Geofísica Internacional (1999), Vol. 38, Num. 1, pp. 17-26

A palaeomagnetic study of Syrian volcanic rocks of Miocene to Holocene age

J. M. Abou-Deeb[1], M. M. Otaki[1], D. H. Tarling[2] and A. L. Abdeldayem[2,3]

[1] *Department of Geology, The University of Damascus, Syria.*

[2] *Department of Geological Sciences, The University of Plymouth, U.K.*

[3] *Now at Department of Geology, University of Tanta, Egypt.*

Received: September 30, 1997; accepted: August 19, 1998.

RESUMEN

Rocas volcánicas del Mioceno y más jóvenes de varias localidades de Siria muestran polaridades normales y reversas después de desmagnetización térmica. Las similitudes en las direcciones medias de magnetización pueden ser usadas para establecer correlación entre lavas. Las polaridades observadas sugieren que algunas de las lavas del Cuaternario son más antiguas de lo propuesto en cartografías previas. Los sitios con direcciones medias reversas e intermedias presentan una dispersión angular mayor que la observada en los sitios de direcciones normales. La dispersión media global es mayor que la esperada de acuerdo con los modelos de variación secular simulados con deriva al oeste o este y el campo dipolar inclinado actual. Los sitios de polaridad normales tienen magnetizaciones dos veces mayores que los sitios de polaridad reversa e intermedia. La dirección media para los sitios del Cuaternario es consistente con el campo dipolar axial, pero para los sitios del Mioceno, con direcciones antipodales de polaridades opuestas, tienen una inclinación media más somera que la dipolar, lo que sugiere un efecto geomagnético o inclinación regional tectónica.

PALABRAS CLAVE: Paleomagnetismo, volcanismo, magnetoestratigrafía, Neógeno, Siria.

ABSTRACT

Miocene and younger volcanic rocks from Syria show both normal and reversed polarities after thermal demagnetisation. Similarities in site mean directions may be used to establish lavas erupted at similar times. The observed polarities suggest that some Quaternary volcanics are older than previously mapped. The site mean directions of reversed and intermediate polarity sites are more scattered than for normal polarity sites, and the overall scatter is larger than would be expected from models of secular variation simulated by westward or eastward drift of the present non axial dipole field. The normal sites are also twice as strongly magnetised as the reversed and intermediate polarity sites. The mean direction of the Quaternary sites is consistent with an axial geocentric dipole model, but the Miocene sites, while having antipodal directions for the two polarities, have a mean inclination that is shallower than the axial dipole field and may indicate persistent geomagnetic effects or possibly regional tilting.

KEY WORDS: Paleomagnetism, volcanism, magnetostratigraphy, Neogene, Syria.

INTRODUCTION AND REGIONAL GEOLOGY

Although there have been recent studies of Miocene volcanics from south of Damascus (Roperch and Bonhommet, 1986), there are still few palaeomagnetic studies within Syria and most were undertaken some years ago (Van Dongen *et al*., 1967). To improve the quantity and quality of the palaeomagnetic information from this region, samples were collected from a sequence of sedimentary and igneous rocks from different parts of Syria (Figure 1). The results from the igneous rocks are described here. Syria occupies the northern part of the Arabian Shield and comprises both tectonically stable and active zones (Ponikarov, 1966; Best *et al*., 1993). The stable zones include the Rutbah uplift in the south-east and the Jordan uplift in the south, separated by the Drouz depression. Ophiolitic rocks were emplaced with other volcanic extrusives in the Jurassic and two phases of volcanism occurred in the Cretaceous (Dubertret, 1933). In the Aleppo region, there was a brief phase of volcanic activity during the Palaeogene (Mouty *et al*., 1992). In Miocene to Holocene times, there was active volcanism over most of Syria, although it occurred predominantly along the margins of the rift zone to the south and south-west. These younger volcanics commenced with subaerial flood basalts in the Early Miocene, mostly 20 to 16 Ma ago, and extended over most of southern Syria, Jordan and Saudi Arabia, although this phase is absent along the coastal zone (Mouty *et al*., 1992). A period of quiescence followed until *c*.8 Ma ago when intensive volcanism commenced over most of Syria, but particularly along the rift margins in the south. Some 400 largely basaltic volcanoes were formed at this time, mostly associated with NNW/SSE fissures. These now form a volcanic shield which is some 1500 m thick in the Drouz depression. This phase of volcanism remained active into prehistoric time; for example, the Majdel Shams volcano (in the Golan Heights) and the Abou Rasein volcano (Jabal Al-

Arab) in south-eastern Syria. The present study was concentrated on Miocene to Holocene flows to the north, south and south-east of Damascus (Figure 1 and Appendix). The Lower Miocene rocks from the south are from the same area as those sampled by Roperch and Bonhommet (1986) but few, if any, appear to be from the same flows. All of the sampled outcrops had only been mapped as separate units, based on their composition and age, with no distinction between different lava flows. Stratigraphic relationships between the igneous rocks are hard to establish as the area largely covered by later igneous rocks and the sediments are mostly of Upper Quaternary and Recent age. Some flows had been radiometrically dated by Ponikarov (1966) and a few other areas have been dated radiometrically using whole-rock K/Ar methods (Mouty *et al*., 1992), although the later was subsequent to the palaeomagnetic sampling. Roperch and Bonhommet (1986) also reported a K/Ar determination for one of their sites. In the field, it is difficult to establish the field relationships between isolated outcrops, even when only a few hundred meters apart, and it was not possible to identify the radiometrically-dated lavas with any degree of certainty. One of the objects of this study was to evaluate the extent to which palaeomagnetism could be used to assist in further chronological differentiation, although some of the data also have geomagnetic significance.

SAMPLING

Quaternary basaltic flows were sampled at 18 separate sites, with 6 samples collected at virtually all sites along the roadside from Damascus towards Suweida in the Jabal Al-Arab area (Figure 1). Fifteen of these sites (S1-15) were isolated outcrops of sub-alkaline basalts, anamesites, scoria and agglomerates from volcanic units that have been mapped as β_4Q_4 (Ponikarov, 1966). Three other sites (S16-18) were from a younger flow of similar composition mapped as β_1Q_4. Upper Pliocene basaltic flows, map unit βN^b_2, were sampled at four sites (H1-4) in outcrops along the roadside from Homs towards Safita in the west. Two independent samples from this area were later dated as 5.5±0.1 and 5.4±0.1 Ma (Mouty *et al*., 1992), probably corresponding to sites H1 and H2 (or H3) respectively. A further five palaeomagnetic sites (H5-9) were obtained from west and north-west of Homs where a lava flow, probably H5 or H6, has since been dated as 8.5±0.8 Ma (Mouty *et al*., 1992). Near to the village of Al-Kisweh, south of Damascus, basalts, plagiobasalts, ankarmites and picrites have been mapped as unit βN^2_1 from which three separate samples have since been radiometrically (K/Ar) dated as 19.2±0.6, 16.7±0.6, 16.7±0.5 Ma (Mouty *et al*., 1992) and one sample had previously been dated at 19.5 Ma (Ar^{39}/Ar^{40}; Roperch and Bonhommet, 1986). These basalts were sampled at nine sites (K1-9) for this palaeomagnetic study. The first two radiometric determinations probably correspond to an uppermost Early Miocene age for the K6-9 sites and the 16.7±0.5 Ma date suggests a mid Early Miocene age for the K13-15 sites. A further nine palaeomagnetic sites (K10-18) were collected from the Tell Abou-Aba area. One flow from this locality was subsequently dated as 24±0.6 Ma (Mouty *et al.*, 1992), probably corresponding to one of the K16-18 sites. Site 24 of Roperch and Bonhommet (1986), with an Ar^{39}/Ar^{40} age of 19.5 Ma, is probably close to sites K6-9 of this study, indicating a possible mid Early Miocene age. The radiometric ages from all of these units suggest that, although mapped as Middle Miocene (Ponikarov, 1966), may be, at least in part, of Early Miocene or even Late Oligocene age. Sites K19-21 are in basalts near Ash-Shegranieyeh and sites K22-30 in the Drowsheh area have been mapped as being of mid Miocene age, but no radiometric checks are available on this stratigraphic age estimate. All rock units were sampled using conventional palaeomagnetic drilling techniques (Collinson, 1983; Tarling, 1983) and virtually all orientations were made using a sun compass. The field cores were sliced to provide standard samples, 2.5 cm in diameter and 2.1 cm height.

MEASUREMENT AND ANALYSIS

The intensity and direction of remanence was measured with a Digico spinner magnetometer (Molyneux, 1971) which has a background noise level of *c*.0.02 mA/m. Incremental thermal demagnetisation, using 9 steps up to 600°C, was undertaken on 8 samples from different sites (Table 1).

Table 1

Parameters defining the behaviour of selected specimens to thermal partial demagnetisation.

Sample	CI	range	Dec_c	Inc_c	da	range	Dec_d	Inc_d
Quaternary								
S 1.5	4.4	20-600	35.1	19.6	5.0	100-300	5.0	10.0
S 9.5	18.5	50-200	293.1	-71.2	3.2	20-550	201.5	-60.2
Upper Pliocene								
H 1.6	19.2	20-400	344.4	52.9	1.3	200-zero	345.3	52.3
H 9.6	20.9	20-300	197.2	-60.3	3.5	100-350	201.5	-60.2
Miocene								
*K1.6	4.0	50-500	307.1	45.8	4.4	300-550	311.6	42.6
*K9.5	1.1	50-200	183.7	8.0		none identified		
K18.1	29.6	200-400	113.9	36.0	1.7	400-550	114.6	35.3
K27.6	24.0	20-300	3.4	31.1	1.9	20-600	3.5	31.5

CI = Consistency Index (SI of Tarling and Symons, 1967) with the range of temperatures over which the declination and inclination of the mean direction (Dec_C; Inc_C) is defined; da = diagonal angle of linearity (MAD of Kirschvink, 1980) with the range of temperatures over which the mean direction (Dec_d Inc_d) is defined. * See text for discussion.

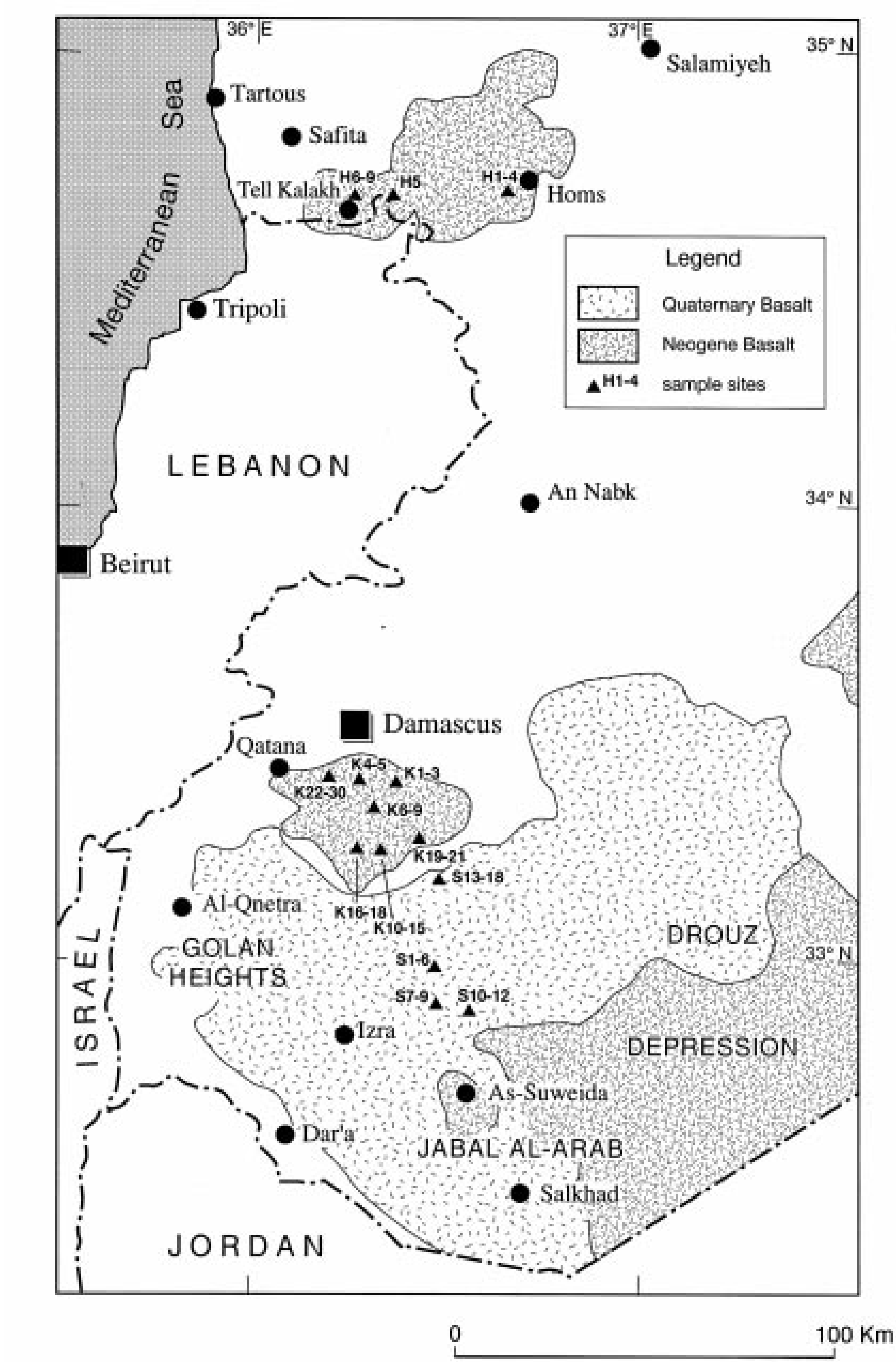

Fig. 1. Outline geological map of Southwestern Syria. The sampling sites are marked and the generalised geology indicated for Neogene to Holocene times.

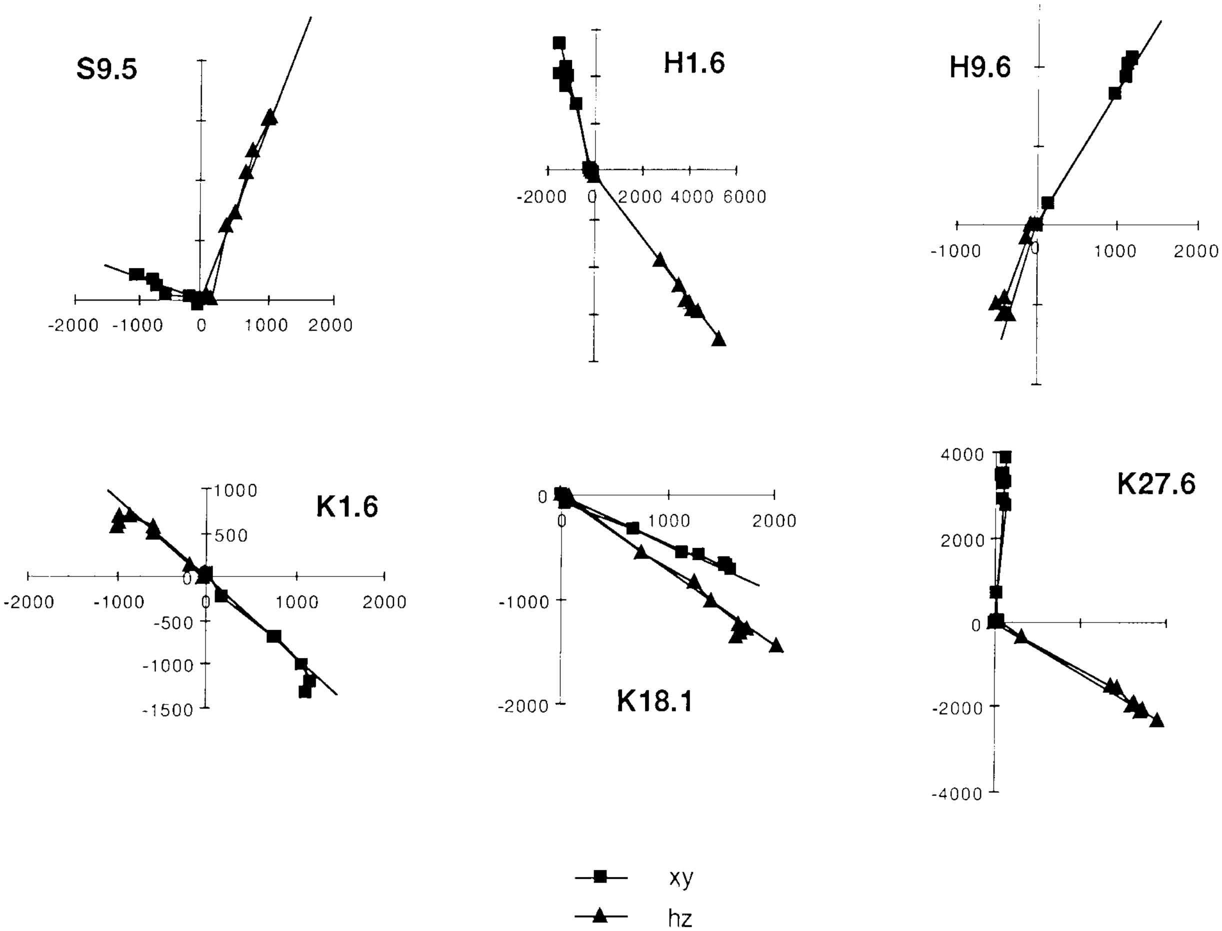

Fig. 2. Examples of thermal demagnetisation behaviour. Cartesian plots of the vector changes during incremental heating (20°, 50°, 100°, 200°, 300°, 400°, 450°, 500°, 550° and 600°C) in zero external magnetic field. The horizontal (x *vs* y) and vertical (h *vs* z), where h = $(\sqrt{(x^2 + y^2)})$, components are shown. The axes are labelled in mA/m units. The best-fitting line, including the origin, is also shown.

(Alternating magnetic field demagnetisation was also undertaken on some specimens, but was ineffective in isolating a characteristic component). Most thermally demagnetised samples showed similar consistent directional behaviour (Figure 2) on consistency (Tarling and Symons, 1967) and linearity (Kirschvink, 1980) tests with only one clear vector being defined for each sample. The ranges over which the consistent directions were defined were generally over slightly lower levels than those identified by the linearity analyses, while the upper limit was marked by a rapid decrease in the length of the vector at temperatures just above 500°C, with consequential decrease in precision and usually accompanied by an increase in low-field susceptibility. Two pilot samples exhibited anomalous behaviour. Sample K9.5 showed irregular changes in the direction and intensity of the vectors at different levels of demagnetisation. The intensity of remanence at 400° and 450°C was 2.5 times the initial intensity and, at these temperatures, the low-field susceptibility, reached 3.7 times its initial value. Consequently no linear component could be identified, although the directions were sufficiently consistent, despite the change in magnetic mineralogy, to suggest a reversed polarity. Sample K1.6 had a maximum Consistency Index between 20° and 100°C, suggesting that viscous components were dominant; the linearity analyses were influenced by a small angular changes with virtually no decrease in vector length. Nonetheless, most sites behaved similarly, with a distinct linear vector being identified between 200 and 400°C, but the low-field susceptibility tended to increase above 350°C. On this basis, all remaining samples were thermally demagnetised at temperatures between 200° and 300°C to enable definition of the characteristic component to be evaluated from the linearity analysis (Kirschvink, 1980).

Well defined linear components were defined as those with a mean diagonal angle (MAD)<5° and were consequently associated with a small angular differences between the two directions. Where the mean diagonal angle exceeded 5° and the separation angle was greater than 10°, each vector was examined more rigorously. In only 11 of the sites was it found that the 200°C vector appeared to include viscous or other components. In 9 of these sites, the

Table 2

Site Mean Characteristic Directions from Suweida (Quaternary)

Site	N/n	Susc.	M_{200}	Dec.	Inc..	*k*	α_{95}	mda	Virtual lat.	Pole long.	Polarity
Quaternary, Holocene (β_1Q_4)											
S16	6/6	924	2137	88.1	23.8	111	6.4	2.1	8.3	117.0	I
S17	6/6	1089	2644	36.6	-42.3	347	3.6	1.1	22.6	180.5	I
S18	6/6	502	6261	322.2	25.6	216	4.6	1.9	50.4	258.8	N
Quaternary, Holocene (β_4Q_4)											
S 1	6/6	340	2853	47.6	16.1	417	3.3	1.8	39.6	144.8	N(i)
S 2	6/6	413	4424	10.6	60.0	937	2.2	2.2	78.4	80.3	N
S 3	6/6	416	1757	36.8	77.7	577	2.8	1.9	50.1	58.3	N
S 4	6/6	749	2815	180.6	-19.5	277	4.0	4.0	-67.0	34.9	R
S 5	6/6	336	3097	164.2	-29.8	71	8.0	1.3	-67.8	80.2	R
S 6	6/6	400	1595	3.9	63.8	80	7.5	2.2	77.2	48.8	N
S 7	5/6	501	7475	26.6	55.1	173	5.8	3.9	67.9	111.9	N
S 8	6/6	405	10051	27.2	64.5	54	9.2	1.9	65.3	85.4	N
S 9	6/6	329	5642	281.7	-73.6	473	3.1	2.8	-22.4	248.9	I
S10	6/6	159	3649	359.4	56.9	402	3.3	0.9	85.4	30.6	N
S11	6/6	219	4125	319.1	59.3	152	5.5	1.2	56.6	330.9	N
S12	6/6	124	3605	1.0	52.3	204	4.8	1.5	89.2	126.2	N
S13	5/6	782	2518	354.2	64.9	240	4.9	3.3	75.6	20.3	N
S14	4/6	804	2868	359.5	63.0	860	3.1	3.6	78.7	34.7	N
S15	6/6	404	1992	350.9	53.9	5355	0.9	0.9	82.3	318.3	N

Estimates of precision *k* and α_{95} (Fisher, 1953) are based on N samples of the n samples collected; mda = the arithmetic mean diagonal angle (MAD of Kirschvink, 1980) for each site. M_{200} is the mean site intensity of remanence at 200°C in mA/m. Susc. is the low-field susceptibility (mSI). The virtual geomagnetic pole (V.G.P.) location is defined by latitude (lat.;-ve S) and longitude (long.; +ve E). The polarity assignments are based on: Normal = N = VGP latitude >50°N; N(i) if 30-50°N. Reversed = R = VGP latitude >50°S; R(i) if 30-50°S. Intermediate = I = VGP latitude <30°N/S.

characteristic direction was calculated as the mean of the sample directions at 300°C as this grouping was smaller (defined using α_{95} - Fisher, 1953) than the separation angle between the 200 and 300°C directions (Tables 2-4). The data from site K10 was too scattered to assign a mean direction, although the sample directions suggested a reversed polarity. Another site, K6, showed more complex behaviour with consistent reversed sample directions at 200°C, but five of the 6 samples became normally magnetised at 300°C (Table 4). The explanation for this behaviour is not clear, but it may indicate that the lava at this site was originally of normal polarity and was later reheated between 200° and 300ºC by a later flow erupted during a reversed chron. As there is no field evidence for, or against, this supposition, two site characteristic directions have been assigned to this site. The average initial site mean intensity was 3.48±0.43 A/m, remaining almost unchanged at 200°C (3.37±0.50 A/m), and only decreasing by some 15% at 300°C (2.87±0.39 A/m).

Interpretations and Conclusions

(a) Magnetostratigraphy

As each lava preserves a record of the geomagnetic field direction during cooling, it should be possible to compare the site mean directions at any locality to establish whether or not any of the sites could possibly be coeval on the basis of the similarity of their mean remanence directions. Few of the site mean directions (Tables 2-4, Figure 3) approach being identical, with the possible exception of sites H2 and H3. Even these are sufficiently different to suggest that the flows were not precisely coeval. Thus the site mean directions can

Table 3

Site Mean Characteristic Directions from Homs-Safita (U. Pliocene βN^{b}_{2}).

Site	N/n	Susc	M_{200}	Decl	Incl.	*k*	α_{95}	mda	Virtual	Pole	Polarity
H1	6/6	764	4122	354.3	50.5	968	2.2	1.6	84.1	272.3	N
H2	6/6	2812	5052	198.5	-18.7	332	3.7	1.1	-59.7	358.2	R
H3	6/6	653	825	187.5	-17.1	104	6.6	*	-63.1	20.0	R
H4	5/6	4789	1954	206.2	-43.5	1022	2.4	2.3	-65.6	321.9	R
H5	6/6	3338	1021	178.3	-52.0	71	8.0	*	-87.5	71.0	R
H6	5/6	4266	1125	184.7	-21.5	107	7.4	*	-66.1	24.8	R
H7	6/6	2104	2600	165.4	-45.8	43	10.4	7.7	-75.4	99.2	R
H8	6/6	6160	1975	162.5	-55.1	119	6.2	*	-75.7	135.0	R
H9	6/6	1583	2503	193.4	-61.7	2224	1.4	0.9	-76.8	264.1	R

Legend as Table 2. * Site mean direction = mean of sample directions at 300°C.

Table 4

Site Mean Characteristic Directions from the Kisweh Area (Mid Miocene (βN_1^2)

Site	N/n	Susc.	M_{200}	Decl	Incl.	*k*	α_{95}	mda	Virtual	Pole	Polarity
K1	6/6	2286	2056	307.1	43.5	745	3.5	1.6	43.7	310.9	N(i)
K2	6/6	2763	2022	133.6	-40.2	2543	1.3	2.7	-48.1	124.2	R(i)
K3	6/6	2213	5867	178.9	-47.2	129	5.9	1.6	-84.9	47.2	R
K4	6/6	2556	1290	182.7	-40.2	19	15.8	19.4	-79.2	22.8	R
K5	6/6	2986	2820	193.0	-35.7	2249	1.4	1.2	-72.1	352.6	R
K6 300C	5/6	1031	593	344.6	34.9	8	28.2	*	70.3	264.5	N
K6 200C	5/6	1031	593	168.5	-25.1	5	32.6	27.2	-67.3	66.5	R
K7	4/6	977	544	145.5	32.7	8	34.1	*	-29.2	74.5	I
K8	5/6	1206	596	121.9	11.1	22	16.7	*	-22.7	102.6	I
K9	4/6	615	3650	165.7	26.6	56	12.4	*	-40.7	54.7	R(i)
K10	0/6	2728	961	scattered;	mda =	23.7°,	α_{95} =	> 90°			(R)
K11	6/6	1953	1309	187.4	-28.9	11	20.9	*	-71.0	13.9	R
K12	6/6	2377	1678	212.5	-14.9	39	10.9	10.4	-50.5	339.4	R
K13	6/6	870	7277	356.8	30.7	814	2.4	1.2	73.1	226.9	N
K14	6/6	338	1090	3.3	31.7	236	4.4	1.5	73.7	205.0	N
K15	4/6	1781	11717	36.9	-1.7	575	3.8	1.5	41.4	163.2	N(i)
K16	6/6	373	408	19.6	34.6	114	6.3	7.6	67.5	160.3	N
K17	4/6	796	4484	27.1	10.1	90	9.7	*	52.2	168.4	N
K18	6/6	997	2799	100.2	28.5	5	32.4	5.3	0.0	108.0	I
K19	6/6	628	2891	187.8	-43.4	7677	0.8	0.6	-79.6	353.7	R
K20	6/6	374	1656	195.2	-36.0	630	2.7	0.9	-71.1	347.0	R
K21	5/6	390	1293	194.6	-41.3	197	5.5	*	-74.1	33.2	R
K22	6/6	721	1013	0.1	46.5	812	2.4	5.3	84.4	215.2	N
K23	6/6	2057	5006	2.1	24.3	141	5.7	1.3	69.2	210.3	N
K24	6/6	2095	6315	0.5	34.9	1922	1.5	0.8	75.8	214.2	N
K25	6/6	1018	5264	1.6	38.3	341	3.6	1.0	78.1	208.9	N
K26	7/7	1957	3998	6.0	32.7	79	6.8	1.0	73.5	195.6	N
K27	6/6	1959	5411	1.8	32.2	712	2.5	1.4	74.0	209.9	N
K28	6/6	1881	6154	8.6	37.9	332	3.7	1.7	75.7	181.8	N
K29	6/6	2006	6160	2.6	36.8	260	4.2	3.1	76.9	205.3	N
K30	6/6	2152	7165	5.1	34.3	285	4.0	0.9	74.7	197.5	N

Legend as Table 3.

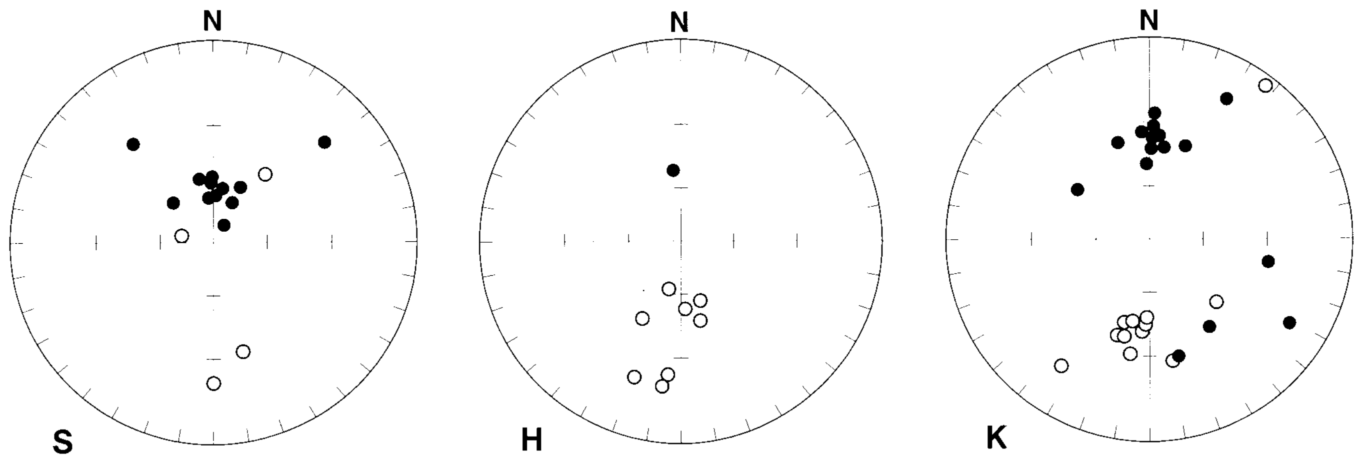

Fig. 3. The mean site characteristic directions. The projection is an equal-angle stereographic projection. Normal site directions are shown solid; reversed site directions are shown as hollow. The Quaternary (S), Upper Plioecene (H) and Lower/Middle Miocene (K) all show normal and reversed polarity, but include clearly anomalous site direction.

be used to distinguish between different flows at the same locality although an identity in direction is only meaningful, in these circumstances, if the precision of the individual site mean directions is high. Even then, identical directions may not necessarily have been acquired at identical times because the geomagnetic field direction can be the same at different times. For example, there are some 11 repeated directions within the British archaeomagnetic record of geomagnetic secular variation during the last 2000 years (Tarling and Dobson, 1995).

Although three separate sites were usually collected at each locality, the stratigraphical relationship between them was usually enigmatic so it is conceivable that different sites could be in the same flow at different outcrops. There is actually little agreement between the site directions at each locality, suggesting that this only happened rarely, if at all. Of the Quaternary sites that might be in an identical flow, only site pair S13-S14 had identical mean directions and small α_{95} values (<5°); the site mean directions for S7-S8 were identical, at a 95% confidence level, but their corresponding precisions were poor (α_{95}>5°). Amongst the Pliocene sites (H), only sites H7 and H8 had overlapping but large 95% precision radii whereby they may be coeval, but the certainty of this must be low. Of the Miocene sites, K13 and K14 had statistically identical directions, while the definition of site K10 was poor. However, all of the sites K22 to K30, from an area of *c*.0.3 km^2, have such similarity that it is possible that they were all derived from a single basalt flow or from flows that were erupted during the same one or two decades. More sophisticated comparisons are not considered meaningful, but it is clear that this technique has been effective in distinguishing those flows that are clearly not coeval, even if the evidence for possible synchroneity must remain ambiguous without the support of field evidence.

Table 5

Polarities and Mean Directions of Syrian Miocene Lavas.

Polarity	N	Decl	Incl	k	α_{95}	
Quaternary Sites (S)						
Normal	12	356.8	60.2	22	9.4	
Reversed	2	172.7	-24.9	-	-	
N + R	14	356.0	56.1	11	12.4	
Upper Pliocene (H)						
Normal	1	354.3	50.5	-	-	
Reversed	8	185.6	-40.3	15	16.7	
N + R	9	4.5	41.5	17	13.1	
Lower/Middle Miocene (K) This Study						
Normal	14	4.6	33.3	47	5.8	This Study
Normal	5	5.6	18.5	15	20.4	R & B
Normal	19	4.9	29.6	25	6.9	combined
Reversed	9	189.4	-35.4	31	9.4	This Study
Reversed	19	177.5	-35.9	29	6.4	R & B
Reversed	28	181.3	-35.9	74	3.2	combined
N + R	47	2.8	-33.4	39	3.4	
Overall Miocene to Quaternary						
Normal	32	2.5	41.7	14	7.1	
Reversed	38	183.6	-37.7	25	4.8	
N + R	70	3.1	39.5	18	4.1	

Calculated giving equal weight to each of N site mean directions. Intermediate sites are excluded as being too few and scattered to be physically meaningful but are discussed in the text. R & B = data from Roperch & Bonhommet (1986).

As the sites are all in middle to low latitudes (*c*.33°N) and are young (≤24 Ma), it is reasonable to assume that the average geomagnetic field would correspond to that of an axial geocentric dipole. Intermediate polarity can thus be defined as the virtual geomagnetic pole lying within 30° of the present Equator, with intermediate (normal) and intermediate (reversed) polarities defined as the virtual geomagnetic pole being between 30° and 50°N, or S, respectively (Tables 2-4). The younger Quaternary sites (S16-18) include only one normal polarity and two intermediate polarity sites. This surprising result suggests that two flows may have been extruded during the Matuyama/Brunhes boundary at 0.78 Ma (Baksi *et al*., 1992) or that they are associated with times of short polarity events, such as the Blake Event at 90-100 ka (Einders and Hambach, 1995). The older Quaternary sites (S1-15) comprise 12 normal, 2 reversed and 1 intermediate polarity sites. This is consistent with most of these lavas being younger than 0.78 Ma, but 2 sites may well be either older or associated with brief polarity events. The Upper Pliocene sites (H) are almost entirely reversed (8 of 9 sites). Such a predominance of a single polarity would be most consistent with eruptions that mostly occurred during chrons 2r.1 and 2r.2, i.e., between 1.98 and 2.60 Ma (Candé and Kent, 1992). The polarities of the Miocene (K) sites (16 normal, 12 reversed, 3 intermediate) are consistent with almost any Miocene age range. If the observations of Roperch and Bonhommet (1986) are included, using the same polarity definitions, then there are 20 normal sites, 31 reversed and 9 intermediate polarity sites. In view of the frequency of polarity changes during the Miocene (Candé and Kent, 1992), the range of radiometric age determinations and the lack of clear stratigraphic controls, it is not practicable to establish magnetostratigraphic correlations using the current observations. Clearly palaeomagnetic techniques provide a cheap alternative to test the synchroneity of separated exposures in the sense of determining if they are of similar or opposite polarity. However, the available stratigraphical controls still largely prevent the identification of specific chrons and hence the production of a stratigraphic table. Future studies need to be in conjunction with other stratigraphic analyses, particularly $^{39}Ar/^{40}Ar$ analyses.

(b) Geomagnetic Implications

The mean initial intensity of remanence of the normal polarity sites (4.62±0.60 A/m) was almost twice that of both the reversed polarity sites (2.29±0.25 A/m) and of the intermediate polarity sites (2.32±0.25 A/m). This difference is not due to a difference in low-field susceptibility as this averages 0.92±0.60 mSI for the normal polarity sites and 2.26±0.25 mSI for the reversed polarity sites. Neither does it appear attributable to differences in the magnitude of the viscous components as the decrease in intensity is almost identical for both polarities at 200°C (N 5%; R 7%), although there is a somewhat greater drop of intensity in the normal sites by 300°C (N 24%; R 10%). This suggests that a similar magnitude viscous temperature component was present in all sites, irrespective of polarity. In terms of directional properties, the individual site mean directions were generally better defined than the grouped mean site directions, suggesting that the site remanences record secular variations. The scatter of site mean directions can therefore be compared with the standard model of present day secular variation (Creer, 1962). The expected scatter in this model is generated by determining the total latitudinal drift of the present geomagnetic field for the appropriate latitude. For the present latitude, 33°N, the expected circular standard deviation of site directions would be some 13°, for the northern hemisphere, or 8° if the present asymmetry between the northern and southern hemisphere is averaged (Creer, 1962, Tarling, 1983). The observed circular standard deviation for the normal polarity sites, including those of Roperch and Bonhommet (1986), is 21.7° and for the reversed polarity sites it is 16.2°. These are both greater than predicted on this simplistic geomagnetic secular variation model and may indicate a greater magnitude of geomagnetic secular variation may have characterised this region during the last 10-20 Ma.

The mean directions expected for this age would be similar to that of the axial geocentric dipole, i.e. Decl. 0.0°, Incl. 52.4°, which is similar to the IGRF field, 3.1°, 48.7°, at the time of collection (1992). Although the Arabian plate has been moving relative to the African and European plates during the time of extrusion of these lavas, forming the Red Sea and Gulf of Aden, the angular change in the orientation of the mean palaeomagnetic direction by such tectonic rotations lies within the precision with which the mean directions have been determined (Table 5). However, the older sites tend to have much shallower inclinations than can be accounted for by the northward translation of the Arabian plate during this time. This could mean that this area was influenced by a shallow component of the geomagnetic field during the Miocene and that this had largely disappeared by Quaternary times. A decreasing tectonic tilt could also be envisaged, possibly related to volcanic loading and/or magma chamber collapse to the south of the area. Both models require further testing and these suggested explanations must be tempered by the large scatter observed between all site directions.

ACKNOWLEDGEMENTS

We are grateful for financial support by the British Council in Sana’a (Yemen) and Damascus (Syria). We particularly thank Dr. Peter Clark of the British Council, Damascus, and officials of the University of Damascus, especially the Head of the Geology Department, Prof. W. Rasol Agha, and officials in the Higher Education Ministry, especially Prof. H. Kharof. We also thank Prof. A. Kh. Al-Maleh, Director of the General Establishment of Geology and Mineral Resources, and Mr. M. Kh. Al-Laham and Mr. Z. Al-Sahar for their help in the field.

APPENDIX

Site locations

Site	Latitude	Longitude	Location
All Suweida (S) sites are of Quaternary (Holocene) age			
Quaternary (Holocene) but younger than S1-15			
S16	33 10 00	36 30 38	300 m E main road, 4 km SE of Buraq
S17	33 10 00	36 30 38	300 m E main road, 4 km SE of Buraq
S18	33 10 00	36 30 38	300 m E main road, 4 km SE of Buraq
Quaternary (Holocene) but older than S16-18			
S 1	32 57 50	36 23 35	3 km E of Jadel towards Damascus
S 2	32 57 50	36 23 35	3 km E of Jadel towards Damascus
S 3	32 57 50	36 23 35	3 km E of Jadel towards Damascus
S 4	32 57 50	36 23 35	3 km E of Jadel towards Damascus
S 5	32 57 50	36 23 35	3 km E of Jadel towards Damascus
S 6	32 57 50	36 23 35	3 km E of Jadel towards Damascus
S 7	32 57 04	36 25 46	E side Dama village
S 8	32 57 04	36 25 46	E side Dama village
S 9	32 57 04	36 25 46	E side Dama village
S10	32 55 46	36 29 06	start of Al Kharsa
S11	32 55 46	36 29 06	start of Al Kharsa
S12	32 55 46	36 29 06	start of Al Kharsa
S13	33 10 52	36 29 06	150 m S of Buraq
S14	33 10 52	36 29 05	near Buraq
S15	33 10 52	36 29 05	near Buraq
All Homs-Safita (H) sites are of Upper Pliocene age (Ponikarov, 1966)			
H 1	34 43 23	36 38 41	7 km W of Homs towards Safita
H 2	34 43 23	36 37 48	8.5 km W of Homs, near Kherbat Al Teen
H 3	34 43 23	36 37 12	W of Kherbat Al Teen
H 4	34 43 03	36 35 55	12 km W of Homs
H 5	34 41 13	36 17 38	2.5 km W of Al Aredda junction
H 6	34 40 54	36 15 00	1 km N of Tel Kalekh, 5 km from fault
H 7	34 40 47	36 13 09	6 km from Tel Kalekh
H 8	34 40 47	36 12 22	as H7, but 8 km from fault
H 9	34 41 46	36 11 27	500m before junction motorway & Safita road
All Kisweh (K) sites are attributed to Mid Miocene (Ponikarov, 1966)			
K 1	33 21 54	36 17 20	3 km E of Al Kisweh, foot Jabal Missyadeh
K 2	33 21 54	36 17 20	3 km E of Al Kisweh, foot Jabal Missyadeh
K 3	33 23 38	36 15 39	N of K1 & 2 in Jabal El Kalb
K 4	33 23 06	36 14 29	3km before Kisweh on right side road
K 5	33 23 06	36 14 29	3km before Kisweh on right side road
K 6	33 20 37	36 16 18	Jabal El Mane
K 7	33 20 37	36 16 18	Jabal El Mane
K 8	33 19 51	36 16 18	500m S of K6 & K7, Jabal El Mane
K 9	33 19 51	36 16 18	500m S of K6 & K7, Jabal El Mane
K10	33 13 29	36 18 53	2 km S of Jub As Safa
K11	33 13 29	36 18 53	2 km S of Jub As Safa
K12	33 13 29	36 18 53	50 m E of K11
K13	33 12 36	36 18 00	2 km S of K12, E of Manket El Hatab
K14	33 12 36	36 18 00	50 m S of K13
K15	33 12 36	36 18 00	100 m S of K14
K16	33 14 00	36 15 00	1 km E of Kammouneh on left side road

K17	33 14 00	36 15 00	200 m NE of K16
K18	33 14 00	36 15 00	50 m S of K17
K19	33 15 00	36 25 28	near Ash Shegranieyeh & geodetic point 738
K20	33 15 00	36 25 28	30 m SE of K19
K21	33 15 00	36 25 28	50 m E of K20
K22	33 24 17	36 07 37	top hill near Drowsheh
K23	33 24 17	36 07 37	top hill near Drowsheh
K24	33 24 17	36 07 37	30 m W of K22-23
K25	33 24 17	36 07 37	50 m W of K24
K26	33 24 17	36 07 37	100 m W of K25
K27	33 24 17	36 07 37	50 m N of K26
K28	33 24 17	36 07 37	N side of hill
K29	33 24 17	36 07 37	20 m W of K28
K30	33 24 17	36 07 37	50 m W of K29

BIBLIOGRAPHY

BAKSI, A.K., V. HSU, M.O. McWILLIAMS and E. FARRAR, 1992. $^{40}Ar/^{39}Ar$ dating of the Brunhes-Matuyama geomagnetic field reversal. *Science, 256*, 356-357.

BEST, J., M. BARAZANGI, D. AL-SAAD, T. SAWAF and A. GEBRAN, 1993. Continental margin evolution of the northern Arabian platform of Syria. *Amer. Assoc. Petrol. Geol., Bull., 77*, 173-193.

CANDE, S. C. and D. V. KENT, 1992. A New Gemagnetic Polarity Time Scale for the Late Cretaceous and Cenozoic. *J. Geophys. Res., 97*, 13917-13951.

COLLISON, D. W., 1983. Methods and Techniques in Rock Magnetism and Palaeomagnetism. Chapman and Hall, London, pp. 503.

CREER, K. M., 1962. The dispersion of the geomagnetic field due to secular variation and its determination for remote times using palaeomagnetic data. *J. Geophys. Res., 67*, 3461-3476.

DUBERTRET, L., 1933. Le Miocene en Syrie et au Liban, Notes et Mémoires Syrie et Liban 1, 13-28.

EINDERS, J. and U. HAMBACH, 1995. A geomagnetic event recorded in loess deposits of the Tonchesberg (Germany): identification of the Blake polarity episode. *Geophys. J. Int., 122*, 407-418.

FISHER, R. A., 1953. Dispersion on a sphere. *Proc. Roy. Soc., A217*, 295-305.

KIRSCHVINK, J. L., 1980. The least-squares line and plane and the analysis of palaeomagnetic data. *Geophys. J. R. astr. Soc., 62*, 699-718.

MOLYNEUX, L. M., 1971. A complete results magnetometer for measuring the remanent magnetisation of rocks. *Geophys. J. R. astr. Soc., 24*, 429-433.

MOUTY, M., M. DELALOYE, D. FONTIGNIE, O. PISKIN and J. WAGNER, 1992. The volcanic activity in Syria and Lebanon between Jurassic and the Actual. *Schweiz. Mineral. Petrogr. Mitt., 72*, 91-105.

PONIKAROV, V. P., 1966. Editor. Explanatory notes on the Geological Map of Syria: Scale 1:1,000,000 Ministry of Industry, Damascus, Syria.

ROPERCH, P. and N. BONHOMMET, 1986. Paleomagnetism of Miocene volcanism from South Syria. *J. Geophys., 59*, 98-102.

TARLING, D. H. and D. T. A., SYMONS, 1967. A stability index of remanence in palaeomagnetism. *Geophys. J. R. astr. Soc., 12*, 443-448.

TARLING, D. H., 1983. Palaeomagnetism. Chapman and Hall, London pp.379.

TARLING, D.H. and M. J. DOBSON, 1995. Archaeomagnetism: An Error Assessment of Fired Material Observations in the British Directional Database. *J. Geomagn. Geoelectr., 47*, 5-18.

VAN DONGEN, P. G., R. VAN DER VOO and TH. RAVEN, 1967. Palaeomagnetic research in Central Lebanon Mountains and in the Tartous area (Syria). *Tectonophysics, 4*, 35-53.

J. M. Abou-Deeb[1], M. M. Otaki[1], D. H. Tarling[2] and A. L. Abdeldayem[2,3]

[1] *Department of Geology, The University of Damascus, Syria.*
[2] *Department of Geological Sciences, The University of Plymouth, PL4 8AA, U.K.*
[3] *Now at Department of Geology, University of Tanta, Egypt.*