the Kiaman Magnetic Interval and could not be used to fix the limits of the Interval more accurately. Recently McElhinny (1969) has discussed the age of the boundaries of the Kiaman Magnetic Interval and suggests its base is more accurately defined by the Paterson Toscanite, which has a K–Ar age of 298 My (Everden & Richards 1962) and its top by the Russian Tartarian results.

2. Geology

The infill of the Paganzo Basin in northwest Argentina (Fig. 1) is of typical continental molasse deposits. The start of deposition followed the Acadian–Breton phase in the development of the Carboniferous Geosyncline to the west of the Basin. The succession continues through the Upper Carboniferous and Permian into the Triassic.

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The deposits are mainly of red sandstones and siltstones. In Lower Paganzo sequences marine intercalations are to be found. A greater uniformity of deposits, and the occurrence of thin lava flows and ash bands, are characteristic of the Middle Paganzo sequence. More variable sediments in the Upper Paganzo complete the succession. After detailed mapping of the Paganzo deposits near the centre of the basin, Azcuy & Morelli (1970) have divided the sequence into three formations: Lagares, La Colina and Amana. These they correlate with the Lower, Middle and Upper Sections of the Paganzo Group which in turn are grossly correlated with the stages, I, II and III of the Paganzo sequence (Bodenbender 1911).

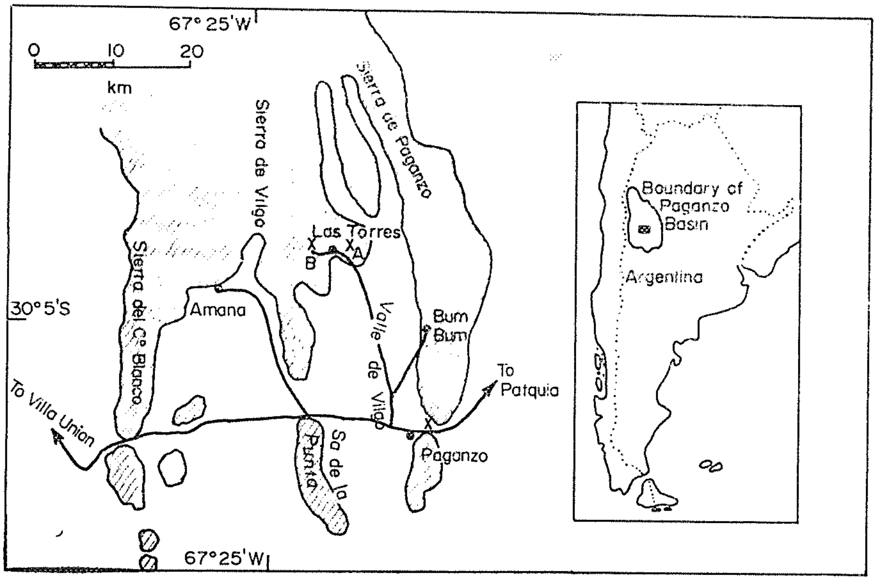

FIG. 1. La Colina lava: collection sites (X).

3. Collection

During 1969 and 1970 sediments from near each of the type localities of the formations, Lagares, La Colina and Amana, and a lava from close to the base of the La Colina sediments, were collected for palaeomagnetic and radiometric investigations. The lava has been collected from two localities separated by 25 km (Fig. 1). The geological mapping of Azcuy & Morelli (1970) has shown that the lava occurs at the same stratigraphical horizon at both localities.

4. Results

Palaeomagnetic results from one of the localities (Paganzo village) have been reported by B. J. J. Embleton (1970a). Radiometric results from both localities, and palaeomagnetic results from the second locality (Las Torres) are presented below. Magnetic polarity results from the associated sediments are cited, and the limits of the Kiaman Magnetic Interval in South America are discussed.

4.1 *Palaeomagnetic studies*

The samples were orientated by use of a clinometer and sun compass, checked with a magnetic compass. Twenty-six one-inch diameter cylinders, one-inch high, were cut from the nine basalt samples collected near Las Torres. The magnetic remanence of the specimens was measured using a P.A.R. spinner magnetometer (Collinson, Creer & Runcorn 1967a) at the Nuffield Palaeomagnetic Laboratory, Newcastle upon Tyne. The natural remanent magnetic directions showed a close grouping (Table 1). Four pilot specimens were then chosen, and alternating magnetic field was used to demagnetize them (Collinson *et al.* 1967b) in seven steps up to 600 Oe (peak field). Stability of the magnetic remanence is demonstrated by the directions of magnetization of all the pilot specimens remaining very similar throughout demagnetization. Further evidence of stability is given by the low and smooth fall of intensity of remanence with increasing demagnetization (Fig. 2(b)). The remaining specimens were A.F. cleaned at 300 Oe (peak field).

The mean sample results have been combined with those which Embleton obtained from the basalt near Paganzo village, to give a south palaeomagnetic pole at 67° S

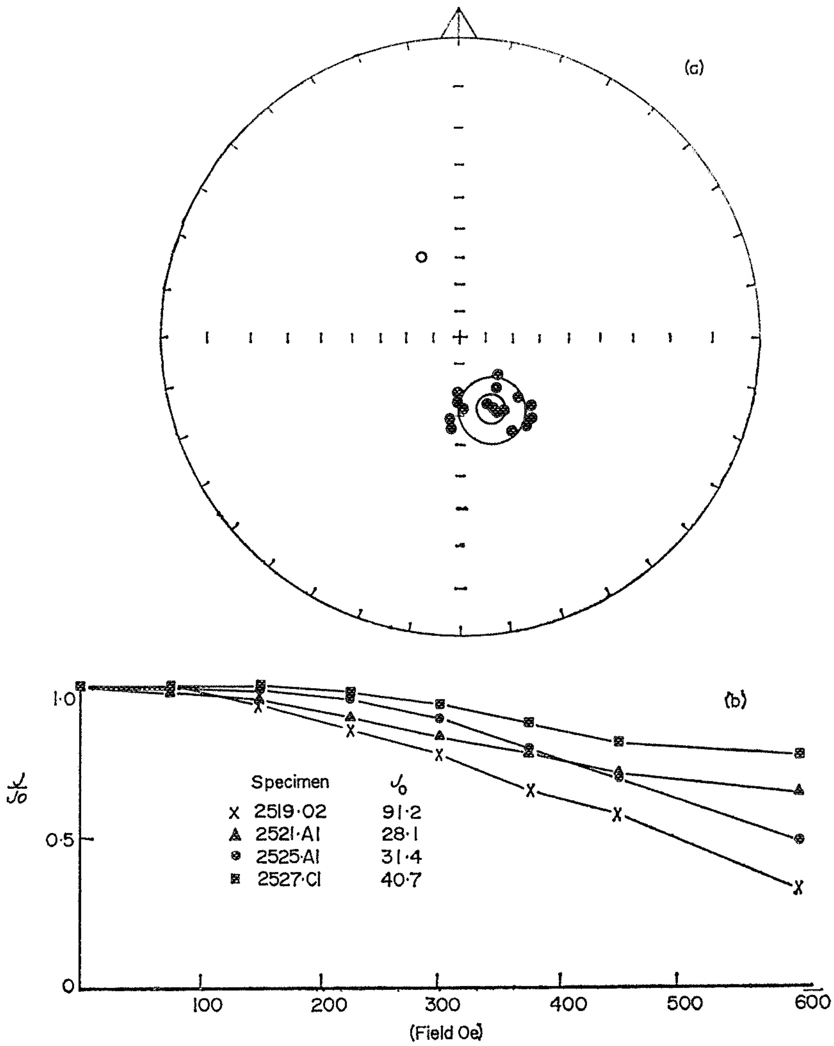

FIG. 2. (a) A.F. cleaned remanent magnetization directions of sample-means of the La Colina lava, with respect to the palaeohorizontal. Open dot (direction up), closed dots (directions down), inner circle (95 per cent circle of confidence), outer circle (standard deviation). (b) Pilot specimens: A.F. demagnetization curves.

Table 1

Mean palaeomagnetic directions and pole positions

Locality	Remanence	N(n)	D°	I°	c.s.d.	α_{95}	Polarity	Lat°	Long°	c.s.d.	α_{95}
Las Torres Site A	n.r.m.	5(14)	156	+62	6·5	6·2	Rev.	67 S	19 W	9·7	9·2
Las Torres Site A	300 Oe	5(14)	156	+62	6·7	6·4	Rev.	67 S	19 W	10·0	9·5
Las Torres Site B	n.r.m.	4(12)	183	+63	6·6	7·5	Rev.	75 S	76 W	8·2	9·4
Las Torres Site B	300 Oe	4(12)	184	+63	6·4	7·3	Rev.	76 S	78 W	8·0	9·1
Las Torres and Paganzo village*	A.F. cleaned	17(50)	155	+60	11·2	5·0	Rev.+Norm.	66 S	12 W	15·5	6·9

All directions are referred to the palaeohorizontal.

N Number of samples
n Number of specimens
c.s.d. circular standard deviation
α_{95} Radius of circle of 95 per cent confidence about mean positions
* Directions from Paganzo village in Embleton (1970a)

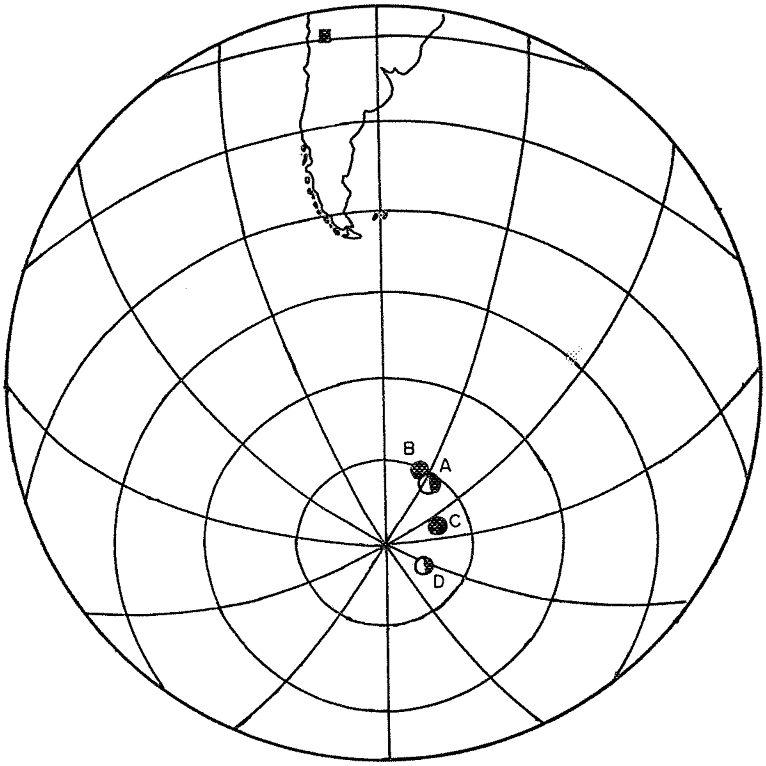

FIG. 3. Palaeomagnetic south pole positions from the Paganzo sediments. Closed circles denote reverse magnetic directions, half-closed circles denote noımal and reverse magnetic directions. A, Lagares formation (Bum Bum and Paganzo village); B, La Colina formation (Paganzo village); C, Amana formation (Paganzo village); D, Upper Paganzo facies (North Paganzo Basin).

13° W, $\alpha_{95} = 7°$, and are summarized in Table 1 and Fig. 2(a). The polarity of the remanence of all samples apart from one measured by Embleton is reversed.

Sediments collected from the Lagares formation both at Paganzo village and Bum Bum (Fig. 1) hold a stable remanence and show both normal and reversed polarities. Four normal periods of the geomagnetic field are recorded in the sediments from Bum Bum. Red sandstones from immediately above the lava at Paganzo village, and at higher stratigraphical levels throughout the La Colina formation, are all magnetized in the reverse direction. Sediments from the base of the Amana formation near Paganzo village are also all of reversed polarity. Red sandstones collected in the north of the Paganzo Basin from sediments of the Upper Paganzo facies are of normal polarity in their lowest section and of reversed polarity above. The palaeomagnetic results from these sediments are to be presented in full in a following paper (in preparation). The results obtained to date are summarized in Fig. 3.

Previous palaeomagnetic measurements of Middle Paganzo sandstones by Embleton (1970b) revealed only reversed magnetizations, while Upper Paganzo sediments included samples of both normal and reversed magnetic directions.

4.2 *Potassium–argon age determinations*

Whole rock potassium–argon age determinations were carried out on hand samples collected from exposures of the La Colina lava near Paganzo and Las Torres. All of the samples are tholeiitic basalts of varying degrees of freshness. Petrological details are given in the Appendix of Samples. Each of the samples was crushed and the 16–30 mesh sieve fraction retained for argon analysis. Part of this fraction was then ground to about 200 mesh size for analysis of potassium. Potassium analyses were carried out using a flame photometer which incorporated a lithium internal standard. The argon analyses were performed by the isotope dilution method on an Omegatron mass spectrometer (Grasty & Miller 1965) using an 'on-line' extraction system similar to that described by Miller & Brown (1964). The results are shown in Table 2.

The age of 266 My obtained from sample 213, which is the most altered of the three specimens analysed, is considered to be anomalously low in view of the argon loss probably associated with the alteration. Samples 220 and 229 showed a lesser degree of alteration and the concordancy between the ages obtained for them is considered to reflect this fact. It would seem improbable that the processes of weathering and alteration operating in two samples collected from sites separated by 4 km should lead to argon loss of precisely the same amount and accordingly the results of about 295 My are believed to provide a valid estimate of the age of the basalt.

Table 2

K–Ar ages from La Colina basalt

Laboratory reference site and location	K_2O (per cent)	Radiogenic Argon Content v/m mm³ gm⁻¹	% Atmospheric contamination	Age. My	
213	0·320, 0·320	$(2{\cdot}98 \pm 0{\cdot}04)10^{-3}$	39·8	263 ± 4	Mean 266 My
Paganzo	Mean 0·320	$(3{\cdot}01 \pm 0{\cdot}05)10^{-3}$	33·8	265 ± 5	
village		$(3{\cdot}06 \pm 0{\cdot}05)10^{-3}$	44·4	269 ± 5	
220	0·288, 0·232	$(2{\cdot}38 \pm 0{\cdot}06)10^{-3}$	42·3	288 ± 7	Mean 295 My
Las Torres A	0·232, 0·231	$(2{\cdot}44 \pm 0{\cdot}04)10^{-3}$	46·7	296 ± 5	
	Mean 0·231	$(2{\cdot}49 \pm 0{\cdot}05)10^{-3}$	43·2	302 ± 6	
229	0·318, 0·318	$(3{\cdot}42 \pm 0{\cdot}05)10^{-3}$	36·2	299 ± 5	Mean 292 My
Las Torres B	Mean 0·318	$(3{\cdot}30 \pm 0{\cdot}06)10^{-3}$	68·8	291 ± 6	
		$(3{\cdot}26 \pm 0{\cdot}06)10^{-3}$	63·4	287 ± 6	

$\lambda_e = 0{\cdot}584 \times 10^{-10}\ \text{yr}^{-1}$ $\quad ({}^{40}K/K) = 1{\cdot}19 \times 10^{-2}$ atom per cent

$\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ \text{yr}^{-1}$

5. Conclusions

All the results from Paganzo rocks have been summarized diagrammatically in Fig. 4 and related to geological time by the radiometric age determined for the La Colina lava, and the known age for the top of the Kiaman Magnetic Interval (McElhinny 1969).

The Lower/Middle Paganzo boundary is dated as being older than 295 My, but due to its proximity to the La Colina lava, the boundary is probably of Upper Carboniferous age.

The Middle/Upper Paganzo boundary has been shown to be older than the top of the Kiaman Magnetic Interval which falls within Upper Paganzo times.

The base of the Kiaman Magnetic Interval has been recognized in South America and falls close to the age of the La Colina lava of 295 My. This correlates well with the age (298 My) obtained from the Paterson Toscanite.

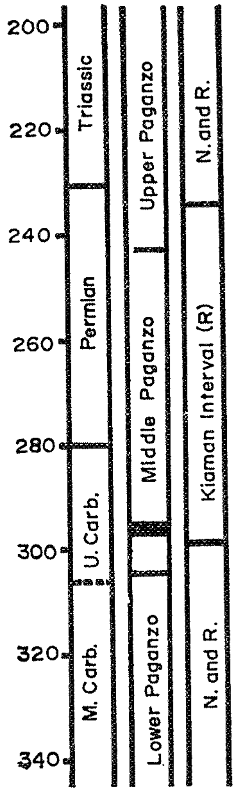

FIG. 4. Correlation of palaeomagnetic data with the Paganzo sequence. The stratigraphic level of the La Colina lava is indicated by the dark horizon in the Middle Paganzo sequence.

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References

Azcuy, C. & Morelli, J., 1970. Geologia de la comarva Paganzo-Amana. El Groupo Paganzo. Formaciones que lo componen y sus relaciones, *Rev. Assoc. Geol. Arg.*, **XXV**, 405–429.

Bodenbender, G., 1911. Constitucion geologica de la parte meridional de La Rioja y regiones limitrofes, *Bol. Acad. Nac. Cienc. Cordoba.* **XX(1)** Cordoba.

Collinson, D. W., Creer, K. M. & Runcorn, S. K. (eds) 1967a. *Methods in Palaeomagnetism*, Chapter 2, Section I, Elsevier, Amsterdam.

Collinson, D. W., Creer, K. M. & Runcorn, S. K. (eds) 1967b. *Methods in Palaeomagnetism*, Chapter 3, Elsevier, Amsterdam.

Creer, K. M., Embleton, B. J. J. & Valencio, D. A., 1969. Comparison between Upper Palaeozoic and Mesozoic palaeomagnetic poles for South America, Africa and Australia, *Earth Planet. Sci. Lett.*, **7**, 288–292.

Embleton, B. J. J., 1970a. Resultados palaeomagneticos del basalto de la Formacion La Colina (Paganzo Medio), La Rioja, Republica Argentina, *Rev. Assoc. Geol. Arg.*, **XXV**, 347–352.

Embleton, B. J. J., 1970b. Palaeomagnetic results for the Permian of South America and a comparison with the African and Australian data, *Geophys. J. R. astr. Soc.*, **21**, 105–118.

Everden, J. F. & Richards, J. R., 1962. Potassium–argon ages in eastern Australia, *J. Geol. Soc. Australia*, **9**, 1–50.

Grasty, R. L. & Miller, J. A., 1965. The Omegatron: a useful tool for argon isotope studies, *Nature*, **207**, 1146–1148.

Irving, E., 1966. Paleomagnetism of some carboniferous rocks from New South Wales and its relation to geological events, *J. geophys. Res.*, **71**, 6025–6051.

Irving, E. & Parry, L. G., 1963. The magnetism of some Permian rocks from New South Wales, *Geophys. J. R. astr. Soc.*, **7**, 295–411.

Khramov, A. N., 1967. The earth's magnetic field in the late Paleozoic, *Izv. Akad. Nauk SSR, Earth Phys. Ser.*, 86–108.

McElhinny, M. W., 1969. The palaeomagnetism of the Permian of southeast Australia and its significance regarding the problem of inter-continental correlation, *Spec. Publ. geol. Soc. Aust.*, **2**, 61–67.

McElhinny, M. W., Briden, J. C., Jones, D. L. & Brock, A., 1968. Geological and geophysical implications of palaeomagnetic results from Africa, *Rev. Geophys.*, **6**, 201–239.

McMahon, B. E. & Strangway, D. W., 1968. Investigation of Kiaman Magnetic Division in Colorado Redbeds, *Geophys. J. R. astr. Soc.*, **15**, 265–285.

Miller, J. A. & Brown, P. E., 1964. *How old is Scotland? Advancement of Science, London*, **20**, 527–538.

Wensink, H., 1968. Palaeomagnetism of some Gondwana red beds from Central India, *Palaeogeog. Palaeoclimatol, Palaeoecol.*, **5**, 323–343.

Zijderveld, J. D. A., 1967. The N.R.M. of the Exeter Volcanic traps (Permian, Europe), *Tectonophys.*, **4**, 121–153.

Appendix of Samples

Specimen numbers refer to the Dating Laboratory specimen collection in the Department of Geophysics and Planetary Physics at the University, Newcastle upon Tyne.

213 Tholeiitic Basalt. 1 km east of Paganzo village, from a road cutting.

Essential minerals: Plagioclase (An50) ~ 45 per cent, Ore ~ 30 per cent. Accessories: Brown glassy groundmass ~ 15 per cent, Orthopyroxene ~ 5 per cent, Epidote ~ 5 per cent. The Pyroxene is highly altered, this alteration is possible the origin of the epidote. The plagioclase crystals are larger and slightly fresher looking than in specimens 220 and 229. Patches of the glass are devitrified.

220 Tholeiitic Basalt. 1·8 km east of Las Torres from a small cliff by a dry river bed.

Essential minerals: Plagioclase ~ 40 per cent, Ore ~ 30 per cent, Orthopyroxene ~ 10 per cent. Accessories: Brown glassy groundmass partly devitrified ~ 20 per cent. Small rounded particles of quartz and/or chalcedony occur in the glass.

229 Tholeiitic Basalt. From a gully cutting the lava 2 km west of Las Torres.

Essential minerals: Plagioclase ~ 45 per cent, Ore ~ 25 per cent, Orthopyroxene ~ 10 per cent. Accessories: Glassy groundmass ~ 20 per cent. The glass is devitrified in places and contains occasional spherulitic chalcedony? patches.