PALEOMAGNETISM OF SEDIMENTARY ROCKS FROM THE PERMIAN IRATI FORMATION, SOUTHERN BRAZIL

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ABSTRACT Seventy dolomite disks from the basal part of the Irati Formation have been analyzed at the Paleomagnetic Laboratory of the University of São Paulo. Both thermal and magnetic cleaning have been carried out and all samples have yielded normal magnetic polarity. A paleomagnetic pole at 83°South, 54°East, $\alpha_{95} = 3.4°$ has been obtained. These results and the comparison with previous paleomagnetic work on the Tubarão and the Passa Dois Groups have led to the conclusion that the Irati age must either be that of the Quebrada del Pimiento Magnetic Event (267 ± 6 m.y.) or that of the Illawarra Zone (Permo-Triassic). The whole of the available paleontological and stratigraphic evidence points out for an age not older than Artinskian, probably Upper Permian for the Irati Formation. Therefore, both paleomagnetic age possibilities could be acceptable. However, the Quebrada del Pimiento age seems to be easier to reconcile with geological data.

RESUMO Foram analisados setenta discos da parte basal da Formação Irati, no Laboratório de Paleomagnetismo da Universidade de São Paulo. As amostras foram submetidas a desmagnetização térmica e magnética, e todas apresentaram polaridade magnética normal. Obteve-se um pólo paleomagnético de coordenadas 83°Sul, 54°Leste, com $\alpha_{95} = 3{,}4°$. Estes resultados e a comparação com trabalho paleomagnético anterior sobre os grupos Tubarão e Passa Dois levaram à conclusão de que a idade do Irati deve ser a do evento magnético Quebrada del Pimiento (267 ± 6 m.a.) ou a da Zona Illawarra (Permo-Triássico). Toda a evidência paleontológica e estratigráfica disponível indica idade não mais velha que artinskiana, provavelmente permiana superior para a Formação Irati. Portanto, ambas as possíveis idades paleomagnéticas poderiam ser aceitáveis, entretanto a idade do evento Quebrada del Pimiento parece mais facilmente conciliável com os dados geológicos.

INTRODUCTION In a previous paper on the paleomagnetism of Paraná Basin Late Paleozoic sediments (Valencio *et al.*, 1975) samples from the Itararé Subgroup and the Corumbataí Formation have been analyzed.

The Irati Formation lies between the Itararé Subgroup, and the Corumbataí Formation and therefore its paleomagnetic pole should be between the poles corresponding to these formations on the apparent polar wander curve. Furthermore, the Upper Paleozoic Magnetic Polarity Column is fairly well known and reversed polarity prevails from Upper Carboniferous to Lower Triassic, except for a few short normal polarity intervals (Magnetic Events) in the so-called Kiaman Magnetic Interval.

The results of the Irati paleomagnetic analysis are presented and considerations both on the apparent polar wander curve and the magnetic polarity column lead to conclusions about the age of this formation.

GEOLOGICAL EVIDENCE *Stratigraphy* The Irati Formation is the basal unit of the Passa Dois Group. This group rests conformably over the Tubarão Group and the two comprise the Late Paleozoic sediments of the Paraná Basin.

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In the State of São Paulo, the Irati Formation conformably underlies the Corumbataí Formation (= Estrada Nova Formation) of the Passa Dois Group and lies above the Itapetininga Formation (Barbosa and Gomes, 1958) or Tatuí Formation (Rocha-Campos, 1967; Soares, 1972). Soares (1972) discussed evidences for a regional disconformity separating the Tatuí Formation (post-glacial) and the Itararé Subgroup (Rocha-Campos, 1967) or formation in the northern Paraná Basin.

In the Paraná Basin the Irati Formation (up to 85 m of thickness) is made up of dark-gray argillites, black carbonaceous and bituminous shales which may intercallate with carbonates (limestone and dolomite) and chert (Northfleet *et al.*, 1969).

In the sampling area (Fig. 1), the sequence consists of rhythmic alternation of subhorizontal centimetric to decimetric carbonate beds and shale. The latter range from black bituminous to gray nonbituminous. Sampling sites 1 and 2 are located at the basal part, near to the contact with the Tubarão Group which in the area is represented by the Tatuí Formation (Rocha-Campos, 1967; Soares, 1972).

Paleontological evidence on the age A general Permian age has been since long time advocated for the Passa Dois Group on basis of the presence of aquatic mesossaurids (*Mesosaurus*, *Stereosternum*) in the Irati Formation and of glossopterids (*Gangamopteris*), arborescent lycopsids (*Lycopodiopsis derbyi*) and leaiid crustaceans (Mendes, 1967) in the rest of the Group. Present knowledge on the distribution of Late Paleozoic marine invertebrates and megaflora assemblages in the Paraná Basin is also indicative of a Permian age not older than

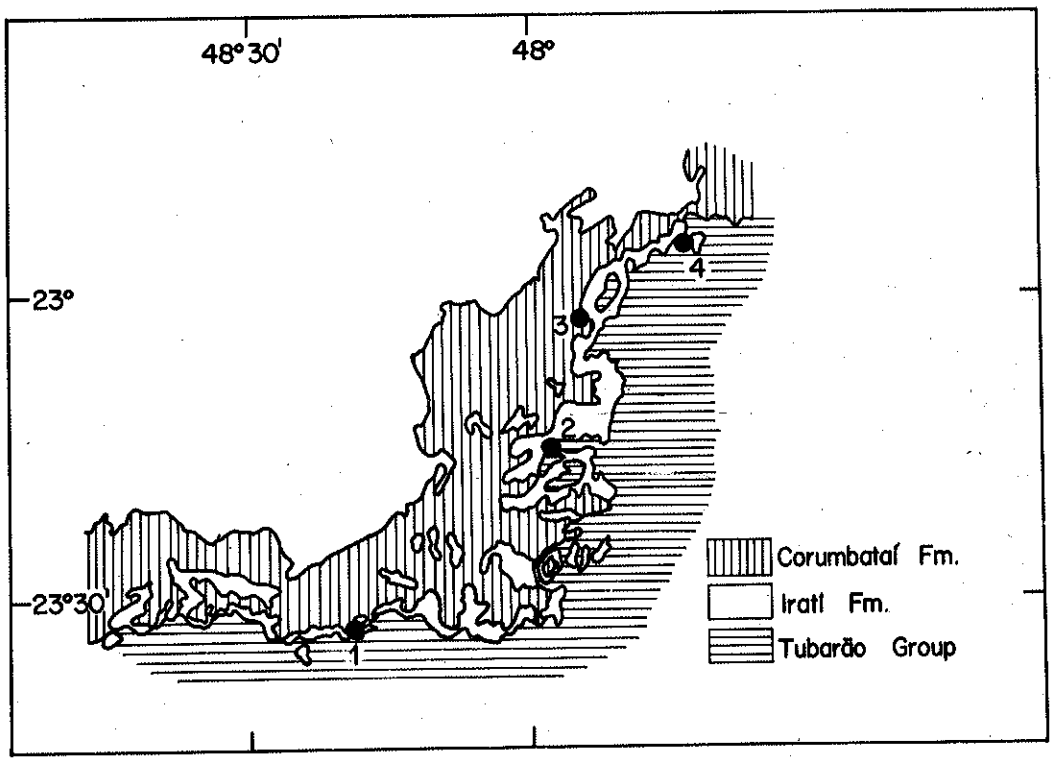

Figure 1 – Schematic geological map with sampling sites: 1) SP270 highway km 195; 2) SP280 highway km 153.2; 3) SP300 highway km 185.6; 4) SP127 highway at Maluf Quarry

Artinskian, probably Upper Permian for the Irati (and rest of Passa Dois Group) (Rocha-Campos, 1973; Rösler, 1975).

Other more specific evidence on the age of the Irati Formation is based on the presence of fossil insects which Pinto (1972) considers similar to species from the USSR. The Irati Formation contains also a microflora which characterizes the bioestratigraphic interval L, which Daemon and Quadros (1970) interpreted as Upper Permian (Kazanian).

Therefore, it seems reasonable to assign an Upper Permian age for the Irati Formation.

PALEOMAGNETIC ANALYSIS Dolomite hand samples have been collected at four different outcrops as indicated on Fig. 1. Samples from sites 3 and 4 have not been adequate for measurements due to an excessively low natural remnant magnetization ($< 10^{-8}$ e.m.u.).

At site 1, only one horizon has been sampled, about 2 m above the contact with the Tatuí Member. The section at site 2 was approximately 4 m thick and 6 horizons have been sampled.

A total of 29 oriented hand samples have been collected. Both sun and magnetic compasses have been used.

Seventy disks have been cut from cores and analyzed using a Digico Spinner Magnetometer. Magnetic stability of the samples has been tested both by magnetic and thermal cleaning.

Examples of thermal and alternate field demagnetization curves are shown on Figs. 2*a*, *b*. Stereographic plots (Figs. 3*a*, *b*) exhibit the average magnetization for each layer respectively before and after cleaning.

The shape of the thermal demagnetization curves, the low coercitivity shown by magnetic cleaning and the Curie temperature which was approximately 400 °C indicate that the samples ferromagnetic minerals must belong to the class of titanomagnetites or generalized titanomagnetites. Chemical composition is $xFe_2TiO_4 \cdot (1-x)Fe_3O_4$, with $0 < x < 1$. For a Curie temperature of 400 °C, $x = 0.67$ (Nagata and Ozima, 1967) and the chemical composition is then $0.67FeTiO_4 \cdot 0.33Fe_3O_4$.

The consistency of results from sites 1 and 2 indicate a good magnetic stability. The average primary remnant magnetization with good precision parameter and its circle of confidence which does not include the present geomagnetic pole indicate the absence of important secondary magnetizations.

Measurements have been averaged for each level and Table I lists the results which have been used in the analysis. The mean direction of stable magnetization for each level has been computed giving unit weight to each specimen and using the method of Fisher (1953).

RESULTS AND DISCUSSION The Upper Paleozoic apparent polar wander curve for South America is shown on Fig. 4 which includes Late Paleozoic paleomagnetic poles satisfying a reliability criterion (Valencio, 1972). The figure also includes the mean polar position for the Irati Formation calculated in this paper, using the virtual geomagnetic poles of Table I and Fisher's statistics. The V.G.P. of level 6 has not been included in the calculation since only one sample was available.

The pole, represented as SAP_{11}, corresponds to 83°South and 54°East, $\alpha_{95} = 3.4°$.

The estimated sedimentation rate for the Irati Formation (Amaral, 1971) and the thickness which has been sampled indicate that at least a good part of the secular variation has been eliminated in the average. However, since only six levels have been used in the calculations, it is possible that secular variation is still affecting the result. This is one of the possible reasons for the Irati pole SAP_{11} to be somewhat away from most of the permian

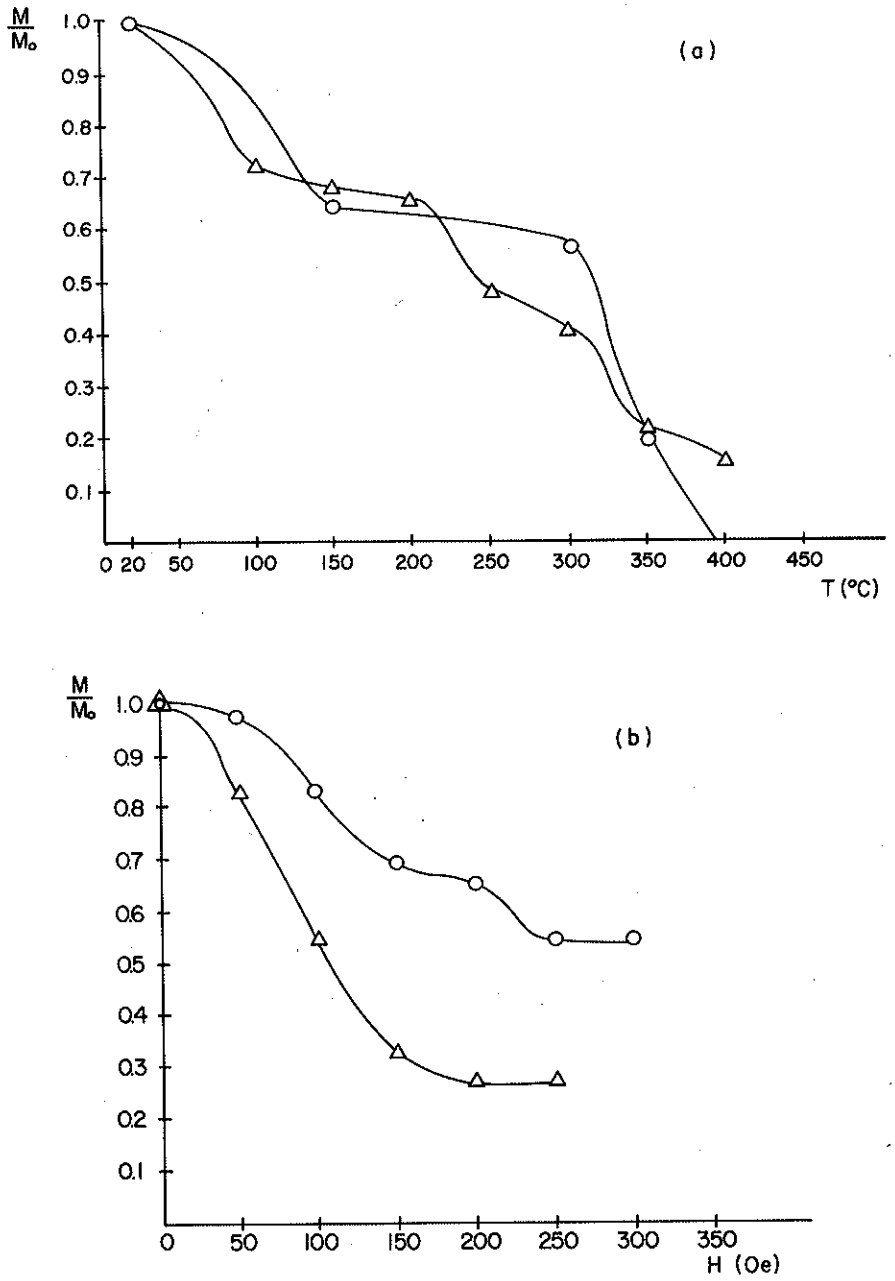

Figure 2 – Examples of thermal (2*a*) and alternate field (2*b*) demagnetization curves

population. It should be noticed however that this pole is close to SAP_9 which corresponds to red beds from the Paganzo Group collected at Rio Chaschuil, Argentina (Thompson, 1972) which included normal and reversed polarity. Oak Creek or at least Quebrada del Pimiento magnetic event age has been assigned to SAP_9 (Valencio, 1972).

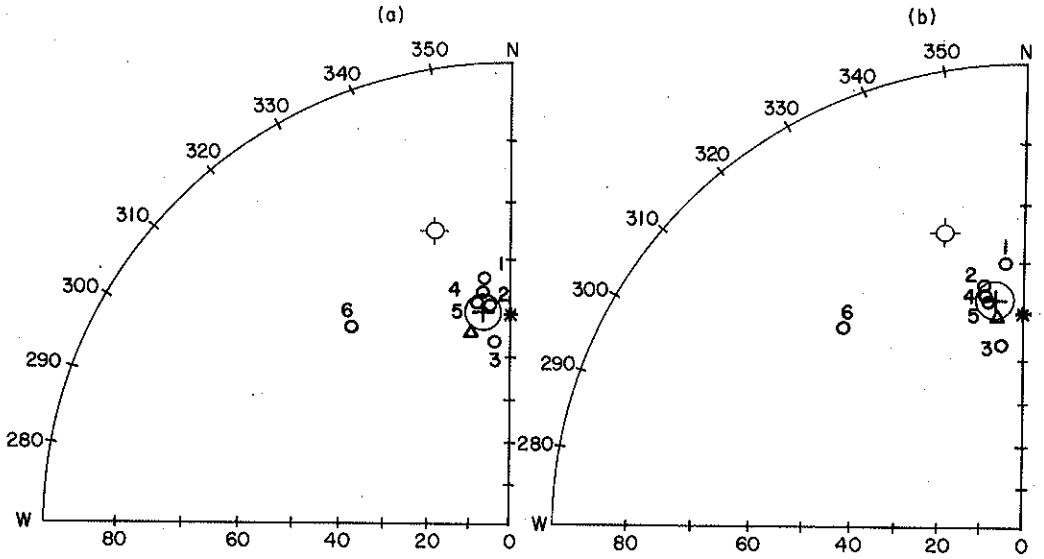

Figure 3 – Stereographic plots of the average magnetization directions for each level before (*a*) and after (*b*) cleaning. Symbols -◯- and * represent the direction of the present geomagnetic and dipolar fields respectively. + represents the average with its confidence circle

Fig. 5 shows the Upper Paleozoic Magnetic Polarity Column (Valencio and Mitchell, 1972) however the geological time scale is that which is under preparation by Armstrong and McDowall. The Quebrada del Pimiento event age (267 ± 6 m.y.) has been recalculated using the new disintegration constants.

The Irati Formation lies over the Itararé Subgroup of the Tubarão Group, which corresponds to Pole SAC_3 of reversed polarity. The paleontological age of the Itararé Subgroup is probably comprised in the interval Upper Carboniferous-Lower Permian (Rocha-Campos, 1973) or Stephanian C-Kungurian (Daemon and Quadros, 1970). On paleomagnetic grounds the age of part of the unit was interpreted as probably Upper Carboniferous by Valencio *et al.* (1975).

Table I – Summary of paleomagnetic data of the Irati Formation, Tubarão Group from the State of São Paulo, Brazil

Site	Level	Sample Number	NRM direction relative to the paleohorizontal					After cleaning magnetization direction					Virtual geomagnetic pole			
			Specimen Number	Dec (°)	Inc (°)	K	α_{95} (°)	Specimen Number	Dec (°)	Inc (°)	K	α_{95} (°)	Lat S(°)	Long E(°)	dψ (°)	dχ (°)
1	1	3	8	349.3	-44.0	58.6	6.3	8	352.7	-40.7	56.2	7.4	83.3	44.7	5.4	9.0
2	1	3	13	353.6	-33.5	110.9	3.9	11	355.7	-31.3	152.1	3.7	82.4	99.0	2.3	4.1
	2	2	8	355.3	-39.5	222.5	3.7	8	351.1	-36.5	86.7	5.9	81.2	60.2	4.0	6.9
	3	2	7	354.7	-47.2	16.6	15.2	7	353.1	-46.7	18.2	14.4	82.2	3.3	11.9	18.5
	4	2	8	353.0	-37.0	491.0	2.5	8	350.5	-36.1	450.5	2.6	80.5	60.5	1.8	3.0
	5	2	7	352.6	-38.4	151.4	4.9	7	351.0	-37.7	170.6	4.6	81.4	55.9	3.2	5.4
	6	1	5	320.5	-33.1	299.2	4.4	5	317.7	-31.0	226.2	5.0	49.9	43.4	-	-

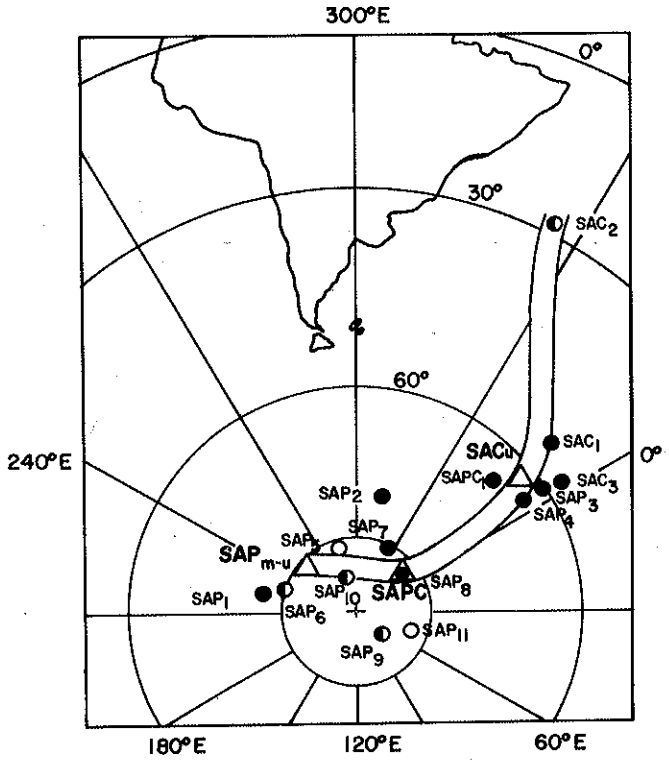

Figure 4 – Upper Paleozoic apparent polar wander curve for South America. SAP_{11} is the Irati pole and the others are named as in Valencio *et al.*, 1975

Pole SAP_{10} of mixed polarity on the other hand corresponds to the Corumbataí Formation of the Passa Dois Group, which overlies the Irati Formation and is considered as Late Permian, both on paleontological and on paleomagnetic grounds (Valencio *et al.*, 1975). These authors interpreted the age of the Corumbataí Formation as Illawarra Zone.

The above evidence thus indicates that the Irati age must lie between those of poles SAC_3 and SAP_{10}.

All samples measured in our analysis, however, have yielded normal polarity. This result would indicate two age possibilities according to the scale of Fig. 5: either, Quebrada del Pimiento or the Illawara Zone. Arguments discussed above discard the possibility of an Oak Creek age for the unit.

A Quebrada del Pimiento age, although acceptable from the stratigraphic point of view, is at present discordant with part of the paleontological evidence. On the other hand, an Illawarra Zone age would imply in the deposition of the entire Passa Dois Group in the Late Permian. The interval sampled for the Irati Formation was, however, not thick enough to reveal an alternation of polarity which characterizes the Illawarra Zone.

Therefore, in accordance with these evidences, the Irati Formation could belong to the normal polarity Quebrada del Pimiento event, of Artinskian-Kungurian age, or to the mixed polarity Illawarra Zone, in the Upper-most Permian. The former is apparently easier to reconcile with the available geological evidence.

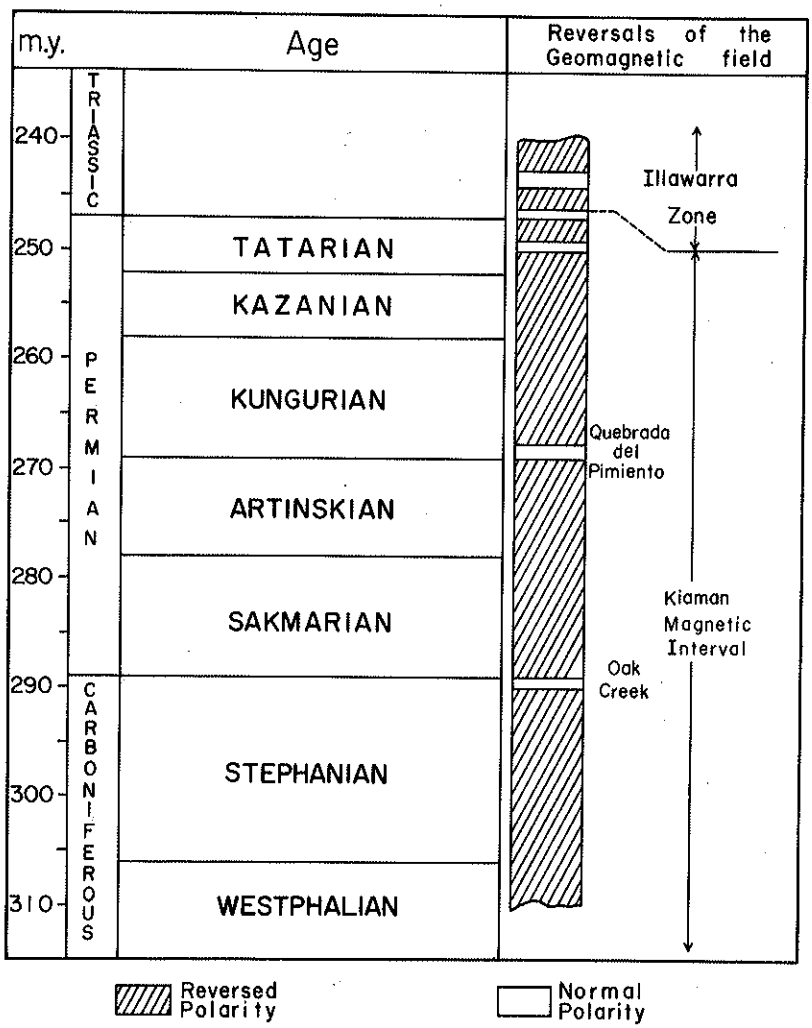

Figure 5 – Upper Paleozoic Magnetic Polarity Column according to Valencio and Mitchell (1972). The geological time scale is that which is under preparation by Armstrong and McDowall

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