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Magnetism of the olivine-nephelinite dyke at Ramsen (Kanton Schaffhausen, Switzerland)[1]

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ABSTRACT

The olivine-nephelinite dyke at Ramsen (Kanton Schaffhausen, Switzerland) gives rise to a distinct local geomagnetic field anomaly. The anomaly originates from the induced and remanent magnetism of the titanomagnetite minerals present which have been oxidized to a variable extent by low temperature oxidation. Magnetic field measurements trace the NNW–SSE striking dyke over a distance of 500 m. The shape of the anomaly is strongly influenced by terrain topography. According to model calculations the top face of the dyke is situated 0 m to 3 m below terrain surface. The dyke has a thickness varying between 0.6 m and 1.1 m and dips steeply towards west.

ZUSAMMENFASSUNG

Der Olivin-Nephelinit-Gang bei Ramsen (Kanton Schaffhausen) ist der einzige Ausläufer des «basaltischen» jungtertiären Hegau-Vulkanismus auf Schweizer Gebiet. Die induzierte und die remanente Magnetisierung der enthaltenen, verschieden stark oxidierten Titanomagnetite verursachen eine lokale Magnetfeldanomalie, die entlang dem NNW–SSO-Streichen des Ganges über eine Länge von etwa 500 m nachgewiesen werden kann. Die Form der am Erdboden gemessenen Anomalie ist stark beeinflusst von der Geländetopographie. Modellrechnungen zeigen, dass die Gangoberkante 0 m bis 3 m unter der Geländeoberfläche liegt. Der Gang besitzt eine Mächtigkeit zwischen 0,6 m und 1,1 m und fällt steil nach Westen ein.

1. Geological introduction

The olivine-nephelinite dyke near Ramsen (Kanton Schaffhausen, Switzerland) is the only extension of the Late Tertiary "Hegau" volcanic intrusives from southern Germany into Switzerland. The intrusion is situated on the slope of a hill to the west of the village Ramsen and cuts through sandy sediments of the Obere Süsswassermolasse (OSM) as a narrow dyke (inset of Fig. 1). In Germany many of these volcanics have been discovered and mapped in detail by magnetic field measurements (LÄUPPI 1962, MÄUSSNEST & SCHREINER 1982).

The so-called "Hegau basalts" are composed of nepheline associated with Ti-rich augite, diopside, Ni-rich olivine, melilite, perowskite (HOFMANN 1956, 1974) and accessory ore minerals. According to the mean modal composition given by KRAUSE & WEISSKIRCHNER (1981) and following the general recommendations by STRECKEISEN

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(1978) these "basalts" have to be designated as olivine-nephelinites (some of them may be olivine-melilitites). Products of the Hegau volcanic activity have been emplaced in the Upper Miocene series of OSM formation during different volcanic episodes:

1. Basal bentonites (deposition at 14.6 ± 0.6 m.y. according to WEISSKIRCHNER 1975).
2. Hegau basal tuffs, about 14 m.y. in age.
3. Upper bentonites.
4. Upper intermediary tuffs.
5. Olivine-nephelinites of debated age.
6. Hornblende tuffs, about 9.4 m.y. old.
7. Phonolites, with 7–8 m.y. representing the youngest phase of the Hegau volcanism.

WEISSKIRCHNER (1975) compiled an undifferentiated absolute age of 11.8 m.y. for the olivine-nephelinites, whereas WAGNER et al. (1975) analyzed the K–Ar ages of the intrusions at Ramsen to be 22.2 m.y., Hohenstoffeln (Germany) 16.0 m.y. and Hoewenegg 9.6 m.y. According to this latter age determination the Ramsen intrusion should be placed at the Oligocene–Miocene boundary at the time of the Untere Süsswassermolasse (USM) sedimentation. Since WAGNER et al. (1975) do not exclude the possibility of age overestimation due to excess argon, further geochronological data are necessary to clarify the observed discrepancies. We consider WEISSKIRCHNER'S (1975) age determination for the Ramsen dyke to be more realistic since it is in accord with the stratigraphic position and the age sequence of volcanic activity in the Hegau province.

2. Magnetic field measurements

In order to investigate the geological situation of the dyke, its extent and depth below surface, the total field magnetic anomaly has been mapped in detail. Two proton magnetometers were used, one recording the field continuously at a magnetically quiet site in the village Hofenacher about 4 km north of Ramsen, whereas the other magnetometer was used to observe the local anomaly caused by the dyke.

Previous studies during student field courses had shown that the anomaly strikes about N–S. Therefore several 10–20 m distant profiles of about 100 m length perpendicular to the anomaly strike were chosen to map the anomaly. Topographic elevation and position of each measuring point along the profiles were carefully determined with a levelling instrument. After the usual reductions a total field anomaly map has been constructed by means of graphical interpolation (Fig. 1).

The anomaly strikes NNW–SSE and is observed over a length of about 500 m. It is never wider than 25 m. Approximative half-width calculations indicate a dyke thickness of 1–2 m and a 0–3 m depth of the top of the dyke under the terrain surface. The anomaly approaches maximum intensities of 500 nT. The maxima vary, however, from place to place and are often followed by more or less pronounced minima up to −200 nT to the east or downhill. These minima are strongly influenced by the terrain morphology which plays an important role for the shape of the anomaly. To the north and the south the anomaly disappears rather quickly. In the south the dyke is probably cut off by Quaternary gravel deposits. The northern end disappears underneath the scree of the small valley.

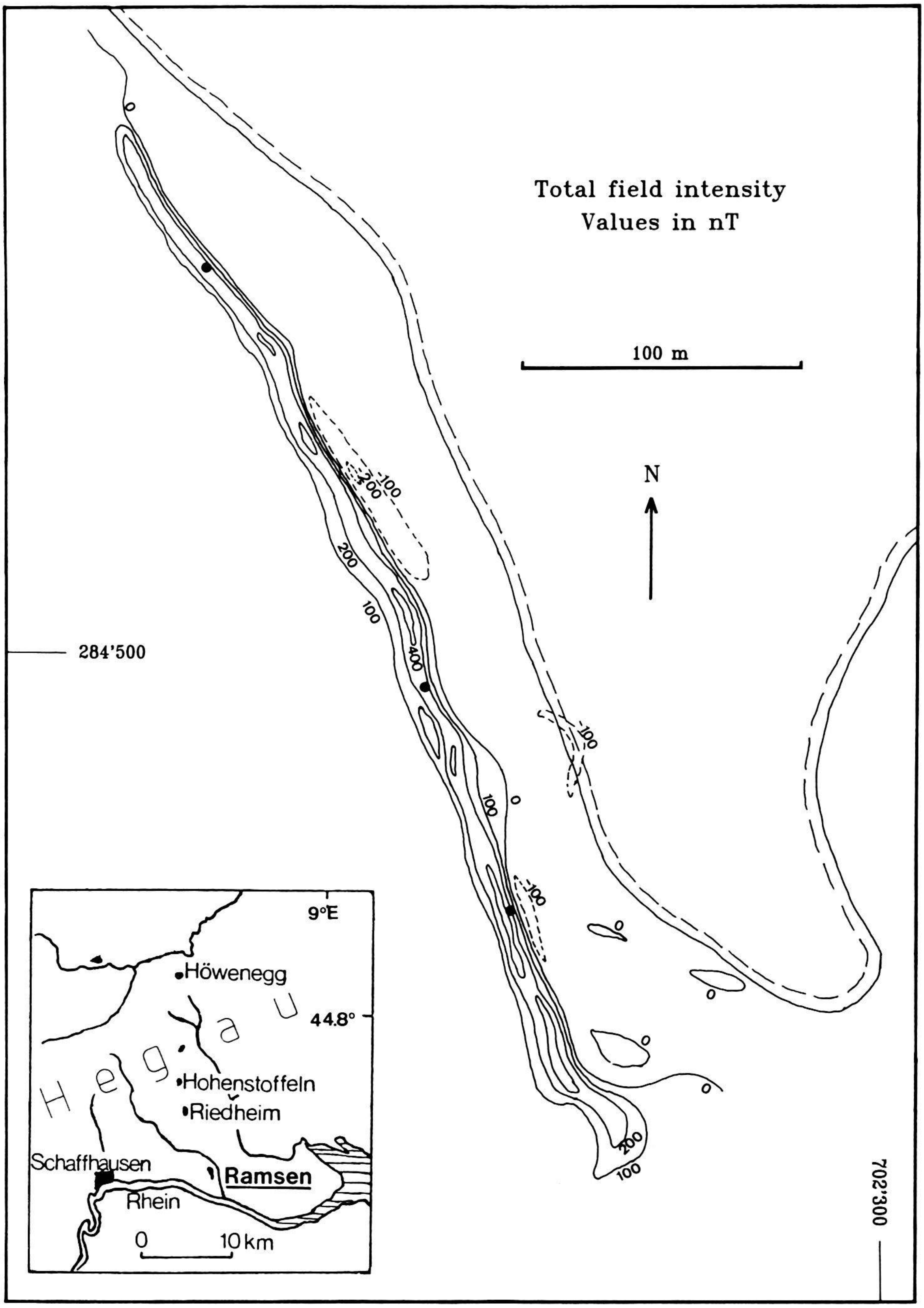

Fig. 1. Total field intensity map of the magnetic anomaly at Ramsen. Inset figure shows the olivine-nephelinite dyke as southernmost extension of the "basalt" exposures of the Hegau volcanic province. Dots indicate the three sites where the dyke has been excavated for rockmagnetic sampling.

3. Rock magnetic properties of the dyke

In order to evaluate the petrologic and the rock magnetic source of the observed anomaly, the olivine-nephelinite dyke was excavated at three places (Fig. 1) and a number of oriented samples was drilled at these sites. The cores were cut into cylindrical specimens (diameter: 2.54 cm; height: 2.25 cm) for laboratory magnetic measurements. Figure 2 summarizes the results of low field susceptibility and natural remanent magnetization (NRM) measurements. The susceptibilities are narrowly distributed around a mean value of 0.0427 (SI-units/cm^3) which suggests a homogeneous concentration of ferromagnetic minerals, whereas the remanence intensities vary strongly from site to site. A mean remanence intensity representative for the whole dyke cannot be determined.

The NRM directions are closely grouped at each drilling site, but the site mean directions differ considerably. This is probably due to secondary components which may have been acquired in situ by lightning or by weathering processes which oxidized the magnetic minerals and thereby increased the magnetic viscosity of the rocks. The NRM

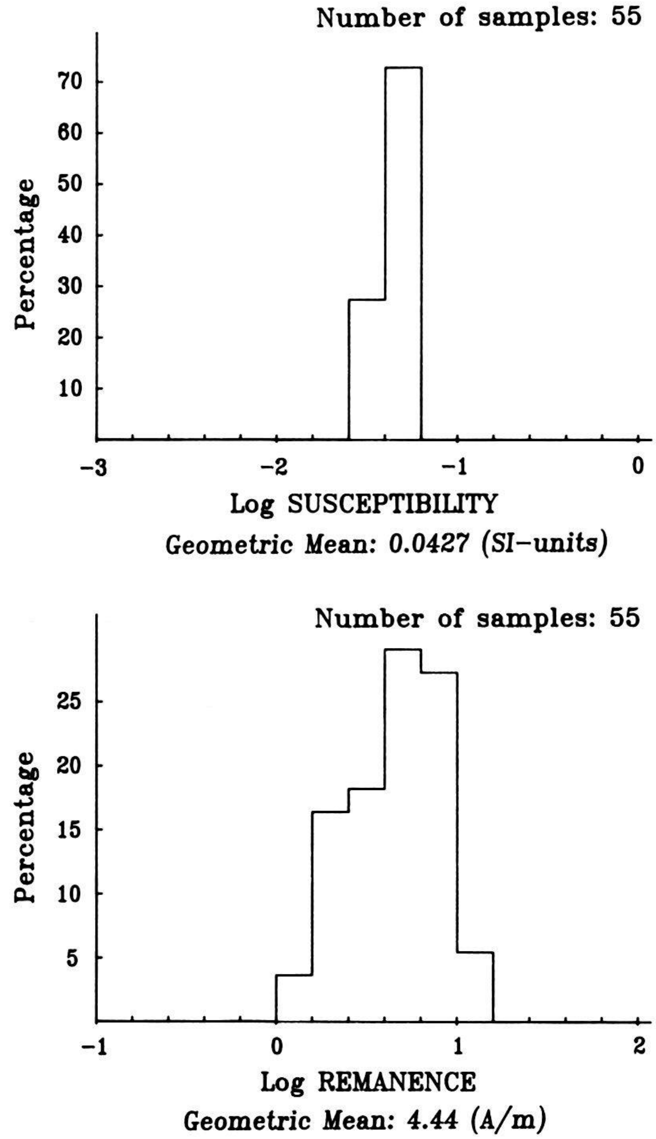

Fig. 2. Histograms of low field susceptibility and NRM intensity.

may also have been modified during the sample extraction procedure or afterwards during laboratory storage. In order to remove these secondary components possibly present in the rocks, several samples were subjected to alternating field (AF) demagnetization and other samples were tested for magnetic viscosity using a storage test in the laboratory field.

Prior to the viscosity test, the samples were measured and then exposed to the Earth's field in a well-determined position. After one month the samples were remeasured. Samples in the original NRM state do not show measurable changes due to viscosity, whereas AF demagnetized samples become highly viscous and are completely remagnetized along the laboratory field direction within the storage time.

During AF cleaning in fields up to 30 mT the NRM intensities are reduced to half of the initial value after application of fields of only 5–7.5 mT magnitude. At site 1 a low coercivity component with southerly declination and shallow negative inclination is initially removed, whereas only minor directional changes are observed at the other two sites. Between 5 and 15 mT the remanence directions remain fairly stable, but the between site scatter is high (Table 1) before and after treatment. At higher fields above 15 mT the NRM vectors become completely unstable. The site mean directions do not coincide with the present local geomagnetic field direction (Decl.: 2.7°; Incl.: 63.2°) either. Similar results have been obtained by WAGNER et al. (1975) who previously sampled at our site 1.

Table 1: *Remanent magnetization of dyke samples. Site mean directions and intensities before and after AF cleaning for N samples. α_{95} cone of 95% confidence.*

	Before AF cleaning					After cleaning at 7.5 mT				
Site	N	Decl.	Incl.	Int. (A/m)	α_{95}	N	Decl.	Incl.	Int. (A/m)	α_{95}
1	26	195.7	21.6	7.63	5.6	8	186.0	75.5	1.71	7.9
2	12	213.1	63.8	3.02	7.7	4	226.5	81.6	1.50	21.0
3	18	333.7	71.2	3.03	3.3	6	327.2	79.7	1.19	2.7

The ore mineral content of the olivine-nephelinite varies between 1.5 to 3% by volume. It consists of titanomagnetites, chromites and traces of pyrrhotite. The major ore minerals are titanomagnetites which occur as euhedral to subhedral grains of variable size up to 250 μm in diameter. About 30% by volume of the titanomagnetites mantle a dull-grey coloured, euhedral chromite core (Fig. 3). Application of magnetic colloid (HELLER & PETERSEN 1982) shows that at room temperature only the titanomagnetites are ferromagnetic, whereas the chromites are paramagnetic (SCHMIDBAUER 1976) and do not attract the colloid (Fig. 3b). The titanomagnetite mantles result from the reaction of early precipitated chromites with a Fe–Ti rich liquid which indicate an origin of the olivine-nephelinite magma in the upper mantle (HAGGERTY 1976). Microprobe analyses (Table 2) in conjunction with J_s–T curves (Fig. 4) show that the titanomagnetites are at least partly oxidized probably due to weathering. Strongly weathered dyke rocks exhibit two distinct Curie points at temperatures which are much higher than those expected for unoxidized Al- or Mg-doped titanomagnetites of the measured chemical composition. The phase with the higher Curie point is not present in fresh looking dyke rocks suggesting a lower

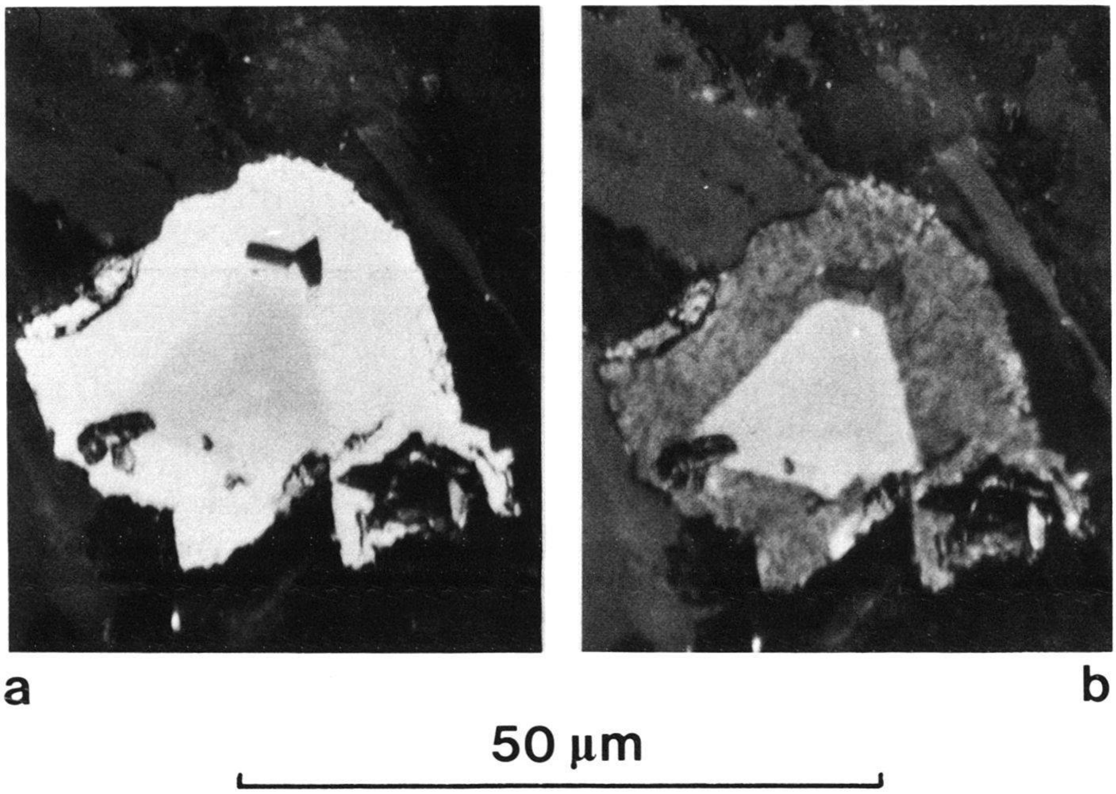

Fig. 3. Polished section photomicrographs of chromite (grey shaded triangle in the grain center) mantled by titanomagnetite (a) without magnetic colloid and (b) covered with colloid.

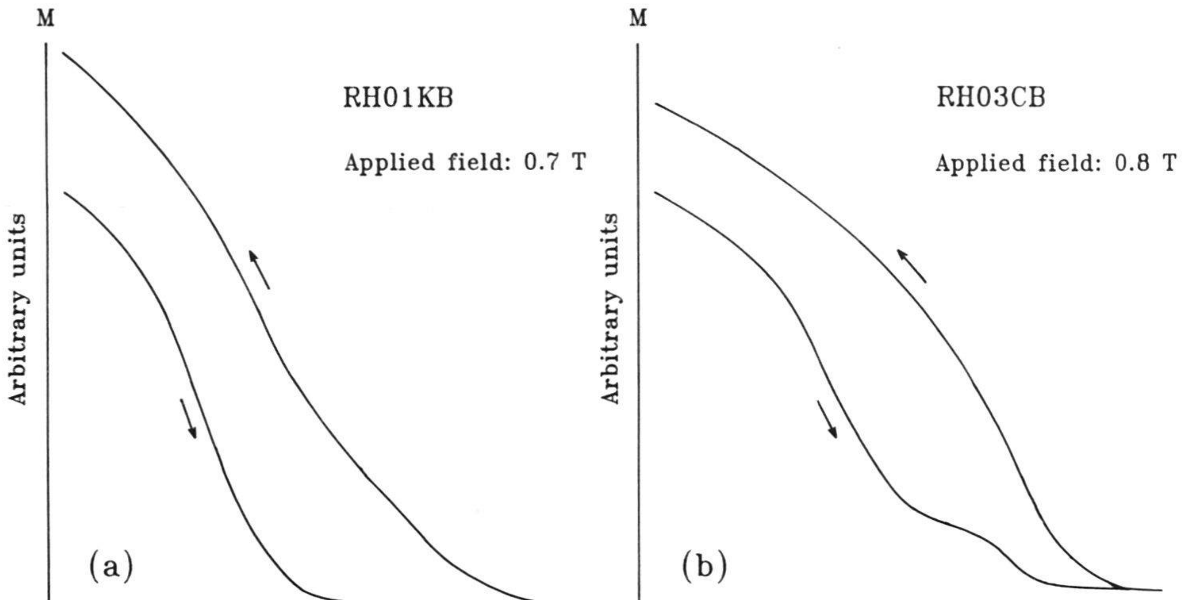

Fig. 4. High field magnetization versus temperature. a: Fresh dyke sample with one Curie temperature at 315 °C. b: Strongly weathered sample with two Curie points at 315 °C and 475 °C.

oxidation degree of the titanomagnetites. The inhomogeneous low temperature oxidation is possibly responsible for the instability and large scatter of NRM directions observed in the surface exposures.

Table 2: *Microprobe analysis of ore grains from the olivine-nephelinite dyke. n: number of analyses. Elements analyzed: Ti, Fe, Mn, Cr, Al, Mg. x: resulting composition parameter in the magnetite-ulvospinel solid solution series.* T_{cs}*: Stoichiometric Curie temperature corresponding to x.* $T_{c\delta}$*: Curie temperature depressed by Al and Mg according to* Richards et al. (1973).

	n	Ti	Fe	Cr	Mn	Al	Mg	Sum	x	T_{cs}	$T_{c\delta}$
		wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%		°C	°C
Titanomagnetite	6	6.57	52.82	0.29	0.72	3.05	3.94	67.61	0.30	360	200
		± 0.63	± 0.80	± 0.24	± 0.15	± 0.97	± 0.78	± 0.45	± 0.04	± 28	
Chromite	4	1.03	20.92	21.25	0.23	12.64	8.65	65.15			
		± 0.25	± 3.84	± 1.47	± 0.08	± 1.39	± 0.64	± 0.83			

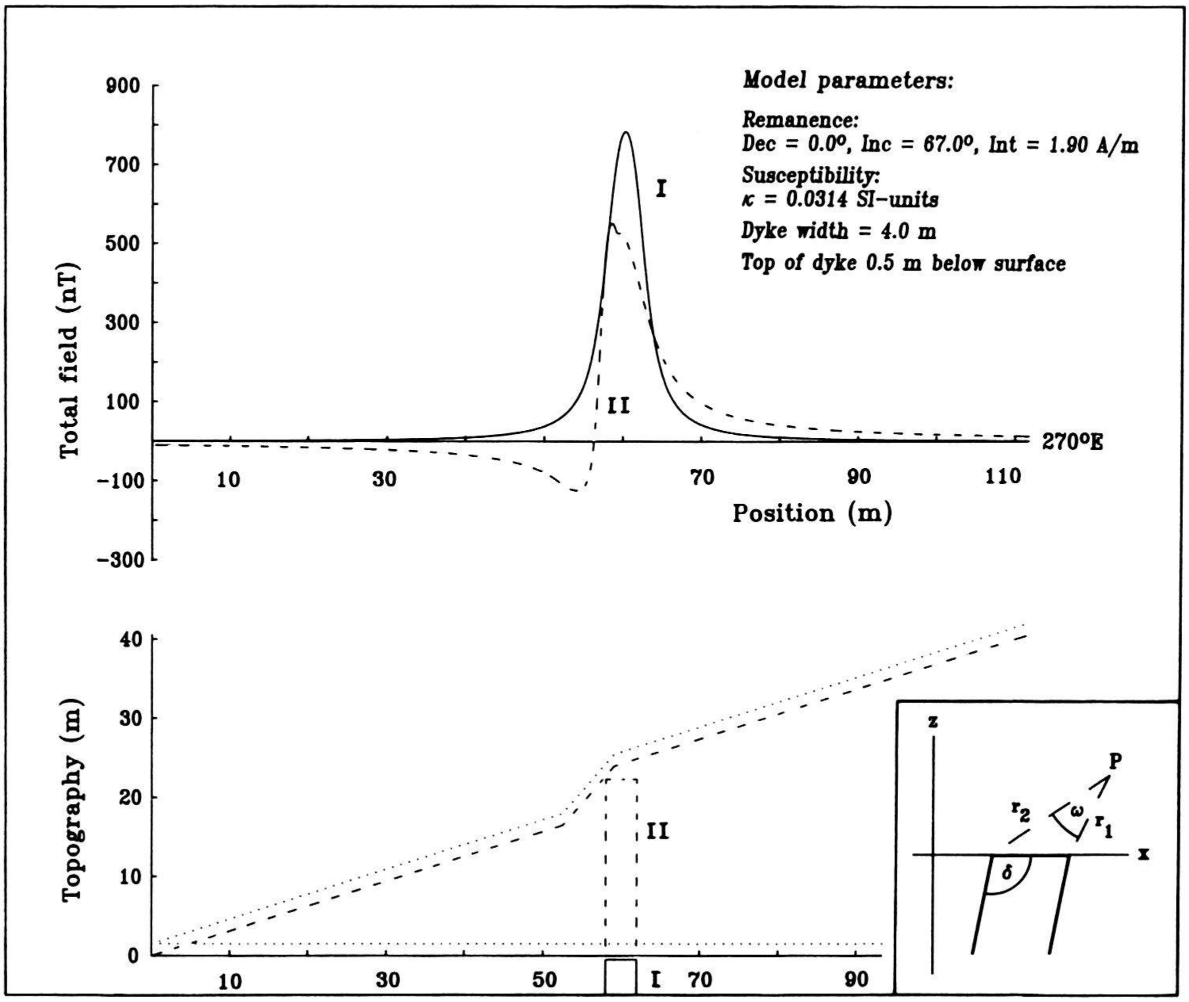

Fig. 5. Effect of topographic step on the total field anomaly of a N–S striking dyke. Dashed lines (Model II) illustrate the situation of an inclined terrain surface with a topographic step, solid lines (I) refer to flat terrain surface. Dotted lines indicate height of the actual measuring profile 1.5 m above terrain surface. The specific model parameters are denoted in the top right corner of the figure. The inset illustrates some parameters used in formulas 1–3.

4. Model calculations and discussion

For the magnetic anomaly interpretation a Fortran program has been written on the assumption that the anomaly is caused by a dyke intrusion. The horizontal, vertical and total field elements of a homogeneously magnetized dyke model which extends laterally and downwards to infinity, are calculated across a profile with varying vertical measurement position. Such a two-dimensional model takes into account the effects of the sides and the top face which is situated at a depth z, whereas the bottom face, supposed to be infinitely remote, does not contribute to the model anomaly. If the measuring profile is horizontal, the depth parameter z remains constant. If the anomaly, however, is situated on the slope of a hill, as it is in Ramsen, the depth parameter is introduced as a variable z' which is measured relative to z. This topography effect is illustrated for a vertical, N–S striking dyke in Figure 5. A step in the terrain topography produces a distinct total field anomaly minimum downhill from the dyke, whereas a symmetric anomaly results for horizontal topography.

From potential theory the field anomaly equations can be derived for a homogeneously magnetized dyke of the shape described above (Gassmann 1949; Egloff 1971):

1. Vertical field:

$$\Delta Z = 2J\{\omega \sin\delta(\sin i \sin\delta + \cos i \cos d \cos\delta) + \ln\frac{r_1}{r_2}\sin\delta(\sin i \sin\delta - \cos i \cos d \cos\delta)\} \quad (1)$$

2. Horizontal field:

$$\Delta H = 2J\{\omega \sin\delta(\sin i \sin\delta - \cos i \cos d \cos\delta) - \ln\frac{r_1}{r_2}\sin\delta(\sin i \sin\delta + \cos i \cos d \cos\delta)\} \quad (2)$$

3. Total field:

$$\Delta T = \Delta Z \sin I + \Delta H \cos I \cos\alpha \quad (3)$$

J, d, i denote intensity, declination and inclination of the induced and remanent magnetization; α ist the profile direction perpendicular to the strike of the dyke and I is the local geomagnetic field inclination; the other parameters are explained by the inset of Figure 5. The program calculates and sums up the field anomalies produced by both the induced and remanent magnetization on 201 equidistant points along a profile with varying topography. A two-dimensional total field anomaly may be modelled, plotted, and fitted to the measured field anomaly by altering some of the input parameters on a given profile. The topography, the azimuth of the profile direction, the earth's total field intensity (T_e = 47,000 nT) and inclination, and the low field susceptibility are entered as constant input parameters for a specific profile. The position of the dyke along the measured profile, the direction and intensity of the NRM vector, the depth below surface, the width, and the dip of the dyke have been introduced as variables.

The model calculations show (Fig. 6) that the induced magnetization of the dyke alone cannot account for the observed anomaly, if the width of the dyke is kept at a realistic value (less than 2 m). Sharply peaked measured anomalies and field observations at the sampling sites point towards a thickness of less than a meter. Therefore the remanent magnetization vector must play an important role.

The measured NRM directions differ largely from sample to sample and between the three sampled sites (see above). The model calculations fit the observed anomalies most closely when the NRM is set parallel to the present geomagnetic field. The measured NRM intensities exhibit large scatter, too. The mean value at site 1, where the dyke rocks are not so strongly weathered, seems to best represent the mean intensity value of the dyke. This mean intensity value and a dip of 75° to the west produced the best correlation between model calculation and the observed anomaly (Fig. 6).

Under the above assumptions we conclude that the dyke has a thickness which varies between 0.6 m and 1.1 m. It strikes NNW–SSE and dips steeply with about 75° to the west. The depth below surface varies between 0 and 3 m. The shape of the anomaly is strongly influenced by the topography. Pronounced downhill minima of variable amplitude occur at those places where hard dyke rocks produce a visible step in the slope topography. The length of the dyke can be traced magnetically over a distance of about 500 m. Its northern and southern ends disappear rather abruptly under Quaternary sediments.

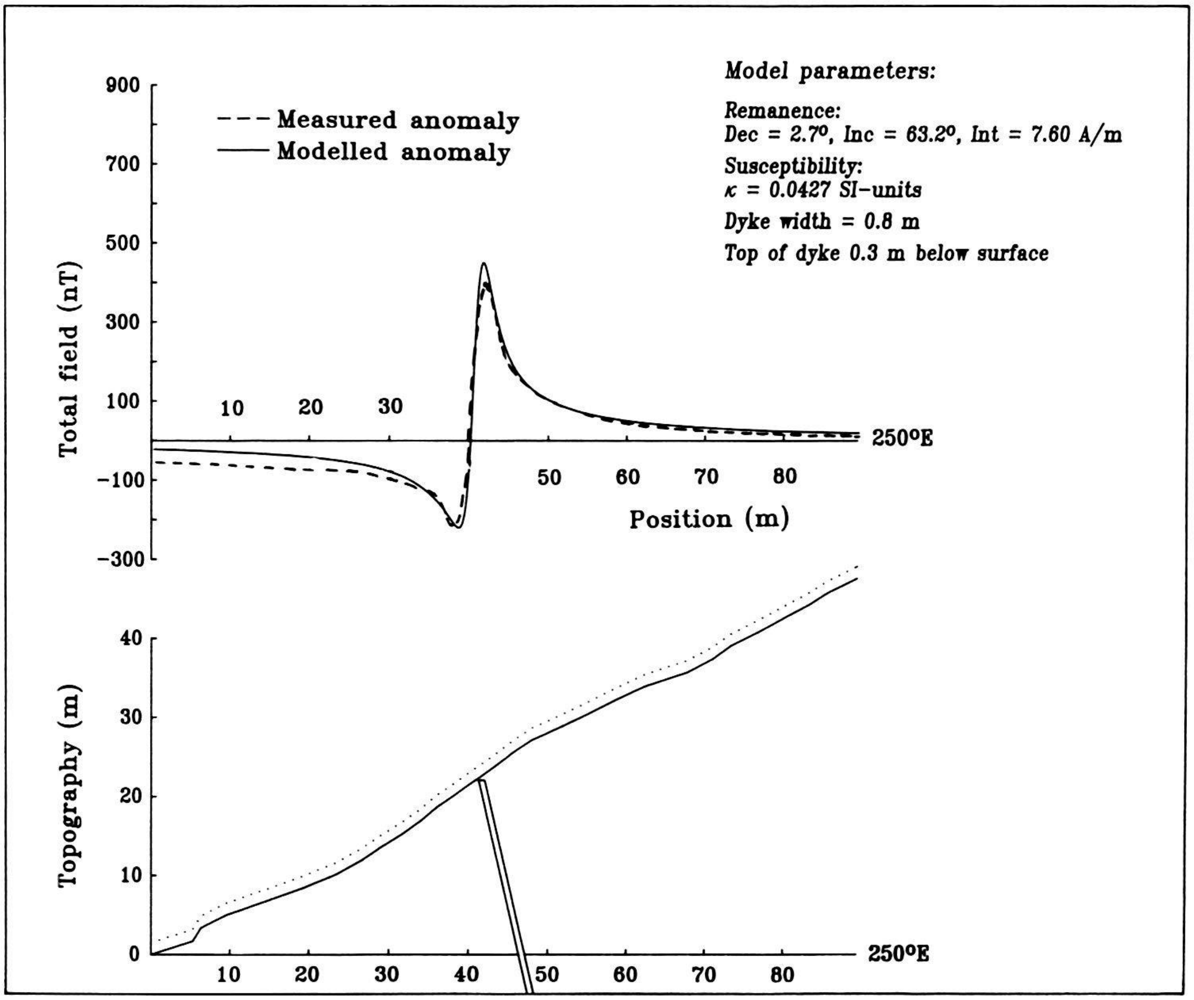

Fig. 6. Comparison between measured (dashed line) and modelled total field anomaly of the dyke on a slope profile at Ramsen.

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