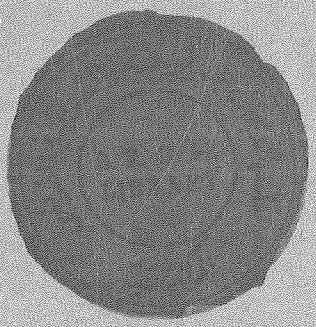
ASSESSMENT OF THE FELSIC PLUTONIC ROCKS IN THE SOUTH AL 'AMĀR AREA

BY
M. LAVAL, L. LE BEL

OPEN-FILE REPORT BRGM-OF-05-19

11 MAR 1986





MINISTRY OF PETROLEUM AND MINERAL RESOURCES
DEPUTY MINISTRY FOR MINERAL RESOURCES
JIDDAH, KINGDOM OF SAUDI ARABIA
1405 A.H. 1985 A.D.

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ABSTRACT

The plutonic rocks of the South Al 'Amar area were emplaced in three phases between 660 and 550 Ma: (1) a tonalite suite, probably contemporaneous with the Al 'Amar and Khnaiguiyah volcanism; (2) granodiorite and calc-alkalic granite; and (3) post-tectonic syenogranite and alkali feldspar granite.

Four major outcrop areas of third-phase granite displaying favorable petrologic features such as the presence of tourmaline and beryl, peraluminous characteristics, and development of greisen, were explored for wolframite and cassiterite. Apart from Jabal Wahwahi, where scheelite occurs in association with tourmaline-bearing quartz veinlets, these areas proved to be barren.

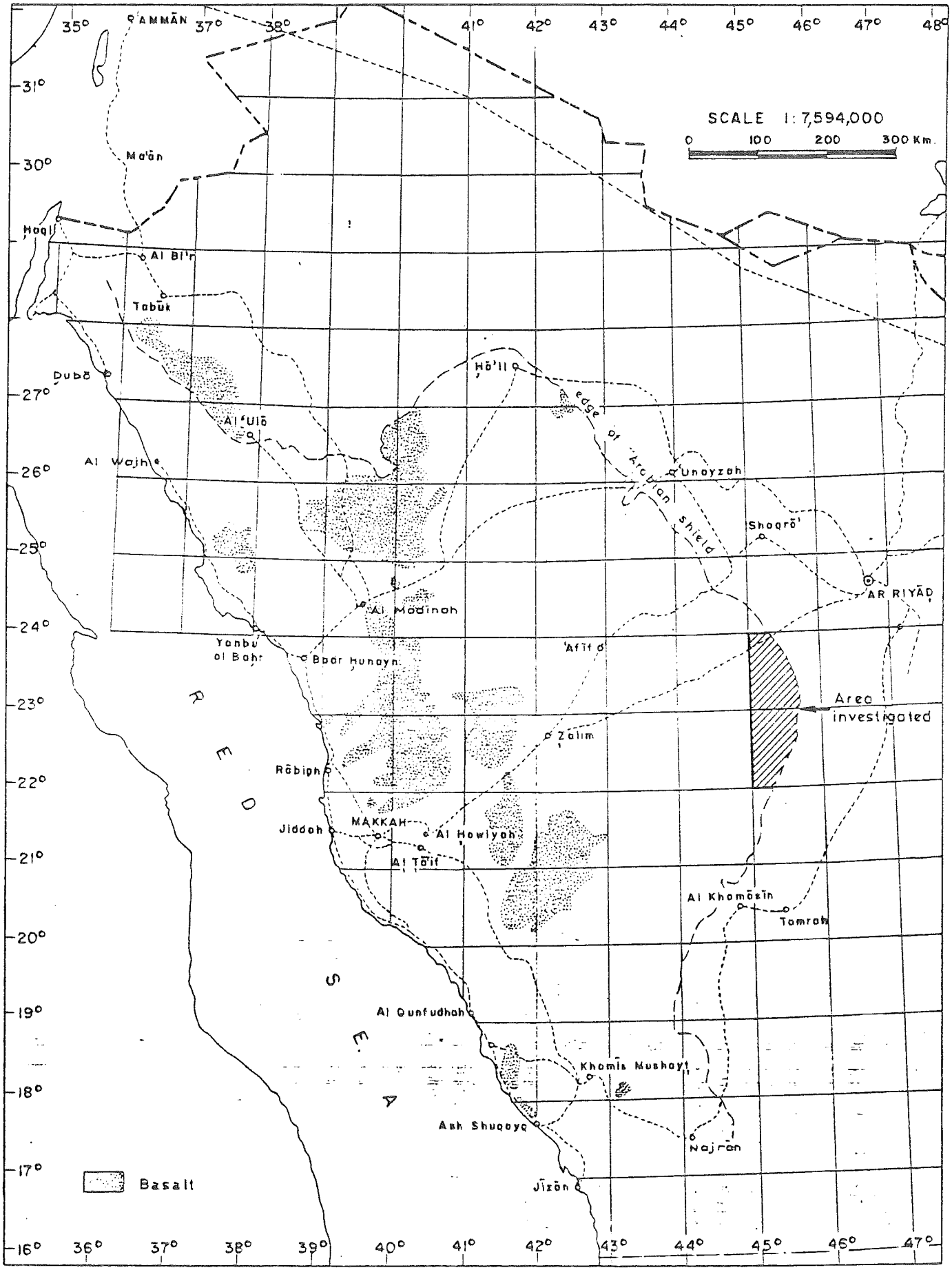
Comparative study of the rare-earth element patterns of several peraluminous Arabian Shield granites associated with wolframite or cassiterite mineralization, and of granites from the South Al 'Amar region, does not indicate the presence of plutons containing cassiterite and wolfram mineralization in the latter area. However, ancient workings in biotite granite at Sinfayn Abu Hurim (assaying up to 2,000 g/t Ag) and the Wadi Gharrah pegmatite occurrences (with 1,000 ppm Mo) justify additional prospecting for silver and molybdenum.

KINGDOM OF SAUDI ARABIA

SOUTH AL 'AMĀR AREA

ASSESSMENT OF FELSIC PLUTONIC ROCKS

LOCATION MAP



1. INTRODUCTION

Abundant work has been carried out in the Al 'Amar area since 1956. Subsequent to the discovery of the Al 'Amar Khnaiguiyah deposits, study was rapidly oriented towards the volcanoclastic sequences in the region, to the exclusion of plutonic assemblages.

After the discovery of deposits related to granitic rocks in the Arabian Shield (Baid al Jimalah, the Midian massif, Bir Tawilah, Jabal Silsilah, etc.), BRGM recommended programs to investigate the metallogenic potential of plutonic rocks in the Al 'Amar-Idsas area, and understanding of the geology of this area has improved.

1.1 GEOGRAPHIC SETTING

The study area is located in the east of the Arabian Shield (fig 1), between longitude 45° E. and the edge of the sedimentary cover, and between latitudes 22 and 24° N., covering an area of about 10,000 km² (photomosaics 116, 117, 130 and 131).

Geomorphologically, the region comprises three zones corresponding to major differences in geology. The area located to the east of the Al 'Amar fault (fig. 2) is composed of well-marked reliefs, the highest point of which is Jabal Bitran. North of the 23rd parallel, but to the west of the Al 'Amar fault, the Abt schists give rise to a fairly smooth topography of small hills between 10 and 20 m high, cut by a dense hydrographic network. South of the 23rd parallel, both types of topography are buried below the reg, with increasingly substantial eolian deposits.

The hydrographic network as a whole flows eastwards across the sedimentary cover.

1.2 PREVIOUS INVESTIGATIONS

Since publication of the first geologic map of the area (Bramkamp and others, 1956), abundant mineral exploration and geologic reconnaissance work has been carried out. Two recent synopses have taken stock of the geology of the Proterozoic rocks in the area: the explanatory notices to the 1:250,000-scale geologic maps of the Wadi ar Rayn (Delfour, in Vaslet and others, 1984) and Wadi al Mulayh quadrangles (Pellaton, in Manivit, in preparation). Abundant mineral exploration and follow-up work has been carried out in the volcanic belts and on auriferous occurrences associated with diorite complexes. However, the only references to outcrop zones of granite plutons are to be found in reports concerned with general exploration work completed in the region (Eijkelboom, 1966a and 1968; Overstreet and others, 1972).

1.3 GEOLOGIC SETTING

The main structural feature of the region is the Al 'Amar fault (fig. 2) which divides the area into two compartments: the Al 'Amar block to the east and the Abt schist block to the west.

According to Delfour (in Vaslet and others, 1984), the stratigraphy of the Upper Proterozoic is as follows: The oldest formation is an ophiolitic complex represented by the listwaenite which dots the Al 'Amar fault, and by a few massifs of serpentinized dunite, harzburgite and pillow basalt (Chevremont and Johan, 1982; Le Metour and others, 1982) comparable to the island arc ophiolites in Cyprus. This sequence is overlain by the Abt schist, which forms a thick and monotonous sequence of intensely folded chlorite and sericite schist (metagraywacke and metapelite). In the Al 'Amar block, the oldest unit (the Al 'Amar group) begins with volcanodetrital facies with an andesitic composition, overlain by felsic rocks with a keratophyric to dacitic composition. The zinc and gold mineralization is located at the interface between these two units (Milesi and others, 1984). The Hamir group is composed of basalt overlain by an arenilitic-pelitic sequence. This volcanic assemblage is intruded by a suite of tonalitic to trondhjemitic plutons which are very widespread to the east of the Al 'Amar fault (fig. 2). Recent geochronologic data (Rb/Sr isochrones on total rock, U/Pb on zircons, and Ar 39/40) indicate that the

plutonic rocks located to the east of the Al 'Amar fault were emplaced between 667 and 609 Ma (fig. 2).

A number of authors (Thekair, 1975; Al Shanti and Mitchell, 1976; Smith and others, 1979; Nawab, 1979; Fleck and others, 1980; Bokhari and Kramers, 1981; Greenwood and others, 1982; Al Shanti and Gass, 1983; Le Bel and Laval, 1985) have interpreted the geology of the Al 'Amar area in terms of plate tectonics. It will be seen below that study of plutonic activity in this region can provide valuable contributions to this concept.

1.4 AIMS AND METHODS

The main aim of the present reconnaissance program was to test the metallogenic potential of the felsic plutonic rocks in the Al 'Amar region. At the same time, a certain amount of data on the petrology of felsic plutonic rocks was acquired, the results of which are described elsewhere (Le Bel and Laval, 1985).

After study of the various existing geologic maps, the granitic rock outcrops were systematically visited to identify petrographic factors for mineralization of felsic origin, i.e.:

(1) Very siliceous leucocratic granite with a fairly high proportion of potassic feldspar (monzogranite, alkali feldspar granite).

(2) Muscovite granite or muscovitized and even greisenized zones within a given pluton.

(3) Granite containing miarolitic cavities filled with quartz and in places muscovite.

(4) Substantial pegmatite development with the presence of tourmaline and beryl.

(5) Development of skarns around the plutons.

Based on these criteria, five zones were selected and studied using soil geochemistry, stream-sediment sampling, panning, and rock geochemistry.

In the case of many outcrops, and particularly in the case of the pale granites, a rock sample was collected for analysis of major and trace elements (Cu, Pb, Zn, As, Ni, Cr, Mo, B, Sn, Ag, Y, Ba, Zr, Co, Sb, Nb, W, Sr, Rb, V and rare-earth elements).

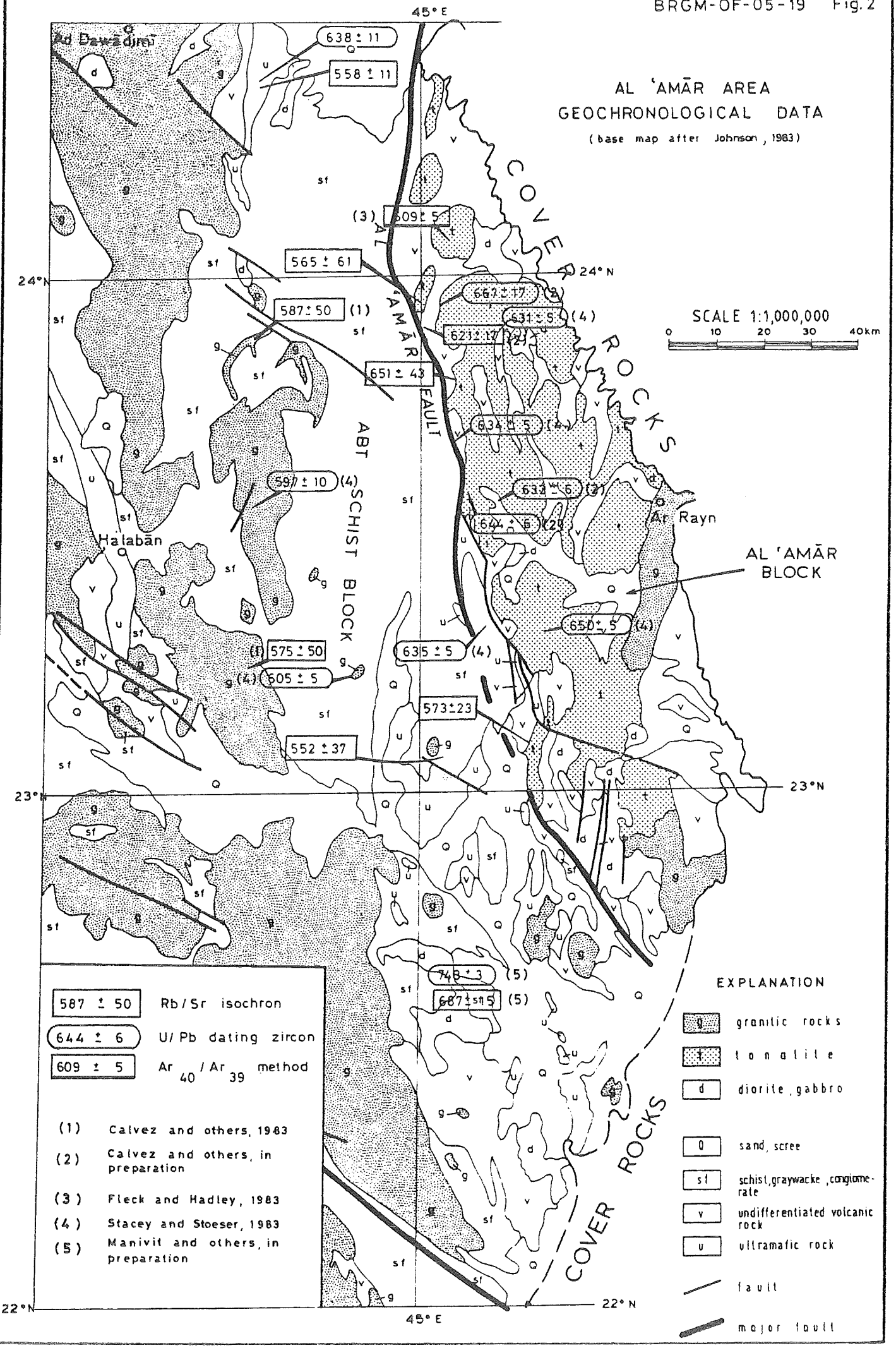

AL 'AMĀR AREA
GEOCHRONOLOGICAL DATA
(base map after Johnson, 1983)
SCALE 1:1,000,000
0 10 20 30 40km
45° E
24° N
23° N
22° N
Ad Dawādimī
Halabān
Ar Rayn
AL 'AMĀR BLOCK
ABT SCHIST BLOCK
AL 'AMĀR FAULT
COVER ROCKS
638 ± 11
558 ± 11
609 ± 5 (3)
565 ± 61
587 ± 50 (1)
662 ± 17 (2)
631 ± 5 (4)
623 ± 17 (2)
651 ± 43
634 ± 5 (4)
597 ± 10 (4)
633 ± 6 (2)
644 ± 6 (2)
650 ± 5 (4)
575 ± 50 (1)
635 ± 5 (4)
505 ± 5 (4)
573 ± 23
552 ± 37
748 ± 3 (5)
687 ± 5 (5)
587 ± 50 Rb/Sr isochron
644 ± 6 U/Pb dating zircon
609 ± 5 Ar40/Ar39 method
(1) Calvez and others, 1983
(2) Calvez and others, in preparation
(3) Fleck and Hadley, 1983
(4) Stacey and Stoeser, 1983
(5) Manivit and others, in preparation
EXPLANATION
granitic rocks
tonalite
diorite, gabbro
sand, scree
schist, graywacke, conglomerate
undifferentiated volcanic rock
ultramafic rock
fault
major fault

Table 1 Geochemical survey in South Al 'Amar Area
Summary of present work
GDAS 5567

Area	MODS no.	Type of geochemistry	Area (km^2)	Sample no.	Total samples
Jabal Wahwahi	04476	Soil geochemistry	19	AMS 1-155	155
		Stream-sediment geochemistry	9	AMS 156-210 AMS 231-236	60
		Alluvial	10	AMS 211-230	20
Jabal Qurayn Shaiban	04415	Soil geochemistry	3.2	AMS 301-494	194
		Stream-sediment geochemistry	5	AMS 495-561	66
		Alluvial	6	AMS 562-580	18
		Rock	0.1		26
Jibal Tasiyah	04477	Stream-sediment geochemistry	1.5	AMS 915-949	35
		Alluvial	1.5	AMS 901-913	13
		Rock	1.5		10
Jabal Lachkar	04478	Stream-sediment geochemistry	0.1	AMS 1001-1019	19
		Alluvial	0.1	AMS 1031-1034	4
		Rock	0.1		7
Jabal al Hamat	00328	Stream-sediment geochemistry		AMS 701-898	198
		Alluvial	7.5	AMS 1050-1079	198
Wadi Araqah	00427	Alluvial	72		64

2. GEOCHEMICAL PROSPECTING IN SEVERAL PLUTONS IN THE AL 'AMAR AREA

Based on bibliographic study and on general reconnaissance of the region, five zones were selected for geochemical investigation (fig. 3):

	MODS no.
Jabal Wahwahi	04476
Jabal Qurayn Shaiban	04415
Jibal Tasiyah	04477
Jabal Lachkar	04478
Jabal al Hamat	00328

Results are recorded in the Geochemical Data Analysis System (GDAS) under study number 5567 (Table 1).

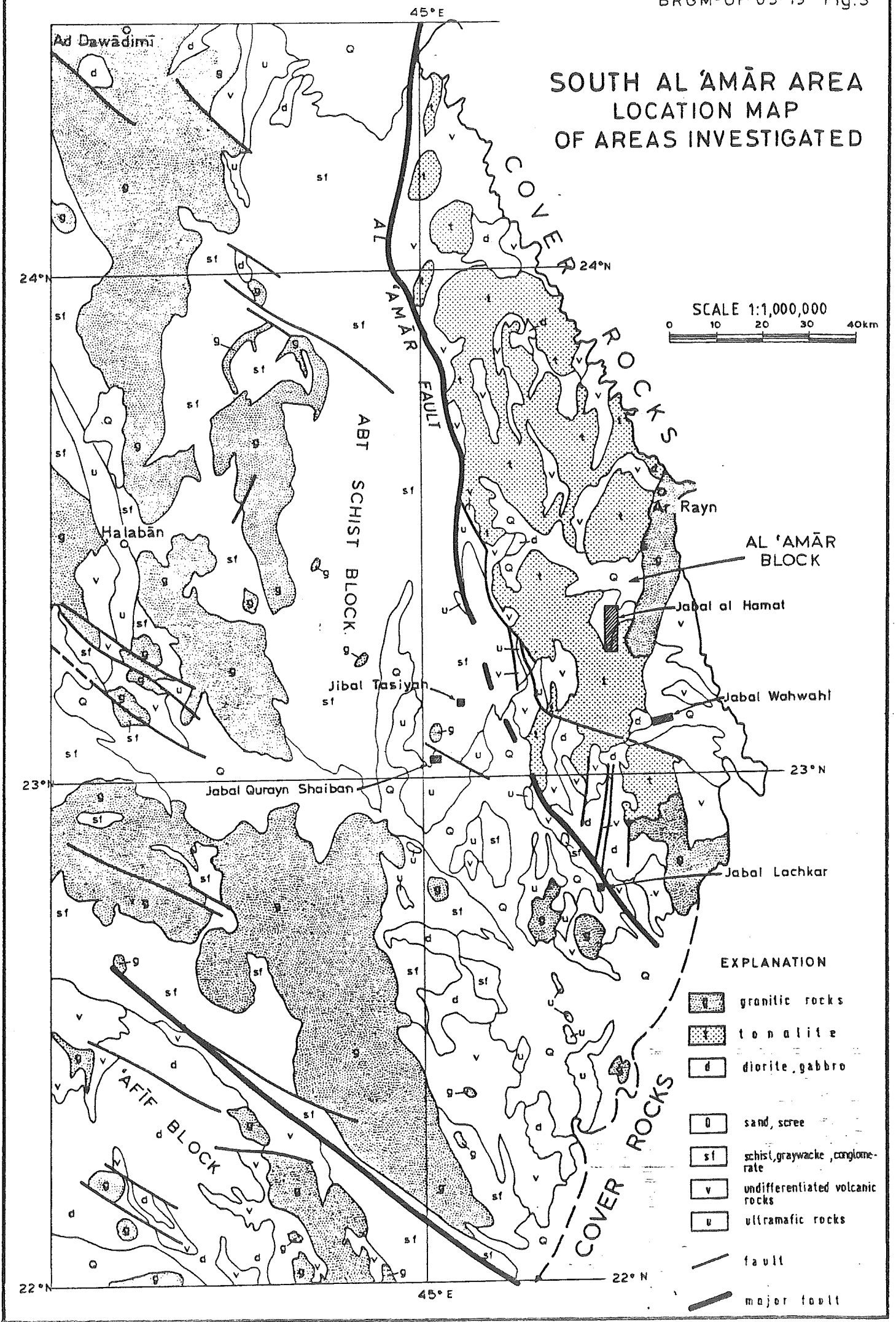
2.1 JABAL WAHWAHI (MODS 04476)

2.1.1 Introduction

The Jabal Wahwahi outcrop area is composed of two massifs (fig. 4) separated by 4 km of reg. The east massif is aligned north/south over about 400 m and was selected for more-advanced investigation because of the favorable petrographic facies and the presence of a wolfram anomaly recorded by Overstreet and others (1972a).

2.1.1.1 Recorded wolfram anomaly (Overstreet and others, 1972a)

The wolfram anomaly was identified in a sample of alluvial concentrate collected southeast of the east massif; it represents the highest anomaly recorded in the Al 'Amar belt (4,000 ppm W). According to Overstreet, this anomaly is due to scheelite disseminated in the granite and in veins of tourmaline-bearing quartz.

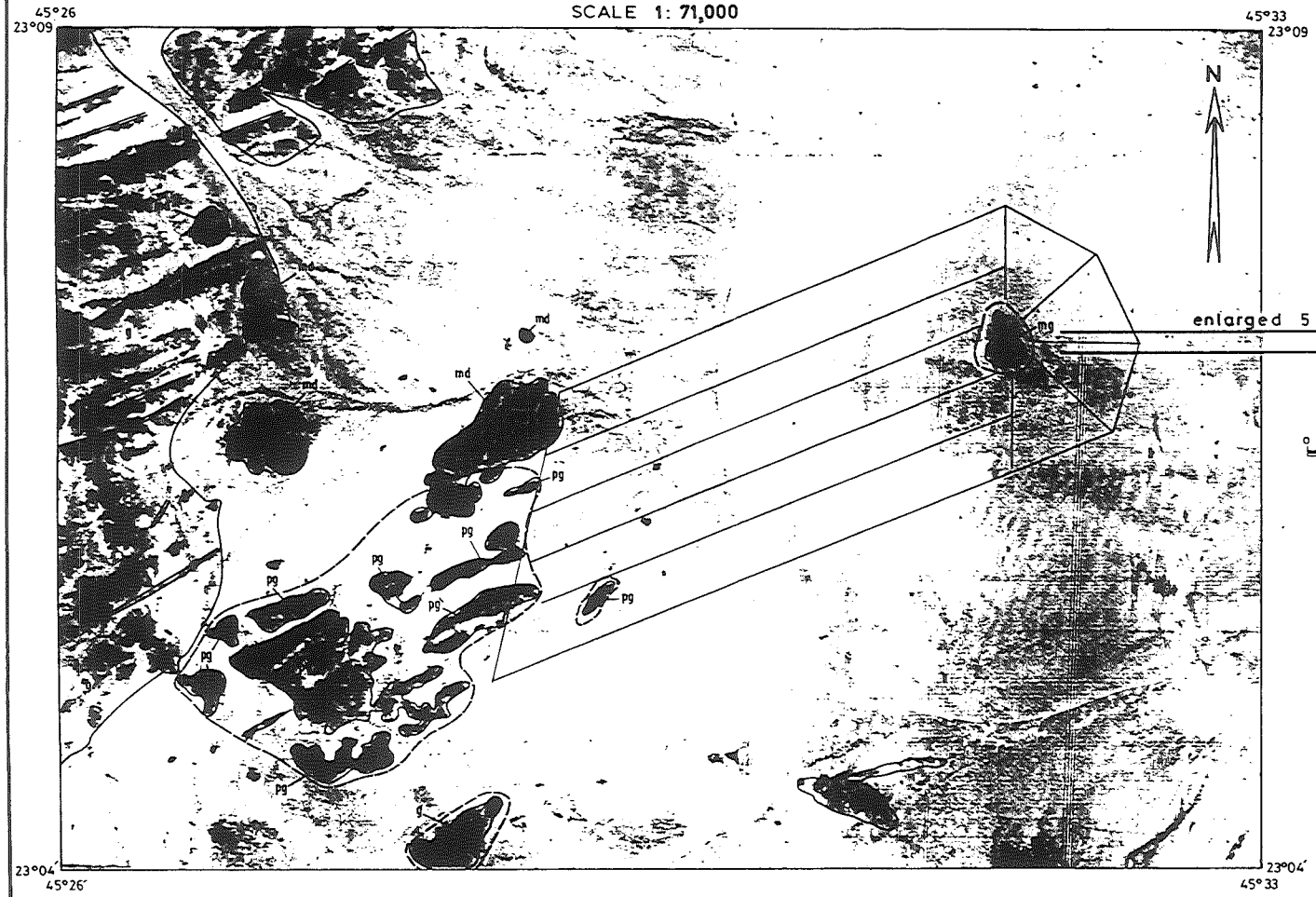


Drawn by Jean NIVOSON

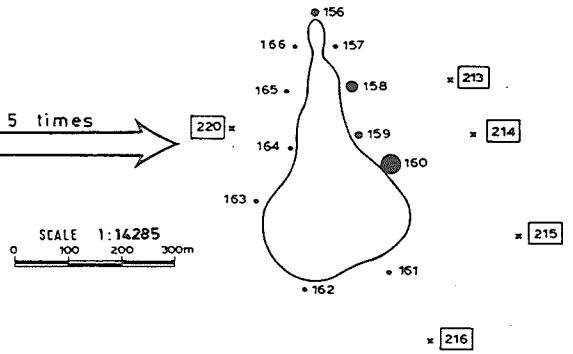
JABAL WAHWAHI : GEOCHEMICAL SAMPLING

After photomosaic 458 and 459

SCALE 1: 71,000



enlarged 5 times



SAMPLE No.	MAGNETIC FRACTION	NON MAGNETIC FRACTION	SCHEELITE
213	23	6798	<1°/₀
214	189	8660	1.5 °/₀
215	15	7934	1.5°/₀
216	<10	2242	<1°/₀
220	<10	430	<1°/₀

EXPLANATION

// : rhyolite dike

mg : miarolitic granite

pg : porphyritic granite

g : undifferentiated granitic rocks

md : microdiorite

area of soil geochemistry

area of stream and alluvial geochemistry

EXPLANATION

Stream sediment samples (•)

• 166 : < 10 ppm W

• 156 : from 10 to 20 ppm W

• 158 : from 20 to 50 ppm W

● 160 : > 50 ppm W

Alluvial samples 216

2.1.1.2 Petrographic facies

Several factors identified in the easternmost jabal attracted attention. This is pale granite with potassic feldspar containing only a few visible small biotite crystals, which is uncommon east of the Al Amar fault. Quartz is well developed, forming large globular crystals (5-6 mm in diameter). In the south part of the massif the quartz is expressed as centimeter-sized pyramid-shaped crystals in miarolitic cavities filled with quartz and pyrite. Sericite is also present in this miarolitic zone, indicating a peraluminous trend. Several centimeter-thick veins of acicular tourmaline-bearing black quartz crop out on the east flank of this hill.

These observations led to selection of the east massif for more-detailed goechemical study. Regional study of the various outcrops shows that the massif can be related to the pluton of pink porphyritic granite to the west (fig. 4).

2.1.2 Petrographic study of Jabal Wahwahi rocks

2.1.2.1 Description

Two separate facies crop out (fig. 4). The isolated hill to the east is composed of pink equigranular granite containing globular quartz and muscovite (sample ML 1211B). The texture is microgranular, displaying phenocrysts of microcline (with perthite and albite in places) or hexagonal quartz. The muscovite is tabular and the rare biotite is destabilized to leucoxene. The plagioclase is albite.

The main massif, located to the west, is composed of pink porphyritic granite containing phenocrysts of albitized microcline and sericitized albite. The biotite crystals are small, brown and very pleochroic, with zircons and apatite. In the west part of the massif are numerous inclusions (between 0.1 and 2-3 m in diameter) of fine-grained microtonalite with a regular grain size; this facies contains brown biotite, green hornblende, plagioclase, quartz and a small proportion of potassic feldspar. The latter facies forms a massif located in the north of Jabal Wahwahi (fig. 4).

2.1.2.2 Major-element geochemistry

Two samples from the hill in the east part of the prospect were analysed: the normal facies (sample ML 1211B) and the granite enriched in miarolitic cavities filled with quartz (sample ML 1211A). It emerges (Table 2) that the zone containing miarolitic cavities filled with quartz is geochemically expressed by an increase in the SiO_2 and K_2O contents and by a decrease in the Na_2O and CaO content. The normal granite in this hill is geochemically similar to the porphyritic granite which crops out to the west of the prospect, but is differentiated by its fairly marked peraluminous composition ($Al_2O_3/Na_2O + K_2O + CaO = 1.25$).

2.1.3 Prospecting at Jabal Wahwahi

Prospecting at Jabal Wahwahi was carried out with two aims:

(1) To confirm the existence of the wolfram anomaly recorded by Overstreet and others (1972).

(2) To identify possible extensions to the anomalous zone.

Because of the petrographic affinities between the miarolitic granite in the east hill and the porphyritic granite in the west, the entire reg zone between the two massifs was prospected.

Table 2 Jabal Wahwahi: Major element geochemistry (percent)

Element	ML 1211A Miarolitic granite	ML 1211B Pink granite	ML 1212 Porphyritic granite	ML 1213 Micro-tonalite
SiO_2	76.89	74.68	74.69	61.40
Al_2O_3	12.34	13.70	13.36	15.73
Fe_2O_3	0.79	1.81	2.00	6.35
MnO	0.03	0.06	0.04	0.09
MgO	0.22	0.09	0.46	2.22
CaO	0.15	0.34	0.96	4.66
Na_2O	2.85	3.03	4.07	4.12
K_2O	5.04	4.96	4.30	2.76
TiO_2	0.07	0.21	0.23	1.02
P_2O_5	0.04	0.06	0.09	0.41
Loss on ignition	1.21	1.52	0.07	0.24
T o t a l	99.64	100.47	100.28	99.01
$Al_2O_3/Na_2O + K_2O$	1.2	1.3	1.18	1.61
$Al_2O_3/Na_2O + CaO$	1.1	1.25	1.02	0.86

2.1.3.1 Study methods employed

All areas of relief in the area (fig. 4) were explored by alluvial geochemistry and by systematic stream-sediment geochemistry of all thalwegs. The reg zone located around the east hill and between the two outcropping massifs was prospected by soil geochemistry. Surface samples were collected in each case. In the case of soil and stream-sediment geochemistry, the 0.315-1 mm fraction was subjected to ICP spectrometer analysis in the BRGM Orléans laboratory. The following elements were assayed: Si, Al, Fe, Mg, Ca, K, Ti, Mn, P, Cu, Pb, Zn, As, Ni, Cr, Mo, B, Sn, Ag, Y, Ba, Zr, Sb, Nb, W, Co, V, Li, Sr, Be, Cd, La, Ce and Bi.

The alluvial samples (16-liter samples concentrated by panning) were examined with an ultraviolet lamp and some were subjected to mineralogic and geochemical study.

2.1.3.2 Results of stream-sediment geochemistry

Four samples from the hill in the east of the prospect display wolfram values above the analysis threshold (10 ppm). All are located (fig. 4) on the east flank of the hill and do not exceed 74 ppm W (AMS 160). Fifty samples from the zone of hills composed of porphyritic granite (to the west) were collected, but none display wolfram values above the analysis threshold. Values for other trace elements in these two zones remain low or below the analysis threshold.

2.1.3.3 Results of alluvial prospecting

Alluvial prospecting has confirmed the existence of a zone anomalous in wolfram around the isolated hill. The four pan samples collected on the east side of this hill display very high wolfram values in the nonmagnetic fraction (2,200-8,700 ppm W) (fig. 4); these values are associated with the presence of scheelite in the concentrates (1-5% scheelite). Mineralogic examination reveals no other minerals of economic interest, and no trace of wolframite.

2.1.3.4 Results of soil geochemistry

Soil prospecting took the form of sampling along five radial profiles 1,000 m long, with the aim of testing possible extensions to the anomalous zone in the east hill. As geologic and petrographic study indicates an affinity between this hill and the porphyritic granite located to the west, six profiles oriented N. 65° E. were sampled every 500 m between the two zones. These surface samples were screened to between 0.315 and 1 mm.

There is no geochemical component which can be used to differentiate the east zone in which the wolfram anomaly identified by stream-sediment and alluvial geochemistry was identified. Like most other trace elements, wolfram values remain everywhere below the analysis threshold. The soil geochemistry of the Jabal Wahwahi reg appears to be effectively influenced by detrital influx from the relief zone located to the west and northwest.

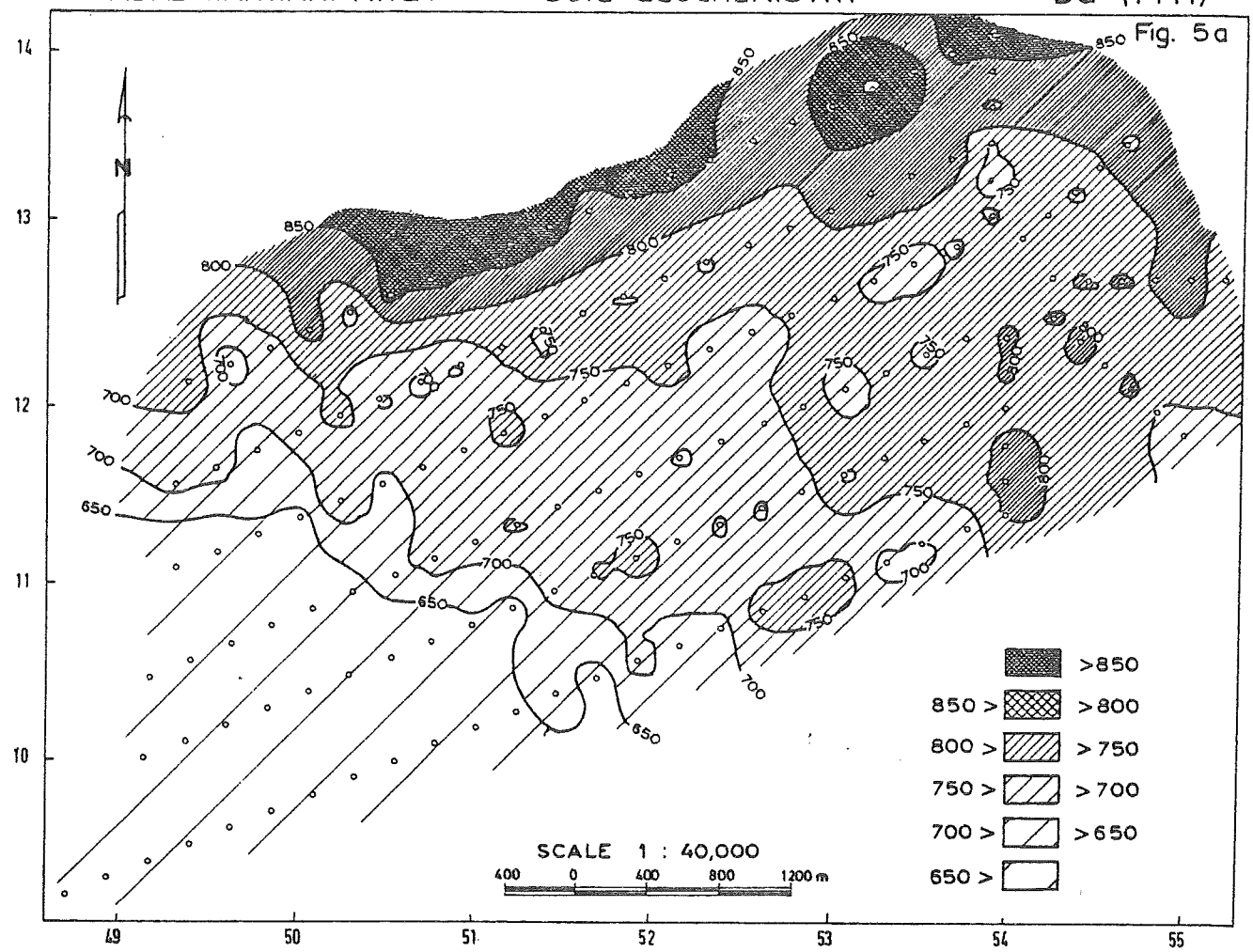
The granite, granodiorite and diorite assemblage in the northwest (fig. 4) is probably the cause of the Ba and Sr gradient (along a north-northwest striking axis, see figs. 5a and b) and possibly partially of the P gradient (fig. 7a). This gradient is perpendicular to the main flow direction of the wadis draining the northwest area. In contrast, the high Ce (fig. 6a), Ti (fig. 7b) and to a lesser extent K (fig. 6b) and P values (fig. 7a) are due to influx from Jabal Wahwahi West, where the porphyritic granite crops out.

2.1.3.5 Rock geochemistry

Ten rock samples from the east hill (GDAS 6615 and 6617) were collected from normal granite, miarolitic granite and quartz veins. Gold values are everywhere below the analysis threshold (20 ppb) and silver values are low (maximum 13 g/t). The wolfram anomalies identified by alluvial geochemistry probably have two separate origins: (1) the quartz veinlets on the east flank where disseminated scheelite is present; and (2) the pyrite in the miarolitic cavities in the granite. This pyrite grades 50 ppm W and 700 ppm Mo.

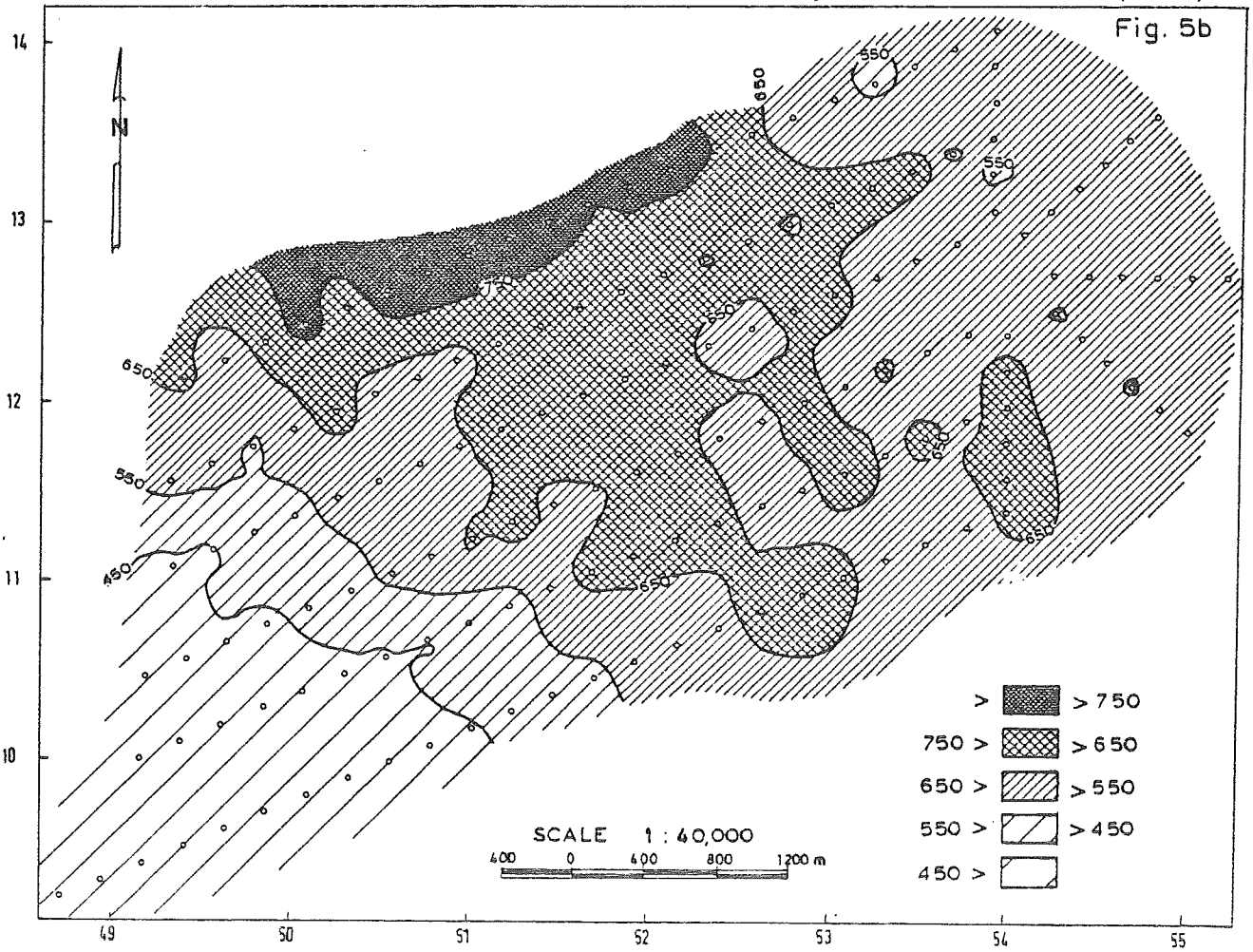
JABAL WAHWAHI AREA SOIL GEOCHEMISTRY Ba (PPM)

Fig. 5a



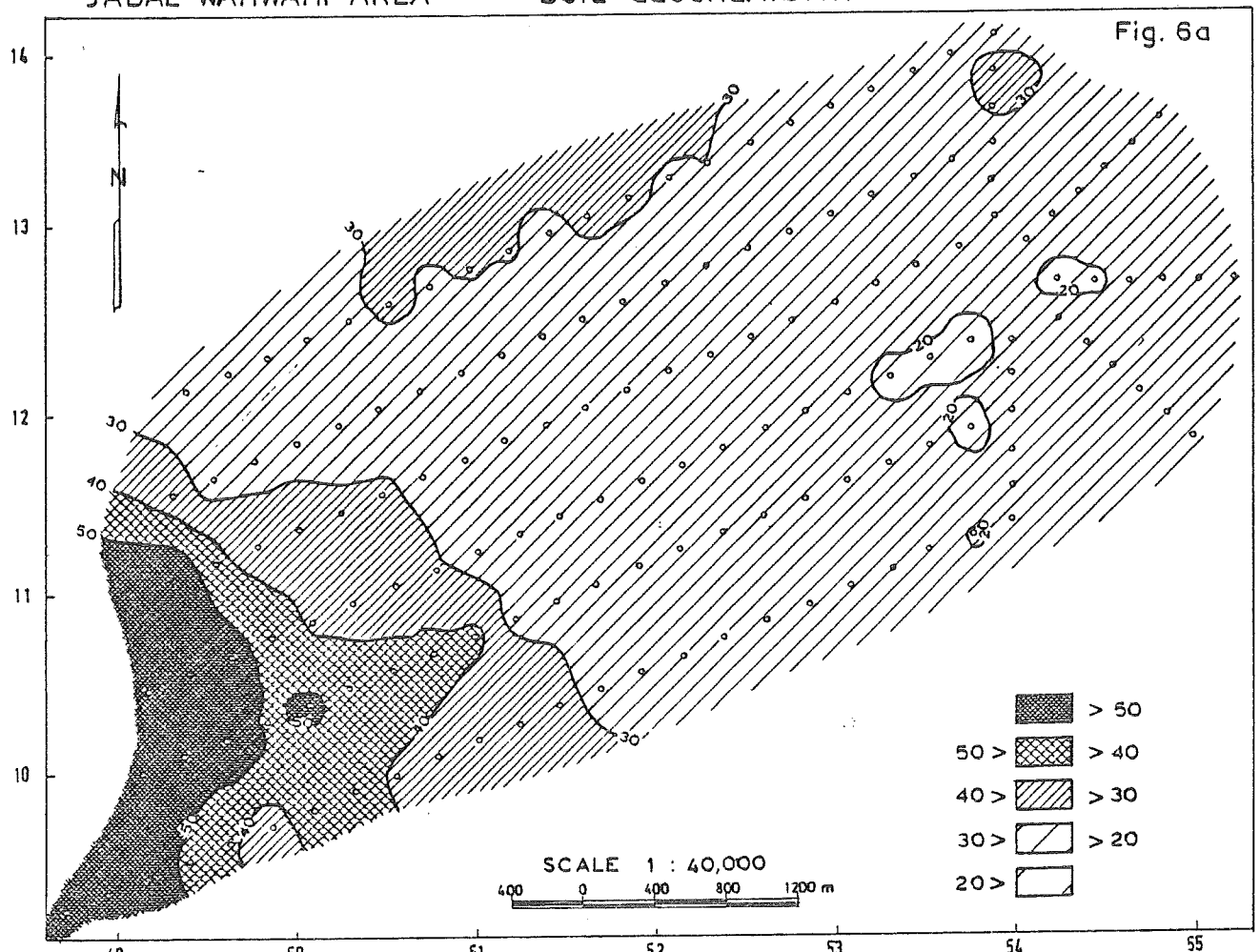
JABAL WAHWAHI AREA SOIL GEOCHEMISTRY Sr (PPM)

Fig. 5b



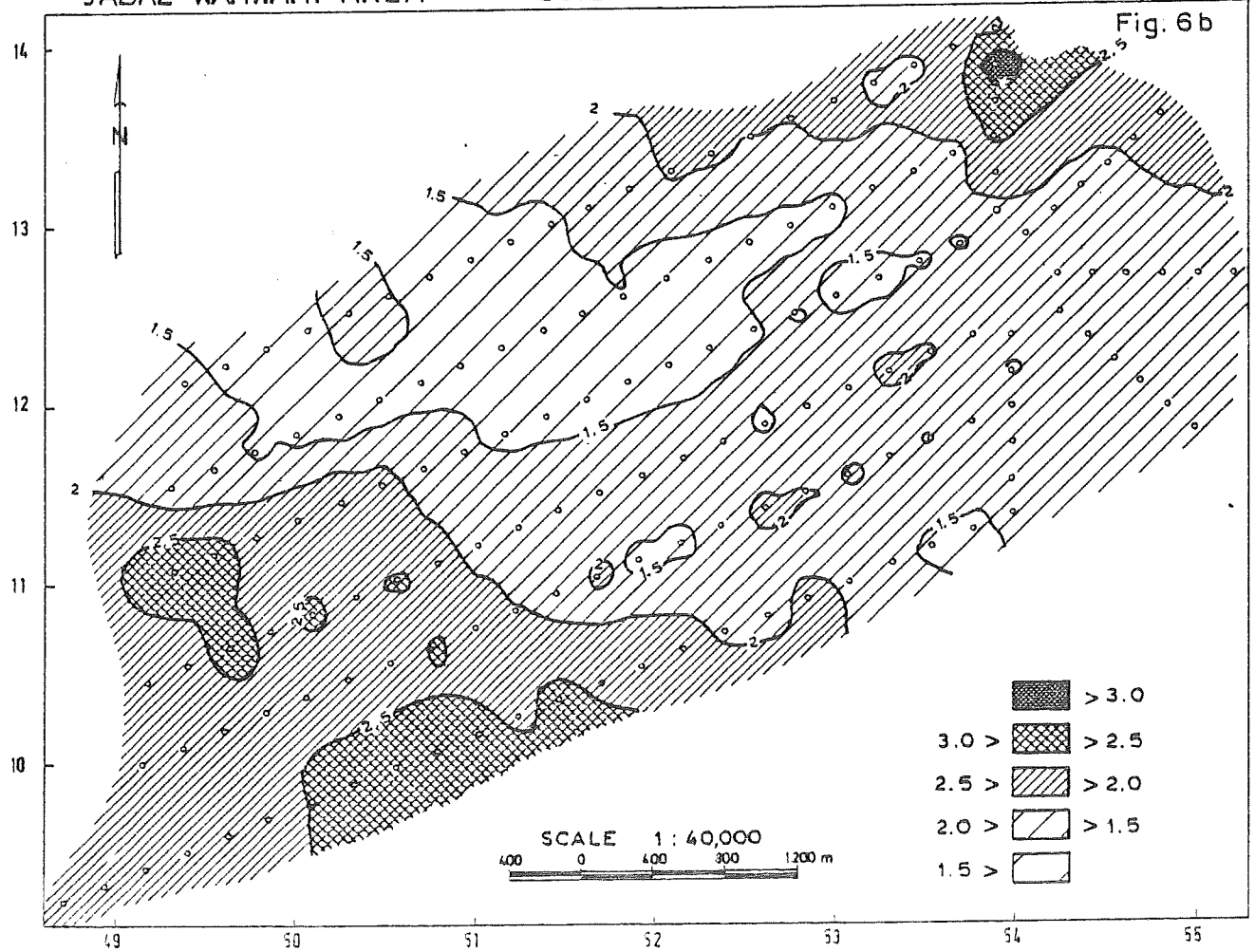
JABAL WAHWAHI AREA SOIL GEOCHEMISTRY Ce (PPM)

Fig. 6a



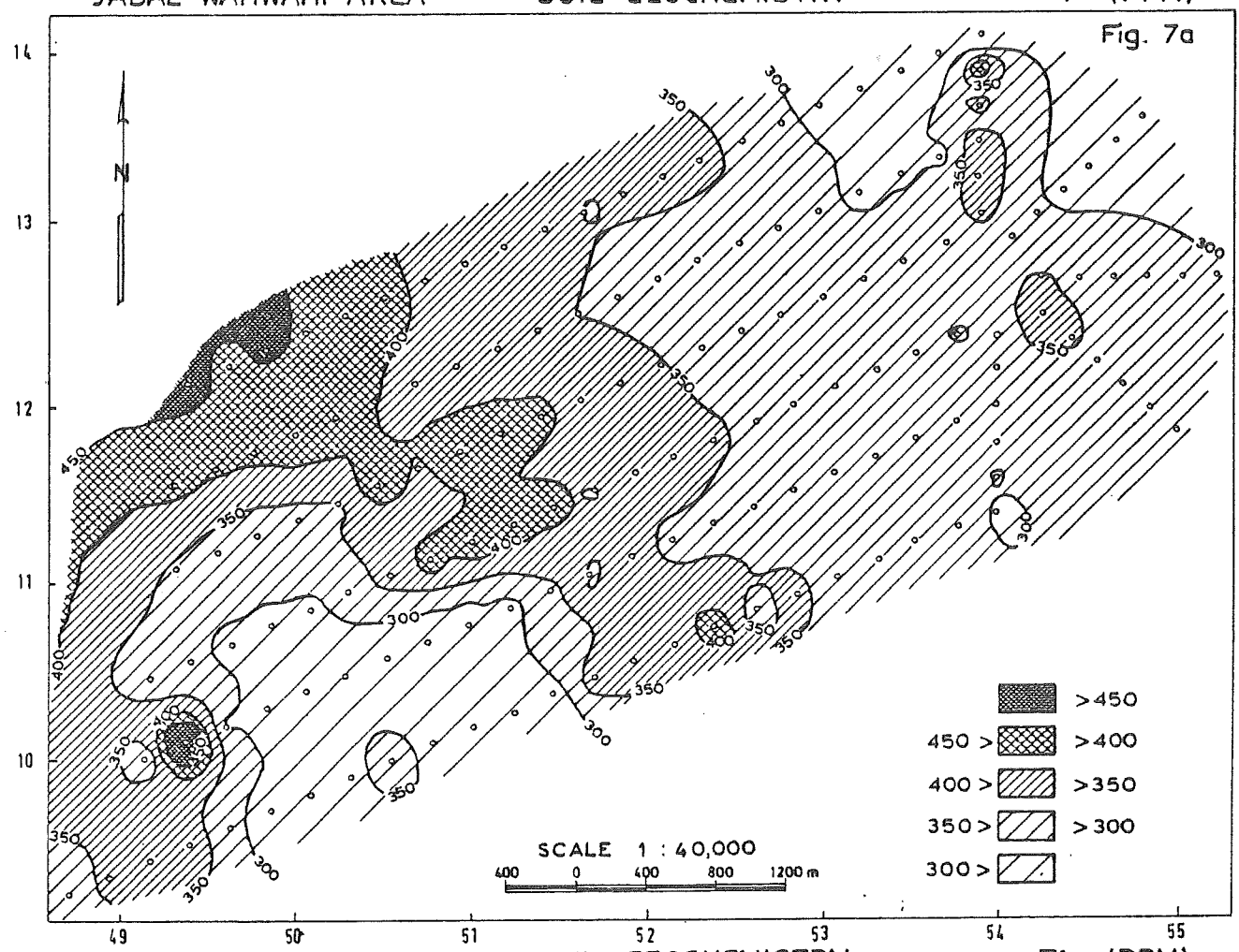
JABAL WAHWAHI AREA SOIL GEOCHEMISTRY K (%)

Fig. 6b



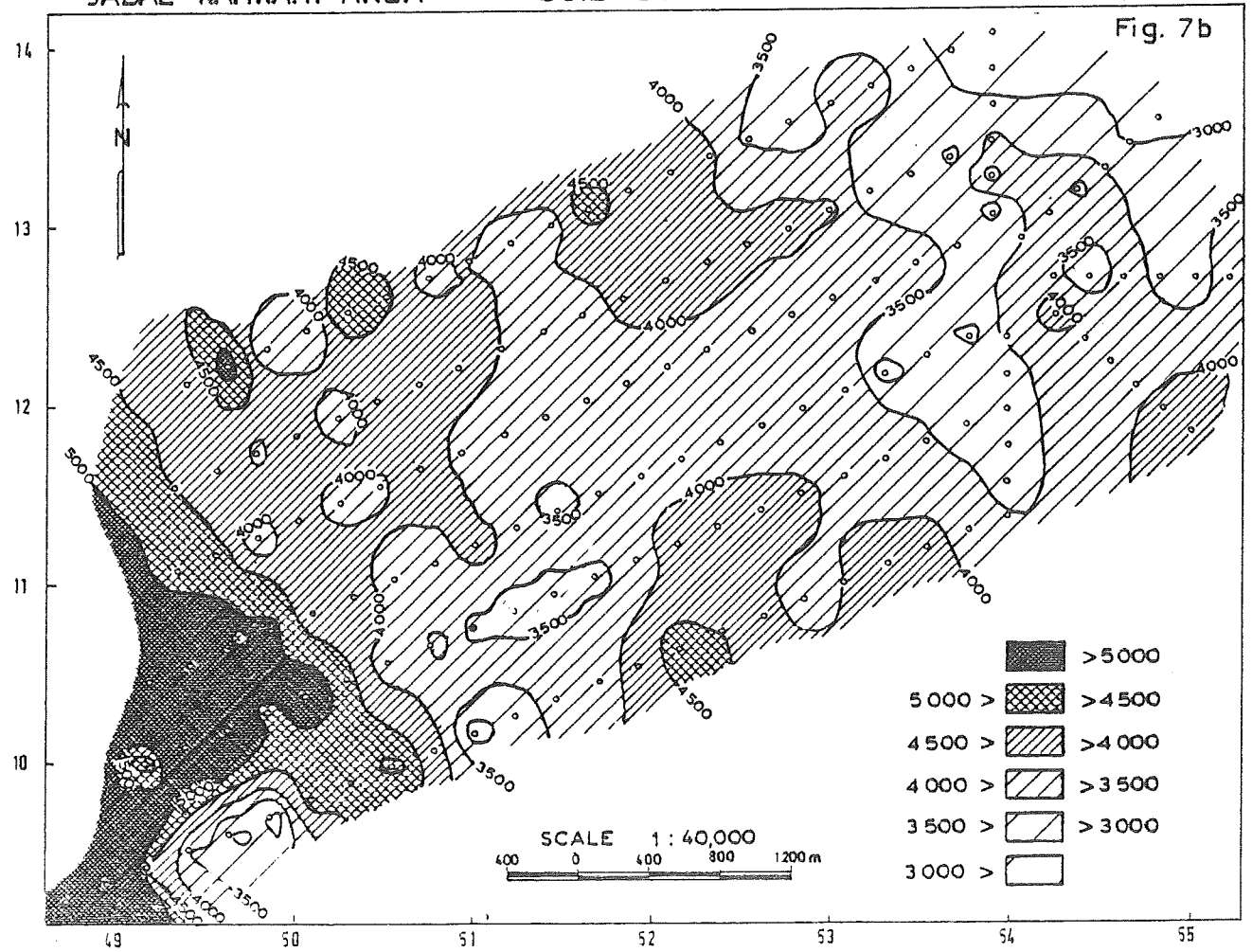
JABAL WAHWAHI AREA SOIL GEOCHEMISTRY P (PPM)

Fig. 7a



JABAL WAHWAHI AREA SOIL GEOCHEMISTRY Ti (PPM)

Fig. 7b



Drawn by Jean NIYOSON R.

2.1.4 Conclusions on study of Jabal Wahwahi

The Jabal Wahwahi area, the only zone selected to the east of the Al 'Amar fault, displays a number of petrographic characteristics favorable for mineralization associated with silicic magmatization. The wolfram occurrence recorded by Overstreet falls within this context. The various phases of geochemical reconnaissance completed during the present study confirm that the occurrence is associated with scheelite disseminated in the rock and in tourmaline-bearing quartz veinlets. However it is also apparent that wolframite is not present, and that there are no extensions to the zone anomalous in wolfram. No additional work is therefore justified.

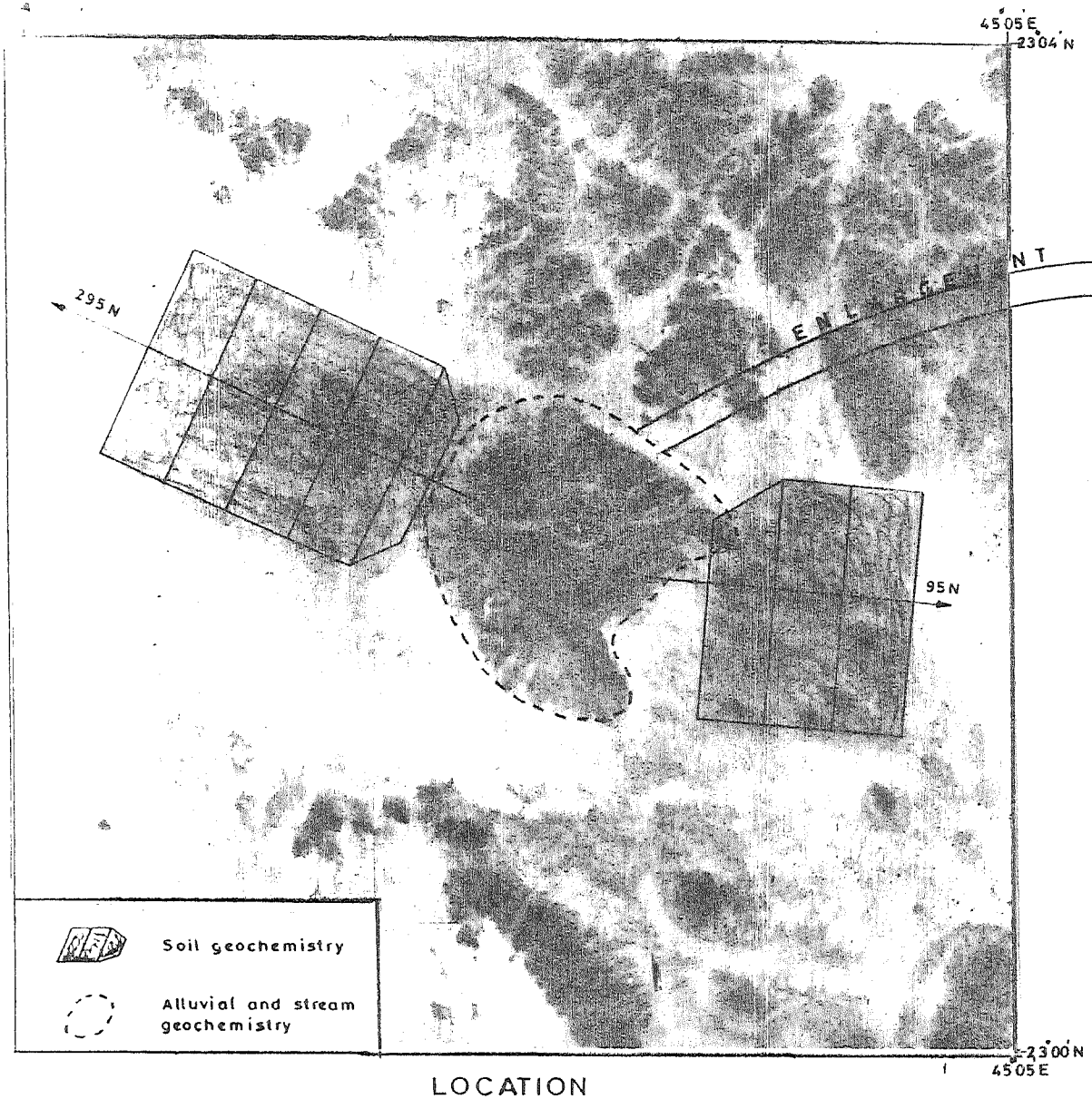
2.2 JABAL QURAYN SHAIBAN PROSPECT (MODS 04415)

2.2.1 Introduction

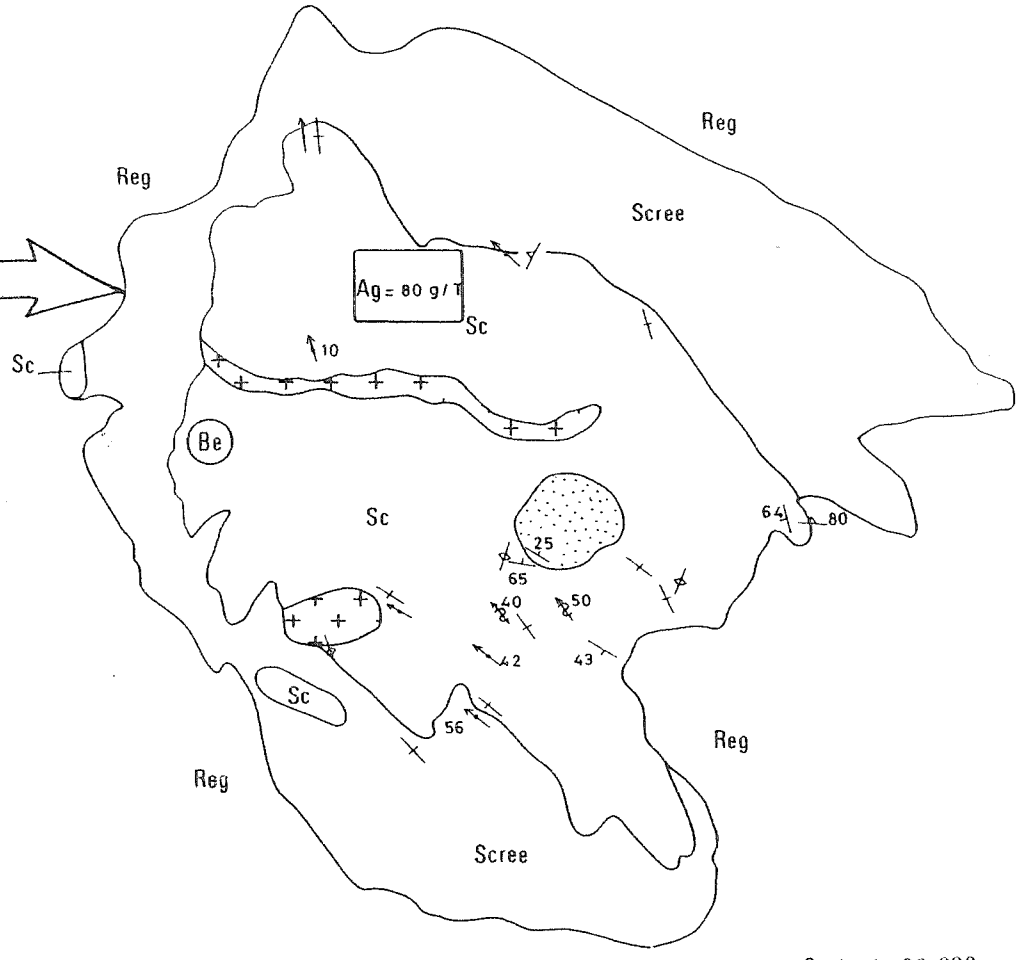
Unlike the Jabal Wahwahi prospect, the Jabal Qurayn Shaiban prospect is located within the Abt schist (fig. 3). This zone was selected for preliminary reconnaisance for various reasons. The granite intrusive into the Abt schist is pale in color, felsic, and apparently fairly evolved; the outcrop area is fairly limited and the topographic level apparently corresponds approximately to the roof of a granite dome; the granite contains muscovite and the principal facies is locally greisenized; green beryl is present at the west extremity of the main granite body.

2.2.2 Geology of Jabal Qurayn Shaiban

Three granite bodies intrude the Abt schist, the largest consisting of an east-striking dike 1,100 m long and 50 m thick (fig. 8).



LOCATION
SCALE 1:50,000
0 1 2km



Scale 1 : 20,000
0 200 400 600m

Reg
Scree

Coarse - grained granite
Fine - grained granite
Sc Abt schist
Mineral lineation
Fold axis
Schistosity 2
Schistosity 1
Be Beryl in quartz vein

JABAL QURAYIN SHAIBAN
GEOLOGIC SKETCH MAP

BRGM-OF-05-19 Fig. 8

2.2.2.1 The Abt schist

The Abt schist consists of a thick sequence of polydeformed slaty schist, mica schist and amphibole gneiss. The internal stratigraphy is hard to establish because of the substantial deformation. Metavolcanic rocks (green dacite and pink rhyolite in meter-thick bands) are rare, alternating with felsic volcanoclastic and volcanodetrital material (metagraywacke containing green hornblende or actinolite, biotite and muscovite-bearing mica schist displaying organic matter and euhedral pyrite grians 0.8 to 1.2 cm in size).

Two schistosities are visible. The lineation of S1 is fairly poorly marked (fig. 8) and is reworked by syn-S2 folds. S2 strikes northwest and is parallel to a mineral lineation (the plunge of which is commonly between 30 and 40° to the northwest). S2 is contemporaneous with a phase of fairly tight folding (between a meter and a decameter in amplitude) with a northwest axis.

2.2.2.2 Granites

The main dike strikes east and consists of pale porphyritic granite containing Carlsbad-twinned euhedral potassic feldspar, muscovitized albite (An ≅ 05), rare biotite, and laths of muscovite. Near the west extremity of the dike, the granite displays a greisen facies with yellow altered residual feldspar, quartz, and abundant muscovite. This body is cut by numerous quartz veins between 1 and 20 cm thick, inclined between 45 and 90°, and mainly striking northeast, although some veins strike north. This white milky quartz displays no muscovite fringe and contains geodes of brown carbonate. One vein contains beryl crystals between 5 and 6 cm in size.

The granite body located on the west flank of the hill (fig. 8) displays the same facies, with many greisenized zones.

The massif in the center consists of aplitic granite, apparently richer in quartz and muscovite.

All these granites clearly cut the S2 schistosity and thus appear to be post-tectonic.

2.2.2.3 Geochemistry of the Qurayn Shaiban granite

Two analyses have been completed, one of the porphyritic facies (ML 1210A) and the other of the greisenized facies (ML 1210C) (Table 3). In both cases, the $Al_2O_3/Na_2O + K_2O + CaO$ ratio of > 1.1 indicates the peraluminous trend of this granite. The greisenized facies is distinguished from the porphyritic granite by a higher SiO_2 content, by a very marked fall in K_2O (1.61%), and by a corresponding increase in Na_2O (+1%). It would appear that this trend represents the first stages of later albitization of the massif.

2.2.3 Prospecting at Jabal Qurayn Shaiban

Prospecting at Jabal Qurayn Shaiban was carried out with the following aims:

(1) To investigate the metallogenic potential of the granite. For this purpose, the hill in which the three massifs crop out was systematically explored (fig. 8) by stream-sediment geochemistry (66 samples) and by panning (18 samples). The quartz veins were also sampled (26 samples).

(2) A program of soil geochemistry was carried out in the surrounding reg in order to identify suboutcropping granitic apexes. A total of 194 samples generally about 100 m apart was collected from 9 profiles on either side of the granite dike (fig. 8).

2.2.3.1 Results of stream-sediment and alluvial geochemistry

The programs of stream-sediment and alluvial geochemistry revealed no promising occurrences and appear to indicate that the granite is barren. Analyses carried out on the nonmagnetic fraction of the alluvial concentrates indicate maximum values of 500 ppm W, due to the presence of scheelite. This scheelite probably originates in the vein system which cuts the east-striking granite dike. However, checks carried out on the quartz

Table 3 Major geochemistry of prospected granites (percent) located west of Al 'Amar Fault

Element	Jabal Qurayn Shaiban		Jibal Tasiyah	Jabal Lachkar	
	ML 1210A	ML 1210C	ML 1277	ML 1217A	ML 1217B
SiO_2	73.98	76.44	72.41	70.64	72.03
Al_2O_3	13.95	13.15	14.30	14.57	14.66
Fe_2O_3	1.40	1.22	1.58	1.67	1.57
MnO	0.04	0.10	0.04	0.04	0.03
MgO	0.09	0.03	0.41	0.18	0.55
CaO	0.83	1.04	1.59	2.4	2.48
Na_2O	3.95	4.84	3.07	4.55	4.54
K_2O	3.89	1.61	3.73	2.55	2.31
TiO_2	< 0.01	< 0.01	0.16	0.22	0.24
P_2O_5	0.03	0.03	0.01	0.01	0.01
Loss on ignition	1.88	1.93	2.83	2.87	1.31
T o t a l	100.05	100.4	100.14	99.69	99.72
$Al_2O_3/Na_2O + K_2O$	1.30	1.35	1.52	1.42	1.47
$Al_2O_3/Na_2O + CaO$	1.14	1.13	1.19	0.99	1.01

veins associated with this body display no wolfram values above the analysis threshold. Only the veins in the central part of the main pluton (fig. 8) are distinguished by high silver values (80 g/t Ag, 137 ppm As), but like all veins in the area contain no gold.

2.2.3.2 Results of soil geochemistry

None of the samples displayed anomalous trace-element values, most being below the analysis threshold.

It is hard to demonstrate any continuity of the granite massif below the reg. Only the potassium (fig. 9a) and chromium contents (fig. 9b) suggest that such continuity is possible. A positive potassium zone and a negative chromium zone parallel to the base lines appear to indicate possible lateral extension of the massif.

2.2.4 Conclusions on study of Jabal Qurayn Shaiban

Despite the petrographic potential of the granite massif (the peraluminous composition, the albite-muscovite alteration and the presence of beryl), the Jabal Qurayn Shaiban prospect proved to be of no economic interest and no target zones were identified.

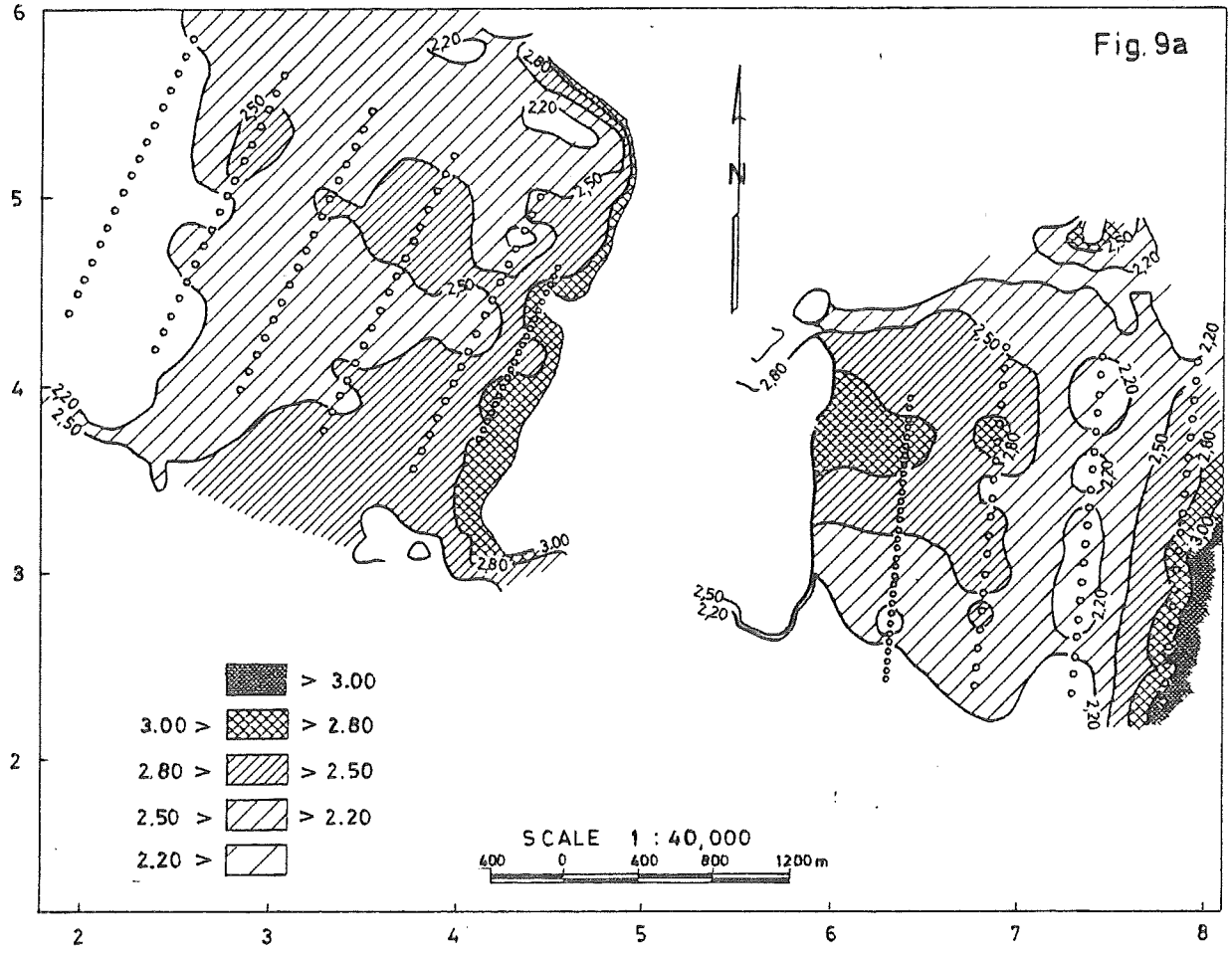
Analyses carried out on samples from greisenized zones in the granite (GDAS 6617) display no anomalies apart from silver values of about 10 g/t.

2.3 JIBAL TASIYAH PROSPECT (MODS 04477)

As in the case of Jabal Qurayn Shaiban, the Jibal Tasiyah area (fig. 3) was selected because the Abt schist at this point are intruded by pale post-tectonic granite displaying a zone in the process of greisenization. This granite forms a subcircular massif of limited dimensions (500 m in diameter).

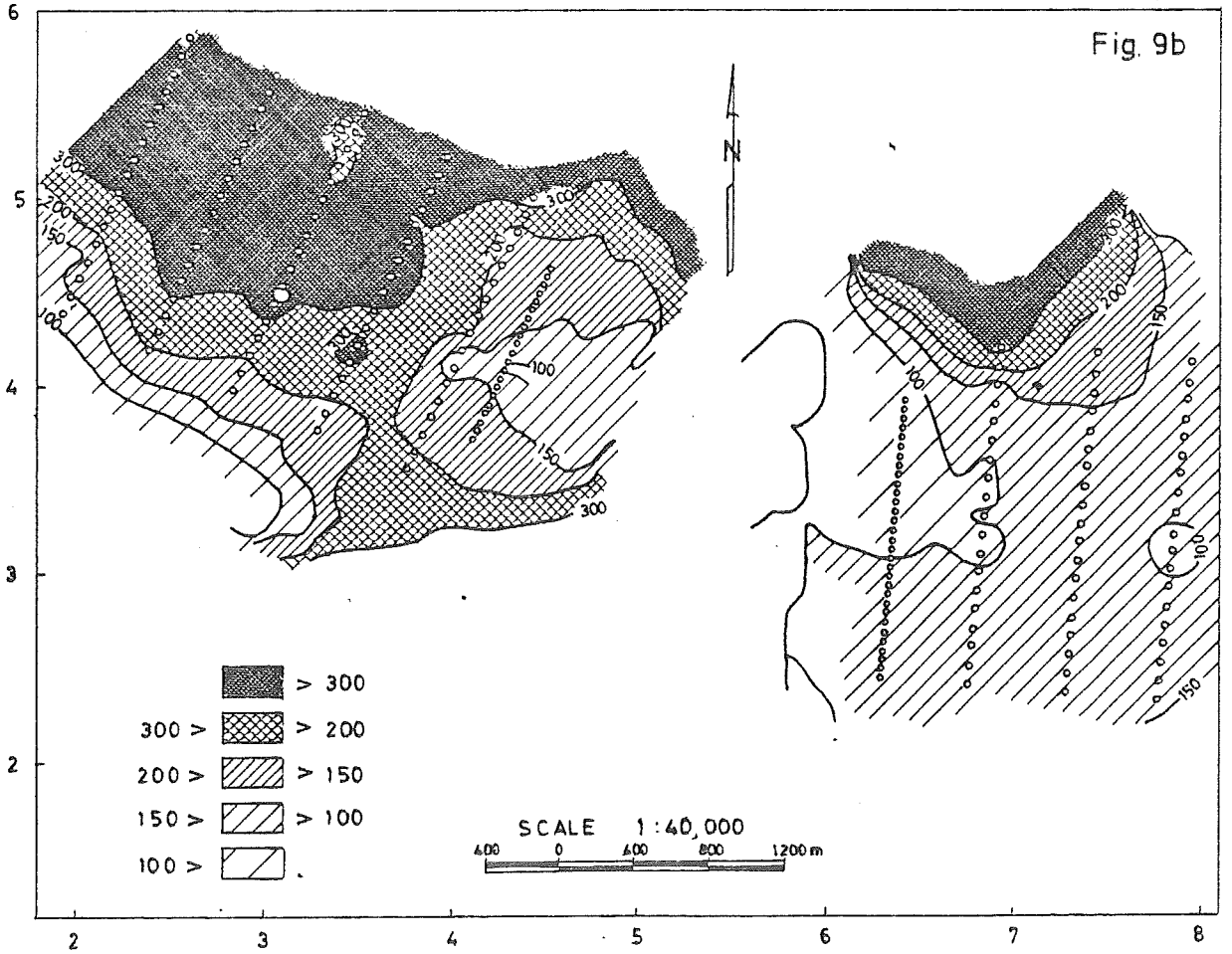
JABAL QURAYN SHAIBAN SOIL GEOCHEMISTRY K (ppm)

Fig. 9a



JABAL QURAYN SHAIBAN SOIL GEOCHEMISTY Cr (ppm)

Fig. 9b



For location see Fig. 3

2.3.1 Geology of the Jibal Tasiyah prospect

The country rocks consist of metagraywacke generally containing chlorite. The vertical S1 schistosity is oriented N. 15 to 30° E. and is affected by isoclinal folds marked by gray exsudation quartz with an axial plane parallel to S1. A schistosity at N. 70° W. develops locally, probably related to folds in decimeter-scale chevrons associated with emplacement of the granite; then biotite is superimposed on the chlorite. The external portion of the granite penetrates this sequence layer by layer and displays two main facies: (1) an equigranular medium-grained biotite granite and (2) a porphyritic granite. The latter is very commonly altered, with saussuritized plagioclase, the development of greenish-yellow muscovite, and even the formation of greisen containing pyrite and muscovite.

This massif is cut by two main systems of milky quartz veins about a meter thick. One system has a meridian strike and a dip of 40° to the east, the other being subhorizontal. These veins pass into the country rocks without having undergone any deformation, and one has been the target of ancient workings, probably for gold. Analytical control of the veins and of the altered granite facies reveals no auriferous concentration (GDAS 6582). The absence of deformation in the vein system related to the granite tends to indicate post-tectonic emplacement.

Analysis of the major elements of the granite (Table 3) demonstrates its peraluminous composition, with an $Al_2O_3/Na_2O + K_2O + CaO$ ratio of 1.19.

2.3.2 Reconnaissance at Jibal Tasiyah

Three criteria led to the selection of this zone for exploration for mineralization of felsic origin:

(1) The presence of a later granite pluton.
(2) The leucocratic and peraluminous nature of the pluton.
(3) The presence of greisen.

The area prospected is limited in size (1,500 x 1,000 m) and displays well-developed centrifugal drainage from the core of the pluton. A total of 35 stream-sediment samples was collected from the immediate edges of the pluton, and 13 alluvial samples were collected for study of the

concentrates. Ten rock samples (quartz, greisen, etc.) were subjected to multi-element analysis.

Examination of the data for alluvial and stream-sediment samples reveals no anomalies, only one sample (AMS 928) being distinguished by a wolfram value of 14 ppm. Rock control samples are equally disappointing. However slight silver and cassiterite values (1.8 and 34 ppm respectively) were obtained for samples collected from the subvertical quartz veins and from the greisen. These values slightly above the analysis threshold are accompanied by an increase in the boron content, which may indicate the presence of tourmaline.

2.3.3 Conclusions on study of Jibal Tasiyah

Despite the premise of fairly-advanced evolution in this granite massif, no occurrences have been identified which might justify additional work.

2.4 PROSPECTING AT JABAL LACHKAR (MODS 04478)

The granite massif at Jabal Lachkar is the southernmost of the plutons prospected in the area and is located to the west of the Al 'Amar fault (fig. 3).

2.4.1 Geology

This granite is located immediately to the southwest of the Al 'Amar fault, where it intrudes the Umm Sulaym formation (Manivit and others, in preparation). It forms a massif 400 m long, rising about 30 m above the surrounding dune field.

The country rocks consist of metagraywacke (greenschist facies) representing the southward prolongation of the Abt schist. The schistosity (N. 45° W.) is subvertical and parallel to the regional structures.

The granite massif comprises two main facies: both are medium-grained and equigranular, contain globular quartz, and are poor in ferromagnesian minerals. The predominant facies is very pale granite containing altered feldspar, leucoxene, and platelets of neoform muscovite in which the

cleavage is marked by oxides; however no greisens develop in this granite. The second facies is confined to the west edge of the massif and contains only green biotite, with abundant sphene and epidote. These two facies are very similar geochemically (Table 3). In relation to the massifs described above, they are characterized by a lower SiO_2 content, a more-marked calc-alkalic composition (CaO = 2.4%), and saturation without an excess of Al_2O_3.

Tectonic phenomena are fairly substantial, with abundant slip surfaces displaying vertical striations that appear to indicate diapiric emplacement. The quartz veins are arranged in two systems about a meter thick, one being oriented N. 40-60° W. and dipping 60-80° to the northeast, and the other subhorizontal. These veins contain micaceous coatings and boxworks displaying pyrite, chrlorite, limonite coatings, and molybdenite.

2.4.2 Prospecting at Jabal Lachkar

The tectonic phenomena and the leucocratic nature of the granite resulted in selection of this massif for geochemical reconnaissance. Because of the eolian cover, such reconnaissance was confined to the granite outcrop zone, about 400 x 200 m in area. A total of 19 stream-sediment samples and 4 pan samples was collected, together with 7 rock samples from quartz veins (fig. 10).

Stream-sediment geochemistry reveals several anomalous values for wolfram (four samples), lead, copper and antimony (fig. 10), distributed in uniform fashion around the massif. Study of the alluvial concentrates confirms these anomalous showings, analysis of the nonmagnetic fraction in two samples indicating wolfram values of >1,000 ppm, due to the presence of scheelite accompanied by mimetite and tourmaline. A gold grain was encountered in one sample (ML 1034).

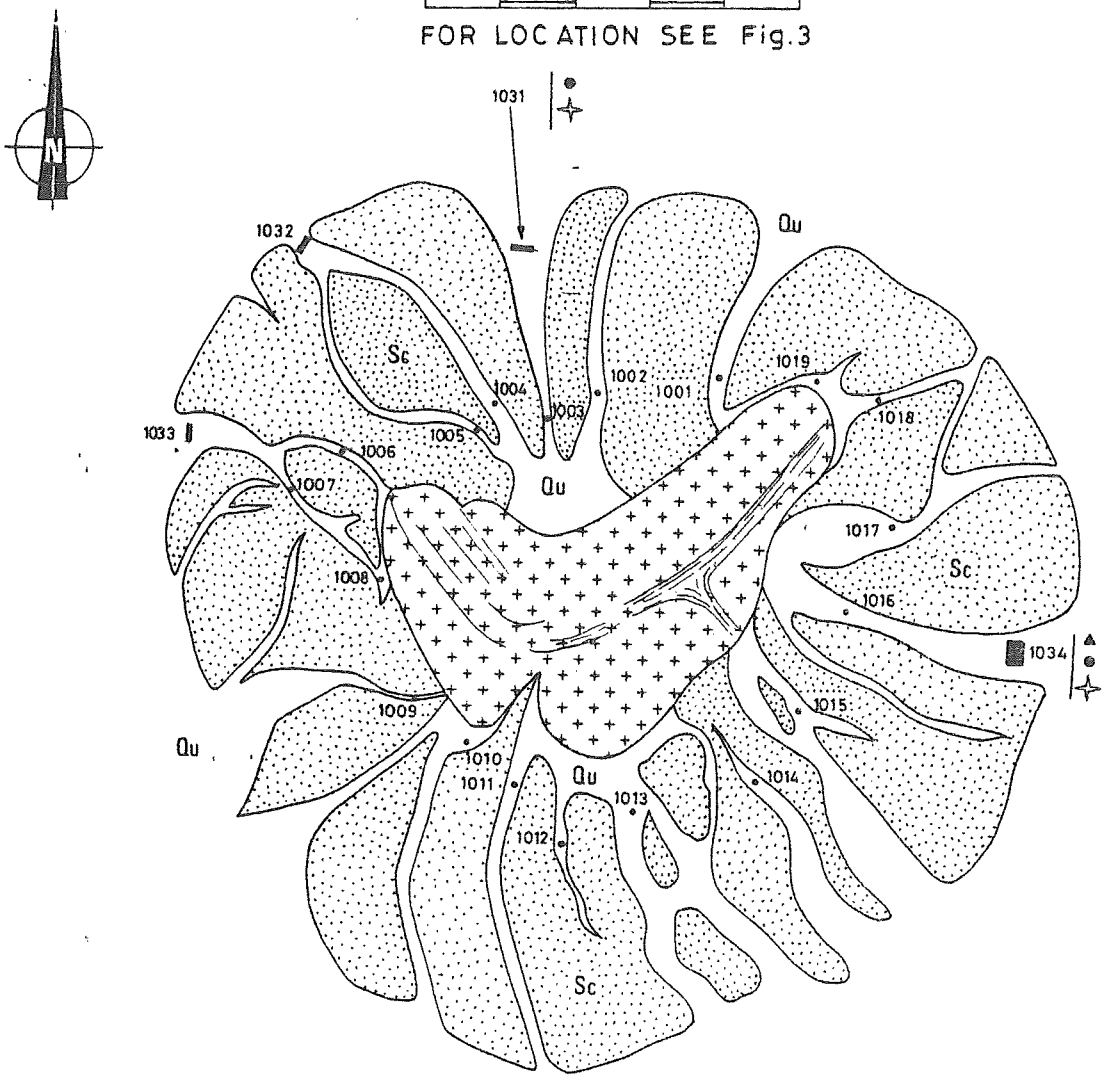
Study of the quartz veins in the massif shows that the mineralization is very attenuated and that the geochemical values observed are probably associated with the boxworks mentioned above. The tourmaline is not visible, but must be very widespread as four rock samples out of seven display boron values of between 50 and 210 ppm. Sample ML 1042 (GDAS 5567) appears to indicate that the primary mineralization consists of sulfosalts:

JABAL LACHKAR
GEOLOGIC SKETCH MAP
AND GEOCHEMICAL SURVEY

SCALE 1:6,000

0 60 120 180 240 300 m

FOR LOCATION SEE Fig.3



Qu Wadi deposits

Sc Scree

+ g + Leucocratic granite

1031 Alluvial sample

▲ Gold

● Mimetite > 1%

✦ Scheelite > 15 grains

• 1007 Stream-sediment sample

RESULTS IN ppm

Sample No.	Sb	Cu	Pb	W
1003			453	56
1006		123		
1010	100			
1011				12
1012				13
1016				36

this sample contains 1,213 ppm Cu, 2,784 ppm Pb, 291 ppm Zn, 1,238 ppm As, 15 ppm Mo, 15 ppm Sn, 247 ppm Ag, 9,181 ppm Sb, 16 ppm W and 101 ppm Bi.

2.4.3 Conclusions on study of the Jabal Lachkar prospect

The results of alluvial and stream-sediment geochemistry, together with the limited extension of the massif, indicate that no additional work can be envisaged.

2.5 JABAL AL HAMAT PROSPECT (MODS 00328)

2.5.1 Geology

Inventory of the metallogenic potential of the granites in the south Al 'Amar area led to examination of the skarns in the Jabal al Hamat region. These skarns are white, contain no sulfides, and display layers of garnet. Eijkelboom (1966) explored and mapped the area and estimated the garnet potential at 100,000 tonnes.

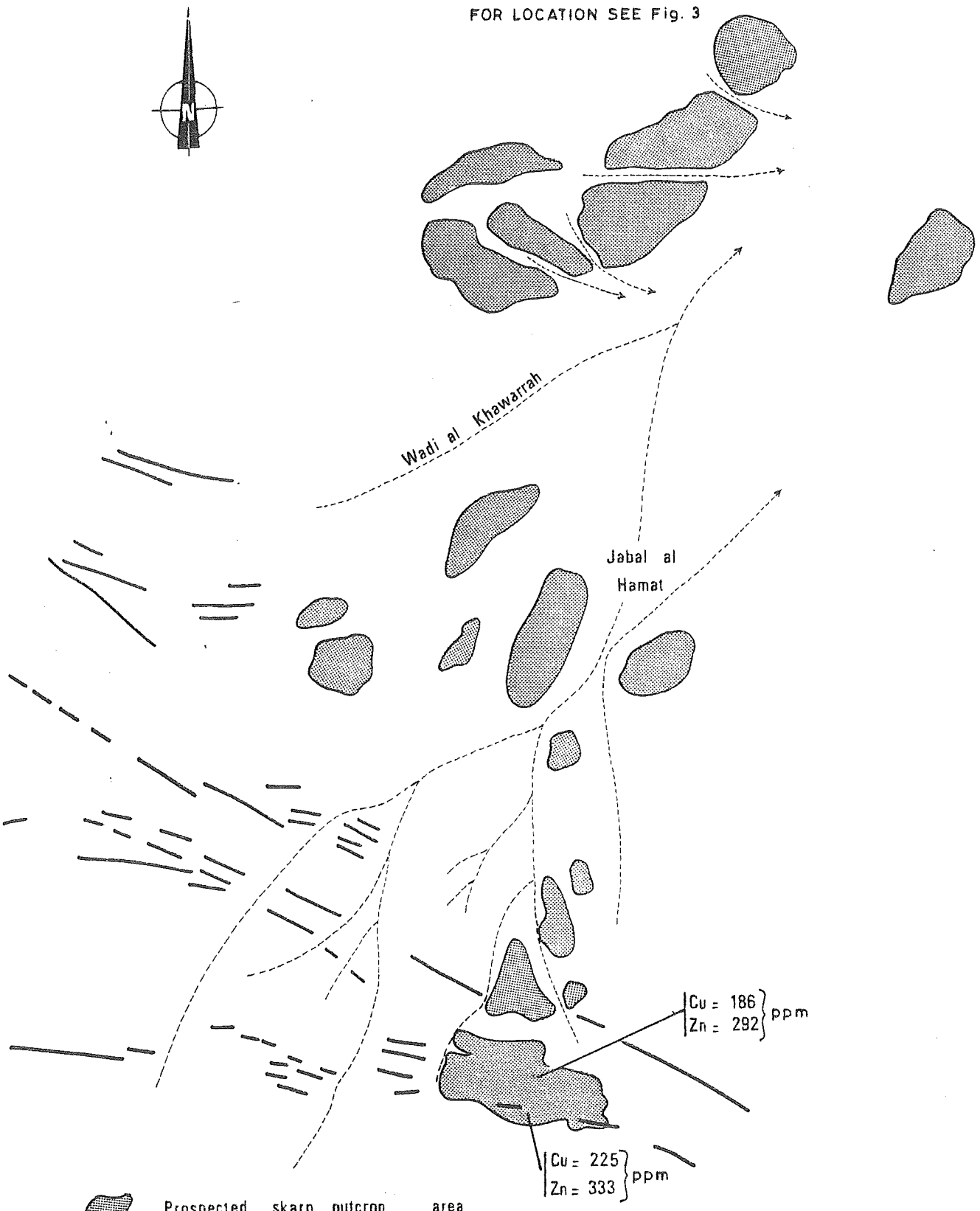
The skarns crop out in a batholith of equigranular quartz diorite (containing green poikilitic hornblende and andesine) and of granodiorite, commonly orthogneissified at the contact with marble (green biotite and hornblende). The carbonate layers are about a decameter thick and display centimeter-scale layering within which (grossular ?) garnet-bearing layers alternate with very pale layers (containing wollastonite, tremolite and large calcite crystals) and darker layers in which diopside is widespread (with a salite composition locally). The accessory minerals are sphene and epidote which develops as megacrystals in quartz veinlets originating from the granodiorite.

2.5.2 Prospecting

Whereas the diorite country rocks have been peneplaned, the skarns form small hills extending from north to south around Jabal al Hamat. Prospecting essentially consisted of stream-sediment sampling around each hill (fig. 11).

No wolfram anomalies due to the presence of scheelite were identified, which confirms the negative conclusions reached as a result of the examination of rock or alluvial samples with an ultraviolet lamp. Only two samples are anomalous in copper and zinc, with values of 2 to 30 ppm (fig. 11).

JABAL AL HAMAT AREA
OUTCROP GEOLOGY
FOR LOCATION SEE Fig. 3



3. OTHER OCCURRENCES IN THE SOUTH AL 'AMAR AREA

During general reconnaissance resulting in the selection of the zones described above, a number of other occurrences were visited.

(1) The ancient workings at Sinfayn Abu Hurim (23°36'12"N.-45°19'33"E.) (MODS 04317)

The ancient workings at Sinfayn Abu Hurim consist of a trench about 100 m long, between 1 and 2 m wide, and oriented N. 85° E., dug in equigranular biotite granite. The barite, malachite, black manganese oxide and limonite mineralization occurs at the walls of a quartz vein. Gold values are 0.84 ppm in the black oxide zones, being 0.57 and 4.25 ppm in the quartz dumps (GDAS 6615). Copper, zinc and particularly silver values are locally very high (Table 4), especially in the barite-bearing layers.

Table 4 Rock sampling at Sinfayn Abu Hurim

Sample no.	Cu ppm	Zn	Ag	Ba	Sb	As	Mineralization
ML 1236A	11664	1177	88.27	9983	5640	1032	Quartz with hematite
ML 1236B	18534	1009	205.35	7556	7686	1058	Quartz with hematite
ML 1236D	112188	5429	2733.30	183529	66848	6960	Limonite with barite and malachite

More-systematic geochemical investigation could thus be carried out on these ancient workings and possibilities are open for other vein zones in the massif.

(2) The Wadi Gharrah quartz hill, MODS 04479 (23°12'32"N.-45°27'41"E.)

The Wadi Gharrah quartz hill is about 100 m in diameter and is composed of pegmatite and white milky quartz displaying rare boxworks and some iron oxide or malachite coatings within which gold values are below the analysis threshold (0.02 ppm). Although no mineralization was identified, very high Mo values (900-1,000 ppm) were encountered in the three rock samples collected from the hill.

Additional investigation should therefore be carried out in order to confirm these values (GDAS 6617).

(3) Silicified zones at Sinfayn al Batan, MODS 04480 (23°14'29"N.-45°22'30"E.)

These silicified zones display veinlets of hematite and manganese oxides (Mn = 10-32%) and gray carbonates which contain gold values of <0.02 ppm. No other metals of economic interest were identified.

(4) The ancient workings at As Sakhen (As Sakhin), MODS 00010 (22°43'49"N.-45°12'11"E.)

The ancient workings at As Sakhen (As Sakhin) consist of two excavations with a total length of 30 m, 6 m wide and 4 m deep, notched in a sequence of black thinly-layered ash-fall cut by a panel of fairly well-crystallized dacite. The ash fall is very cataclased, with coatings of hematite and malachite. Gold values are low (0.35 g/t). A gossan grading 0.5 g/t Au develops at the surface.

(5) The ancient workings at Sumakh, MODS 04316 (23°03'43"N.-45°25'42"E.)

The ancient workings at Sumakh consist of an excavation 10 x 3 m in dimension at the foot of a hill composed of gabbro and coarse-grained diorite. The dumps are fairly insignificant, consisting of quartz with platy jointing displaying hematite veinlets and specks of chrysocolla. The mining village is small, and the remains of three or four buildings are visible. Gold values in the quartz dumps are 2.7 g/t, but are only 2 g/t in the weathered debris.

(6) The ancient workings at Wadi ar Rabwah, MODS 04481
(22°33'14"N.-45°01'10"E.)

The ancient workings at Wadi ar Rabwah extend for several hundred meters in a massif comprising fairly well-differentiated diorite, granodiorite and pale tonalite cut by N. 60° W.-striking dacite veins. Quartz veins abound, but it would appear that only those cutting the pale tonalite have been worked. The volume of dumps consisting of milky quartz with ferruginized joints is everywhere fairly low. Gold values are very varied, ranging from nil to 2.5 g/t, and the low proportion of quartz veins rules out any additional work on this occurrence.

(7) The ancient workings at Wadi Araqah, MODS 00427
(22°26'33"N.-45°03'27"E.)

These ancient workings were explored by Brosset (1974) during exploration of the Umm Sulaym quadrangle. Brosset records gold values of 7-10 g/t in two decameter-scale quartz veins, and mentions several ferruginous bodies in a diorite massif. A total of 64 alluvial samples was therefore collected from the massif as a whole (72 km²) in order to attempt to identify other occurrences.

Results are negative, but in the absence of any geochemical signature for the two known occurrences, it is possible that panning accompanied by the collection of surface samples is an inadequate method of exploration in this setting of substantial eolian cover.

4. SOME PETROLOGIC ASPECTS OF THE SOUTH AL 'AMAR AREA

4.1 INTRODUCTION

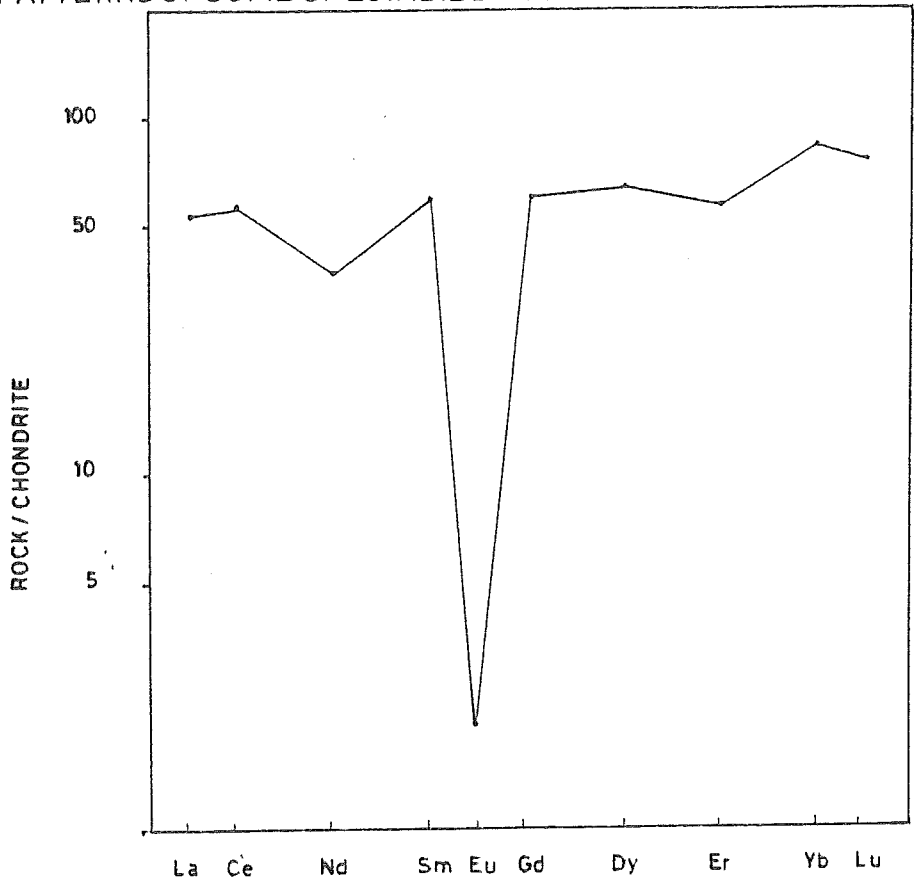
As mentioned in section 1.4, the various plutons were visited before selection of the five prospect zones. The most-leucocratic bodies were systematically sampled and analysed, together with several more-basic facies, the aim being to determine magmatic relationships. Together with the major elements, the following trace elements were analysed: Cu, Pb, Zn, As, Ni, Cr, Mo, B, Sn, Ag, Y, Ba, Zr, Sb, Nb, W, Co, Cr, V, Sr and Rb. The following group of lanthanides was also analysed: La, Ce, Nd, Sm, Eu, Gd, Dy, Er, Yb and Lu.

4.2 ANALYSIS OF RARE-EARTH ELEMENT PATTERN

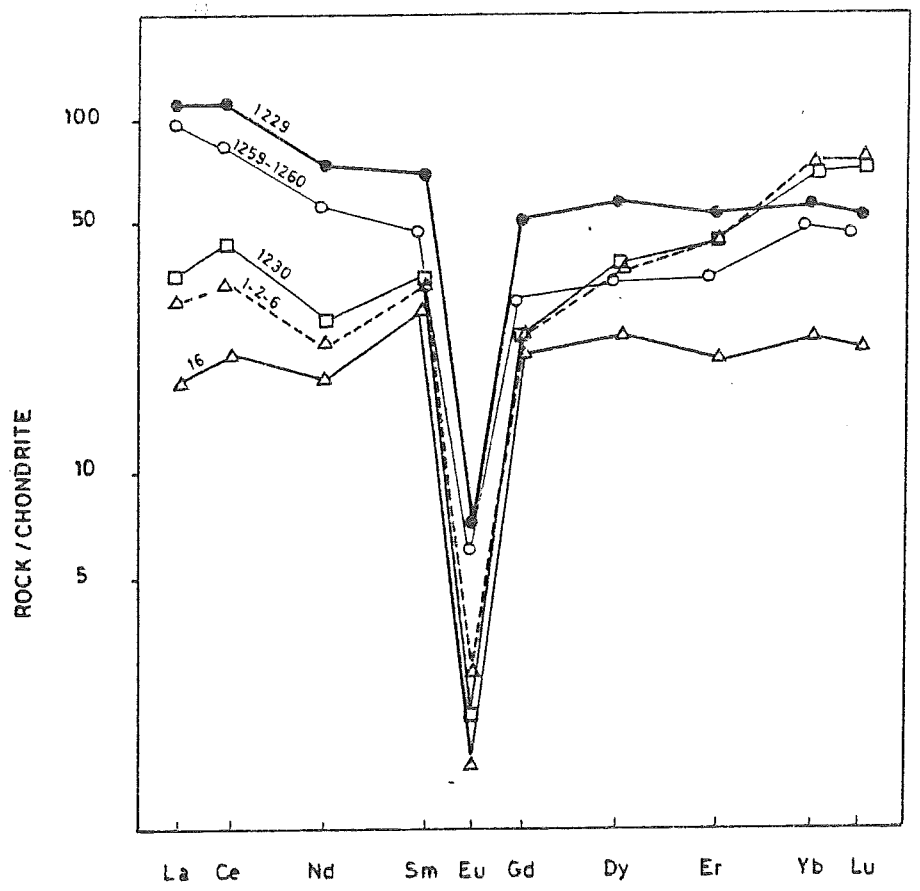
As a result of observations made by Le Bel (in preparation) on the granite that accompanies the wolframite mineralizaion in the Xihuashan mine (a production of 3,000 tonnes/day grading 0.25% WO_3) of the Jiangxi tungsten province in China, the metalliferous potential of the granites in the south Al 'Amar area was tested by study of the rare-earth element pattern. Observations made at the Xihuashan mine show that the pattern in this granite displays a "seagull" shape (fig. 12a) characterized by a high negative europium anomaly and by the absence of any apparent fractionation of heavy rare-earth elements in relation to light rare-earth elements.

Rapid bibliographic investigation (Taylor and Fryer, 1983; Harris and others, 1983) accompanied by several tests carried out on granites from the Arabian Shield which are genetically related to tungsten mineralization (Baid al Jimalah, Bir Tawilah) or on specialized or evolved granites (Jabal Sahhah, Jabal Sitarah, Jabal Khinzir) located not far from the prospect zone demonstrate the identity of the rare-earth element pattern (fig. 12b). From these limited data, the rare-earth element pattern for each leucocratic massif visited was established, the aim being to determine further prospect zones in addition to those already selected.

CHONDRITE-NORMALIZED RARE-EARTH ELEMENT
PATTERNS OF SOME SPECIALIZED GRANITES IN THE ARABIAN SHIELD AND IN CHINA



12a granite of Xihuashan (China)



12b specialized granites of Arabian shield

1229 Jabal Sahhah
1230 Jabal Sitarah
1259 . 1260 Dikes of Baid al Jimalah
1.2.6 microgranite dikes (Bir Tawilah)
16 granite north of Bir Tawilah

4.3 GEOLOGY

To the east of the Al 'Amar fault, plutonic rocks are very extensive, more so than volcanic rocks. Field studies resulted in the subdivision of plutonic rocks into three groups.

Group 1

The first group consists of diorite, tonalite, trondhjemite, and rarer gabbro. This group represents a magmatic suite which crops out in large complexes, in places zoned from the center to the periphery, displaying common mineral lineation and foliation in the external envelope. This assemblage intrudes the thick volcanic sequence of the Al 'Amar-Khnaiguiyah region, but its extension is confined to the Al 'Amar block, i.e. to the area east of the fault. The only sample located to the west of this fault and assigned to the first group (ML 1225) consists of olivine gabbro displaying a cumulate structure and belonging to the ultrabasic complexes in the south.

Group 2

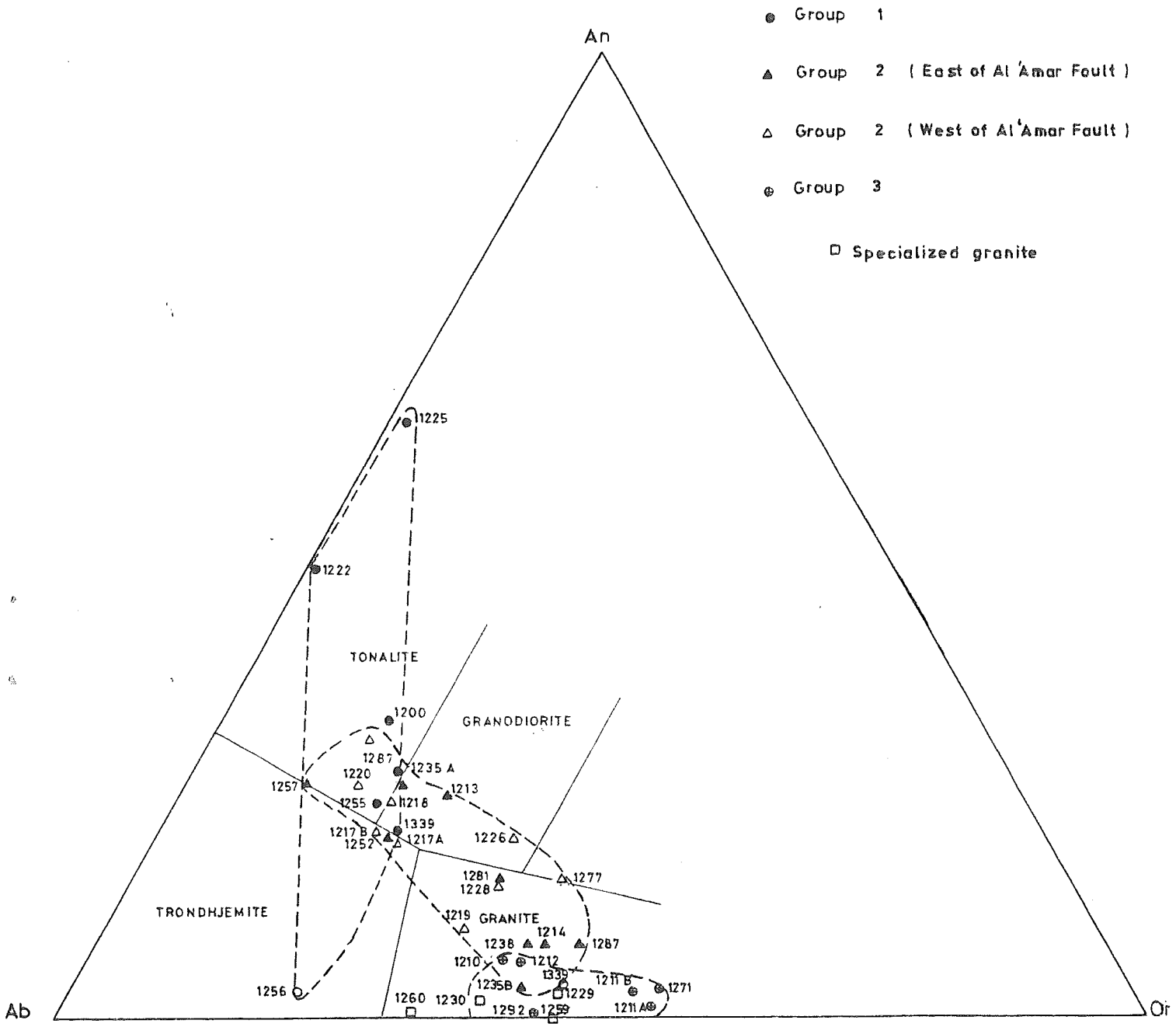
The second group is composed of batholiths of granodiorite and calc-alkalic granite, either equigranular or oriented, intrusive into the tonalite suite and distributed on either side of the Al 'Amar fault.

Group 3

The third group consists of alkali feldspar granite and syenogranite, generally pink in color, forming small massifs which are fairly rare in the Al 'Amar block and more common in the Abt schist. These fine-grained to porphyritic equigranular granites commonly contain globular quartz and in places muscovite; the potassic feldspar is microline. They cut the assemblage of other plutonic facies, forming meter-scale veins in the group 2 granites.

O'CONNOR Ab-An-Or DIAGRAM, SHOWING THREE GROUPS IN AL 'AMAR AREA PLUTONIC ROCKS

(modified after Barker, 1979)



4.4 GOECHEMISTRY OF AL 'AMAR AREA PLUTONISM

4.4.1 Geochemistry of major elements

Analysis results of collected samples (see fig. 15) are given in Table 4. When these values are featured on an Ab-Or-An diagram (fig. 13) it can be seen that the fields occupied by the three groups are imbricated, despite clear individual characteristics.

The group 1 samples are very dispersed within the field of tonalite and trondhjemite. Apart from intense variations in the SiO_2 content, this is due to variable CaO and Na_2O values, the K_2O content being everywhere below 2.5%. The group 2 samples are characterized by a constant Ab/An + Ab ratio (30-40% anorthite), extending from the tonalite field to the granite field as a function of the increased SiO_2 content. When the results for these samples are featured on a K_2O/SiO_2 diagram (fig. 14a), two clans emerge within the granites located to the west of the Al 'Amar fault, one with a low K_2 content and the other with a higher K_2O content. Group 3, together with some specialized granites of the eastern part of the Shield (Baid al Jimalah, Jabal Sahhah, and Sitarah) is characterized by low proportions of anorthite.

4.4.2 Geochemistry of trace elements

Two aspects were tackled in connection with study of trace elements:

(1) Some metallic elements (Ag, Cu, Pb, Zn, Sn, Mo and W) may be of direct interest where they display anomalous values. Silver everywhere displays values below the analysis threshold (0.50 ppm) except in the Hajlan rhyolite where rock samples grade 3 ppm. This rock is also characterized by high Nb (>400 ppm), Zr (>2,000 ppm) and Y (>200 ppm) values.

In the Al 'Amar area *sensu stricto*, none of the granites are anomalous in tin or tungsten (Table 4): only the granite from outliers (Jabal Sitarah, Sahhah, and Baid al Jimalah) displays values above the threshold (20-60 ppm). Two samples of later rhyolite also contain values above the threshold: the Hajlan rhyolite (ML 1273, fig. 15) grades more than 400 ppm and the Jabal Dab rhyolite (ML 1338, fig. 15)

Table 5 MAJOR- AND TRACE-ELEMENT GEOCHEMISTRY OF ROCK SAMPLES IN THE AL 'AMAR AREA

	Group 1							Group 2																			Group 3							Specialized granites		
								West of Al 'Amar Fault										East of Al 'Amar Fault									East of Al 'Amar Fault					West of Al 'Amar Fault				
Element	1255A	1339A	1256	1222	1200	1225	1287A	1218	1226	1217A	1217B	1219	1228	1277	1209D	1209E	1220	1235A	1252	1281	1238	1287B	1214	1235B	1213	1237	1339F	1212A	1211B	1211A	1292	1210A	1271	1129	1230	1260
SiO_2 (%)	72.4	73.48	77.05	78.32	64.57	47.99	61.67	68.46	69.34	70.64	72.03	71.21	71.52	72.41	63.91	75.58	66.26	69.0	71.79	71.98	74.66	76.1	76.92	77.0	61.4	72.51	76.39	74.7	74.68	76.89	76.83	73.98	77.9	76.89	76.28	77.02
Al_2O_3 (%)	12.93	14.28	11.26	11.31	15.09	17.57	19.21	15.53	14.3	14.57	14.66	15.36	14.17	14.3	16.77	13.12	15.62	15.25	15.37	13.82	13.67	12.25	12.89	12.72	15.73	15.4	11.83	13.3	13.7	12.34	12.11	13.95	10.9	2.26	12.6	12.26
Fe_2O_3t (%)	4.33	2.6	2.05	1.58	6.21	11.05	4.37	3.3	4.09	1.67	1.57	2.26	2.16	1.58	4.77	1.14	3.72	3.22	2.11	2.05	1.63	1.09	1.17	0.82	6.35	2.05	1.23	2.0	1.81	0.79	1.13	1.4	1.86	1.56	1.13	0.71
MnO (%)	0.08	0.06	0.04	0.02	0.08	0.17	0.05	0.06	0.07	0.04	0.03	0.06	0.03	0.04	0.06	0.03	0.07	0.07	0.04	0.04	0.05	0.02	0.03	0.02	0.09	0.05	0.02	0.04	0.06	0.03	0.02	0.04	0.04	0.04	0.06	0.02
MgO (%)	0.93	0.51	0.26	0.15	1.86	6.56	1.32	1.05	0.95	0.18	0.55	0.45	0.84	0.41	1.72	<0.01	1.61	1.26	0.71	0.47	0.2	0.09	0.15	*	2.22	0.47	0.18	0.46	0.09	0.22	0.09	0.09	0.09	0.09	0.15	0.15
CaO (%)	3.11	2.17	1.31	4.88	4.02	11.58	4.21	3.4	2.4	2.4	2.48	1.31	1.88	1.59	4.13	0.67	3.94	3.27	2.58	1.71	0.97	0.59	0.84	0.41	4.66	3.12	0.45	0.96	0.34	0.15	0.29	0.83	0.37	0.41	0.22	0.32
Na_2O (%)	3.83	3.67	4.34	2.6	3.83	2.48	5.24	4.51	3.7	4.55	4.54	4.6	4.02	3.07	4.96	4.39	4.4	4.3	4.61	3.64	4.04	3.63	3.61	3.96	4.12	4.77	3.46	4.07	3.03	2.85	3.82	3.95	2.74	3.94	4.3	4.39
K_2O (%)	1.8	2.17	1.68	0.09	1.73	0.2	2.55	2.23	3.57	2.55	2.31	3.82	3.77	3.73	1.69	4.21	2.00	2.16	2.38	3.4	4.34	4.41	4.20	4.27	2.76	1.19	4.52	4.3	4.96	5.04	4.31	3.89	5.07	4.75	3.92	3.2
TiO_2 (%)	0.38	0.22	0.17	0.27	0.64	0.73	0.81	0.33	0.5	0.22	0.24	0.27	0.3	0.16	0.75	0.03	0.37	0.28	0.31	0.2	0.26	0.10	0.18	0.11	1.02	0.17	0.15	0.23	0.21	0.07	0.08	*	0.18	0.14	0.04	0.07
P_2O_5 (%)	*	*	0.91	*	0.12	< 0.01	0.19	0.01	0.03	*	*	0.03	*	*	0.2	0.06	0.02	*	0.08	*	*	*	*	*	0.41	*	< 0.01	0.09	0.06	0.04	0.34	0.03	*	*	*	0.32
L.O.I. (%)	0.31	0.63	0.63	0.43	2.32	1.47	0.41	0.87	1.4	2.87	1.31	0.62	0.93	2.83	0.25	0.15	0.92	0.63	0.46	2.05	0.09	0.40	0.09	0.27	0.24	0.5	0.9	1.52	1.21	0.18	0.56	1.88	0.23	0.56	0.58	0.85
Σ	100.1	99.79	99.7	99.65	100.48	99.8	100.03	99.75	100.39	99.69	99.72	99.99	99.62	100.12	99.23	99.30	98.93	99.44	100.44	99.36	99.91	98.68	100.08	99.58	98.52	100.21	99.24	100.28	100.46	99.63	99.2	100.04	99.38	100.43	99.28	99.31
Rb (ppm)	55	31	48	**	26	<10	59	55	109	84	52	120	80	134	29	63	45	63	64	148	123	99	164	96	64	17	66	149	177	169	147	111	136	255	669	222
Sr (ppm)	169	114	94	373	323	582	966	561	307	335	588	363	475	81	629	53	697	389	888	336	149	161	152	59	802	360	28	198	197	98	66	76	33	**	**	65
Ba (ppm)	318	391	553	55	454	139	1057	515	779	1058	1224	675	960	515	379	133	567	646	1220	887	554	517	364	805	890	473	598	438	1186	917	107	360	82	95	13	201
V (ppm)	83	38	12	119	115	299	86	47	78	35	35	25	44	46	99	<10	90	**	172	42	**	12	16	**	124	19	<10	35	36	**	12	18	18	**	13	21
K/Rb	271	581	290	-	552	-	359	336	271	252	368	264	391	231	-	-	-	284	308	190	292	369	212	369	-	-	2.35	239	232	247	243	290	309	154	48	3.41
Rb/Sr	0.32	0.04	0.51	-	0.08	-	0.06	0.09	0.35	0.25	0.08	0.33	0.16	1.65	0.07	1.18	0.06	0.16	0.07	0.40	0.82	0.61	1.07	1.62	0.079	0.047	0.0468	0.75	0.89	1.72	2.22	1.46	-	-	-	0.32
Sr/Ba	0.53	0.29	0.16	6.78	0.71	4.18	0.91	1.08	0.39	0.31	0.48	0.53	0.49	0.15	1.65	0.40	1.27	0.60	0.72	0.38	0.26	0.31	0.41	0.07	0.90	0.76	0.05	0.45	0.16	0.10	0.61	0.21	0.40	-	-	0.32
La (ppm)	13.6	21	14.5	13.9	12.95	2.80	14.29	11.4	23.2	24.1	5.1	32.5	24.3	8.7	12.60	6.19	12.50	13.8	8.4	21.4	22.1	21.2	14.7	6.5	39.04	5.70	25.86	29.2	25.7	15.1	46.0	12.9	98.4	33.0	10.4	23.08
Ce (ppm)	32.4	49.2	31.1	32.7	28.84	8.49	33.62	20.6	48.3	16.2	7.8	60.2	46.7	11.7	22.66	8.89	24.04	24.9	11.4	33.1	37.2	38.5	23.7	10.9	76.94	9.00	47.93	58.3	44.7	27.1	95.0	29.3	215.1	84.0	34.9	61.82
Nd (ppm)	15.3	22.4	14.7	17.6	14.81	3.09	17.90	8.9	19.1	5.2	3.9	21.7	16.9	6.8	10.70	1.67	10.55	10.3	3.9	12.3	12.3	12.9	8.8	4.50	32.79	4.33	22.44	21.6	16.8	9.5	41.6	10.3	98.3	42.6	15.6	27.12
Sm (ppm)	4.10	5.6	4.2	4.82	3.67	1.37	4.94	1.8	4.3	1.1	0.86	3.6	3.3	1.5	2.52	0.46	2.25	1.9	0.07	1.8	2.3	2.2	1.9	0.79	5.77	0.97	3.89	4.2	3.3	1.8	9.4	2.3	16.4	12.7	6.5	6.38
Eu (ppm)	0.74	0.62	0.76	0.76	1.02	0.62	0.79	0.41	0.97	0.29	0.28	0.92	0.80	0.51	0.83	0.03	0.59	0.58	0.43	0.49	0.65	0.57	0.42	0.27	1.54	0.39	0.32	0.41	0.61	0.32	0.71	0.25	0.64	0.52	0.16	0.36
Gd (ppm)	3.9	5.4	4.3	4.8	3.24	0.99	4.76	1.4	2.9	0.56	0.77	2.6	2.3	1.1	1.94	0.37	1.91	1.4	0.67	0.92	1.9	1.6	1.2	0.78	4.47	0.59	3.20	3.8	2.6	1.4	8.5	2.2	12.3	12.9	6.3	7.44
Dy (ppm)	4.5	6.5	4.8	6.2	3.31	1.25	6.21	1.5	3.4	0.50	0.53	2.0	1.8	1.2	1.65	0.22	1.69	1.1	0.27	1.16	1.1	1.2	1.0	0.36	2.97	0.75	2.83	3.3	2.1	0.98	9.2	1.8	8.3	18.4	11.9	10.85
Er (ppm)	3.3	4.7	3.4	4.4	1.98	0.92	4.33	1.0	2.2	0.49	0.43	1.3	1.1	0.74	0.91	0.40	0.98	0.6	0.21	0.66	0.99	0.87	0.76	0.36	1.52	0.41	2.18	1.8	1.3	0.61	5.6	1.2	4.6	11.4	9.4	7.68
Yb (ppm)	3.8	5.5	3.3	4.8	1.87	0.70	4.73	0.98	2.2	0.28	0.26	1.2	0.92	0.68	0.73	0.23	0.98	0.5	0.19	0.63	1.0	0.76	0.75	0.34	1.18	0.49	2.66	1.6	1.2	0.56	5.5	0.9	4.1	11.7	14.5	11.64
Lu (ppm)	0.59	0.89	0.50	0.74	0.27	0.09	0.72	0.14	0.23	0.04	0.04	0.17	0.12	0.09	0.11	0.04	0.14	0.07	0.05	0.08	0.19	0.10	0.12	0.06	0.16	0.08	0.45	0.19	0.19	0.08	0.72	0.1	0.5	1.6	2.2	1.74
Y (ppm)	34.9	49.6	34.5	45.8	21.57	7.60	44.86	9.9	22.5	3.6	2.8	11.9	10.6	8.4	9.39	1.96	10.29	6.6	2.1	7.9	8.3	7.7	7.7	3.8	15.80	5.71	22.01	20.6	13.8	6.6	57.8	11.9	44.9	122.8	100.1	70.41
$(La/Yb)_N$	2.3	2.4	2.9	1.9	3.26	3.10	1.82	7.6	6.9	57.2	13.1	18.3	17.4	8.5	7.94	9.89	6.28	16.6	29.4	22.4	14.5	18.4	12.9	12.6	16.68	4.70		12.1	13.1	17.8	5.4	9.6	16.0	0.4	-	-
Yb_N	18.2	26.8	16.1	23.2	8.99	3.37	22.74	4.7	10.7	1.3	1.2	5.6	4.4	4.7	3.51	1.11	4.71	2.6	0.9	3.0	4.8	3.6	3.6	1.6	5.67	2.36		7.6	6.2	2.7	26.7	4.2	19.4	69.6	-	-
$\Delta Eu=Eu^*_N/Eu_N$	1.7	2.8	1.9	1.9	1.12	0.64	2.02	1.2	1.2	0.87	0.87	1.1	1.1	0.83	0.90	2.76	1.17	0.90	1	0.85	1	1.0	1.0	0.93	1.11	0.68		3.2	1.5	1.5	4.1	2.9	7.0	8.0	12.7	-
$\delta^{18}O$/00 vs. SMOW	7.8		7.0	6.3				8.2	9.3	-	-	-	-	-	-	-	-	7.4	-	-	7.4	7.6	8.7	8.0	-	-		7.7	-	9.9	-	10.7	-	-	-	-	-

All elements determined using emission spectrometry with microwave or ICP sources (CRPG***, Nancy, France).

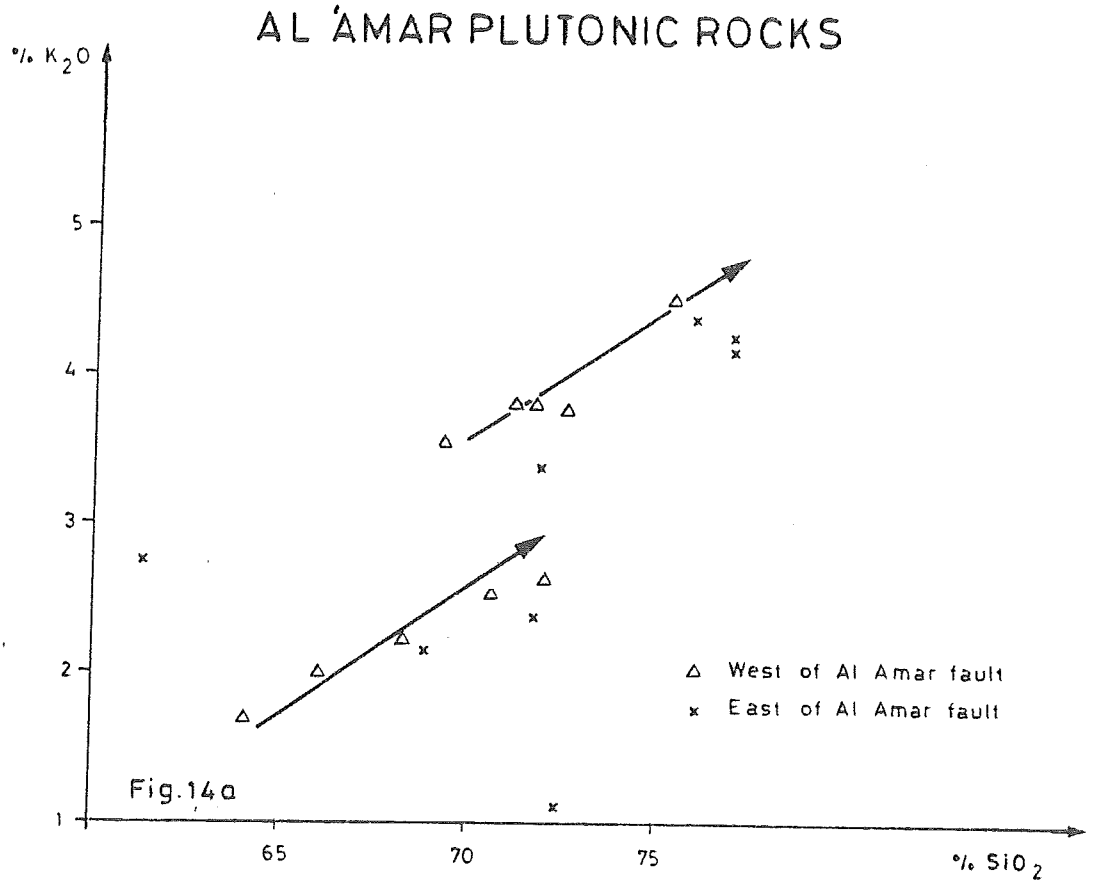
* indicates trace amounts of oxide

** indicates values below 10 ppm.

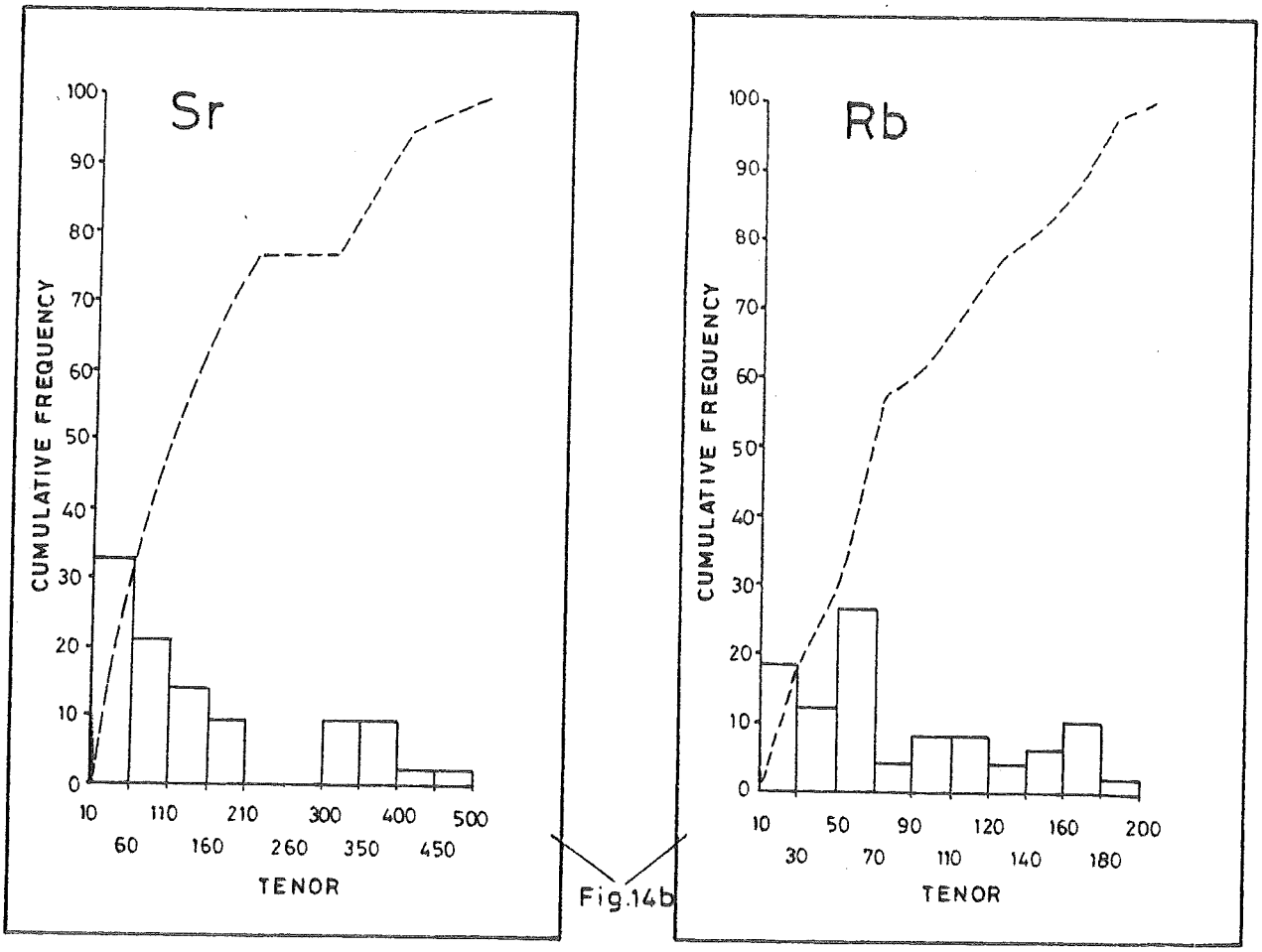
Fe_2O_3t indicates total Fe

$$Eu^*_N = \frac{Sm_N + Gd_N}{2}$$

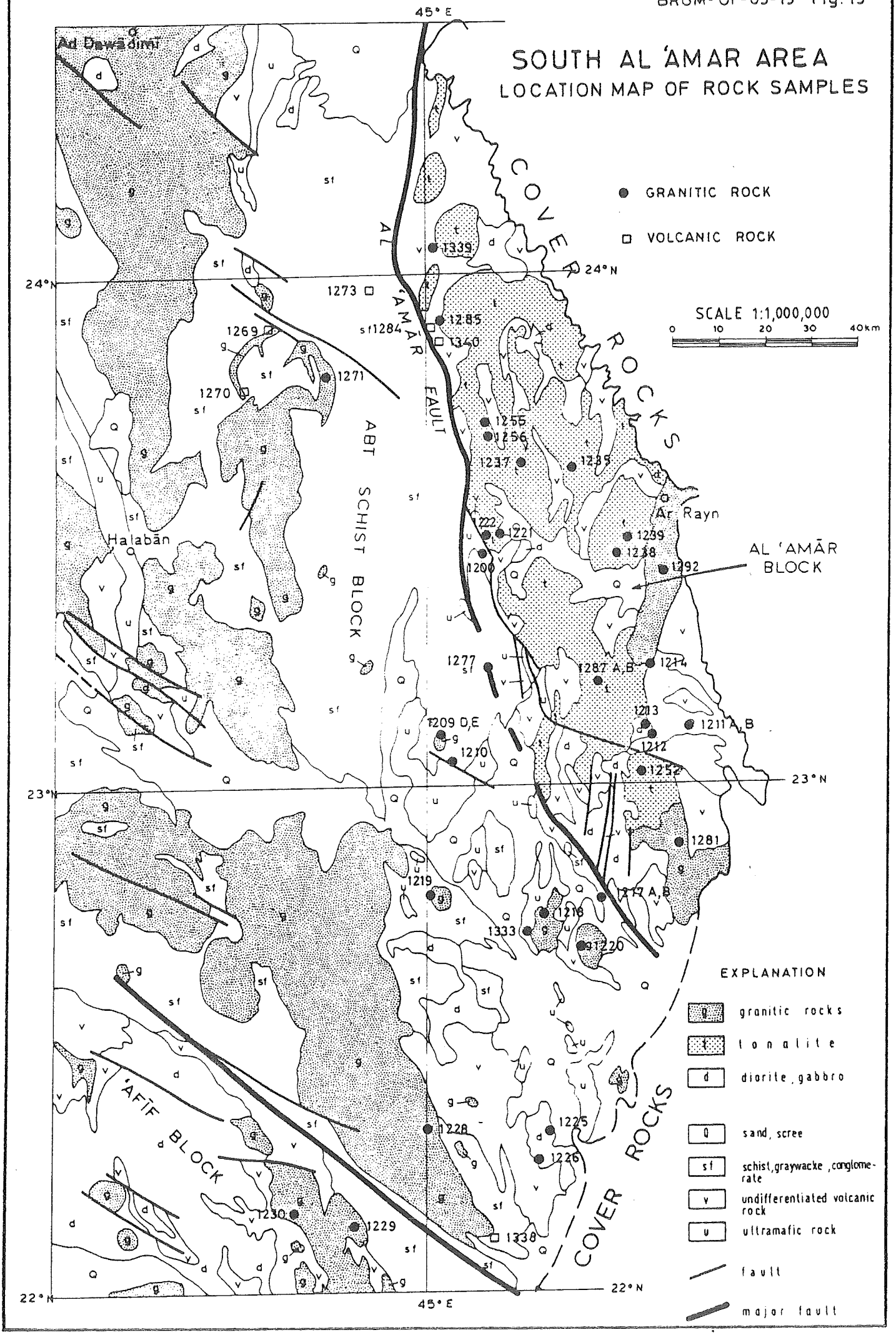
*** Centre de Recherches Petrographiques et Geochimiques du Centre National de la Recherche Scientifique (CNRS).



GROUP 2 PLUTONIC ROCKS : K_2O/SiO_2 diagram (%)



Sr and Rb histograms


SOUTH AL 'AMAR AREA
LOCATION MAP OF ROCK SAMPLES
GRANITIC ROCK
VOLCANIC ROCK
SCALE 1:1,000,000
0 10 20 30 40km
45° E
24° N
23° N
22° N
Ad Dawādimī
Halabān
Ar Rayn
AL 'AMĀR FAULT
ABT SCHIST BLOCK
AL 'AMĀR BLOCK
'AFĪF BLOCK
COVER ROCKS
1339
1273
1284
1285
1340
1269
1271
1270
1255
1256
1237
1235
1222
1221
1200
1239
1238
1292
1277
1287 A,B
1214
1209 D,E
1213
1211 A,B
1210
1212
1252
1281
1219
1217 A,B
1218
1333
1220
1228
1225
1226
1230
1229
1338
EXPLANATION
granitic rocks
tonalite
diorite, gabbro
sand, scree
schist, graywacke, conglomerate
undifferentiated volcanic rock
ultramafic rock
fault
major fault

is apparently anomalous in tin (28 ppm) and boron (352 ppm). Sample ML 1338 also contains disseminated fluorite and thus displays several indicators favorable for mineralization of felsic origin.

The granite massif at Jabal al Zurq (ML 1281, fig. 15) is about a hectometer in extension and is anomalous in molybdenum (45 ppm). This is a calc-alkalic granite which intrudes the Hulayfah group volcanic rocks in the region south of Ar Rayn. It contains pyrite, chalcopyrite and molybdenite visible in outcrop.

(2) Although of no direct interest from an economic viewpoint, the geochemistry of trace elements such as Ba, Y, Rb, Sr, etc., may be used to support the conclusions of major-element geochemistry and petrography. The distribution of Rb and Sr in the rocks of this area shows (fig. 14b) that this is not a homogeneous population, Rb displaying a trimodal distribution reminiscent of the three groups identified in the field and from major-element geochemistry. Each of these groups is well characterized on the Rb/Sr diagram (fig. 16).

The trondhjemite-tonalite sequence displays low Rb values (<50 ppm) and relatively high Sr values (100-800 ppm), whereas the group 2 granite and granodiorite display higher Rb values (50-150 ppm) and very variable Sr values, leading to substantial variations in the Rb/Sr ratio. The field occupied by alkali feldspar granites and syenogranite (group 3, figure 16) partially overlaps that occupied by group 2, but displays slightly higher Rb values and small amounts of Sr.

4.4.3 Rare-earth element geochemistry

As mentioned in section 4.2, the rare-earth elements have been used directly to determine massifs favorable for Sn-W mineralization, but here again study of the rare-earth elements provides information on petrogenesis.

4.4.3.1 Direct exploration

None of the granites studied in the Al 'Amar region (fig. 17) displays the rare-earth element pattern sought, i.e. a pattern with nil fractionation

(due to enrichment in heavy rare-earth elements) and a high negative europium anomaly (fig. 12). As a consequence, no zones for further prospecting were identified in the area. Despite this, it is interesting to note that the four plutons prospected for tin or tungsten (ML 1210, 1211, 1217 and 1277) do not display the rare-earth element pattern (fig. 17) described in Figure 12. The negative results of geochemical prospecting thus provide preliminary proof of the reliability of this prospecting tool.

4.4.3.2 Results of rare-earth element geochemistry

The three groups of granite identified first in the field and then by geochemistry (of major and trace elements) each display a characteristic rare-earth element pattern (fig. 17). The rare-earth element patterns in the tonalite suite (group 1) are only slightly differentiated (an $(La/Yb)_N$ ratio ranging from 1.9 to 2.9), with nil differentiation of heavy rare-earth elements and a slight negative europium anomaly ($Eu^*_N/Eu_N \cong 2-3$).

The group 2 granite and granodiorite display radically different patterns in which rare-earth fractionation is substantial (an $(La/Yb)_N$ ratio ranging from 6 to 22) and negative europium anomalies are absent (figs. 17c and d). There is a slight difference between the granites to the west and east of the Al 'Amar fault, the former being generally richer in rare-earth elements (fig. 17d). These patterns as a whole may be fairly satisfactorily explained by amphibole crystallization and fractionation. A few samples (ML 1252, 1217A and 1217B) display very low heavy rare-earth element content which may be due not only to a simple magmatic fractionation phenomenon: a fluid phase may also have been involved. The pegmatite veins which cut the granites commonly display this kind of pattern (fig. 18).

The group 3 granites display fractionated pattern ($(La/Yb)_N \cong 6-18$) but also display a very developed negative europium anomaly ($Eu^*_N/Eu_N \cong 2-6$) which probably implies plagioclase fractionation.

These parameters are summarized in Figure 19, on which $(La/Yb)_N$ is plotted as a function of $(Eu^*/Eu)_N$. Each group of rocks occupies a distinct field and none interferes with the field occupied by specialized granites. In the Al 'Amar region, only the Hajlan rhyolite (section 4.4.2) displays a pattern similar to these granites.

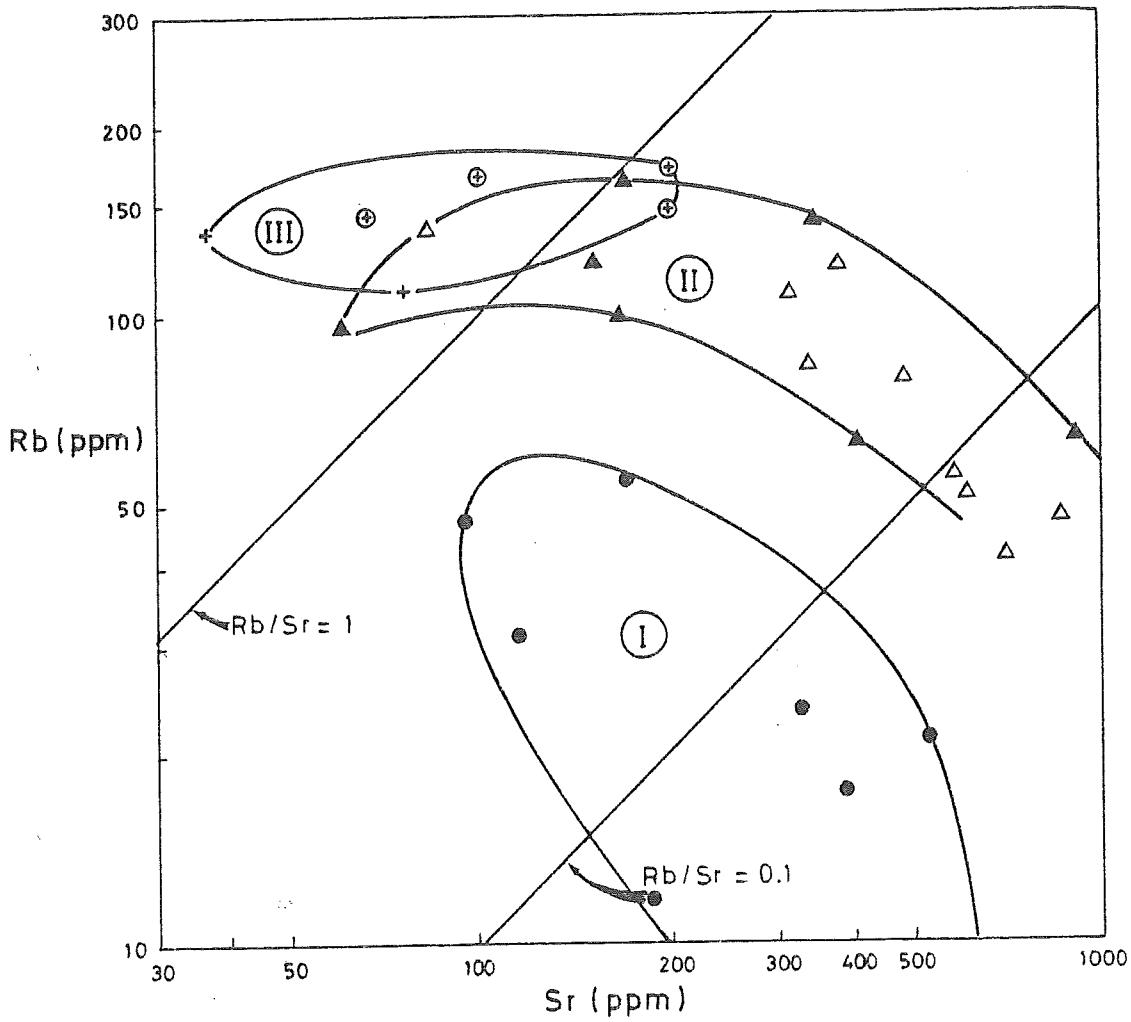
4.5 GEOTECTONIC INTERPRETATION OF THE AL 'AMAR AREA

In order to explain the formation of the Arabian Shield (Greenwood and others, 1982; Stoeser and Camp, 1984) and of the Al 'Amar area in particular (Thekair, 1975; Al Shanti and Mitchell, 1976; Smith and others, 1979; Nawab, 1979; Fleck and others, 1980; Al Shanti and Gass, 1983), many authors have proposed a model based on island arc accretion.

The geochemistry of the felsic plutonism provides several contributions to understanding of the Al 'Amar area.

From a geochronologic viewpoint (fig. 3), it is of interest to note that the oldest known age in the Al 'Amar block does not exceed 660 Ma, whereas the youngest (550 Ma) has been identified in the Jabal Qurayn Shaiban granite (Calvez and others, in preparation). As has been suggested elsewhere (Calvez and Laval, 1984), if account is taken of the regional geochronology (age determinations and variations in initial strontium levels), of the geochemistry (major elements, trace elements and rare earths), and of oxygen isotope data, the Al 'Amar block may be regarded as an intra-oceanic island arc formed between 660 and 550 Ma (fig. 20). The first magmatic period (660-630 Ma) corresponds to the Al 'Amar volcanism and to emplacement of the tonalite sequences (formation of a primitive arc crust). This was followed by calc-alkalic plutonism during collision of the arc with the 'Afif block (620-600 Ma). Subsequent to internal overthrusting within each of these blocks (580-550 Ma), magmatism of intracrustal origin developed, in places displaying peraluminous charateristics. Whereas the plutonism belonging to this episode is apparently barren, the abnormal trace-element values in the felsic volcanic rocks (Hajlan rhyolite, Jabal Dab rhyolite) may be indicative of metallogenic potential.

Rb/Sr DIAGRAM, SHOWING THREE GROUPS IN AL 'AMAR AREA PLUTONIC ROCKS



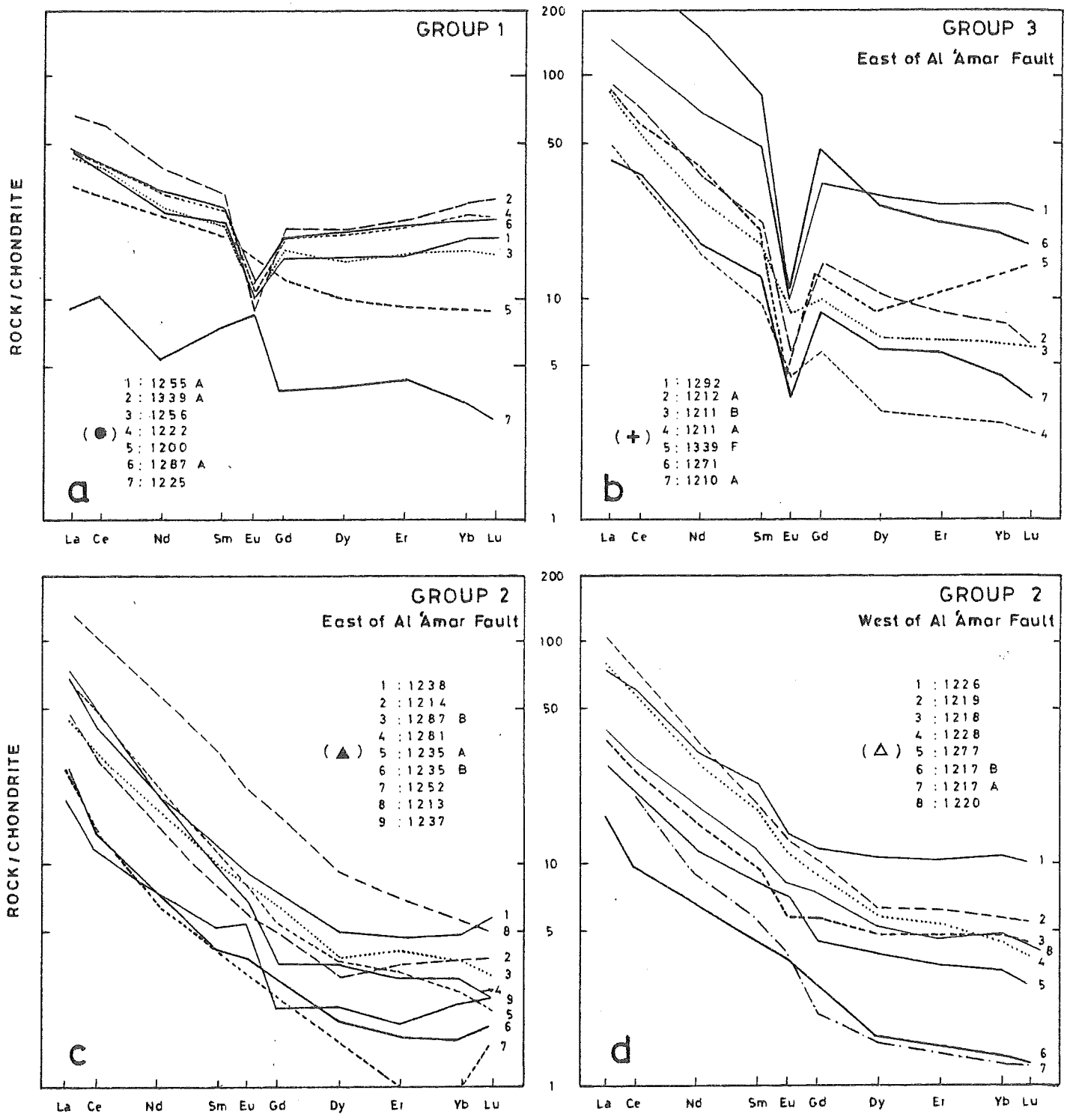
● Group 1

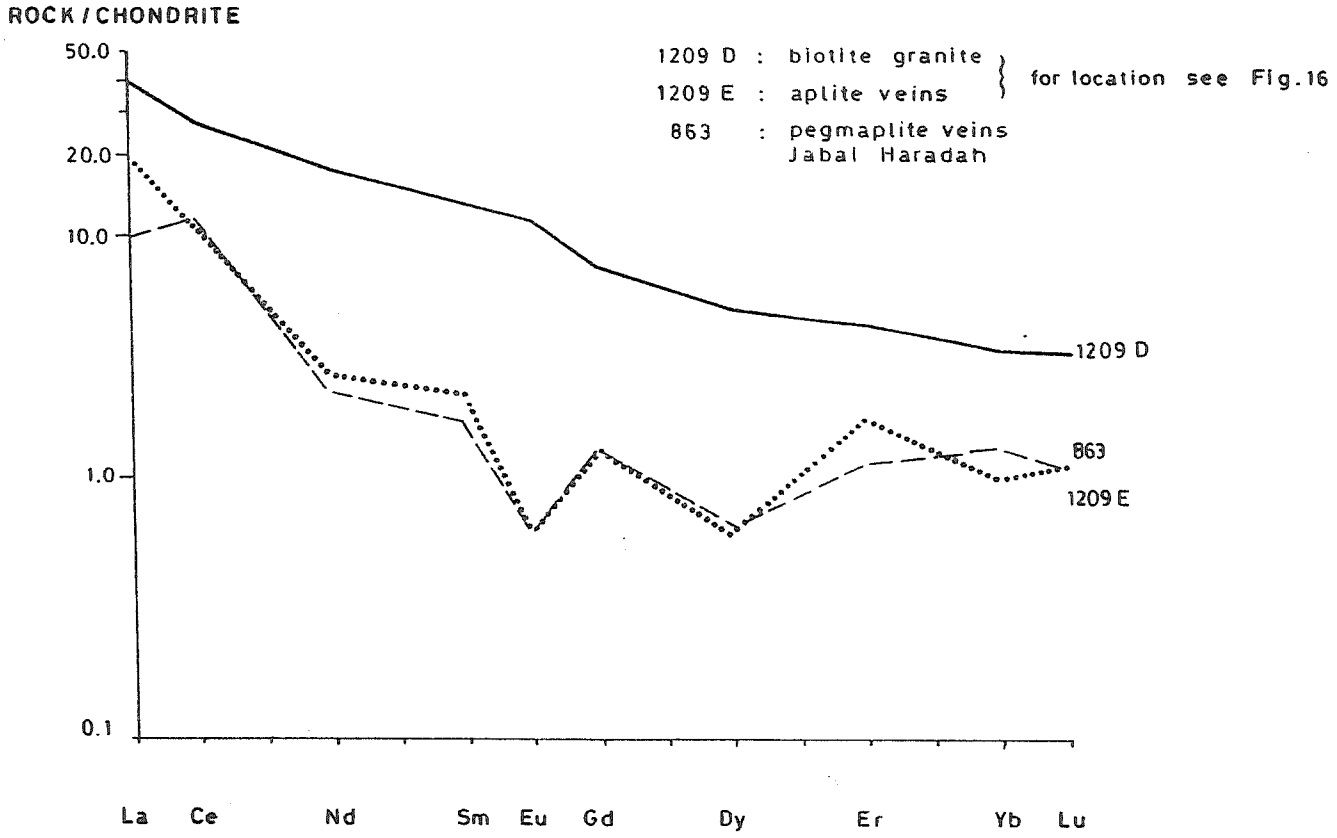
▲ Group 2 (East of Al 'Amar Fault)

△ Group 2 (West of Al 'Amar Fault)

⊕ Group 3

AL 'AMAR AREA PLUTONIC ROCKS
RARE-EARTH PATTERN OF SAMPLES OF GROUPS 1, 2 AND 3

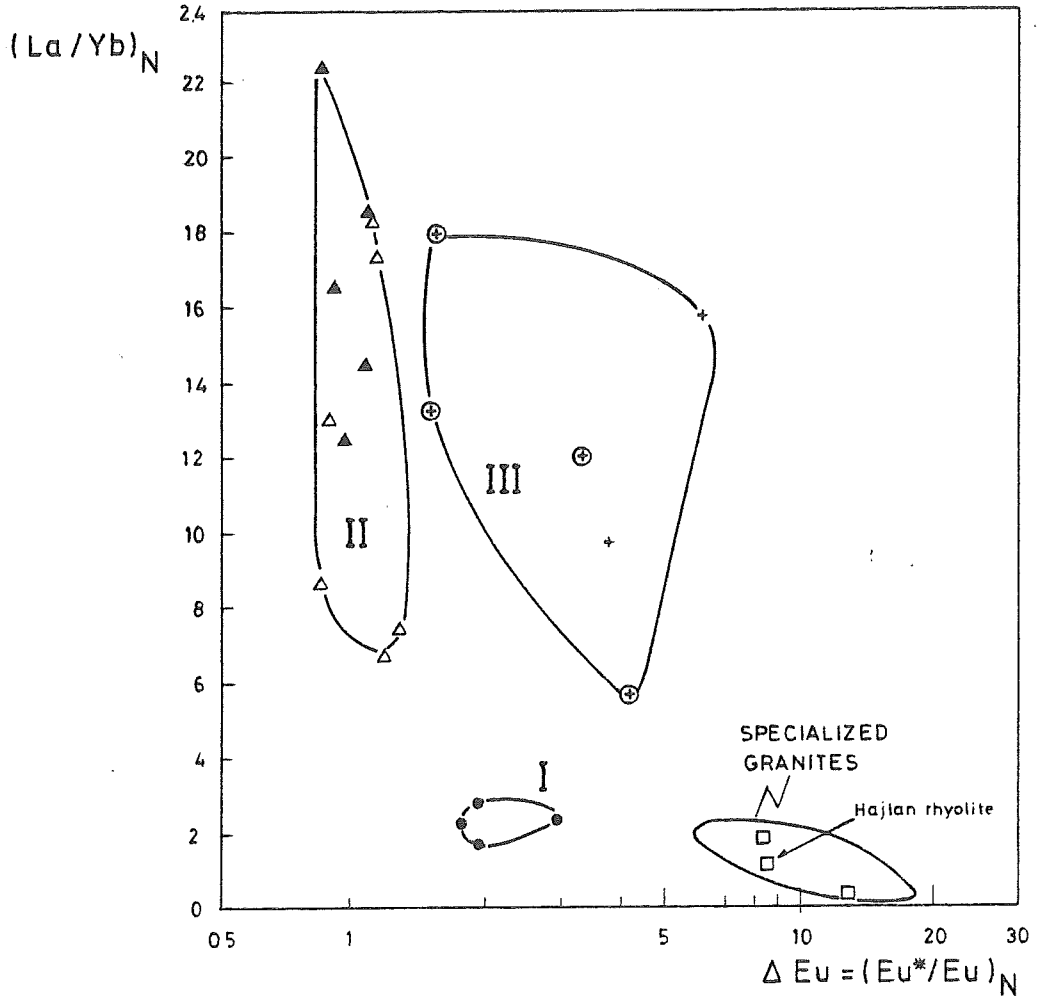




AL 'AMAR AREA

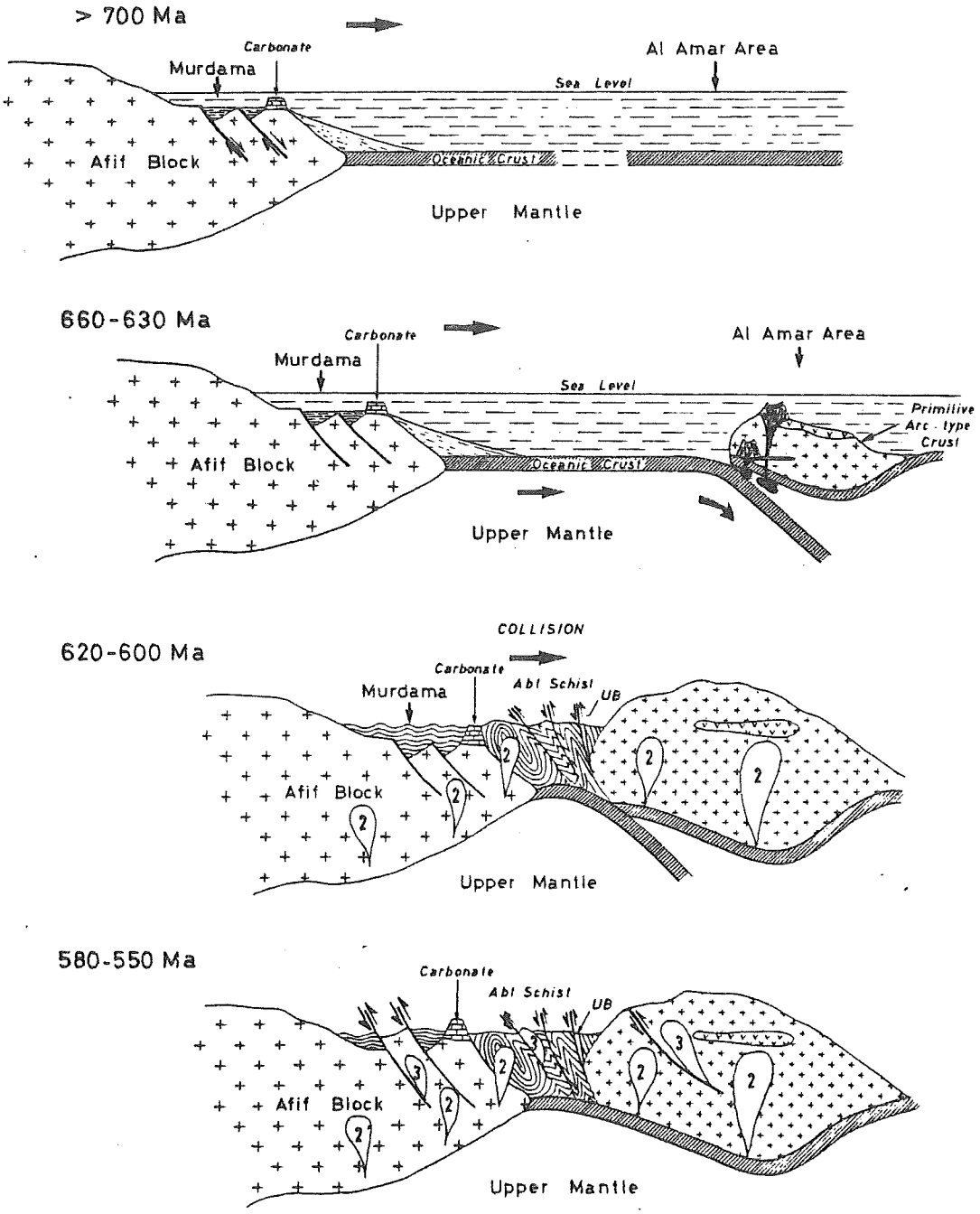
CHONDRITE-NORMALIZED RARE-EARTH ELEMENT PATTERN OF ALTERED GRANITE AND APLITE VEINS

AL 'AMAR AREA PLUTONIC ROCKS
$(La/Yb)_N$ / Δ Eu DIAGRAM
SHOWING THREE GROUPS AND SPECIALIZED GRANITES



Field of specialized granites was established with samples from Jabal Sahhah, Jabal Sitarah, Jabal Hawshat, south rim of Jabal Khinzir, Baid al Jimalah, Jabal Qutn (Stuckless and others, 1982), Bir Tawilah, Fawwarah granite of Silsilah Ring complex (Du Bray, 1984), Leucogranite of Sabaloka complex (Sudan), Jabal Eyob (Sudan).

GEOTECTONIC INTERPRETATION OF THE AL 'AMAR AREA



5. CONCLUSIONS

The study of plutonic rocks in the south Al 'Amar area confirms the latest hypotheses on the geotectonic evolution of this region as an intracratonic island arc. It is not very likely that economic wolframite or cassiterite deposits would exist in such a context, and the tests carried out on the most evolved granites in the region gave negative results. On the other hand such a regional environment favors the presence of molybdenite (grades of 900-1000 g/t in rock have been found at Wadi Gharrah) associated with pegmatite, of which there are numerous occurrences in the region, and silver (grades of 0.1-2.7 kg/t at the Sinfayn Abu Hurim occurrence). Additional work is required to confirm these occurrences and explore them further, and to direct exploration towards this type of mineralization.

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7. DATA STORAGE

7.1 DATA-FILE BRGM-DF-05-22

7.1.1 Reference

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7.1.2 Contents

(1) Rock sampling: 1:100,000-scale photomosaics 116, 117, 130 and 131 with dyeline print; 1:50,000-scale photomosaic 456.

(2) Jabal al Hamat: 1:60,000-scale aerial photographs (6791 WSA 43 and 6587 WSA 42) showing location of stream-sediment samples.

(3) Jabal Lachkar: 1:20,000-scale photograph (5793 WSA 37) showing location of rock alluvial and stream-sediment samples.

(4) Jibal al Tasiyah: 1:20,000-scale aerial photograph (6622 WSA 42) showing location of rock, alluvial and stream-sediment samples; 1:50,000-scale photomosaic 459.

(5) Jabal Qurayn Shaiban: 1:20,000-scale aerial photograph (6073 WSA 39) showing location of rock, alluvial and stream-sediment samples; 1:50,000-scale photomosaic 459 showing location of soil geochemistry.

(6) Jabal Wahwahi: 1:60,000-scale aerial photograph (6616 WSA 42) showing location of alluvial and stream-sediment samples; 1:50,000-scale photomosaics 458 and 459 showing location of soil samples.

(7) Wadi Araqah: 1:60,000-scale aerial photograph (4123 WSA 25) showing location of alluvial samples.

(8) GDAS study numbers: 5567
6615
6582
6583
6617

(9) Photocopy of field notebook.

7.2 MINERAL OCCURRENCE DOCUMENTATION SYSTEM (MODS)

The MODS data for occurrences included in report are as follows:

MODS no.	Identification	Comments
	NEW DISCOVERIES	
04316	Sumakh (22°03'43"N., 45°25'42"E.)	New entry 01/85
04317	Sinfayn Abu Hurim and ancient workings (23°36'12"N., 45°19'33"E.)	New entry 01/85
	MAIN GEOCHEMICAL SURVEY ZONES, PRESENT WORK	
04476	Jabal Wahwahi	Updated 02/86
04415	Jabal Qurayn Shaiban	"
04477	Jibal Tasiyah	"
04478	Jabal Lachkar	"
00328	Jabal al Hamat	"
	OTHER OCCURRENCES	
04479	Wadi Gharrah quartz hill (23°12'32"N., 45°27'41"E.)	Updated 02/86
04480	Sinfayn al Batan silicified zone (23°14'29"N., 45°22'30"E.)	Updated 02/86
00010	As Sakhen (As Sakhin) ancient workings (22°43'49"N., 45°12'11"E.)	Updated 01/86
04481	Wadi ar Rabwah ancient workings (22°23'14"N., 45°01'10"E.)	Updated 02/86
00427	Wadi Araqah ancient workings (22°26'33"N., 45°03'27"E.)	Updated 02/86