Earth and Planetary Science Letters, 41 (1978) 441–450

[4]

PALEOMAGNETISM AND ORE MINERALOGY OF SOME BASALTS OF THE GEIRUD FORMATION OF LATE DEVONIAN – EARLY CARBONIFEROUS AGE FROM THE SOUTHERN ALBORZ, IRAN

H. WENSINK [1], J.D.A. ZIJDERVELD [2] and J.C. VAREKAMP [1]

[1] *Geological Institute, State University of Utrecht, Oude Gracht 320, Utrecht (The Netherlands)*
[2] *Paleomagnetic Laboratory, State University of Utrecht, Budapestlaan 17, Utrecht (The Netherlands)*

Revised version received September 15, 1978

Basaltic lavas from the southern Alborz, an area about 40 km northeast of Tehran, Iran, have been paleomagnetically investigated. The lavas are of Late Devonian–Early Carboniferous age, and belong to the basal member of the Geirud Formation. At 11 sites a total of 80 cores was drilled.

Detailed analyses by means of progressive demagnetization of the natural remanent magnetization (NRM) were made both by the application of alternating magnetic fields and by heating. Also, on a number of specimens a study was done both with thin sections and with polished sections. There proved to be general agreement between the properties of the characteristic NRM and the kind of Fe-Ti oxides in the lavas. In the case of specimens containing magnetite only the characteristic NRM was entirely removed at temperatures just below 600°C, or in alternating fields up to 1500/2000 Oe peak value; on the other hand, in specimens containing both magnetite and a substantial part of hematite (martite) the final part of the characteristic remanence was removed at temperatures above 600°C, and this remanence resisted alternating fields above 2000 Oe peak value. From the characteristic site-mean directions of 5 sites an average paleomagnetic direction is computed with $D = 210.8°$, $I = 66.9°$, and $\alpha_{95} = 3.9°$.

This result might be taken as an indication that at the Devono-Carboniferous transition the southern part of the Alborz was located in the present Indian Ocean off the Arabian coast.

1. Introduction

In the Djadjerud and Lalun valleys in the southern part of the Alborz, about 40 km northeast of Tehran, Iran (Fig. 1), oriented samples were collected from basaltic lavas of Late Famennian to early Tournaisian age (transition Devono-Carboniferous). The material has been subjected to paleomagnetic analyses in order to determine characteristic remanent directions of magnetization.

The aim of this study is to use the data for plate-tectonic reconstructions. The position of the Alborz in upper Paleozoic times will be considered in relation to that of the Laurasian and the Arabic-African plates.

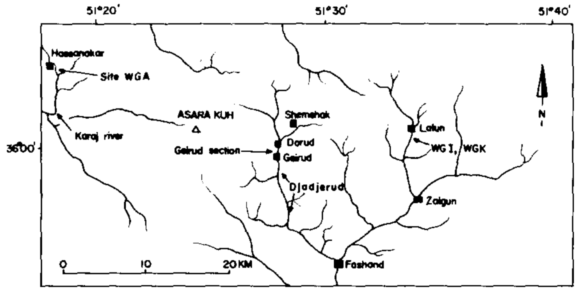


Fig. 1. Map of the Djadjerud area north and northeast of Tehran, Iran, with sampling sites of the Geirud basalts.

2. Geology of the area

North of Tehran the Alborz Mountains run approximately WNW-ESE. The central part of this orogenic belt can be subdivided into seven structural units, viz. from north to south: (1) Caspian Plane; (2) North Mesozoic Border Zone; (3) Paleozoic Central Ranges; (4) Central Tertiary Zone; (5) South Paleozoic-Mesozoic Zone; (6) South Tertiary Zone; (7) South Frontal Depression. The Alborz is a typical block-faulted orogene, where folding was of minor importance [1,2]. Sampling for paleomagnetic research was done in the South Paleozoic-Mesozoic Zone. In the area northeast of Tehran, this zone has an anticlinal structure with a tectonically reduced southern limb and with a fold axis dipping to the east. In the Djadjerud valley the southern limb has completely disappeared. Here, one comes across the northern limb with Paleozoic and Mesozoic sediments dipping steeply north.

The sediments of Paleozoic and Early Mesozoic age of the Alborz can be subdivided into two main groups. The lower group, composed mainly of detrital sediments, is of Late Precambrian and Cambrian age. The upper group consists of detrital and platform sediments from the Late Devonian up to and including the Triassic. From the area northeast of Tehran no deposits are reported of Ordovician, Silurian, and Early and Middle Devonian age. Detrital sediments with intercalated volcanic rocks of the Geirud Formation immediately overlie sediments of Cambrian age. The Geirud Formation extending from the Late Devonian to Early Permian is covered by detrital and calcareous sediments of the Dorud Formation of mainly Lower Permian age, which, in turn, are overlain by limestones of the Ruteh and Nesen Formations. Limestones of the Triassic Elikah Formation form the top of this group [3,4].

The Geirud Formation shows its maximum development in the Djadjerud region with a thickness of up to 1000 m. Four members can be distinguished. The basalts sampled for our paleomagnetic study are found intercalated between shales and sandstones in the lowest member A (Fig. 2). No volcanics are encountered in the subsequent members B, C and D of the Geirud Formation.

The abundance of fossils in the intercalated limestones of the Geirud Formation permits the dating of the successive members. According to Gaetani [5] member A has an age from Late Famennian to Middle Tournaisian. The volcanics are situated on top of the plant-bearing beds, to which a Late Famennian age is ascribed. An Early to Middle Tournaisian age can be attributed to the upper beds of member A [5]. Member B with fossil-bearing limestones and shales is a time equivalent of the Lower Carboniferous Mubarak Formation. Member C – characterized by dolomitic limestones – is poor in fossils, but probably has a

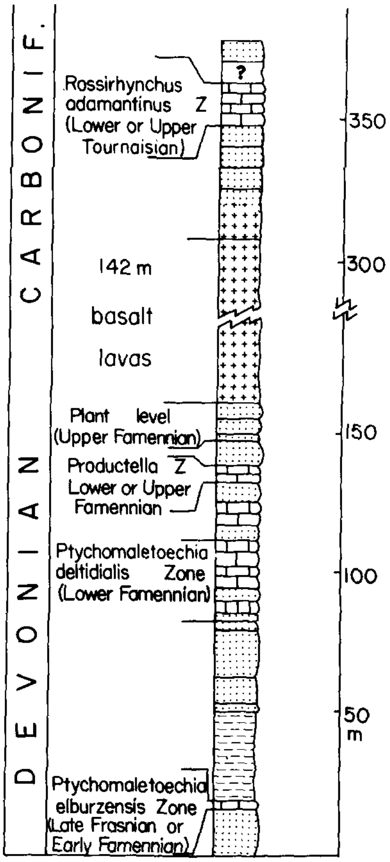


Fig. Section of Member A of the Geirud Formation in the Djadjerud valley with identified zones after Gaetani [5].

Late Carboniferous age, because the overlying fossil-bearing variegated shales and limestones of member D have an Early Permian age [6].

3. The Geirud basalts

In the Djadjerud area the volcanics are exposed with short interruptions over an east-west lateral distance of about 25 km. Westwards the lavas peter out, and in the Karaj valley they are seen only sporadically. Further to the west in the Teleghan valley northwest of Karaj, Sieber [7] reports a sequence of up to 100 m diabases which – according to him – are effusive rocks, being intercalated in sediments attributed to the Geirud Formation. Towards the east the volcanics disappear in the ENE-plunging nose of the anticlinal structure.

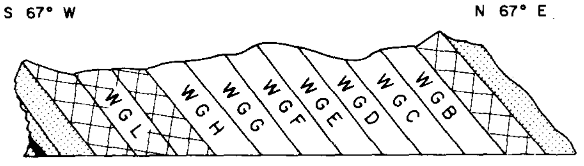


Fig. 3. Section of part of Member A of the Geirud Formation showing intercalated basalt lavas with site indications. Djadjerud valley between Geirud and Dorud, southern Alborz.

Good outcrops of the volcanic rocks can be seen in the obsequent valley of the Djadje river between the villages of Geirud and Dorud. Here, the volcanic sequence is 142 m thick and is built up of about 11 individual lava flows (Fig. 3). The lavas are very probably subaerial.

In each lava flow, usually both a scoriaceous basal part and a vesicular top can be seen; pillow structures were not encountered. Also, good exposures are found both in the Lalun valley with a lava sequence thickness of 60 m, and in the Zaigun valley northeast of the village of Zaigun, where the lava series is 80 m thick.

Included in this study is a basic sill exposed in the Karaj valley near the village of Hassanakar. This 15 m thick sill, intercalated in the Geirud sediments, is possibly related to the Geirud volcanics [8].

4. Sampling in the field

A portable drill with a coring tube of 25 mm inner diameter was used for collecting oriented samples in the field. Oriented cores were obtained from eight lava flows in the Djadjerud valley (sites WGB, -C, -D, -E, -F, -G, -H and -L) and from two lavas in the Lalun valley (sites WGI, and -K), as indicated in Fig. 1. A minimum of six cores was drilled from each flow/site. Ten cores were collected from the basic sill in the Karaj valley (WGA). A total of 80 cores was sampled.

5. Paleomagnetic research

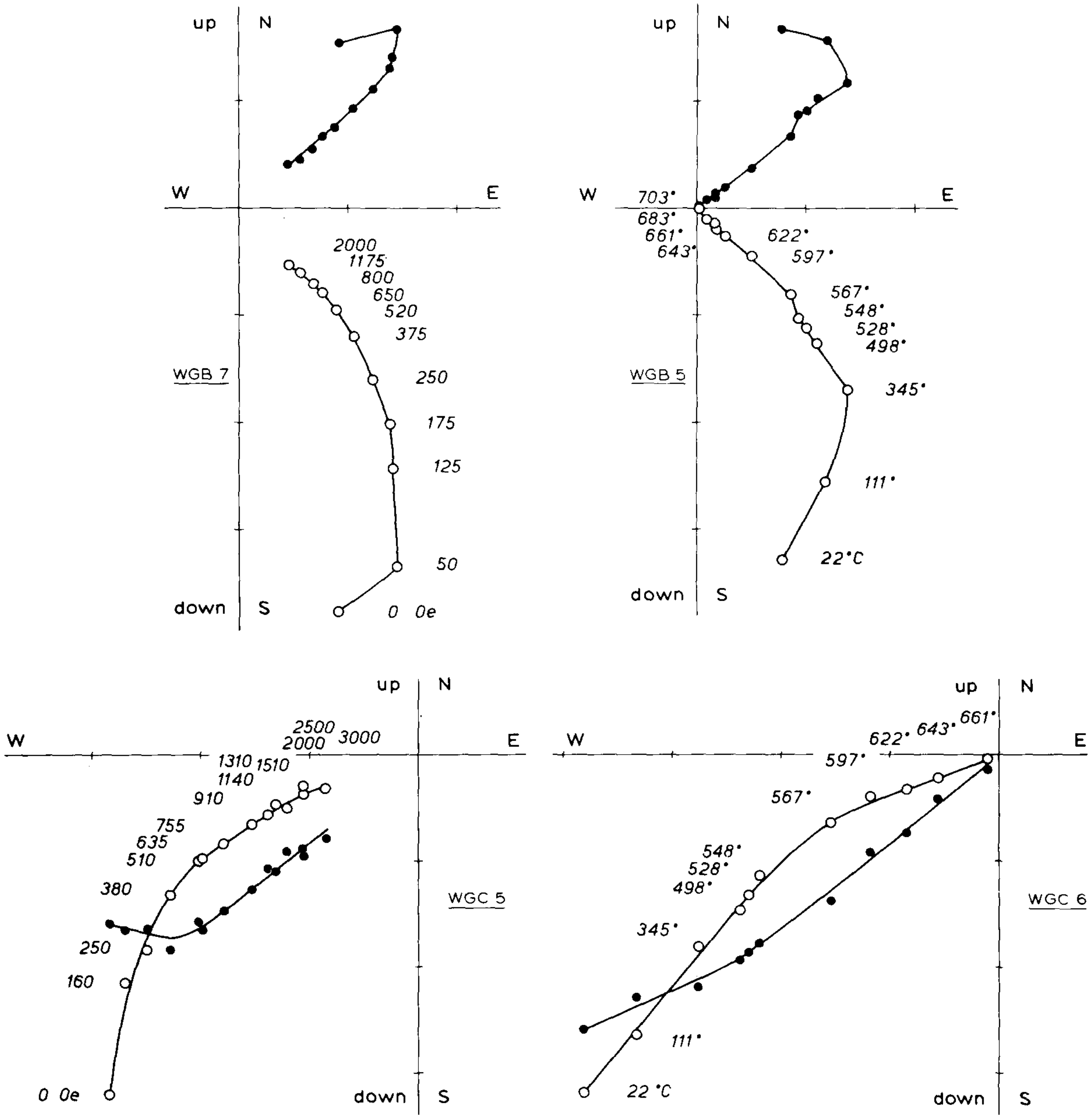
In the laboratory the cores were cut into specimens each 22 mm long. Usually, one specimen from each core was used for further analysis. The specimens were measured with the standard equipment available, viz. with astatic magnetometers [9] and with a spinner magnetometer [10].

Progressive demagnetization of the natural remanent magnetization (NRM) was carried out both with alternating magnetic fields and by heating in order to determine the various components and their properties. For a better check on the reliability of the results, from each site certain specimens were demagnetized in alternating magnetic fields and others were demagnetized thermally. Progressive alternating field demagnetization was performed in 5 to 10 successive steps up to 1000 Oe, and in a few cases up to 2000 Oe peak value.

Progressive heating was done in an argon atmosphere and in at least 10 successive steps. For each specimen the directions and intensities of the part of the NRM remaining after each successive step of demagnetization were plotted in an orthogonal projection in a diagram (Fig. 4), which permits the detection of all NRM components present in the specimen [11]. There proved to be no fundamental differences between the results obtained with alternating magnetic fields and the results obtained by heating.

In low alternating fields and at moderate temperatures a soft, low blocking-field remanence component was removed which had a direction different to that of the harder, high blocking-field part of the NRM. According to general experience this soft, low blocking-field component can be assumed to be of secondary origin. In the present case this secondary component had a downward direction and, curiously enough, in most cases a westerly declination. Progressive alternating magnetic field treatment showed that after the application of a field strength of 400 Oe peak value the secondary magnetic components have usually been removed. With progressive heating, temperatures of above 500°C were usually needed to reveal the other, high blocking-field component of the natural remanence. This hard, high blocking-field part of the NRM has highly consistent directions among the various specimens from a single site (Fig. 5), and is defined as the characteristic NRM. Within a single site, alternating magnetic fields and thermal treatment yielded identical directions for the characteristic NRM. This similarity can be seen in Fig. 5, where directions obtained by the two different demagnetization methods are plotted without distinction, and in Table 1, where combination of such characteristic NRM directions leads to small cones of confidence. The decay of the characteristic remanence during alternating field demagnetization and especially during thermal demagnetization discloses something about the nature of the carriers of this remanence (Fig. 6). So among the examples of Fig. 4 the thermal demagnetization diagrams of the specimens from sites WGB and WGC show not only that there is a strong decrease between 500 and 600°C, attributable to magnetite, but also that part of the characteristic remanence is removed at temperatures above 600°C and thus must reside in hematite.

The part of the characteristic remanence carried by magnetite and that part carried by hematite have identical directions. The presence of hematite remanence can be detected too from the alternating



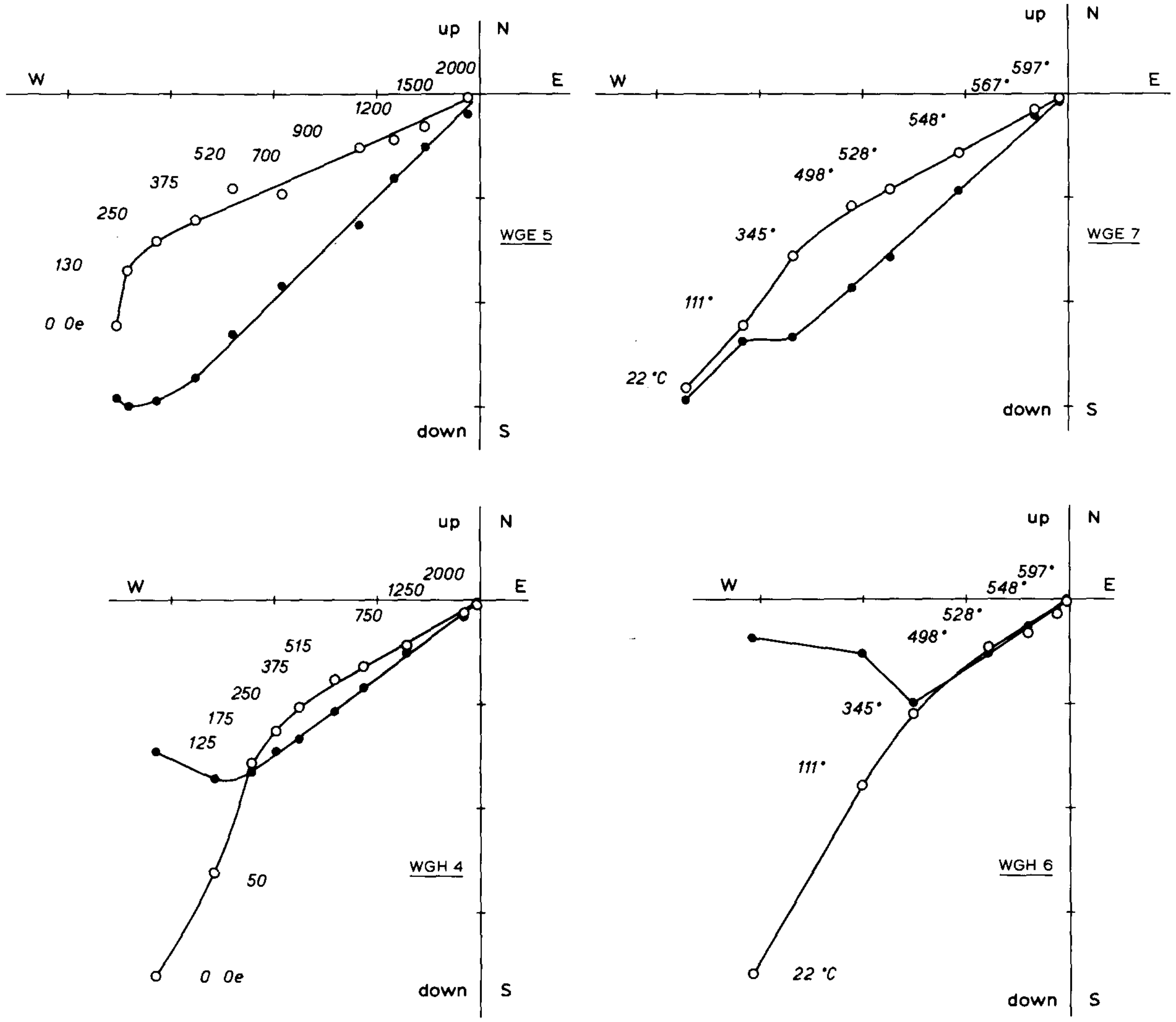


Fig. 4. Comparative diagrams showing the progressive demagnetization both with alternating magnetic fields and by heating of specimens of four individual sites. The plotted points represent successive positions in orthogonal projection of the end of the resultant NRM vector during progressive demagnetization. Solid and open circles denote the projections on the horizontal and on the east-west vertical plane, respectively. The numbers in the diagrams WGB 7, WGC 5, WGE 5, and WGH 4 represent the peak strength in oersteds of the alternating demagnetizing field; those in diagrams WGB 5, WGC 6, WGE 7, and WGH 6 denote the temperature applied in degrees centrigrade. Each unit on either axis represents in 10^5 emu/cm^3 for WGB 7: 3.5; WGB 5: 5.7; WGC 5: 8.2; WGC 6: 7.7; WGE 5: 79; WGE 7: 28; WGH 4: 15.3; and for WGH 6: 17.5.

magnetic field demagnetization diagrams of both specimens WGB 7 and WGC 5, because part of the characteristic remanence withstood alternating fields up to 2000 Oe peak value. The other four demagnetization diagrams in Fig. 4, pertaining to sites WGE and WGH, are examples of characteristic remanent magnetizations probably residing in magnetite alone. The total NRM proved to be entirely eliminated either after heating to 600°C or after alternating magnetic field treatment with 2000 Oe peak value.

The demagnetization diagrams presented in Fig. 4 are typical for all the demagnetization results obtained. In all cases the characteristic NRM appeared to reside in either magnetite alone or in magnetite

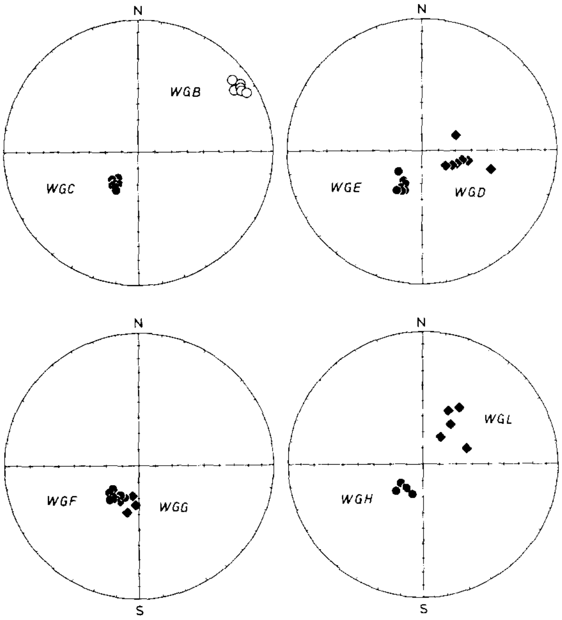


Fig. 5. Equal area projections of the characteristic remanent magnetization directions of specimens of eight individual Geirud lava flows after tectonic correction. Full symbols denote that the north-seeking poles are pointed downward; open circles indicate that north-seeking poles are pointing upward.

plus hematite. Although, with our present knowledge about rock magnetic properties, it seems to be a hazardous procedure to determine the magnetic minerals from remanence decay curves, it will be shown in the following paragraph that our preliminary determinations are supported by observations on polished sections.

The paleomagnetic analyses with alternating magnetic field and thermal demagnetization proved to be most successful with the specimens of the eight lava flows of the Djadjerud valley. For six sites, in the demagnetization diagrams of *all* specimens collected, the characteristic NRM direction could be easily recognized (Table 1). With two sites, WGG and WGL, the characteristic NRM direction could be determined with sufficient accuracy only for a number of the specimens investigated. This was due to the fact that the alternating magnetic field demagnetization did not always result in distinct cleaning and the thermal demagnetization yielded scattered results.

The lavas in the Lalun valley (sites WGI and WGK) are severely cracked. In all specimens from site WGI a clearly secondary remanent magnetization with recent geomagnetic direction predominated the NRM, and made an accurate determination of the characteristic remanence impossible. An attempt to estimate the characteristic direction yielded for site WGI the approximation 190/−23 (in situ), while the large α_{95} of 24° is a clear indication as to uncertainty. In the specimens from site WGK the secondary remanence was so important that even an approximation of the characteristic NRM could not be deduced. The same

TABLE 1

Mean characteristic directions of magnetization of Geirud lavas

Localities	Sites	*N*	*T*	*D*	*I*	*k*	α_{95}
Djadjerud	WGB	7	af/th	57	−12	548	2.6
Djadjerud	WGC	7	af/th	215	66.5	731	2.2
Djadjerud	WGD	7	af/th	103.5	65	51	8.5
Djadjerud	WGE	7	af/th	210	65.5	302	3.5
Djadjerud	WGF	8	af/th	217.5	66.5	431	2.7
Djadjerud	WGG	4	af/th	195	66	189	6.7
Djadjerud	WGH	5	af/th	218	69.5	236	5.0
Djadjerud	WGL	5	af/th	37.5	60	43	11.8
All *		5 **		211	67	380	3.9

N is the number of specimens included in the ultimate analysis; *T* is the demagnetization procedure applied: af and th are alternating magnetic fields and heating, respectively; *D* and *I* are the declination and inclination in degrees of the magnetization direction after correction of tilt of the lavas; *k* is the precision parameter [17]; α_{95} is the semi-angle of the cone of 95% confidence in degrees.

* Excluded in the combined result are the data from sites WGB, WGD and WGL.

** Number of sites (lava flows) included in the analysis.

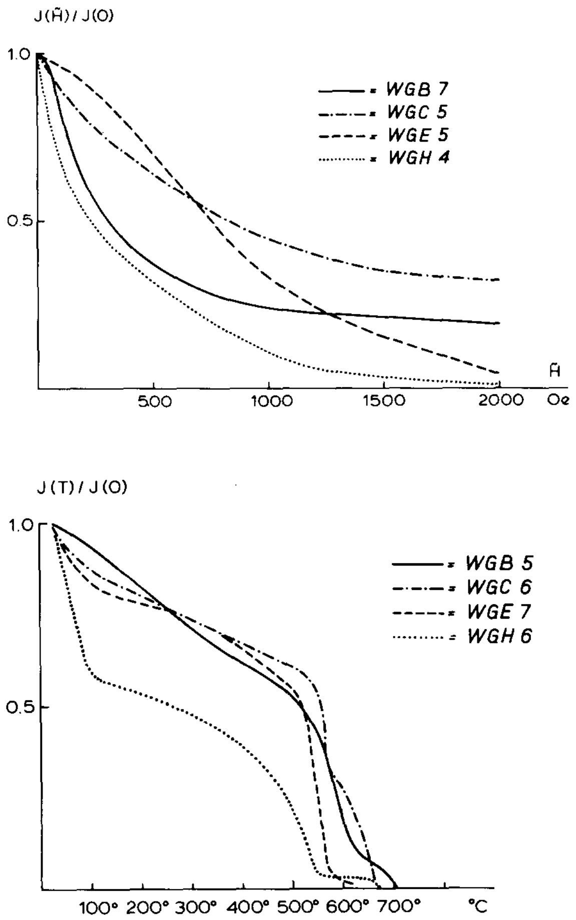


Fig. 6. Comparison of normalized alternating magnetic field and thermal decay curves of the natural remanent magnetization of specimens of four individual sites.

unfortunate configuration was encountered with the specimens of the sill WGA from the Karaj valley.

6. Mineralogy of the basalts

The mineralogical composition of the lava flows was studied from thin sections and polished sections.

Although a number of flows show alteration, their basaltic character is quite clear. Porphyritic textures with phenocrysts of plagioclase and with a (sub) ophitic groundmass are observed in six lava flows; there are also non-porphyritic lavas with microcrystalline (sub)ophitic textures. The main constituents are plagioclase, augite and opaques. The anorthite content of the plagioclase is rather low, and usually ranges from 10% to 15%. Anorthite contents of over 40% are encountered with flows WGB and WGK. The low anorthite content of the plagioclase is mainly a result of albitisation during alteration of the rock. Augite is a common constituent, usually partly altered into chlorite and calcite. Cloudy leucoxene was observed. The mineral assemblage points to a basaltic rock with spilitic character.

The sill WGA, sampled in the Karaj valley west of the Djadjerud valley, is an unaltered rock with a coarse ophitic texture. Labradorite and augite (possibly Ti-bearing) are the main constituents. Opaques are present both as huge crystals and aggregates, and as finely dispersed particles. No olivine was found. The study of polished sections revealed that (titano) magnetite, ilmenite, hematite and leucoxene are the main Fe-Ti oxides present. Among these oxydes magnetite is the distinct primary magnetic mineral. A lamellar intergrowth of magnetite and ilmenite was observed, but this is not a frequent phenomenon in the basalts studied. The ilmenite is often found altered to sphene and leucoxene. Very common was the phenomenon of martitisation, i.e. the oxidation of magnetite into hematite which starts with the occurrence of lamellae of hematite along the octahedral planes of the magnetite crystals. Such a martitisation often occurs during the cooling of the lava flow, shortly after its deposition. Hematite was also found as solitary crystals. The leucoxene observed is probably a secondary alteration product of ilmenite and mainly of augite.

There is general agreement between the alternating magnetic field and thermal demagnetization results and the observations on the polished sections. All characteristic natural remanences showed a magnetite-like part in their behaviour, and in fact all basalt specimens proved to contain primary (titano)magnetite. With those specimens containing magnetite and a substantial amount of hematite (respectively martite) part of the characteristic NRM was removed at temperatures above 600°C and resisted alternating fields above 2000 Oe peak value. On the other hand, the characteristic remanence of samples, with practically no hematite and magnetite only, became entirely removed in temperatures just below 600°C or in alternating magnetic fields up to 1500/2000 Oe peak value.

7. Summary of the paleomagnetic data

Site-mean directions of the characteristic NRM of the Early Carboniferous Geirud basalts could be determined with sufficient accuracy only for the sequence of flows sampled in the Djadjerud valley. Because the direction of this characteristic NRM in situ differed considerably from the present local geomagnetic direction, this characteristic NRM must be of older origin. Since, moreover, it appeared that a substantial part of this characteristic NRM resided in the primary magnetic mineral magnetite, it is most plausible to assume that the characteristic NRM is the original thermoremanence. This assumption is supported by the observation that part of the characteristic NRM resided in hematite found as a deuteric (i.e. depositional) alteration in the primary magnetite; it is difficult to imagine a simultaneous remagnetization of both magnetite and hematite, unless there has been a regional warming up of the area, for which there are no indications.

The characteristic site-mean directions are given in Table 1 after correction of the dip of the strata. This dip remained constant over the whole lava sequence in the Djadjerud valley and was 50° in the direction N64°E (strike and dip: 334°/50°). Correction for this dip was made by simply rotating the site-mean direction over the amount of the dip around the strike as rotation axis. This was done because it was felt that the plunging of the anticlinal axis observed to the east of the Djadjerud valley was not important in the Djadjerud valley itself.

Most of the site-mean directions were found to be close together, which indicates that the direction which was characteristic for each of the sites is characteristic for the whole group of sites. The characteristic site-mean directions of three sites, however, deviate from this common characteristic direction. Most outstanding is the characteristic direction of site WGB, which moreover seems to represent a polarity that is opposite to the other characteristic site-mean directions. The characteristic directions of the other two sites (WGD and WGL) deviate by at least 40° from the mean characteristic direction of the other sites; this discrepancy is somewhat large to be explained by ordinary secular variation. The progressive demagnetization diagrams of the NRM in the specimens of the three deviating sites gave no indications of any aberrations (see e.g. Fig. 4, site WGB), but in the case of the specimens from the sites WGD and especially WGL the characteristic remanence was difficult to determine; this can be seen too from the relatively large α_{95} for both sites. Furthermore, from field evidence it appears unlikely that the sites WGB, WGD and WGL were in later basaltic injections, viz. in sills. In brief, it is not possible to give an easy explanation for the deviating directions obtained for the sites WGB, WGD and WGL. They do, however, represent definite deviations; and the overall mean characteristic NRM direction of the Geirud lavas in the Djadjerud valley is given by the average of the close characteristic site-mean directions of the 5 sites WGC, WGE, WGF, WGG and WGH (Table 1). Moreover, in spite of its uncertainty the approximated characteristic site-mean direction from site WGI of the Lalun valley (D = 190°, I = −23° before tilt correction, and α_{95} = 24°; bedding strike and dip: 270°/72°) the overall mean characteristic NRM direction of the lavas in the Djadjerud valley present some sort of a positive fold test. Table 2 gives the pole position corresponding to the overall mean characteristic NRM direction of the Geirud lavas. In the next paragraph it will be taken

TABLE 2

Virtual geomagnetic pole position of Geirud lavas

Positions of sites		Position of pole			
latitude (°N)	longitude (°E)	latitude (°S)	longitude (°E)	δ_p	δ_m
36	51.5	0.2	32.1	3.9	5.3

δ_p and δ_m are the semi-axis of the oval of 95% confidence for the pole position.

as a paleomagnetic pole, but given the scarcity of data and density of the site-mean directions used, it might be only a virtual geomagnetic pole.

8. Tectonic implications

One single paleomagnetic result derived from Late Paleozoic rocks of the Alborz Mountains does not enable us to present dramatic plate tectonic conclusions for this area. Nevertheless, some tentative remarks can be made. The pole position corresponding to the mean characteristic remanent direction of magnetization found for the Geirud lavas is situated near Lake Victoria in Central Africa (Table 2). The position of this Geirud paleomagnetic pole relative to the Eurasian [12] and Gondwanaland [13,14] polar-wander curves makes it unlikely that during the Carboniferous northern Iran was part of the Eurasian plate. The Geirud paleomagnetic data indicate that during the Paleozoic the Alborz region was part of the former Gondwanaland. A similar conclusion, based on paleomagnetic evidence from Infra-Cambrian rocks and iron ores of the Bafq area, has been reached for Central Iran [15]. With regard to the more precise position of northern Iran within the reconstruction of Gondwanaland it should be remembered that the age of the Geirud lavas is just at the end of the Middle Paleozoic, Gondwana "quasi-static interval", which lasted from Silurian until the Early Carboniferous (Group B [13]). Paleomagnetic pole positions for this quasi-static interval are situated in southern Africa in the area between 10°S and 30°S, and 10°E and 30°E. The removal of the Geirud paleomagnetic pole to this area implies a shift of northern Iran to the Indian Ocean off the Arabian coast.

The inclination of the Geirud paleomagnetic direction indicates that in the Late Devonian–Early Carboniferous northern Iran was situated at a (probably southern) latitude of about 50°. The mean quasi-static interval pole position for that period has its 50° southern parallel of latitude crossing the southeastern Arabian coast at about the present 15°N. A Late Paleozoic position of the present block mosaic of Iran with respect to the African plate off the southeastern Arabian coast is in agreement with the reconstructions of the "Iranian-Afghan plate" as deduced by Krumsiek [16] from preliminary paleomagnetic data from Afghanistan.

Acknowledgements

The authors would like to thank the Directors of the Geological Survey of Iran, Tehran, for their help during the work in the field. They greatly appreciate the assistance given by the staff of Her Majesty's Embassy of The Netherlands in Tehran, Iran. Financial support was received from The Netherland's Organisation for Pure Scientific Research (ZWO).

References

1 A. Gansser and H. Huber, Geological observations in the Central Elburz, Iran, Schweiz. Mineral. Petrogr. Mitt. 42 (1962) 583–630.
2 J. Stöcklin, Structural history and tectonics of Iran: a review, Am. Assoc. Pet. Geol. Bull. 52 (1968) 1229–1258.
3 J. Dellenbach, Contribution à l'étude géologique de la région située à l'est de Téhéran (Iran), Diss. Strassbourg (1964) 120 pp.
4 R. Assereto, Geological map of the Upper Djadjerud and Lar valleys with explanatory notes, Ist. Geol. Univ. Milano, Ser. G, Publ. 232 (1966) 86 pp.
5 M. Gaetani, The geology of the Upper Djadjerud and Lar valleys (North Iran), II. Palaeontology. Brachiopods and Molluscs from Geirud Formation, Member A (Upper Devonian and Tournaisian), Rev. Ital. Paleontol. 71 (1965) 679–770.
6 N. Fantini Sestini, The geology of the Upper Djadjerud and Lar valleys (North Iran), II. Palaeontology. Brachiopods from Geirud Formation, Member D (Lower Permian), Rev. Ital. Paleontol. 72 (1966) 9–52.
7 N. Sieber, Zur Geologie des Gebietes südlich des Taleghan-Tales, Zentral-Elburz (Iran), Diss. Zürich (1970) 127 pp.
8 C. Lorenz, Die Geologie des oberen Karadj-Tales (Zentral-Elburz), Iran. Mitt. Geol. Inst. E.T.H. Univ. Zürich, N.F. 22 (1966) 114 pp.
9 J.A. As, The astatic magnetometers at De Bilt, in: Methods in Paleomagnetism, D.W. Collinson, K.M. Creer and S.K. Runcorn, eds. (Elsevier, Amsterdam, 1966) 66–68.
10 V. Jelínek, A high sensivity spinner magnetometer, Stud. Geophys. Geod. 10 (1966) 58–78.
11 J.D.A. Zijderveld, Paleomagnetism of the Esterel rocks (Krips Repro B.V., Meppel, 1975) 199 pp.
12 J.D.A. Zijderveld and R. van der Voo, Palaeomagnetism in the Mediterranean area, in: Implications of Continental Drift to the Earth Sciences, Vol. 1, D.H. Tarling and S.K. Runcorn, eds. (Academic Press, London & New York, 1973) 133–161.
13 M.W. McElhinny and J.C. Briden, Continental drift

during the Paleozoic, Earth Planet. Sci. Lett. 10 (1971) 407–416.
14 H. Wensink, The structural history of the India-Pakistan subcontinent during the Phanerozoic, in: Progress in Geodynamics (Royal Netherlands Academy of Arts and Science, Amsterdam, 1975) 190–207.
15 H. Becker, H. Förster and H. Soffel, Central Iran, a former part of Gondwanaland? Palaeomagnetic evidence from Infra-Cambrian rocks and iron ores of the Bafq area, Central Iran, Z. Geophys. 39 (1973) 953–963.
16 K. Krumsiek, Zur Bewegung der Iranisch-Afghanischen Platte, Geol. Rundsch. 65 (1976) 909–929.
17 R.A. Fisher, Dispersion on a sphere, Proc. R. Soc. London, Ser. A, 217 (1953) 295–305.