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Dual Magnetic Polarity Measured in a Single Bed of Cretaceous Pelagic Limestone From Sicily*

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Abstract. A single bed of Cretaceous pelagic limestone from Sicily which varies in colour from red to white gives antiparallel magnetic directions after partial demagnetization. "Reversed" polarities occur in the white portion of the bed whereas almost exactly antiparallel directions of "normal" polarity characterise the red. The remanence in the case of the white variety is due to detrital magnetite, and that in the red is due to haematite. The haematite grew through its critical volume after slumping but before tectonic folding, and was probably derived from a goethitic precursor. The haematite magnetization significantly post-dates the detrital magnetization and the age relationship has important implications not only for magnetic stratigraphy in red beds, but also for the study of diagenesis in iron bearing sediments.

Key words: Palaeomagnetism – Pelagic limestones – Colour variations – Diagenesis.

1. Introduction

The Scaglia-type pelagic limestones are a characteristic Cretaceous facies in the Periadriatic region. They were deposited in basins on the southern margin of the Mesozoic Tethys. The Adriatic continental margin had a characteristic pre-orogenic morphology of carbonate platforms and basins which were elongated more or less parallel to the junction between the continental and oceanic crust (D'Argenio, 1976). The Mesozoic platform and basin carbonates are relatively free of detrital influence partly because the morphology inhibited sediment transport, partly due to the extensive development of shallow water carbonates over potential source areas, and partly due to the arid climate on the southern margin of the Mesozoic Tethys (Bernoulli and Jenkyns, 1974).

In western Sicily, at the village of Terrasini (near Palermo airport), Scaglia limestones of Late Cretaceous age crop out (see Catalano et al., 1973). The

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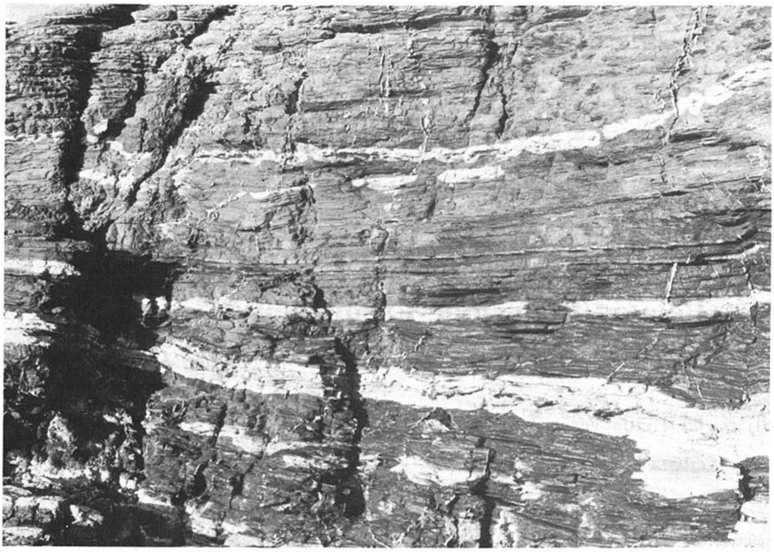

Fig. 1. The Upper Cretaceous Scaglia limestones of Terrasini (Sicily), showing the relationship between the red and white varieties. The uppermost white bed has an average thickness of about 50 cm

Fig. 2. The single bed which gives the dual polarity, dampened to accentuate the red/white colour contrast

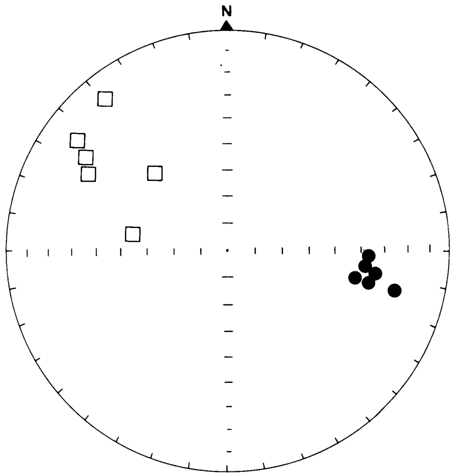

Fig. 3. Stereographic plot of magnetic directions of six samples from the white part (squares) and six from the red part (circles) of the same bed, after thermal demagnetization at 200° C and 600° C respectively. The open symbols represent negative inclinations and the closed symbols positive inclinations

limestones vary in colour from white to red and this colouration is generally tied to bedding, although variations in colour along a single bed occasionally occur (Fig. 1). Palaeomagnetic samples have been collected from one bed of variable colour (Fig. 2). The samples taken from the red portion of the bed yield "normal" polarity and those from the white give "reversed" polarity, the directions being almost exactly antiparallel (Fig. 3) after thermal demagnetization at 200° C for the white and 600° C for the red. Above these demagnetization temperatures, the magnetic intensities are generally too weak for precise measurement, reflecting the variable blocking temperature spectra of the two Scaglia varieties. Assuming that a self-reversal process is not the cause, this dual polarity indicates that one of the two magnetizations significantly post-dates the other. The magnetic properties of this Scaglia are very different to those of a similar Scaglia facies in Umbria (Lowrie and Alvarez, 1975). The declination of the "normal" directions (~100°, Fig. 3) is a result of tectonic rotations during the Neogene deformation of the Sicilian continental margin (Catalano et al., 1976).

2. White Scaglia

The magnetic properties characteristic of the white variety of Scaglia are summarised in Figure 4. Blocking temperature spectra (Fig. 4a) were found by monitoring the decay of an isothermal remanent magnetization (IRM) acquired in a 10 KOe. field, using equipment developed by Heiniger and Heller (1976). The instrument is not sensitive enough for the natural remanent magnetization to be treated in this way. The maximum blocking temperature of over 600° C indicates that at least part of the IRM is held by haematite.

The rate of acquisition of IRM in increasing d.c. fields gives a measure of the coercivity spectrum of the magnetic mineralogy. The spectrum associated with the white Scaglia (Fig. 4b) is generally bimodal indicating a low coercivity

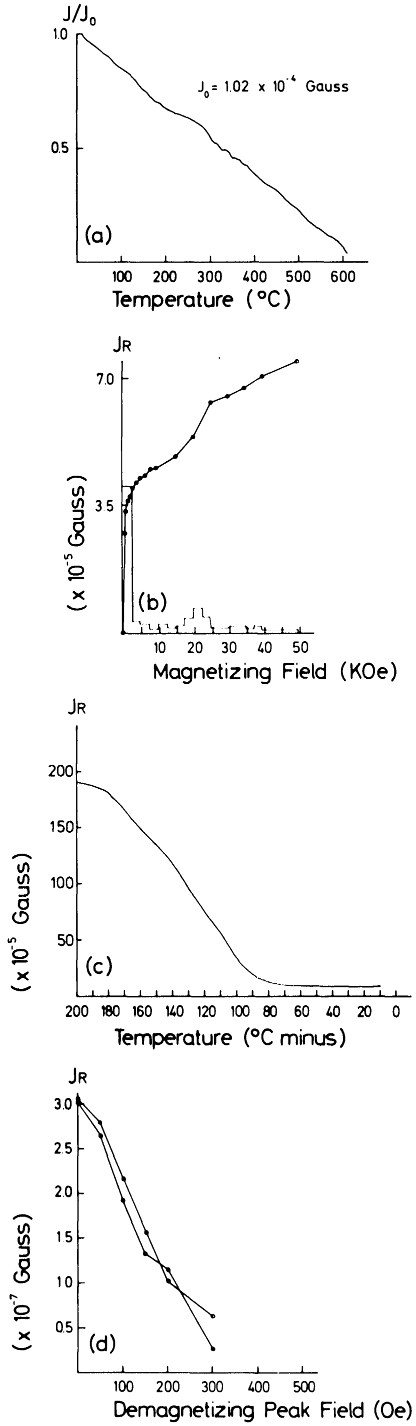

Fig. 4

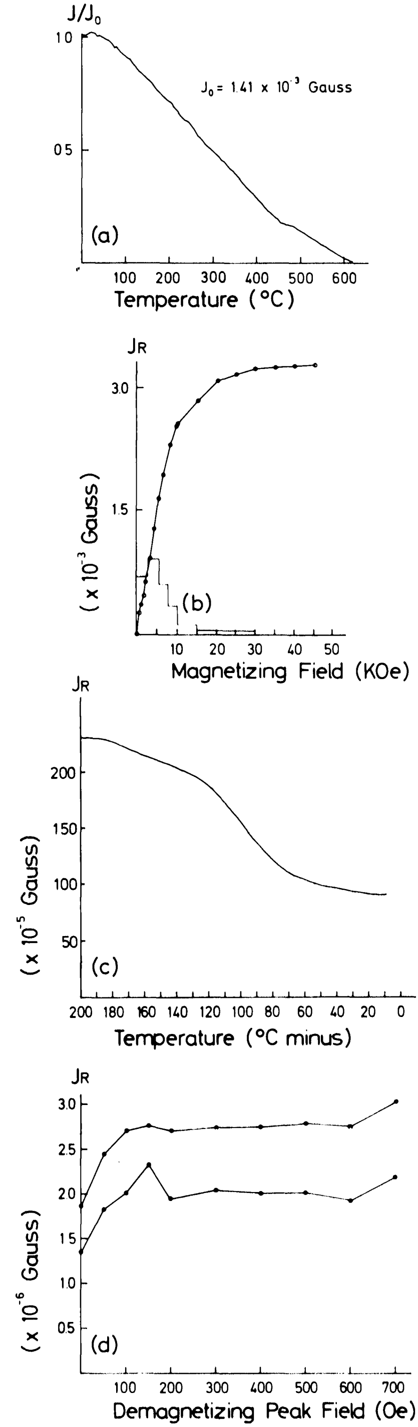

Fig. 5

Fig. 4a–d. Some magnetic properties of the white Scaglia. **a** Continously measured blocking temperature curve of IRM. **b** IRM acquisition curve **c** Decay during heating of IRM imposed at liquid nitrogen temperature. **d** Intensity change during alternating field demagnetization

Fig. 5a d. Some magnetic properties of the red Scaglia (caption for **a**, **b**, **c** and **d** as for Fig. 4) component together with a variable contribution from a high coercivity component. The low coercivity material is probably magnetite and the higher coercivities may be due to the haematite seen in the blocking temperature spectrum. The samples generally do not attain saturation remanence even after introduction into fields of over 50 KOe. Therefore, if the higher coercivity mineral is haematite, it has unusually high coercivity. However, the anisotropy constants of naturally occurring haematite are poorly known and internal stresses in fine grained haematite may produce these coercivities.

An IRM from a 10 KOe field was given to various samples of white Scaglia at liquid nitrogen temperature. The behaviour of the remanence was then monitored during warming up to room temperature. The isothermal remanence decays to about 5% of its original value (Fig. 4c). An IRM (10 KOe) was then given to the same sample at room temperature and the magnetization of the sample measured continuously down to liquid nitrogen temperature. Negligible change in magnetization intensity occurred indicating that the decay represented by Figure 4c is not due to a change in spontaneous magnetization (Js) with temperature but is due to low blocking temperatures of superparamagnetic grain sizes. Either haematite or magnetite could be producing this superparamagnetic effect although the large reduction in magnetization (1.4×10^{3}G) on heating to room temperature suggests that magnetite, with its much larger spontaneus magnetization, is the superparamagnetic phase. As the spontaneous magnetization of haematite is about 1% that of magnetite, a large concentration of haematite would be necessary to give the same effect, and one might expect the Scaglia to be red in this case.

The natural remanent magnetization (NRM) of the white Scaglia is weak ($\sim 2 \times 10^{-7}$G) and the median destructive field on alternating field demagnetization is about 150 Oe (Fig. 4d). This suggests that the natural remanence is held by the low coercivity fraction seen in the IRM acquisition curves (Fig. 4b) rather than the higher coercivity material. The low coercivity mineral is probably a magnetite.

3. Comparison With the Red Scaglia Variety

The magnetic properties of the red variety of Scaglia are summarised in Fig. 5. The maximum blocking temperature (Fig. 5a) indicates that haematite contributes to the IRM acquired in a 10 KOe. field, and a slight flexure in the curve may correspond to a magnetite blocking temperature.

The IRM acquired by the red Scaglia is much higher than that acquired by the white variety in the same field. The red variety generally reaches saturation in fields of the order of 30 KOe (Fig. 5b) and has a unimodal coercivity spectrum which may be due to the pigmentary haematite alone or a combination of haematite and a very minor amount of magnetite. The absence of the very high coercivities which are seen in the white Scaglia, suggests that the haematite has larger grain size in the red variety.

An IRM acquired at liquid nitrogen temperature decays to 40% of its original value during heating to room temperature (Fig. 5c) indicating that, compared to the white Scaglia, a smaller fraction of the IRM resides in superparamagnetic grain sizes. Again, cooling an IRM acquired at room temperature indicates negligible dependence of spontaneous magnetization (Js) on temperature. The fall in magnetization in the case of the white variety (Fig. 4c) is somewhat greater than that for the red (Fig. 5c). Assuming that the magnetite is detrital, one would expect a similar magnetite concentration and grain size distribution in both red and white varieties, as they are adjacent samples from the same bed. The white variety therefore probably contains more superparamagnetic haematite, which may be the finer-grained part of the same grain-size distribution which gives the high coercivities (Fig. 4b).

The natural remanence of the red Scaglia was so stable against AF demagnetization that the median destructive field could not be measured. During demagnetization to 700 Oe, the intensity showed no significant change between 200 Oe and 700 Oe (Fig. 5d) suggesting that haematite is the principle remanence carrier. The intensities generally *increase* during the early stages of alternating field demagnetization (Fig. 5d) indicating that an antiparallel component is being removed. The subtracted vector is very consistent during alternating field demagnetization for both the red and the white Scaglia (Fig. 6a). This vector is

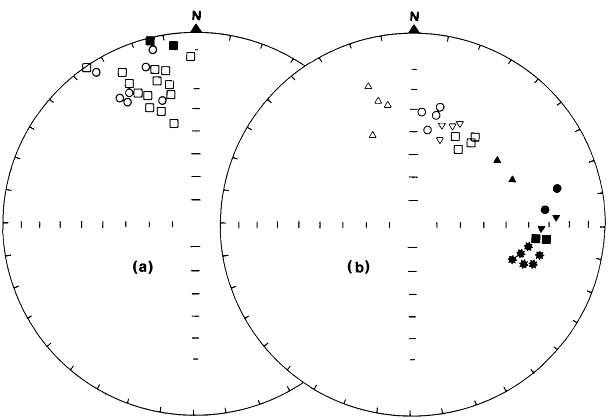

Fig. 6. a Subtracted vectors during alternating field demagnetization from 50 Oe to 100 Oe for red (circles) and white (squares) samples. Other demagnetization intervals give similar directions. Open symbols represent negative inclinations and closed symbols positive inclinations
b Directional changes of four white (open symbols) and two red (closed symbols) samples during alternating field demagnetization. Open symbols represent negative inclinations and closed symbols positive inclinations.

White samples Negative inclinations	Red samples Positive inclinations	Peak field
△	▲	NRM
○	●	50 Oe
▽	▼	100 Oe
□	■	150 Oe
	✱	200–400 Oe

close to the directions obtained from the white variety after thermal demagnetization at 200° C (Fig. 3). This, together with the directional changes during a.c. demagnetization (Fig. 6b) which tend to follow paths from reversed to normal polarity, indicates that the primary (reversed) magnetite magnetization vector is being removed in both white and red Scaglia varieties during a.c. cleaning leaving a magnetization vector with an increasing secondary component of normal polarity due to haematite. In the case of the red variety, a.c. fields greater than 200 Oe produce the same magnetic directions as thermal demagnetization up to 600° C (Fig. 3). This cleaned direction (Fig. 6b) is probably attributable solely to pigmentary haematite.

4. The Origin of the Magnetic Minerals

The magnetic properties of these Scaglia limestones are related to their colour. Haematite is the dominant natural remanence carrier in the red variety and magnetite is dominant in the white. It is impossible that both minerals could be of detrital origin, not only because of their antiparallel magnetizations, but also because of the physical nature of colour variations within a single bed. The magnetite is probably detrital, and the reversed magnetization of the white Scaglia may well represent the geomagnetic field at the time of deposition. The haematite is secondary and has been derived during diagenesis from a precursor. The colour variations in this Scaglia are maintained around slump folds (a spectacular example is shown in Fig. 7). Therefore, the colour variations cannot be the result of later selective leaching, and the properties of the sediment

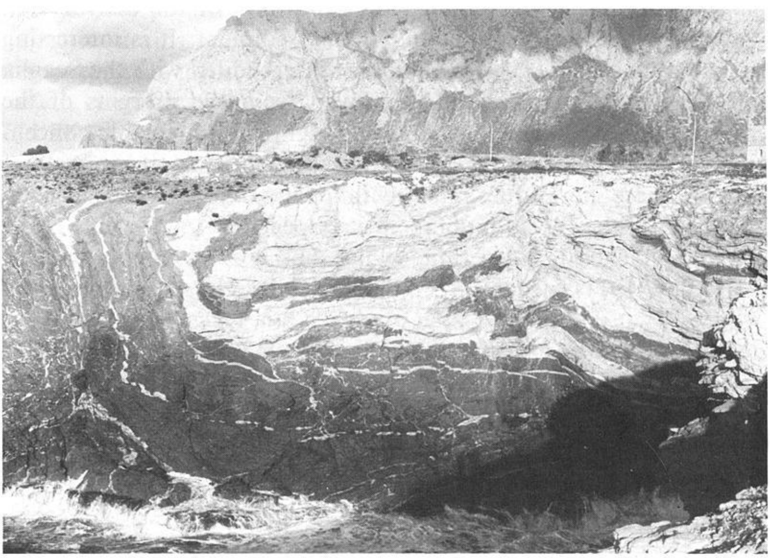

Fig. 7. Large slump fold showing that the colour variations are maintained around the curvature of the fold. The house and lamp-posts at the top of the cliff give the scale

which control the colour variations are an inherent feature of the soft sediment.

The haematite in these Scaglias may have originated in a number of different ways.

(a) Oxidation of magnetite: this seems unlikely as the intensity of remanence of the red Scaglia is about one order of magnitude greater than that of the white variety. This would most probably *not* be the case if magnetite was the precursor of the haematite.

(b) Haematite pigment in red sandstones often occurs as a result of the diagenetic breakdown of iron silicates into iron oxide and clay minerals (Walker, 1967a, 1967b; Walker, Ribbe and Honea, 1967; Turner and Archer, 1975). The oxidation of iron-bearing detrital clay can also produce pigmentary haematide (Walker and Honea, 1969). In the case of the Scaglia, these alteration processes *may* contribute, but it is unlikely that enough iron-bearing detritus has been introduced into these pelagic basins to account for the haematite pigment.

(c) Haematite in sediments can be formed by the dehydration of goethite. The Mesozoic basinal facies of the southern Tethys have been likened to recent abyssal sediments on the ocean floor (Trümpy, 1960; Garrison and Fischer, 1969). The environment of deposition was similar in that these sediments were uninfluenced by sources of terregeneous detritus and the sedimentation rate was very low. Goethite is a common constituent of modern pelagic sediments deposited on the abyssal plain. Therefore, by analogy, goethitic oxy-hydroxides may well have been deposited from sea-water in this Scaglia basin. In addition, a very similar pelagic facies of Jurassic age in Western Sicily contains fossil manganese nodules (Jenkyns, 1970). Goethite is an important constituent of manganese nodules and therefore goethite was deposited in a Jurassic environment analogous and adjacent to this Scaglia basin. Variable organic content in the Scaglia limestones may control either the deposition or the dehydration product of the goethite, and hence the colour of the sediment. It is interesting to note that the turbidites which occasionally occur interbedded with the Scaglia are always white. The turbiditic material is derived from the margins of the basin where sedimentation rates were probably too high for appreciable concentration of goethite. Although it seems likely that goethite was the precursor of the haematite in these limestones, no goethite apparently remains, as it does not manifest itself in the blocking temperature spectra (Fig. 4a, 5a). However, we have some evidence that goethite, which has a Néel temperature at around 110° C (Hedley, 1971), occurs in similar facies Scaglia limestones from the Southern Alps.

Chemical analysis of the red and white Scaglia collected from a varicoloured bed at the same Sicilian locality indicates that the total iron content in the red (0.68%) and in the white (0.65%) is the same within the experimental uncertainty. The concentration of Fe^{3+} varies from 0.55% for the red to 0.40% for the white. As the total iron contents are the same, the differences in colour and magnetic properties are not the result of selective deposition. It is proposed that whereas in the red Scaglia, the goethite reverted to haematite, in the white variety only a small proportion of the goethite altered to haematite, the bulk

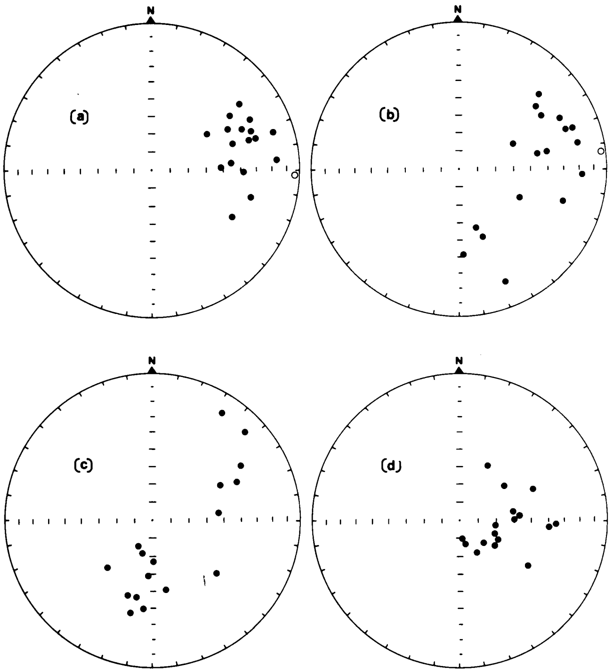

Fig. 8a–d. Thermally cleaned sample directions from a slump fold **a** before and **b** after bedding correction; and from a tectonic fold **c** before and **d** after bedding correction

reverting to a non-ferromagnetic mineral such as pyrite. Pyrite has been observed optically only in the white Scaglia.

The dual polarity indicates that the time interval between fixing of detrital magnetite grains and the growth of haematite through its critical volume was at least the time taken for a polarity inversion. The timing of diagenetic haematite growth can also be limited by the application of a fold test to both a tectonic fold and a soft sediment slump (Fig. 8) which indicates that the remanence was retained by the haematite before Miocene folding but after the Maestrictian/ Paleocene synsedimentary slumping.

Further palaeomagnetic studies of this nature will provide information on the timing of this and other diagenetic processes in iron bearing sediments.

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References

Bernoulli, D., Jenkyns, H.C.: Alpine, Mediterranean, and Central Atlantic Mesozoic Facies in Relation to the Early Evolution of the Tethys. In: Modern and Ancient Geosynclinal Sedimentation. R.H. Dott & R.H. Shaver (eds.). Society of Economic Paleontologists & Mineralogists, Special Publication No 19. 129–160 (1974)

Catalano, R., Channell, J.E.T., D'Argenio, B., Napoleone, G.: Mesozoic Palaeogeography of the Southern Apennines and Sicily. Mem. Soc. Geol. It. **15**, 95–118 (1976)

Catalano, R., Maniaci, G., Renda, P., Urso, G.: Un Esempio di Evoluzione Sedimentaria nelle Facies di Bacino dei Monti di Palermo la Successione Mesozoico-Terziaria di Cala Rossa (Terrasini). Geologica Romana XII, 151–175 (1973)

D'Argenio, B.: Le piattaforme Carbonatiche Periadriatiche una Rassegna di Problemi nel Quadro Geodinamico Mesozoico dell'Area Mediterranea. Mem. Soc. Geol. It. XIII (2), 1–28 (1976)

Garrison, R.E., Fischer, A.G.: Deep-water limestones and Radiolarites of the Alpine Jurassic. In: Depositional environments in carbonate rocks. G.M. Friedman (ed.), Soc. Econ. Paleontol. Mineral. Spec. Publ. **14**, 20–56 (1969)

Hedley, I.G.: The Weak Ferromagnetism of Goethite (α-FeOOH). Z. Geophys. **37**, 409–420 (1971)

Heiniger, Ch., Heller, F.: A high temperature Vector Magnetometer. Geophys. J. Roy. Astron. Soc. **44**, 281–288 (1976)

Jenkyns, H.C.: Fossil Manganese nodules from the West Sicilian Jurassic. Eclogae Geol. Helv. 63/3, 741–774 (1970)

Lowrie, W., Alvarez, W.: Paleomagnetic evidence for the Rotation of the Italian peninsula. J. Geophys. Res. **80**, 1579–1592 (1975)

Trümpy, R.: Paleotectonic Evolution of the Central and Western Alps. Geol. Soc. Am. Bull. **71**, 843–908 (1960)

Turner, P., Archer, R.: Magnetisation History of Lower Old Red sandstones from the Gamrie Outlier, Scotland. Earth Planet. Sci. Lett. **27**, 240–250 (1975)

Walker, T.R.: Formation of red beds in modern and ancient deserts. Geol. Soc. Am. Bull. **78**, 353–368 (1967a)

Walker, T.R.: Colour of Recent sediments in tropical Mexico: a contribution to the origin of red beds. Bull. Geol. Soc. Am. **78**, 917–920 (1967b)

Walker, T.R., Honea, R.M.: Iron content of modern deposits in the Sonoran Desert: a contribution to the origin of red beds. Bull. Geol. Soc. Am. **80**, 535–544 (1969)

Walker, T.R., Ribbe, P.H., Honea, R.M.: Geochemistry of hornblende alteration in Pliocene red beds, Baja California, Mexico. Bull. Geol. Soc. Am. **78**, 1055–1060 (1967)

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