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Paleomagnetism of red beds of Early Devonian age from Central Iran

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Paleomagnetic results are reported from 13 sites of red beds of Early Devonian age from Central Iran. Detailed paleomagnetic analyses were carried out. Two types of partial progressive demagnetization were applied, one using alternating magnetic fields, the other heating. These procedures resulted in the detection of the characteristic remanences with a mean direction with $D = 24.2^\circ$, $I = 1.3^\circ$ ($\alpha_{95} = 10.1^\circ$). The paleomagnetic pole is located at 51.3°N , 163.7°W . If one shifts the Iranian landmass to its most likely position in the Gondwana configuration, then the position of the paleomagnetic pole coincides with the alternative polar wander path [14,15] which crossed South America in early Middle Paleozoic times.

1. Introduction

In order to make a paleomagnetic study we collected rock material from red, fine-grained detrital sediments of predominantly Early Devonian age. The sampling took place in Central Iran, north and northeast of Kerman. The mountains in this area provide beautiful sections in rocks of Late Precambrian through Late Mesozoic age. Fortunately, the geology of the area has been studied in detail, and reliable geological maps are available [1]. The purpose of this paleomagnetic research was to isolate the characteristic remanence directions in the collected rock specimens. If these are primary directions, we can determine the paleolatitudinal position of the area at the time of the deposition of the sediments. Moreover, paleomagnetic data of Early Devonian age from Iran may support the supposition that in Paleozoic times Iran formed part of Gondwana [2–4].

2. Geology of the sampling localities

The sampling was carried out at three localities: near Hutk; in the Kuh-i-Tizi (Sharp Mountains); and between Rizu and Chabdjareh (Fig. 1). We collected both oriented hand samples and oriented cores. Subsequently, we shall describe both the position of the sampling sites in the sections at these localities and the stratigraphy.

Hutk. The section near Hutk, about 35 km to the NNW of Kerman, is located in an anticlinal structure trending ESE-WNW. The sampling was done in the lowermost part of the section; material was collected here, at four sites (WSDA, -B, -C, -D). The sequence consists of an alternation of red sandstones and red shales with a thickness of over 30 m. The red beds are overlain by 16 m black limestones, the fossils of which point to Late Givetian age (Late Middle Devonian). In the Morad area, about 30 km towards the SSW, fossiliferous sediments deposited at the boundary between Early and Middle Devonian cover red beds comparable to those near Hutk.

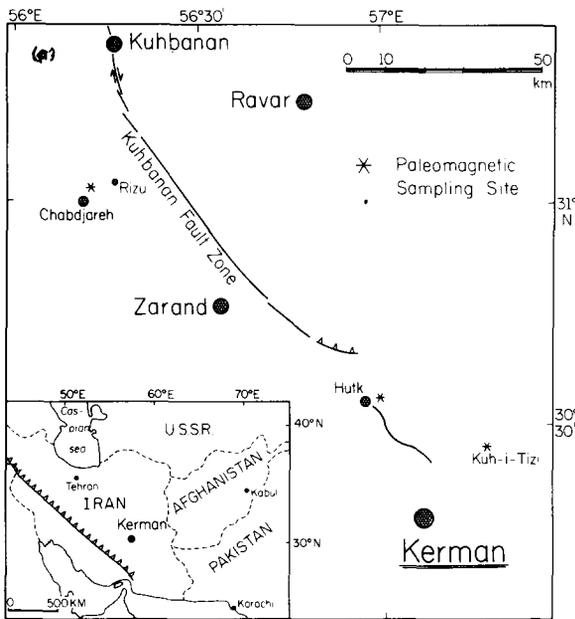


Fig. 1. Map of the area between Kerman and Kuhbanan in Central Iran with the paleomagnetic sampling localities of red beds of Early Devonian age.

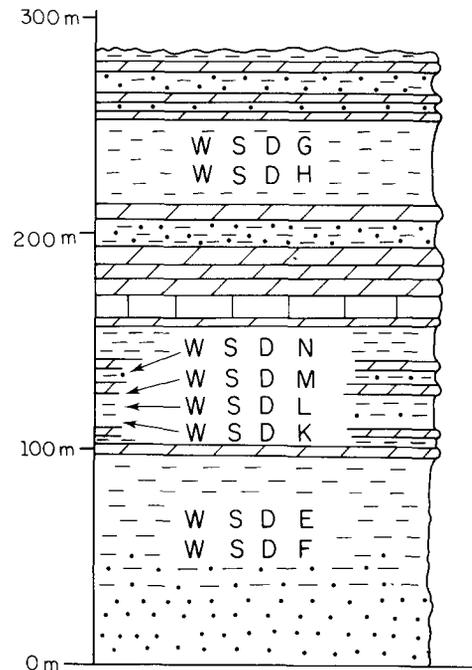


Fig. 2. Stratigraphic column of the sedimentary sequence of Early Devonian age in the Kuh-i-Tizi area, with the location of the paleomagnetic sampling sites.

Kuh-i-Tizi. The area of Kuh-i-Tizi, about 20 km to the northeast of Kerman, is built up of an anticlinal structure, the axis of which bends from SE-NW in the south to south-north in the north. At the western limb of the Tizi anticline a section is exposed with a thickness of about 1100 m. The lowermost part of the section consists of 300 m of sandstones of "Old Red" facies. In the opinion of Huckriede et al. [1] these sediments may have an Early Devonian age, although the possibility of a Cambrian age (Desu Series) cannot be ruled out. The red sandstones are covered by a series of red shales, in which many thin beds of dolomite are intercalated. In this series, which has a thickness of 280 m, material was collected at eight sites (WSDE, -F, -K, -L, -M, -N, -H, -G; Fig. 2). Then follows a sequence of 50 m thickness with limestones, quartzites, and dolomites; the index fossils in the limestones point to a Frasnian age (Early Late Devonian). The section continues with 230 m non-clastic sediments of Late Devonian age, which in turn are overlain by sediments of Carboniferous through Triassic age.

Rizu-Chabdjareh. The section between Rizu and Chabdjareh, at about 40 km northwest of Zarand, is located at the northwestern limb of a syncline. Here, a sedimentary sequence is exposed with a thickness of at least 1700 m. The lowermost part of this section consists of about 1000 m of variegated sediments of Cambrian and Ordovician age, and is overlain by a 490 m thick series built up of quartzites, dolomites, and red shales. Our sampling sites WSDO, -P are located about 80 m below the top of the latter series. Dolomites of post-Devonian age cover the red bed series. In the area between Kerman and Sagand in Central Iran, Huckriede et al. [1] studied a great number of sections. They came to the conclusion that the sequence of red beds, in which our paleomagnetic sites are located, has an Early Devonian age. Sections with intercalations of marine fossiliferous sediments, however, indicating an Early Middle Devonian age, do occur.

3. Paleomagnetic procedures

In the field we collected from the combined sites 67 oriented cores and 31 oriented hand samples. This furnished us with a collection of 129 specimens for paleomagnetic analysis. The specimens from site WSDO were not included in this analysis, because from these specimens we could not obtain characteristic remanences.

All specimens were subjected to partial, progressive demagnetization procedures; 54 specimens were treated with alternating magnetic fields (AF method); 42 specimens were subjected to progressive heating; progressive AF treatment with subsequent heating was applied to 33 specimens.

The measurements of magnetization were made partly with a Schönstedt JR 3 magnetometer, and partly with a ScT superconducting magnetometer. The initial magnetic intensities of the specimens range between 2×10^{-3} and 8×10^{-3} A/m; the intensities of the specimens from the sites near Hutk are usually lower than those from the Kuh-i-Tizi specimens. The specimens from site WSDP near Chabdjareh have high initial remanence intensities with an average of 7×10^{-2} A/m. Pro-

gressive AF demagnetization was applied in 8 up to 12 successive steps with a maximum peak value of 300 mT (3000 oerstedt). An analysis with vector diagrams shows that AF treatment is very often successful in removing the secondary components of magnetization [5]; it turned out that AF demagnetization with peak fields of 60 mT is usually enough to isolate the characteristic remanence direction (Fig. 3; WSDG 4A).

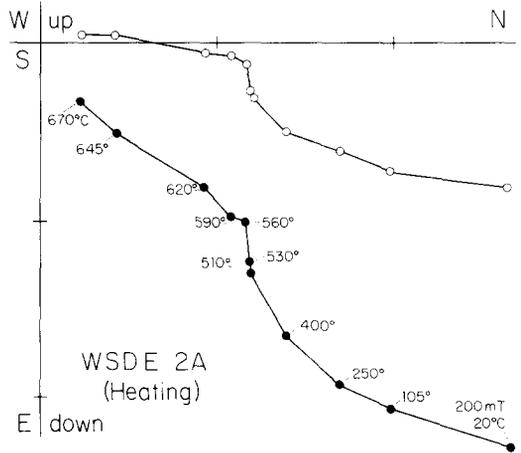
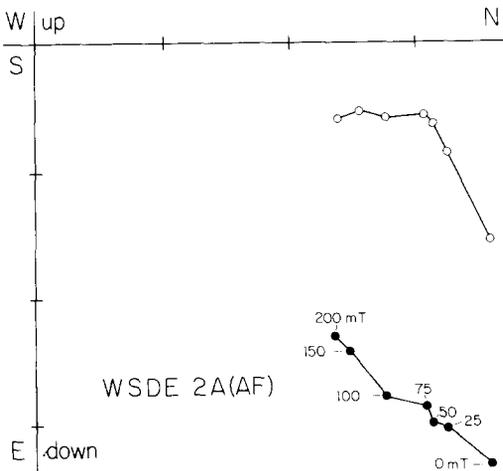
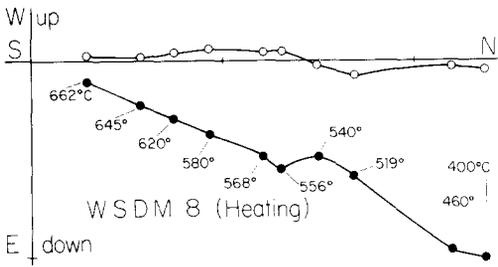
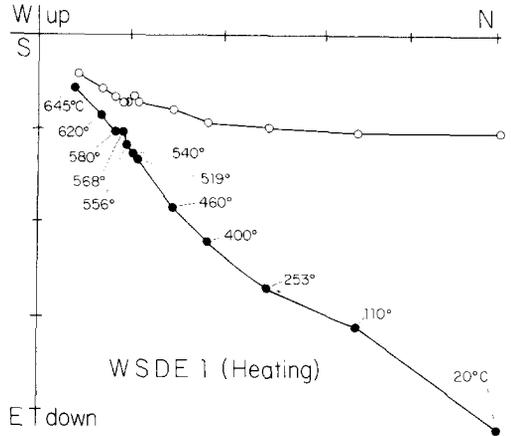
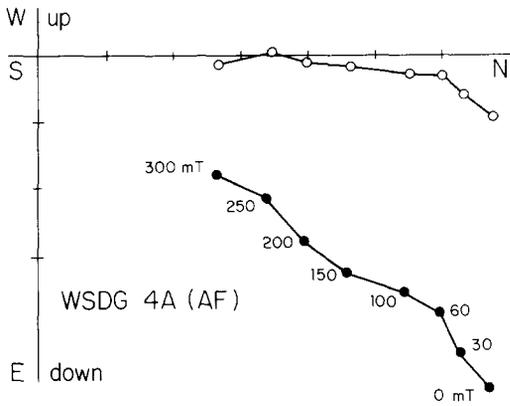
We applied thermal progressive treatment in 8–14 successive steps up to a maximum of 680°C. The demagnetization diagrams show that the characteristic remanence usually becomes isolated after heating at about 500°C (Fig. 3; WSDE 1). About 20–25% of the original remanence is left after heating at 580°C (Curie point of magnetite is 578°C). With progressive heating the decay of the remanence intensity is gradual until a minimum value of 660°C is reached; and example shows a section of the vector path between 400 and 600°C (Fig. 3; WSDM 8). Hematite is an important carrier of remanence.

Progressive AF treatments applied to specimens from sediments followed by demagnetization procedures with progressive heatings often furnish

TABLE 1
Paleomagnetic data from red beds of Early Devonian age in Central Iran

Sites	Strike-dip	<i>E</i>	<i>N</i>	AF	Th	AF+Th	<i>D</i> (°)	<i>I</i> (°)	<i>k</i>	α_{95} (°)
WSDA	302–44 NE	3	4	3	3	1	11.3	1.8	24	18.9
WSDB	323–28 NE	1	5	3	2	1	23.0	6.3	26	15.2
WSDC	269–83 N	4	6	3	4	3	10.1	–10.8	7	27.5
WSDD	269–83 N	2	10	3	1	8	23.1	–24.2	18	11.7
WSDE	315–56 NE	4	8	6	3	3	36.5	15.8	14	15.4
WSDF	310–57 NE	2	11	5	5	3	183.6	–27.4	18	11.2
WSDG	318–55 NE	–	14	6	5	3	38.1	–6.6	59	5.2
WSDH	318–53 NE	–	14	6	3	5	30.2	–9.6	32	7.4
WSDK	317–45 NE	–	10	2	4	4	35.7	7.5	23	10.2
WSDL	324–50 NE	–	7	4	3	–	35.5	6.1	94	6.3
WSDM	320–54 NE	–	8	4	3	1	29.9	–1.5	152	4.5
WSDN	320–54 NE	–	8	4	3	1	29.0	–1.7	137	4.7
WSDP	38–59 SE	–	8	5	3	–	3.9	–26.4	18	13.3

Strike and dip denote the mean attitude of the sites, where the samples were collected. *E* and *N* are the number of specimens excluded from and included in the ultimate analysis, respectively. AF, Th, and AF+Th are the demagnetization procedures applied to the indicated number of specimens, with alternating magnetic fields, heating, and alternating magnetic fields and subsequent heating, respectively. *D* and *I* are the declination and inclination in degrees of the characteristic magnetization direction after correction of tilt. *k* is the precision parameter; α_{95} is the semi-angle of the cone of 95% confidence, in degrees [23].



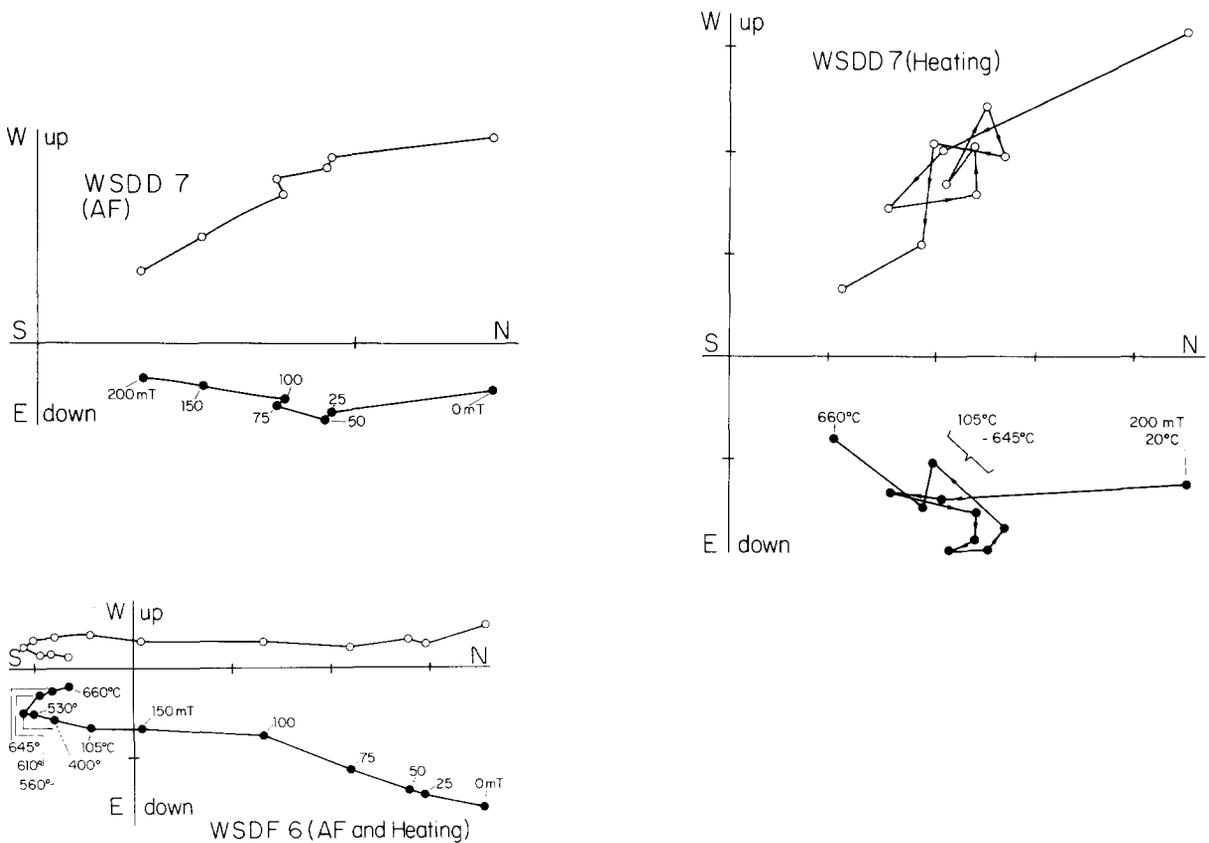


Fig. 3. Diagrams showing the progressive demagnetization of specimens from WSD sites of sediments of Early Devonian age from Central Iran, with alternating magnetic fields (AF)—WSDG 4A; with heating only—WSDE 1, WSDM 8; and with AF and subsequent heating—WSDE 2A, WSD 7 (in two diagrams) and WSD 6 (in one diagram). The plotted points represent in orthogonal projection successive positions of the end of the resultant NRM vector during progressive demagnetization. Solid and open circles denote the projections on a horizontal and on a north-south vertical plane. The numbers denote, “with AF treatment”, the peak strength in mT ($1 \text{ mT} = 10 \text{ Oe}$), and, “with heating”, the temperature applied in $^{\circ}\text{C}$. In the diagrams each unit on either axis represents $1 \times 10^{-3} \text{ A/m}$ ($1 \times 10^{-6} \text{ emu/cm}^3$). The characteristic remanence is obtained if the vector of remanence is a straight line which is directed towards the centre of the coordinate system and which decreases in length only, without changing its direction during subsequent steps of progressive demagnetization.

reliable data concerning the characteristic remanences [6]. We applied AF treatment to 33 specimens in seven successive steps up to a peak value of 200 mT; subsequently, these specimens were heated in nine successive steps up to a maximum value of 670°C . If AF treatment results in a very slow decay of the remanence intensity, subsequent heating can be successful. The example shows that the stable end point of the magnetization vector is not reached until the specimen is heated to 560°C (Fig. 3; WSDE 2A, two diagrams). However, quite often, subsequent heating is not needed; then, if

progressive heating is applied, the magnetization vector remains in situ (Fig. 3; WSD 7, two diagrams). The specimens from the site WSD 6 reveal a characteristic magnetization with reversed polarities. Some specimens from this site definitively needed to be heated, subsequent to AF treatment, in order to isolate the stable component of remanence (Fig. 3; WSD 6). Fortunately, the direction of this component of remanence agrees with the overall characteristic direction of magnetization.

TABLE 2

Mean characteristic remanence directions of red beds of Early Devonian age in Central Iran

Locality	<i>N</i>	<i>D</i> (°)	<i>I</i> (°)	<i>k</i>	α_{95} (°)
Hutk	4	16.8	-6.7	28	17.7
Kuh-i-Tizi	8	30.2	4.7	25	11.3
All sites	13	24.2	-1.3	18	10.1

N is the number of sites included in the ultimate analysis. See also caption to Table 1.

4. Paleomagnetic results

Carefully applied demagnetization procedures led to the detection of the characteristic component of magnetization in the majority of the specimens studied. From the 129 specimens included in the analysis, a total of 113 specimens from 13 different sites revealed stable remanence directions. The characteristic remanence may have been acquired before the deformation of the sediments, because the fold test was positive with $\alpha_{95} = 16.0^\circ$ and $\alpha_{95} = 10.1^\circ$ before and after tectonic correction, respectively. It should be noted, however, that the sampling areas are located quite far apart. Fortunately, there is a site with a reversed direction of remanence (site WSDP); this indicates that the characteristic remanences most likely originated during or very soon after the deposition of the sediments.

The mean characteristic remanence directions of the individual sites are listed in Table 1. In Table 2 we have listed the mean values computed

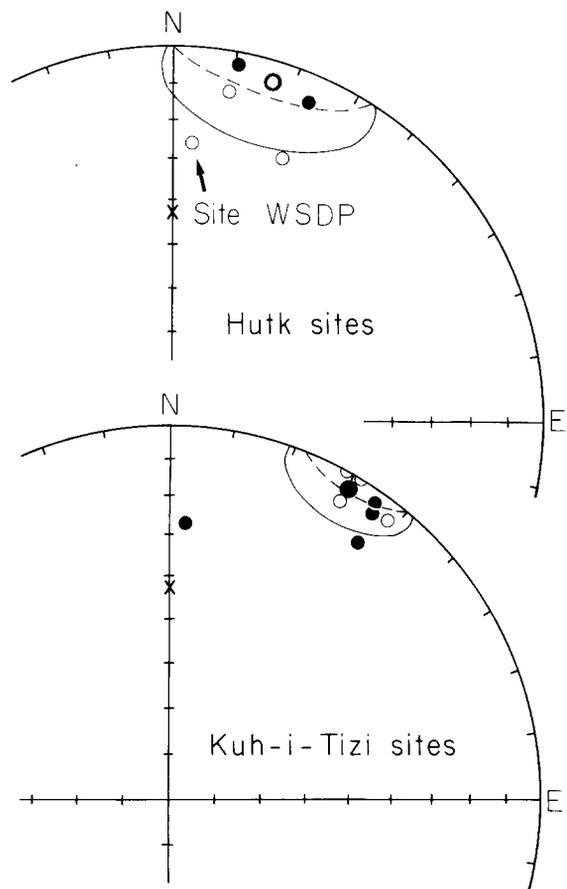


Fig. 4. Equal area projections of the characteristic remanence directions of individual sites from the Early Devonian red beds north of Kerman, with their overall mean. The projections are provided with 95% ovals of confidence. Open symbols denote upward-pointing directions; closed symbols denote downward-pointing directions. The cross marks the downward-pointing local direction of the present axial geocentric dipole field.

TABLE 3

Virtual geomagnetic pole positions of red beds of Early Devonian age in Central Iran

Locality	Positions of localities		Position of pole				Paleo-latitude (°N/S)
	lat. (°N)	long. (°E)	(°S)	(°E)	δ_p	δ_m	
All sites	30.5	57.2	51.3	16.3	5.1	10.1	0.7
Hutk	30.6	57.0	52.4	28.7	8.9	17.8	3.4
Kuh-i-Tizi	30.45	57.3	49.9	6.0	5.7	11.3	2.3

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

from the combined sites of the Hutk and the Kuh-i-Tizi localities; the mean value of all 13 sites included in this research is also presented in this table. The paleomagnetic pole positions are listed in Table 3. The mean characteristic remanence directions of the individual sites are plotted in two equal area projections, one showing the Hutk sites and the other showing the Kuh-i-Tizi sites; the overall mean direction is inserted in each projection (Fig. 4).

Recently, Soffel [7] in a compilation of his paleomagnetic research in Iran has presented data from sediments of Devonian age, collected at two different localities, viz., near Bagh-Golshan (57.07°E, 33.67°N), and near Sarda (57.0°E, 30.6°N); the latter locality is situated not far from our sampling locality at Hutk. The sediments near Bagh-Golshan revealed a reversed characteristic remanence direction. In the ultimate analysis, the author has included a total number of 31 specimens from five sites. After elimination of one site with a strongly deviating remanence direction, the mean characteristic magnetization after tectonic correction has a direction with $D = 350^\circ$ and $I = 10^\circ$. This result deviates slightly from the ultimate remanence direction presented in this paper.

5. Interpretation of the paleomagnetic data

Central Iran is surrounded by fundamental faults along which both translational and compressional movements occurred in Late Mesozoic and Tertiary times. Paleomagnetic results derived from sediments of Mesozoic age point to rotations of smaller blocks that are located in and near the fault zones [6]. Paleomagnetic data derived from volcanics of Eocene age [8,9] show that several blocks performed rotations, e.g. the Lut block; the area near Nain; an area in the southern part of the Central Alborz. Compression tectonics in a zone between the Eurasian and the Africa-Arabian plates resulted into post-Cretaceous movements at many places [8].

In the opinion of Davoudzadeh et al. [10] a central east Iranian microplate could have performed a counter-clockwise rotation of 135° since Triassic times. If this in fact occurred, paleo-

geographical and geological problems of some areas in the northern and eastern parts of this microplate would be adequately solved. The paleomagnetic data presented by these authors do not permit conclusions to be drawn concerning pre-Triassic times.

We are of the opinion that no rotations are required for the interpretation of the paleomagnetic results presented in this paper: viz., they are not required for interpreting the southern part of the Central Iranian block, where our sampling sites are located.

It will be argued that the position of the paleomagnetic pole derived from the red beds of Early Devonian age from Central Iran fits rather well on the alternative polar path for Gondwana through South America in Mid-Paleozoic times. The course of the apparent polar wander relative to Gondwana in Early and Middle Paleozoic times has been a matter of dispute. Until a few years ago it was generally accepted that in the Gondwana reconstruction with Africa at its present location, the polar path passed through Africa from a position to the north of this continent in Cambrian times towards a position near the boundary with Antarctica in Late Carboniferous times [11,12]. Australian paleomagnetic data have largely contributed to the construction of the Gondwana polar wander curve. However, paleomagnetic data derived from rocks of Paleozoic age from south-eastern Australia showed consistent discrepancies, which resulted in an independent drift history being proposed for this area [13]. Alternative polar paths for Gondwana from Cambrian through Devonian times have been proposed. Morel and Irving [14] have constructed a path with a bend from north to south through Africa with additional loops over South America and East Africa in Silurian to Early Devonian, and Middle to Late Devonian times, respectively (Fig. 5). These authors have included the data from southeastern Australia, because, in their opinion, the Tasman fold belt was located not very far from the main part of Australia. For the construction of another alternative polar path Schmidt and Morris [15] have used the same arguments. However, their curve differs considerably, because these authors used the antipoles of the Cambrian and Ordovician data. This

resulted in a wander of the south polar path from east of Australia in Cambrian times to far in the southern ocean in Ordovician times and towards South America in Silurian times. The section of the polar path in the Devonian agrees fairly well with the path proposed by Morel and Irving [14].

A number of geodynamic models has been pre-

sented for Iran and adjoining areas [16–18]. In one of the recently published, detailed paleogeographical evolutions of the region since Cambrian times no large displacements are shown during the Triassic [19]. In our opinion, geological and paleomagnetic data from Iran and Afghanistan support a Gondwana position for an Iranian-

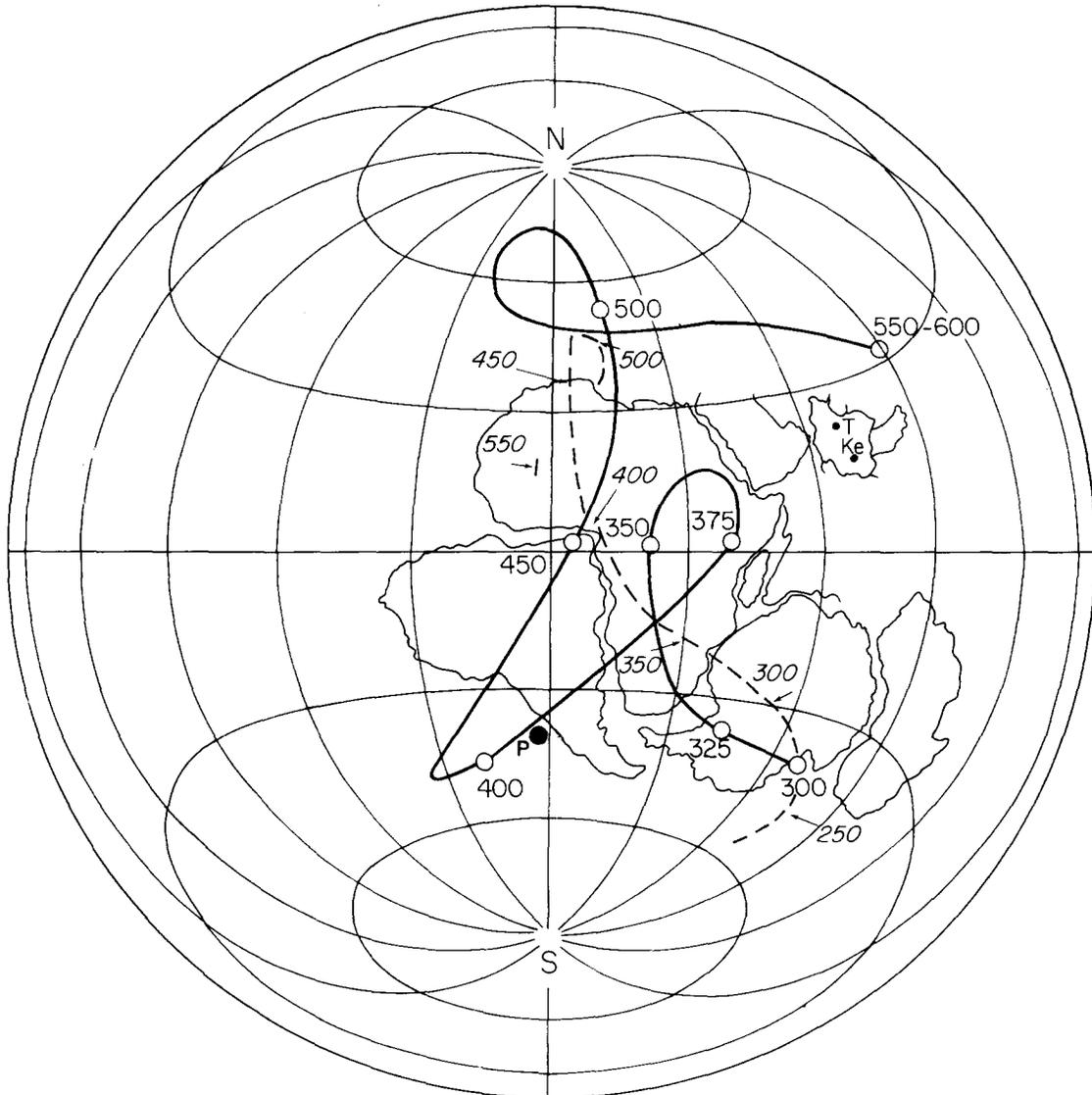


Fig. 5. Map showing the reconstruction of Gondwana relative to the present position of Africa. The map is provided with two polar wander paths for Paleozoic times: the conventional path [11,12] and the alternative path [14], which are indicated with a dashed line and a full line, respectively. *P* is the position of the paleomagnetic pole that is derived from Early Devonian sediments of Central Iran after the area has been shifted towards its most likely location in the Gondwana configuration.

Afghan microcontinent in Paleozoic times [20]. The paleomagnetic data derived from rocks of pre-Jurassic age from Iran point to a possible ancient position of the microcontinent in the present Arabian Sea just off the Arabian coast [4,6]. From the data presented in this paper one can derive that in Early Devonian times the area with red beds was positioned near the paleoequator (Table 3). Without the application of an additional rotation we can shift the Iranian-Afghan microcontinent from its present position to its ancient location in the Gondwana configuration in pre-Jurassic times, relative to Africa's present position. Then, the position of the Early Devonian paleomagnetic pole will move towards a position at about 5°W, 40°S (Fig. 5). This position is very near to the alternative polar wander path for Gondwana in Early Devonian times. Because of the rapid polar shift in Devonian times, earlier paleomagnetic data derived from basalts of the Alborz of Late Devonian to Early Carboniferous age are not in conflict with the present result [21]. The area of extrusions in the Alborz was located at a paleolatitude of 50°.

In the reassembly of continents for the successive periods [22] the paleopositions of Gondwana in Mid-Paleozoic times are based on the alternative paleomagnetic data. Considering the equatorial position of the sampling areas in Early Devonian times, the position of the Iranian-Afghan microcontinent fits well into the Gondwana reconstruction in those times.

The paleomagnetic data derived from the sites near Hutk do not coincide with those of Kuh-i-Tizi (Tables 2, 3; Fig. 4). The discrepancy can be explained in terms of differences in age between the sampled sections. According to Morel and Irving [14] there was a rapid shift of the pole relative to Gondwana in Devonian times; this shift may express the difference in the positions of our poles. If this is true, the section sampled in the Kuh-i-Tizi represents older rocks than the section sampled near Hutk.

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