*Geol. Bull. Univ. Peshawar, 1986, Vol. 19, pp. 47–60*

# MAGNETIC PROFILES ACROSS THE NORTHERN SUTURE, KOHISTAN, NW PAKISTAN

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ABSTRACT

*The northern boundary fault (Northern Suture) of the Kohistan island arc terrain separates Cretaceous arc sediments and volcanics from Palaeozoic shelf sediments of the Asian plate. Arc rocks are more magnetised than Asian plate rocks, and ultramafics along the suture are very strongly magnetised. Four magnetic profiles across the suture show the following features :*

*a) a gradual north to south decrease in total field of about 15 nT/km*

*b) Asian plate sediments are magnetically quiet and in only one profile does the Northern Suture have a magnetic anomaly*

*c) within the arc sequence, anomalies are associated with the sediment/volcanic boundary and large anomalies occur over granodioritic plutons.*

*We have modelled the best-defined anomaly across the arc sediment/volcanic boundary using a cartoon structure consistent with the surface geology.*

## INTRODUCTION

### Geology

The Kohistan island arc (Tahirkheli, 1979; Bard *et al.,* 1980; Coward *et al.,* 1982, 1985) consists of supracrustal volcanic and sedimentary rocks, intruded by acidic to intermediate plutonic rocks which pass south into a layered mafic igneous complex and then amphibolites (figure 1A). It is separated from Indian plate gneisses to the south by the Main Mantle Thrust (MMT) and from Palaeozoic sediments of the Asian plate to the north by the Northern Suture. East of the Nanga Parbat Syntaxis is the Ladakh arc sequence (Dietrich *et al.*, 1983), bounded to the north by the Shyok Suture and to the south by the Indus Suture. The sutures converge further east and it is the southern one which is believed to mark the line of major ocean closure between India and Asia (Coward *et al.*, 1985).

The arc sediments and volcanics are mainly lower Cretaceous in age (review in Pudsey *et al.*, 1986) though the Ladakh volcanics may range down to Jurassic (Dietrich *et al.*, 1983). Radiometric ages for the arc batholith range from 102 to 40 Ma and for the Karakoram batholith from 120 to 100 Ma with a few Tertiary ages (Coward *et al.*, 1985). Most of the deformation (large-scale east-west isoclinal folding in the south, tight to open folding and thrusting in the north) had taken place by about 90–100 Ma (Petterson and Windley, 1985) and all the Eocene granites are post-tectonic.

The subject of this paper is the Northern Suture from Gilgit to Chitral (Figure 1B). Unlike the MMT with its high-pressure rock assemblages blueschists and garnet ± pyroxene granulites) the Northern Suture is generally a zone of tectonic melange up to 4 km wide, of low metamorphic grade. It separates arc sediments (slates, volcaniclastic sandstones, turbidites and limestones) or volcanics (andesitic lavas and tuffs) from slates and quartzites of the Asian plate (Darkot Group, dated as Devonian to Permian (Ivanac *et al.*, 1956; Calkins *et al.*, 1981). Southeast of Chitral a leformed dioritic pluton intrudes the melange, and west of Yasin the suture is reduced to some 150 m in width by small post-tectonic granites. The melange includes blocks of limestone, quartzite, volcanic greenstone, red shale, several types of conglomerate and altered ultramafics in a slate matrix. A detailed account of the suture is given by Pudsey (1986). The attitude of the Northern Suture varies repeatedly along strike, from north-dipping through vertical to south-dipping, and the surface geology affords no clues to its attitude at depth.

**Previous Geophysical Work**

There have been few attempts to use potential field methods to examine near-surface structural features in northern Pakistan. Marussi (1980) concentrated on gravity studies: his Bouguer and isostatic anomaly maps provide information on crustal thickness over the Karakoram – Hindu Kush – Pamir region. Malinconico (1982) collected gravity and total field magnetic data along a traverse crossing the Northern Suture, MMT and Main Boundary Thrust in western Kohistan, and along two sections of the Karakoram Highway crossing the Northern Suture and MMT, with station spacings of about 3 km. Bouguer anomaly variations across the Northern Suture were of the order of 500 gu near Chitral and 1000 gu in the Hunza valley (Figure 1). Two-dimensional models of these data suggested that near Chitral the boundary between the island arc and Asian Plate

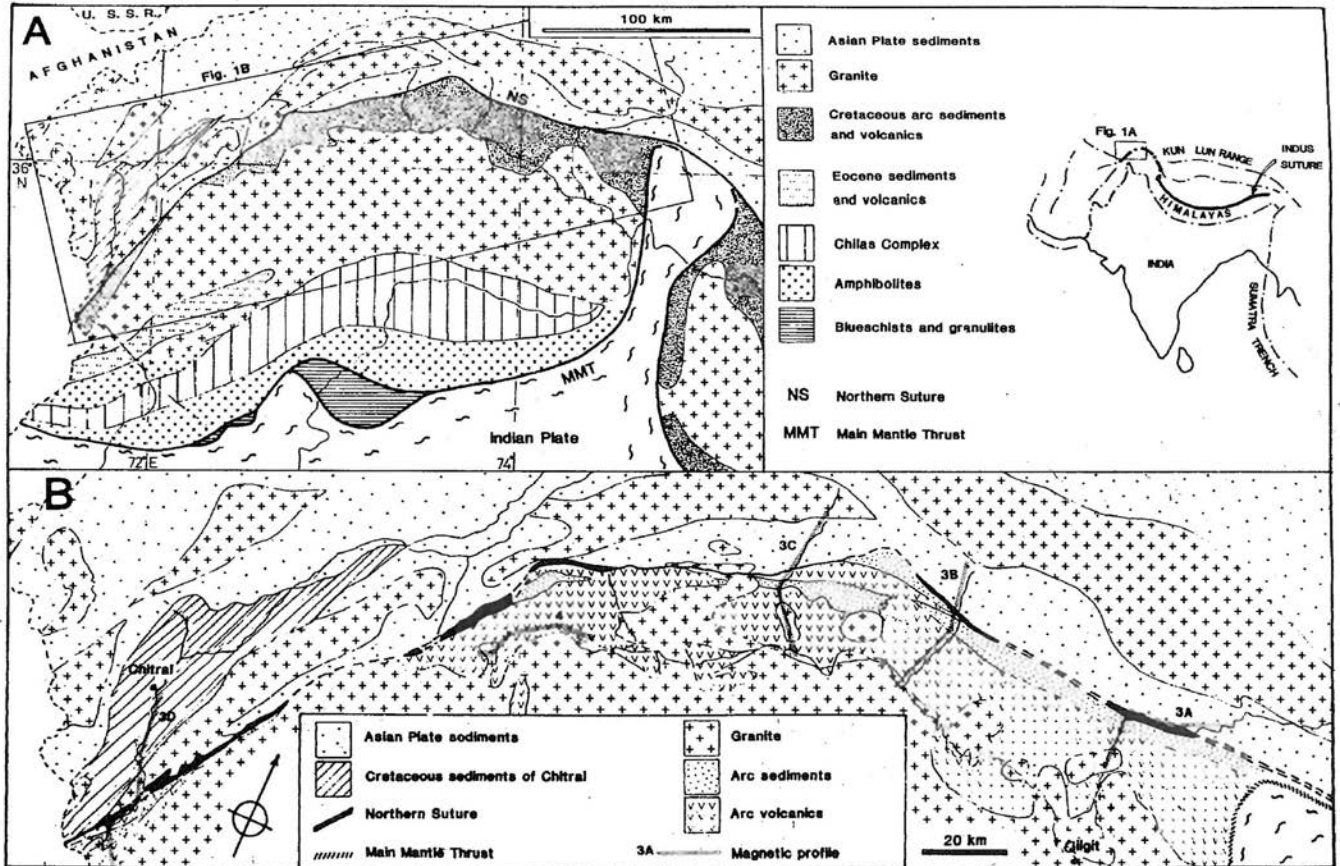



Figure 1A The Kohistan arc terrain: for location at NW Himala yan syntaxis, see inset map from Pudsey (1986). Cretaceous sediments in NW are shown by diagonal shading.

1B Geology along the Northern Suture, with location of magnetic profiles. Simplified from Pudsey (1986).

dips north at 15° near the surface, steepening to the base of the arc sequence at about 8 km depth. The Hunza valley profile was more difficult to model, lacking a good estimate of the regional gravity field, but Malinconico suggested a near-vertical Northern Suture, with the base of the arc sequence at 9–10 km depth. Malinconico's magnetic data show no anomalies over the suture, though the Chitral traverse does include a long-wavelength anomaly apparently associated with the complete island arc sequence.

We made a rough estimate of the magnetisation of rock samples from Kohistan by placing them near the search coil of a fluxgate magnetometer. Arc volcanics and sediments were more strongly magnetised than Asian plate sediments, and suture zone serpentinites were the most strongly magnetised of all. This suggested that a magnetic survey across the suture with closer station spacings might be useful. Accordingly CJP collected the magnetic data in 1983, during fieldwork primarily concerned with geological mapping.

## METHODS

### The Survey

A GM–122 Barringer Research proton precession magnetometer was used to measure the total magnetic field along the traverses. Stations were located using the U.S .Army map series U502 at a scale of 1:250,000 with enlargements to 1:50,000 made for some areas. Malinconico's (1982) data were plotted on the maps to construct figures 3A and D. For the profiles 3B and C the jeep odometer was used to establish stations at 1 km spacing along the roads (effectively 1 station per 700 or 800 m perpendicular to strike). Closer spacing in areas of high gradient was achieved by spacing 100 m intervals. Station positions were adjusted where necessary to avoid such magnetic sources as steel bridges and power cables. The magnetometer bottle was deployed at least 30 m away from the jeep: by experiment, the vehicle did not affect the instrument if it was more than 25 m away.

### Errors

Diurnal variation was measured during all or part of 4 days in Gilgit (Figure 2). The variation is small compared with the measured anomalies (see below) and there is no consistent pattern. Diurnal variation was therefore ignored.

Local topography in the Karakoram is extremely rugged. Sharma (1966) showed that magnetic terrain effects could theoretically be significant in hilly regions where the magnetic susceptibility of the rocks is of the order of 0.01 SI units. Gupta and Fitzpatrick (1971) showed that anomalies of 100 to 700 nT may occur over the foot and top of slopes typified by susceptibilities of 0.02. Four of the susceptibilities listed in Table 1 reach this order of magnitude.

However all the values in Table 1 were determined assuming the remanent magnetisation vector is parallel to the present Earth's field, providing a value for maximum effective susceptibility. The true value will be less than that listed. Also, from inspection of the profiles, there appears to be no dramatic variation between those measurements taken in the bottom of valleys and those partway up mountains, in regions of slowly varying magnetic field. No terrain correction was therefore applied to our data; however, a useful future study in this area would be to examine possible topographic effects in detail.

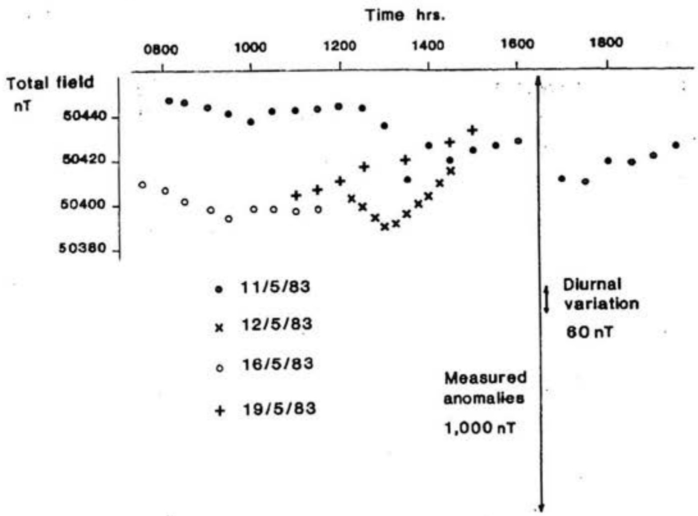



Figure 2 Magnetometer diurnal variation, measured on 4 different days at the same place in Gilgit. The total variation is 60 nT and the maximum variation in any one day is 40 nT: this is small compared to the amplitude of the measured anomalies (double-ended arrows: not to same scale as graph).

It will be noted from Figure 3 that the major valleys are generally floored by alluvium: this may reach 200 or 300 m in thickness. Such a thickness of alluvium between magnetometer and solid geology will reduce the short-wavelength variation of the recorded signal. Yet the good correlation between geology and the profile signature suggests the alluvium is not masking very much of the signal.

**Magnetic Remanence and Susceptibility Measurements**

To extend the value of this reconnaissance study, a few samples representing most of the major rock units were selected for remanence and susceptibility measurements. The remanent magnetisation of 23 unoriented samples was examined using an SM–2 spinner magnetometer. No cleaning was attempted. The values range from 0 to 2500 nT (Table 1). Repeat measurements showed that the values were accurate to approximately ± 5%.

TABLE 1 : REMANENT MAGNETISATION, SUSCEPTIBILITY AND MAXIMUM EFFECTIVE SUSCEPTIBILITY OF THE MEASURED SAMPLES.

| Group | Sample | Rock type | Remanence, $J_R$ nT | Susceptibility SI units | Maximum effective susceptibility SI units |
|---|---|---|---|---|---|
| | IK 722 | granite | 967 | 1.43 x 10-3 | 0.021 |
| 1 | IK 732 | granite | 64 | 0.20 ,, | 0.001 |
| | K 799 | granodiorite | 98 | 2.00 ,, | 0.004 |
| | C 55 | diorite | 195 | 0.65 ,, | 0.005 |
| | C 54 | metabasalt | 2871 | 8.02 ,, | 0.065 |
| | C 71 | andesite | 195 | 0.84 ,, | 0.005 |
| | IK 680 | andesitic tuff | 0 | 0.21 ,, | 0.000(2) |
| | IK 725 | andesitic tuff | 82 | 0.08 ,, | 0.002 |
| | IK 728 | andesitic tuff | 4 | 0.08 ,, | 0.000(2) |
| 2 | K 53 | pyritic basalt | 1289 | 2.51 ,, | 0.028 |
| | K 394 | andesite | 29 | 0.21 ,, | 0.001 |
| | K 792 | agglomerate | 3 | 0.10 ,, | 0.000(2) |
| | K 801A | andesite | 25 | 0.16 ,, | 0.001 |
| | KM 8 | basalt | 88 | 0.28 ,, | 0.002 |
| | K 194 | greywacke | 126 | 2.83 ,, | 0.005 |
| | K 375 | conglomerate | 10 | 0.10 ,, | 0.000(3) |
| 3 | K 422 | limestone | 1 | 0.06 ,, | 0.000(1) |
| | K 581 | conglomerate | 1 | 0.08 ,, | 0.000(1) |
| | K 690 | greywacke | 6 | 0.08 ,, | 0.000(2) |
| | K 1269 | limestone | 469 | 0.13 ,, | 0.010 |
| | K 292 | sandstone | 59 | 0.19 ,, | 0.001 |
| 4 | K 306 | sandstone | 1 | 0.10 ,, | 0.000(1) |
| | K 516 | slate | 25 | 0.07 ,, | 0.001 |

Explanation of Table 1

Group 1 Arc plutonics

2 Arc volcanics

3 Arc sediments

4 Asian Plate sediments

Maximum effective susceptibility =

$$\frac{|\overline{J_R}| + K\,|\overline{T}|}{|\overline{T}|}$$

where T has been taken as 50,000 nT.

Susceptibility measurements were made using a Sharpe SM–4 Casey-Foster Bridge, calibrated for the sample size used (2.5 cm cores). Repeat measurements showed that the values were accurate to ± 0.1%. Because the instrument is designed for 7.5 cm cores, it is probable that the absolute errors are somewhat greater than this.

The main features of the results are :

i) Both the remanence and susceptibility values vary by at least one order of magnitude in all the rock units except the Asian plate sediments.

ii) The plutonic rocks have large and variable remanence and susceptibility values.

iii) Except for sample K194, remanence and susceptibility values for the arc sediments and Asian plate sediments are similar.

iv) Arc volcanics generally have higher remanence and susceptibility values than arc sediments. The susceptibility values reported by Malinconico (1982) are rather similar for arc sediments and volcanics, the total range being only one order of magnitude (0.001 to 0.01). Our results suggest that noticeable differences may be present.

## RESULTS

The four magnetic profiles across the Northern Suture are shown in Figure 3, with a summary of the geology for each traverse.

**Hunza Valley (Figure 3A)**

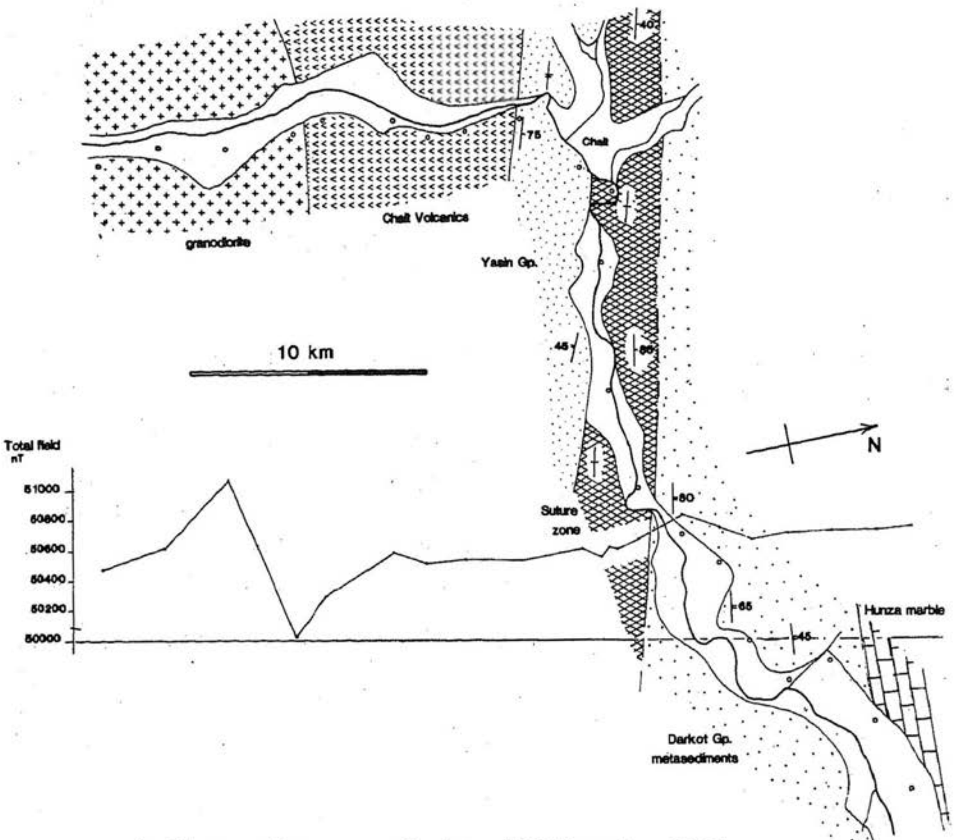
Asian plate sediments are here metamorphosed to garnet-mica schists, decreasing in metamorphic grade in the south and increasing to sillimanite-K-feldspar gneisses in the north. The Hunza marble is a very coarse calcite marble with phlogopite and Cr-spinel, and lenses of biotite schist. The suture zone has a steep east-west planar fabric. Altered ultramafic blocks (serpentinites and talc schists) are confined to a zone about 200 m wide near its southern edge near Chalt, but volcanic greenschist blocks up to 200 m x 1 km occur throughout. The arc sediments are fine to coarse greywackes and slates: both these and the Chalt volcanics (lavas and tuffs) are tightly folded, but overall dip steeply north and are right way up. The tonalite is foliated, medium-to coarse-grained and biotitic.

The main feature of the magnetic profile is the large edge effect at the tonalite/volcanic boundary. The profile is almost flat through the sediments and volcanics and across the suture zone, though this may be partly an artefact of wide station spacing. There is no station very near the ultramafic outcrops.

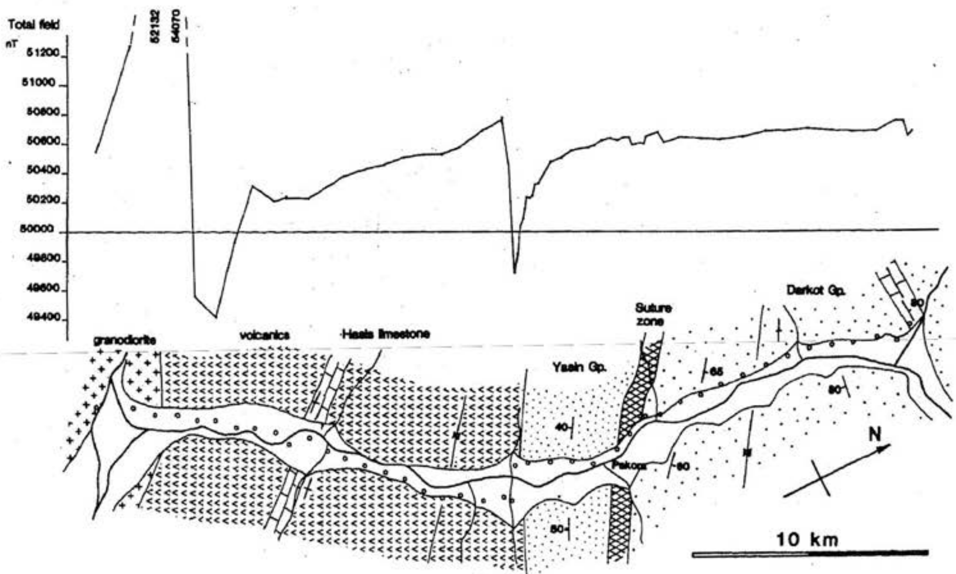
**Ishkuman Valley (Figure 3B)**

Darkot Group sediments (Ivanac *et al.*, 1956) here consist mainly of slates with euhedral biotite and ilmenite, with isolated thick quartzites and minor conglomerates and pebbly slates. They lie in a tight syncline. There is one limestone unit, and the southern edge of the Karakoram batholith is about 2 km beyond the northern end of the profile. The suture zone dips moderately south

Figure 3 Magnetic profiles across the Northern Suture: Locations on Figure 1B. Open circles are magnetometer stations. Unshaded areas along the valleys are alluvium. Data are projected on to a line perpendicular to strike in each case.




A Hunza valley: magnetic data of Malinconico (1982)

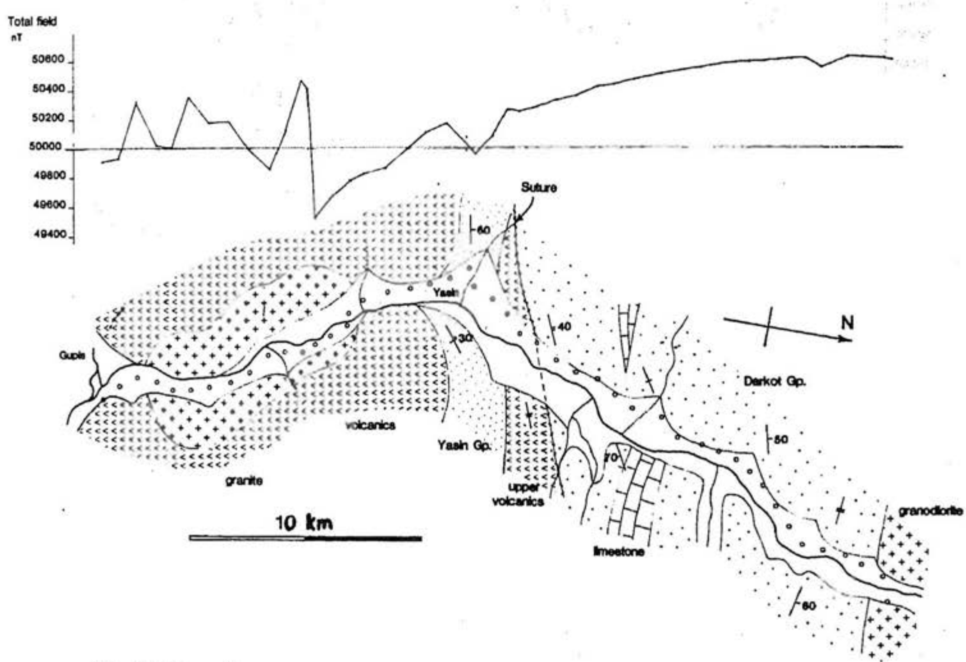



B Ishkuman valley: all the closely-spaced stations are not marked and has a steep down-dip linear fabric. Most of the blocks are quartzite and dolomite, and the slate matrix is soft and carbonaceous. Serpentinite was found as abundant debris about 3 km WNW of the main valley. Arc sediments (Yasin Group, Ivanac *et al.,* 1956) are slates ,locally silty and with a few volcanogenic conglomerates. They dip south and are probably repeated in isoclinal folds. The "volcanics" include bedded volcaniclastic sandstones in the north and a 500 m limestone as Hasis. Massive lavas predominate further south (see Coward *et al.,* 1985 for cross section). The granodiorite is foliated and biotitic.

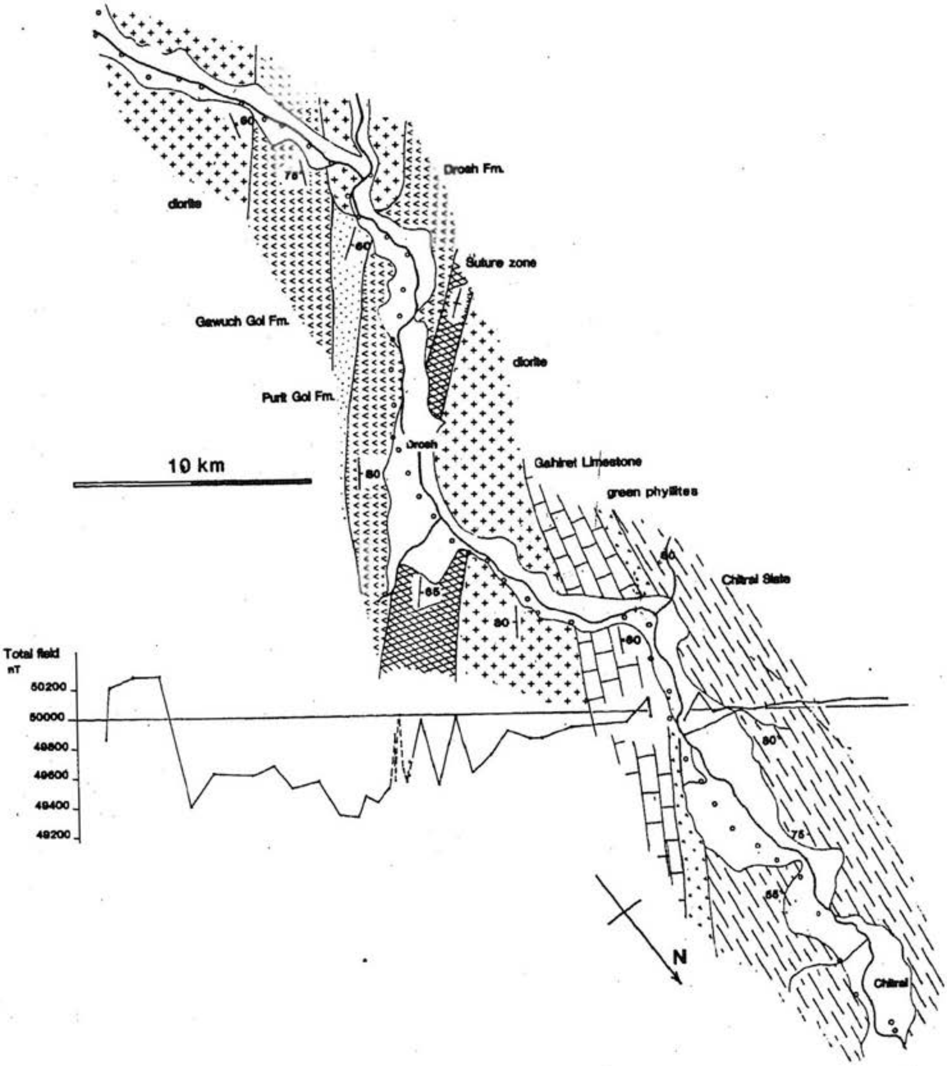
The magnetic profile is marked by very high readings at two stations near the southern edge of the volcanics. Lack of time prevented further investigation of this area but the suture zone and the sediment-volcanic boundary were investigated in detail. Superimposed on the overall north-south gradient of about 150 nT in 30km are short-wavelength low-amplitude fluctuations across the suture, and a very steep anomaly of over 1000 nT at the base of the sediments. The Hasis limestone has no magnetic signature at all.

**Yasin Valley (Figure 3C)**

The profile extends north to the margin of the Karakoram Batholith, here a coarse biotite-granodiorite. Karkot Group sediments are slates without metamorphic biotite, continuing the westward decrease in metamorphic grade, with some sandstones and pebble conglomerates. They dip mainly north and include one limestone. The Northern Suture is much narrower than in the Hunza and




C Yasin valley




D Kunar valley: magnetic data of Malinconico (1982)

Ishkuman valleys: it contains fault breccia of local lithologies and also slices of red shale. The arc sequence includes a unit of fine-grained volcanic greenschist (with thin slices of serpentinite at the base) above the Yasin Group sediments. The latter include some 500m of slates overlying limestones, turbidites and coarse volcaniclastics. Thick mafic sills intrude the sediments 5km east of the main valley. The volcanics are mainly massive andesitic lavas. A small pluton of medium-grained biotite-granodiorite intrudes the volcanics, and the Kohistan Batholith outcrops just south of Gupis.

The gentle southward decrease in total field is again seen in the northern part of the magnetic profile, but particularly within the small pluton there are large and apparently unsystematic fluctuations. There is an anomaly across the arc sediment/volcanic boundary similar to that observed in the Ishkuman valley, but the wider station spacing in the Yasin valley precludes direct comparison between the two profiles.

**Kunar Valley (Figure 3D)**

At the western end of the Kohistan arc (Figure 1B) part of the Karakoram Batholith abuts against the Northern Suture, and is succeeded to the northwest by a unit of sediments at least partly Cretaceous in age. The structure of this unit is not well known, but slates in the middle lie in an antiform: they are followed to the northwest by Cretaceous limestone (Pudsey *et al.*, 1985) and to the southeast by a (?volcanic) green phyllite unit and another limestone. The rock units in Figure 3D are, from north to south, as follows :

i) Chitral slate: slate, strongly deformed, some turbidites and ash beds

ii) green phyllites: chlorite-actinolite-epidote phyllites and schists

iii) Gahiret limestone: coarse calcite marble with a mica-schist unit in the middle

iv) diorite: foliated, with less deformed intermediate and acid minor intrusives

v) Suture zone: mainly slates with beds of quartzite and limestone, some tectonic slices of serpentinite and talc-dolomite schist, large blocks of limestone

vi) Drosh Formation: porphyritic andesite lavas, some red shales

vii) Purit Formation: mainly red shales with some sandstones and conglomerates

viii) a small granodiorite pluton

ix) Gawuch Formation: greenschist-grade tuffaceous metavolcanics with a few thin marbles

x) foliated diorite.

The whole succession dips steeply northwest except for the more intensely deformed Chitral slate.

In the south there is again a large magnetic anomaly over the margin of pluton. Steep anomalies of up to 400 nT occur in the Drosh Formation and suture zone. The sediments in the north are magneticall quiet save for a small fluctuation over the green phyllites.

## DISCUSSION

The reconnaissance nature of this study limits the conclusions which can be drawn concerning the magnetic structure of the near-surface geology across the Northern Suture. The following points are of interest and warrant further examination.

i) Although the initial impetus for the study came from observing the very high magnetisation of a serpentinite from the suture zone itself, the conclusion of Malinconico (1982) that traverses across the Northern Suture show little response to crossing the structure appears to be supported. We suggest that the magnetic signature of the suture is very dependent on local rock types: serpentinite blocks may only reach tens of metres across and it is easy to miss their effect altogether.

ii) The different signatures across the arc volcanic/sediment contact (Figure 3) may be partly explained by the variable magnetisation values for the

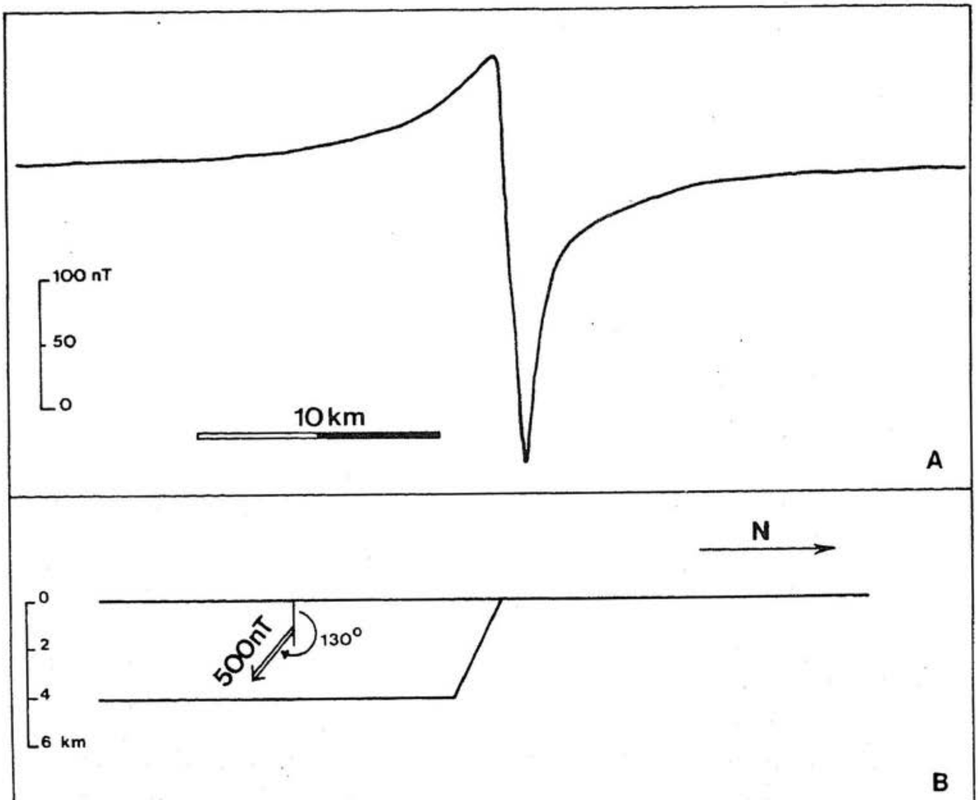



**Figure 4 Theoretical total field anomaly (A) derived from the structure and magnetisation vector shown in 4B.**

volcanics and sediments (see above). We have modelled the well-defined anomaly across this contact in Ishkuman Valley. A simple model of the structure derived from the gravity model of Malinconico (1982) and modified to accommodate a) the local dip of the volcanic/sediment boundary and b) a resultant magnetisation vector consistent with the volcanics being more magnetic than the sediments and the whole section being overturned, provides an anomaly similar in shape to that observed (Figure 4). Although this model is not definitive it demonstrates that the observed anomaly is consistent with structure deduced from the surface geology. To construct a model which predicts the orientation at depth of the boundary and the thickness of the relevant magnetic units, a comprehensive suite of oriented samples is required from across the boundary.

iii) The plutons appear to be associated with a marked variability in the magnetic field. Since in general the surrounding arc volcanics and sediments are associated with a relatively uniform field, the subsurface contact between plutons and country rock may be possible to model, again provided oriented samples are available.

*Acknowledgements.* CJP thanks the Natural Environment Research Council for a research fellowship and provision of a field vehicle, and the Northern Areas Works Organisation and the Gilgit Police Department for co-operation in the field. Peter Whiteman and Nazir Khan gave valuable field assistance. Ian Luff supplied some rock samples and Mike Brooks made the remanence measurements. This study is an outgrowth of a joint British Universities – Peshawar University geology project.

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