

REAPPRAISAL OF PALEOMAGNETIC DATA FROM GARGANO (SOUTH ITALY)

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ABSTRACT

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The platform limestones of Apulia (Italy) outcropping in the Gargano peninsula have been restudied. Paleomagnetic research has been carried out on Upper Cretaceous, Lower Cretaceous and Jurassic rocks. Despite the low intensities of the NRM (10–100 $\mu\text{A/m}$), all samples (268) could be cleaned by stepwise A.F. and/or thermal demagnetization treatments. NRM directions could be determined accurately and reproducibly for 85% of the samples, using a ScT cryogenic magnetometer and double precision measuring procedures. NRM of the Jurassic limestone is carried by secondary haematite and the results are therefore rejected from further consideration. The Upper and Lower Cretaceous limestones have an NRM carried by magnetite. Minor bedding tilt corrections improve the grouping of the site-mean results. The Upper Cretaceous “Scaglia” limestone (Turonian–Senonian) reveals a characteristic mean direction of decl. = 327.7°, incl. = 38.2°, α_{95} = 4.3° (21 sites), while the Lower Cretaceous “Maiolica” limestone (Neocomian–Aptian/Albian) reveals a characteristic mean direction of decl. = 303.1°, incl. = 35.1°, α_{95} = 8.7° (8 sites). The Cretaceous results show a post-Aptian/Albian counterclockwise rotation of about 25°, which is expressed by the smeared distribution of the Late Cretaceous site-mean results, and a post-Senonian (i.e. Tertiary) counterclockwise rotation of the same amount with respect to the pole. These results are in excellent agreement with contemporaneous paleomagnetic results from other peri-Adriatic regions. A Tertiary counterclockwise rotation of all the stable Adriatic block is strongly supported by the new results.

INTRODUCTION

In the last decades many paleomagnetic studies have been undertaken in the Western Mediterranean and have contributed to a better understanding of the geodynamic history of the Alpine fold belt (VandenBerg and Zijdeveld, 1982). Crucial in all reconstructions of the Alpine geodynamic history is the movement of the continental crust south of the Alps, geographically described as the Italian peninsula. In terms of plate tectonics this continental fragment is frequently referred

to as the Apulian or Adriatic block. The present paper is another effort to add new information about its geodynamic history. A major complication of paleomagnetic research in Alpine folded regions is the difficulty in discerning the effects of small-scale tectonics and megatectonics. This applies especially to the Apennines and certainly to northwestern Umbria, where the majority of the paleomagnetic studies have been carried out. Extrapolation of paleomagnetic data to an overregional scale is usually hampered by the uncertain influence of local tectonics. Only comparison of paleomagnetic results from geographically and tectonically different areas will reveal the effects of local tectonics in the results.

The present research was undertaken to check the validity of earlier geodynamic interpretations, which were mainly based on paleomagnetic data (Channell et al., 1979; VandenBerg, 1979a, 1979b). Since the autochthony of Umbria (northwestern Apennines) has been questioned (Channell et al., 1978), the interpretation of the paleomagnetic results from that area becomes uncertain in terms of megatectonic movements. Only comparison of paleomagnetic data from unquestionable autochthonous areas, such as the Apulian platform, can show whether the sofar deduced movements of the Adriatic block were correct or biased by local tectonic phenomena. However, the extant paleomagnetic studies in Apulia/Gargano have not revealed conclusive results (Channell and Tarling, 1975; Channell, 1977; VandenBerg and Wonders, 1979).

GEOLOGY AND SAMPLING LOCALITIES

Sediments of the Apulian platform outcrop in Apulia/Gargano in western Yugoslavia, and on some of the Ionian Islands. The outcrop is comprised of essentially shallow water limestones of Mesozoic age. Its continuation below the Adriatic Sea is well known because of extensive exploration for oil. The Mesozoic series are flatlying and only affected by normal faulting during the Alpine orogeny. In the west the Apulian platform has been overthrust by the sedimentary series of the Southern Apennines, and in the east it is overthrust by the series of the Dinarides, but in the opposite sense. The Gargano peninsula (Fig. 1) is best described as a horst, uplifted during a phase of normal faulting in the Late Tertiary. Due to the uplift even sediments of Jurassic age outcrop and the bedding tilts hardly ever exceed 10°. The sediments in the northeast of the Gargano peninsula are carbonatic in a facies transitional to a pelagic one, while the sediments in the south are developed as neritic carbonates typical for the Apulian platform (Vezzani, 1975).

In the centre of the Gargano peninsula (Fig. 1, legend no. 5) the *Reef limestone of Monte Sacro* is exposed consisting of a biogenic non-stratified reef limestone with corals and algae of Kimmeridgian–Tithonian age. This formation separates the sediments in pelagic facies of northeast Gargano from those in the littoral to neritic facies of southwest Gargano. In the northeast it is covered by the *Limestone and dolomite of Monte Jacotenente* (Fig. 1, legend no. 4), a well-stratified thick sequence

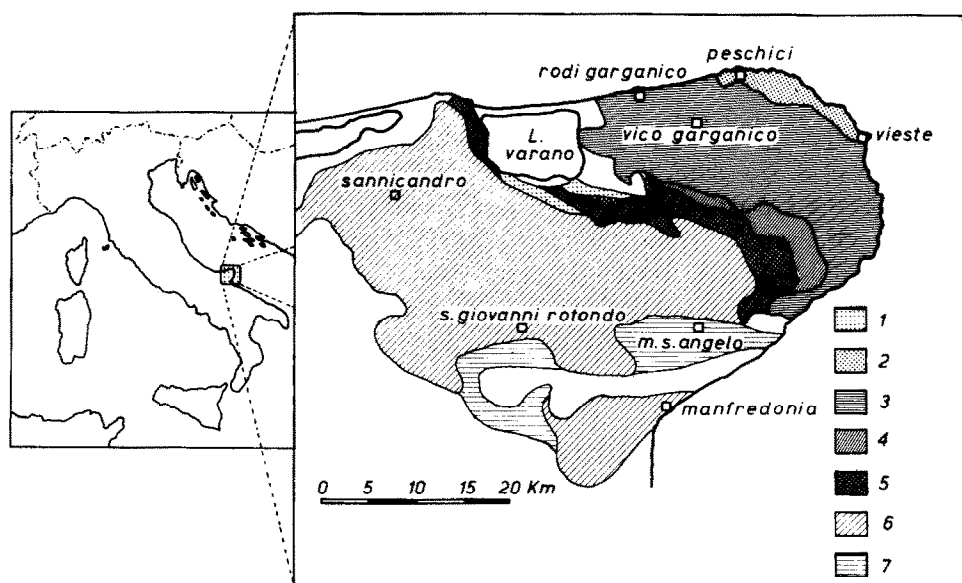


Fig. 1. Geological map of the Gargano peninsula (South Italy). 1 = Bryozoan limestone (Miocene); 2 = nummulitic limestone of Peschici (Paleocene–Middle Eocene); 3 = “Maiolica” and “Scaglia” limestone (Lower and Upper Cretaceous); 4 = limestone and dolomite of Monte Jacotenente (Upper Jurassic–Lower Cretaceous); 5 = reef limestone of Monte Sacro (Upper Jurassic); 6 = oolitic limestone of Coppa Guardiola (Upper Jurassic); 7 = bioclastic limestone of Mattinata (Lower Cretaceous).

with bands and nodules of chert, of Upper Jurassic to Berrasian–Valanginian age. Towards the northeast it is covered by two successive open marine Cretaceous formations (Fig. 1, both legend no. 3)—“Maiolica” limestone—with bands and nodules of chert, characterized by the presence of rare detrital levels, Neocomian–Aptian/Albian in age, and the “Scaglia” limestone, alternating with marls and of Turonian–Senonian age. The “Scaglia” limestone is covered along the coast by the *Nummulitic limestone of Peschici* (Fig. 1, legend no. 2), an alternation of compact limestone (with corals and echinoids) and calcarenites with *Alveolinae* and *Nummulites* of Paleocene–Middle Eocene age. Locally a *Bryozoan limestone* (Fig. 1, legend no. 1) of Miocene age is exposed, transgressive and present only in small bodies.

Towards the southwest the Upper Jurassic *Reef limestone of Monte Sacro* is partly covered and partly replaced by the *Oolitic limestone of Coppa Guardiola* (Fig. 1, legend no. 6), an oolitic and detrital-organogenic limestone of Kimmeridgian–Tithonian age. This formation passes gradually upward in three backreef formations (Fig. 1, all legend no. 7): (1) *Bioclastic limestone of Mattinata*, organo-genetic-detrital limestone with chert and of Lower Cretaceous age; (2) *Organogenic limestone of Monte Sant’Angelo*, a Cenomanian–Turonian rudistid limestone with

thick beds, detrital levels and breccias; and (3) “Chalk” of *Monte Acuto*, a white, granular and friable Senonian limestone with rare intercalations of rudistid limestone.

Three formations were sampled for this paleomagnetic study. In the south, close to the city of S. Giovanni Rotondo, several exposures of Upper Jurassic limestone belonging to the *Oolitic limestone of Coppa Guardiola* have been sampled (52 core samples). In the north and south of Vico del Garganico many localities with exposures of the so-called “Maiolica” and “Scaglia” limestone were sampled (71 and 145 samples respectively). Most localities of an earlier paleomagnetic study of the “Scaglia” limestone in the area north of Vico del Garganico by Channell (1977) were resampled.

LABORATORY TREATMENT AND MAGNETIC PROPERTIES

The 268 collected core samples were sliced into cylinders (specimens of 2.2×2.5 cm) at “Fort Hoofddijk” paleomagnetic laboratory. All measurements were carried out with a ScT cryogenic magnetometer, interfaced to a microcomputer which enables a standard procedure of immediate calculation and checking of statistical parameters (\sim standard deviation) indicative of the quality of the measurements. The initial intensities of the natural remanent magnetizations (NRM) of 80% of the specimens varied from 10 to 100 $\mu\text{A}/\text{m}$, while the remaining 20% had higher NRM intensities, between 100 and 600 $\mu\text{A}/\text{m}$. These extremely low magnetizations demanded a special “double precision” measuring procedure. When a specimen reached NRM intensity values of less than 30 $\mu\text{A}/\text{m}$, which is about eight times the intensity of the sampleholder, then the whole measuring procedure was repeated four times and the NRM vector was calculated using the mean value of the four independent determinations. In addition the empty sampleholder was measured and its remanence was subtracted from the result. This procedure, although slowing down the measuring speed appreciably, resulted in an acceptable accuracy and reproducibility of the NRM vector of specimens which had intensities as low as 15 $\mu\text{A}/\text{m}$. Only 15% of the samples had to be rejected because of their very low initial NRM intensities.

Pilot specimens from all localities were demagnetized in alternating fields and thermally in 10–15 progressive demagnetization steps. AF and thermal demagnetization revealed essentially the same characteristic NRM vector. Only minor secondary magnetization components are present in the Early and Late Cretaceous samples (sample codes IGF and IGE resp.) as is shown in Figs. 2 and 3. These secondary magnetizations are removed in alternating fields above 7.5 mT and at temperatures around 110°C. The characteristic magnetization component is generally completely removed in alternating fields up to 25 mT and at temperatures above 500°C (Figs. 2 and 3). Normalized thermal decay curves (Fig. 3) depict a rather linear decrease of the magnetization during progressive heating. This magnetic behaviour points to

IGF 95-101	7	318.6	48.6	8.6	336.0	47.7	5	4.8	259.8	66.6	4.1	6.3
IGF 102-113	6	326.9	52.8	17.5								
IGF 114-121	6	328.5	59.4	9.9								
IGF 122-127	5	306.6	37.8	4.4								
IGF 128-131	4	309.1	38.8	9.0	315.7	31.5	4	16.2	266.4	44.8	10.2	18.2
IGF 132-135	4	316.0	39.3	6.9								
IGF 136-145	5	318.3	57.5	14.8								
Mean of all IGF sites (L. Cret.)					327.7	38.2	21	4.3	259.2	56.1	3.0	5.1
IGE 1- 6	6	317.3	46.3	4.6								
IGE 7- 16	7	308.1	47.3	7.2								
IGE 17- 25	6	316.1	49.4	4.9								
IGE 26- 36	6	309.0	36.0	10.0								
IGE 37- 44	5	306.4	26.4	11.9								
IGE 54- 59	6	318.2	43.8	14.9								
IGE 60- 65	5	324.0	41.4	10.8								
IGE 66- 71	6	321.4	37.1	7.4								
Mean of all IGE sites (E. Cret.)					303.1	35.1	8	8.7	279.9	37.2	5.8	10.0

* n = number of samples; D = declination; I = inclination; α_{95} = radius of the circle of 95% confidence; N = number of sites; dP/dm = error in paleolatitude and paleolongitude respectively.

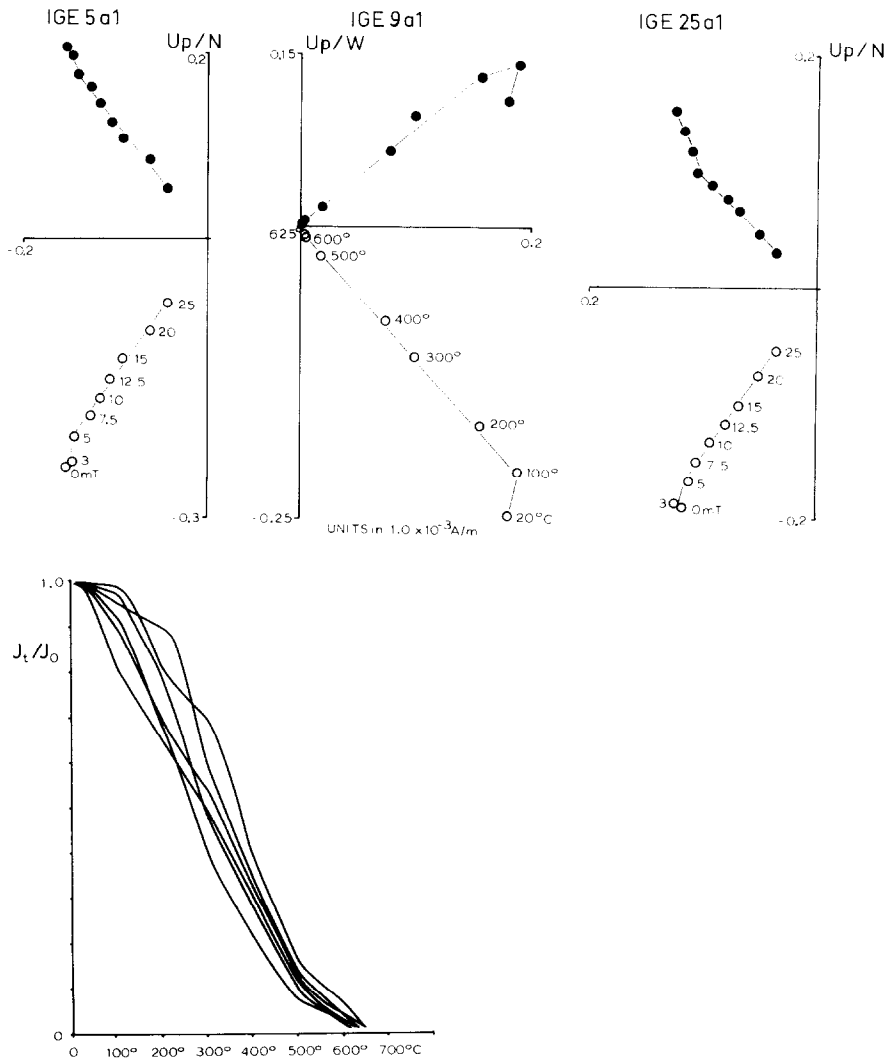


Fig. 3. Orthogonal projection diagrams showing the vector path of the N.R.M. upon demagnetization of Lower Cretaceous "Maiolica" limestone samples. Below the figure normalized decay curves are shown.

of the Upper Jurassic limestones is carried by secondary haematite. These samples have been omitted from further consideration.

All remaining specimens were demagnetized in a six-step AF demagnetization procedure and the characteristic NRM vectors were determined using orthogonal projection diagrams. Fisherian statistics were applied for calculation of the mean NRM directions (Table I). The minor bedding tilt of 5°–10° slightly improved the grouping of the mean result. The α_{95} values (Table I) are quite low, especially when

one takes into account the low intensities of the studied samples. The earlier paleomagnetic results obtained by Channell (1977) revealed much higher α_{95} values for the very same Upper Cretaceous sediments as the present study, despite the fact that most sites sampled by Channell (1977) have been resampled for the present study.

DISCUSSION

As pointed out before, the Gargano peninsula belongs to the stable Apulian platform which stretches below and all around the Adriatic Sea. In addition it is hardly deformed by the Alpine orogeny and therefore the paleomagnetic results from this stable platform are crucial for a correct interpretation of the geodynamics of the whole area including the Italian peninsula and western Yugoslavia. However, paleomagnetic results from this region recently gave rise to conflicting interpretations. Channell (1977) argued that the paleomagnetic results point to a close relationship with the Southern Alps and that the Late Cretaceous paleopoles are not offset to the east relative to Africa by a post-Late Cretaceous counterclockwise rotation. VandenBerg and Wonders (1979) considered that Channell (1977) had given too much weight to the paleomagnetic data from Gargano by using site-mean results which had an α_{95} of more than or equal to 20° for computation of the overall mean value. Actually VandenBerg and Wonders (1979) showed that if more severe reliability criteria are applied ($\alpha_{95} \leq 15^\circ$) the paleomagnetic data from southern Italy are not significantly different from those of northwestern Umbria, and hence led to a completely opposite interpretation (VandenBerg, 1979a, 1979b). The major problem in the interpretation of the paleomagnetic data from Gargano arises from the fact that the exact age of the Upper Cretaceous limestones is not very accurately known. A paleomagnetic study of the Upper Cretaceous bauxite occurrences in Campania and Southern Gargano (Table II, Channell and Tarling, 1975) revealed for the latter only four usable sites and the interpretation was even more com-

TABLE II

Earlier paleomagnetic results from the Southern Apennines

<i>N</i>	<i>D</i> (°)	<i>I</i> (°)	α_{95}	Rock type	Age	Region	Author *
04	342.4	36.0	4.2	bauxites	L.-U. Cret.?	Gargano	(1)
05	322.4	28.2	7.0	bauxites	L.-U. Cret.?	Campania	(1)
17	335.0	37.8	6.5	Scaglia Lst.	U. Cret.	Gargano	(2)
Mean paleomagnetic direction if severe reliability criteria are applied:							
15	326.5	37.0	5.9	bauxites + Lst.	U. Cret.?	S. Italy	(3)

* References: (1) Channel and Tarling (1975); (2) Channell (1977); (3) VandenBerg and Wonders (1979).

plicated because of the uncertain age of the NRM carried by the bauxites. Most likely the NRM has the age of the overlying Senonian limestones rather than the age of the underlain Middle Cretaceous series. Since a counterclockwise rotation of about 25° occurred during the Late Cretaceous, a correct interpretation of the age is absolutely crucial. Channell assumed an early Late Cretaceous age for the bauxite and the "Scaglia" limestone that is younger than the Late Cretaceous rotation, and concluded that no post-Early Tertiary counterclockwise rotation occurred for the Apulia/Gargano area. On the other hand VandenBerg and Wonders (1979) noted the elongated distribution of the Late Cretaceous paleomagnetic results and interpreted this as indicating to a late- or synrotational age for the paleomagnetic data. Consequently they assumed a post-Early Tertiary counterclockwise rotation to have occurred in addition to a Late Cretaceous rotation.

The mean result of the earlier study by Channell (1977) (Table II) only differs in declination from the present Late Cretaceous result (see Table I). However, the mean value of the Late Cretaceous data from all southern Italy (Table II) calculated by VandenBerg and Wonders (1979) using strict reliability criteria, is in perfect accordance with the present Late Cretaceous result, but differs significantly with the Early Cretaceous result (see Table I). The conclusion seems justified that the rather high scatter on site level of the earlier study by Channell (1977) has negatively influenced the results.

INTERPRETATION

The interpretation of the present paleomagnetic data in terms of rotations with respect to the pole leaves very little room for speculation. The declination value of the Early Cretaceous series differs by 25° from the Late Cretaceous results (see Table I). This can only indicate that, since Neocomian–Aptian/Albian times a counterclockwise rotation occurred, which continued in the Late Cretaceous. Moreover the presently available paleomagnetic poles from Gargano coincide perfectly with those from the stippled Umbrian pattern of Fig. 4: the Early Cretaceous result from Gargano is very close to the contemporaneous result from northwestern Umbria, pole U_2 in Fig. 4 (Channell and Tarling, 1975), while the Late Cretaceous results exactly follow the Late Cretaceous part of the Umbrian pattern. The mean Late Cretaceous paleomagnetic declination (Table I) differs by more than 30° from the present magnetic field declination which indicates a post Late Cretaceous counter-clockwise rotation of the same amount with respect to the pole. In addition the inclination value indicates a northward movement of the area in post-Late Cretaceous times. These movements have been recognized before in the paleomagnetic results of northwestern Umbria (see review VandenBerg and Zijdeveld, 1982).

Recently Early and Late Cretaceous paleomagnetic data have become available from the Istria peninsula (Márton and Veljovic, 1983). The Istria peninsula belongs to the same stable platform as Apulia/Gargano and the paleomagnetic results from

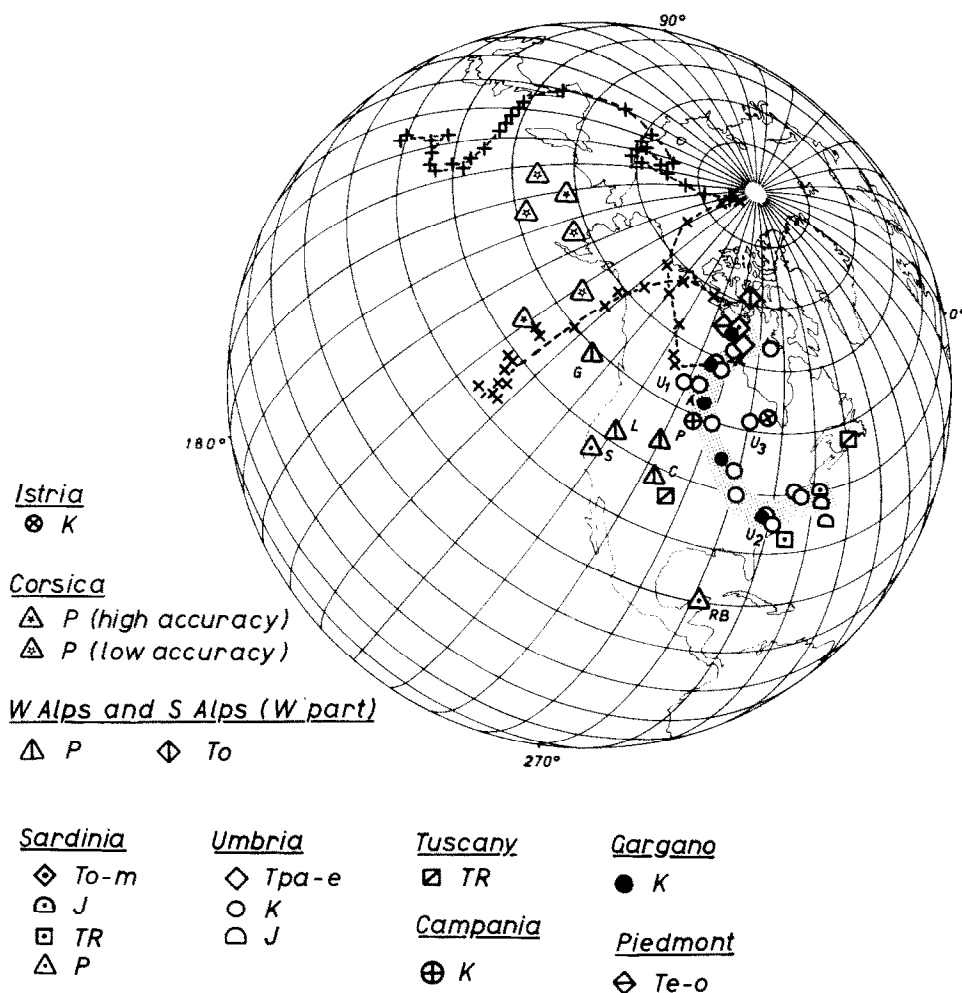


Fig. 4. Equal area projection of the paleomagnetic poles of the Western Mediterranean area compared with the apparent polar wander curves for Eurasia (vertical crosses) and Africa (diagonal crosses). For references the reader is referred to VandenBerg and Zijdeveld (1982). Some poles are identified by a letter: C = Collio and Auccia volcanics; G = Guil volcanics; P = Ponsonniere volcanics; L = Lugano volcanics; S = Gallura volcanics and RB = redbeds of Sardinia; A = overall mean Late Cretaceous result for southern Italy (VandenBerg and Wonders, 1979); U_1 = overall mean Late Cretaceous–Paleocene of Umbria, and U_2 = overall mean Early Cretaceous of northwestern Umbria (Channell and Tarling, 1975); U_3 = mean Early and Late Cretaceous of northwestern Umbria (Lowrie and Alvarez, 1975). Plain open symbols without label depict the Jurassic–Cretaceous–Early Tertiary loop (shaded zone) of northwestern Umbria according to VandenBerg (1979a).

that area are as crucial as those from Gargano. In Fig. 4 the overall mean paleopoles of Late and Early Cretaceous age for Istria (Márton and Veljovic, 1983) and northwestern Umbria (paleopole U_3 ; Lowrie and Alvarez, 1975) are plotted for

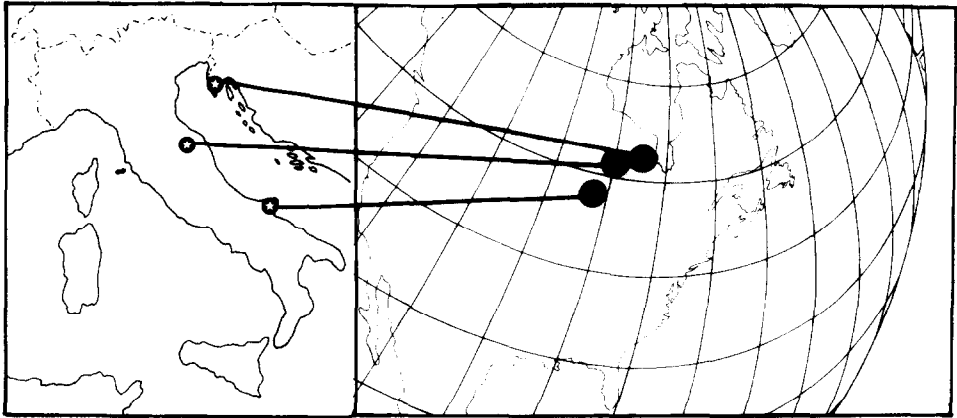


Fig. 5. Comparison of the overall mean Early and Late Cretaceous paleopoles of peri-Adriatic areas: Istria (Márton and Veljovic, 1983), northwestern Umbria (Lowrie and Alvarez, 1975) and Gargano (present study).

direct comparison. In Fig. 5 these mean poles as well as the overall mean paleopole for Gargano has been plotted. It is very obvious that the differences between these paleopoles are not significant on a 95% probability level of 5° , despite the wide geographical distribution of the sampling localities around the Adriatic Sea and the completely different tectonic history of the regions concerned. This strongly supports the interpretation (VandenBerg, 1979a; VandenBerg and Zijdeveld, 1982) that these peri-Adriatic areas belong to the same autochthonous continental block.

CONCLUSIONS

The earlier interpretations of the paleomagnetic results from Gargano by Channell (1977) are not supported by the present study because they were hampered by low accuracy and the lack of data from different geological ages. The present paleomagnetic data indicate a two-phase movement history for Gargano/Apulia. First, there is a counterclockwise rotation of about 25° from Neocomian–Aptian/Albian times far into the Late Cretaceous and second, a counterclockwise rotation of about 30° in post-Early Tertiary times to account for the eastward offset of the Early and Late Cretaceous paleomagnetic poles. The paleomagnetic results from Gargano are in perfect agreement with contemporaneous results from northwestern Umbria and from the Istria peninsula, and therefore strongly support earlier reconstructions based on the existence of a coherent continental Adriatic block only decoupled from the African plate in a post-Early Tertiary phase (VandenBerg, 1979b).

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