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MINERAL CHEMISTRY AND PETROGENESIS OF AMPHIBOLITE ROCKS NW OF RAS GHARIB, NORTHERN EASTERN DESERT, EGYPT.

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ABSTRACT

Amphibolites occur as layers and lenses within two gneiss bodies exposed northwest of Ras Gharib. Petrographically the amphibolites comprise pyroxene-, hornblende-, and biotite- amphibolite.

Petrochemical analyses of 12 selected amphibolite samples reveal a metaigneous parentage similar to volcanic rocks found in island arcs with tholeiite affinity for most of the studied amphibolites.

Plotting of amphibole formula proportions in a number of discriminant diagrams reveals low pressure conditions for the study rocks and most coincidence with Abukuma and Aracena high-temperature, low-pressure metamorphic facies type.

Thermobarometric evaluation of the metamorphic conditions indicates a probable range of pressure 2-3 kb and temperature nearly 600°C for these amphibolites.

INTRODUCTION

The amphibolite rocks constitute an important rock type among the Precambrian rocks of Egypt particularly in the Eastern Desert. They have been considered as the oldest rock unit in several publications (Mansour and Bassyuni, 1954; Moustafa and Abdallah, 1954; Shukri and Lotfi, 1954; Amer and Mansour, 1955; Ghanem, 1972; Takla et al.,1991a & b; Khudeir et al., 1992). The amphibolites occur in association with different rock units in the basement rocks of Egypt, viz. the older gneisses (Takla et al., 1991a & b; Khudeir et al., 1992), the metasediments (El-Ramly, 1972), Abu Fannani Schists (Akaad and Noweir,1980), the metavolcanics (El-Ramly and Akaad, 1960), Abu Diwan Formation (Akaad and Noweir, op.cit), and metamorphosed gabbro (Sabet et al., 1972; Akaad and Noweir, op.cit). Besides these regionally metamorphosed amphibolites, the basic members of the metavolcanics locally yield some amphibolites as a result of foliated and are enclosed by Dokhan volcanics with sharp contact. The foliation strikes NW-SE and dips 30° to 60° to the NE.

All investigated amphibolite varieties exhibit well developed foliation. Both hornblende and plagioclase are stretched and segregated into parallel layers exhibiting well developed foliation.The amphibolites are represented by pyroxene-, hornblende-, and biotite-amphibolite.

Hornblende encloses some pyroxene relics in pyroxene amphibolites. Most hornblende crystals are sieved by fine inclusions of plagioclase, quartz, opaques, sphene and apatite. **The plagioclase** is principally andesine in composition. Labradorite occurs in some amphibolite rock varieties, reflecting a higher metamorphic grade and /or the influence of bulk chemistry and mineralogy. Plagioclase encloses fine inclusions of hornblende, quartz, opaques, sphene and apatite giving rise to poikiloblastic texture. Generally, the plagioclases are variably altered to zoisite or clinozoisite and kaolinite. The slightly fresh crystals show tapering twin lamellae. **Quartz** forms xenomorphic strained crystals filling interstitial spaces between other minerals and occur as fine rounded grains enclosed within plagioclase and hornblende in biotite amphibolite. **Pyroxene** is represented by diopside and augite in pyroxene amphibolite. **Biotite** is variably altered to green chlorite. It commonly encloses opaques, sphene, zircon and apatite. **Garnet** is mostly almandine rich and is present only in biotite amphibolite as accessory mineral.

GEOCHEMISTRY OF AMPHIBOLITES

Major and trace element analyses of 12 rock samples (Table 1) were carried out by X-ray fluorescence spectrometry at the Geochemistry Department of the GeoForschungsZentrum Potsdam in Germany. The chemical characteristics of the analysed amphibolites are reviewed and their chemistry is compared with amphibolites of different tectonic setting in an attempt to identify a possible protolith for the study amphibolites. Average analyses of each rock variety is normalized to MORB (Pearce, 1980) and are ploted in Figure 2.

With the exception of Na_2O and K_2O, the amphibolites have maintained basaltic major element concentrations during metamorphism and deformation. They display a narrow range of SiO_2 (46.1-52.3 %). Most thermal metamorphism around some of the Younger granite plutons (El-Ramly and Akaad, op.cit ; Sabet, 1972).

The amphibolite rocks of the extreme northern Egypt have unfortunately remained the least studied. Schurmann (1966) considered the amphibolites north-west of Ras Gharib at Wadi Um Arta as primary gneisses of banded plutonic rocks belonging to the infrastructure. Ghanem (1972) published a geological map for the northern part of the Eastern Desert of Egypt on a scale 1:40.000 reduced to 1:250.000 on which the oldest rock unit includes gneisses, amphibolites and hornblendites. He mentioned that the contact between this rock unit and the older granitoids is commonly gradational. He gave chemical analysis for one amphibolite sample for major elements. Takla et al. (1991a&b) published a map on scale 1:40.000 reduced to 1:250.000 showing metamorphic rocks at Wadis Um Arta and Wadi Um Tenasib including amphibolite, gneiss and migmatite.

The present paper focuses on the amphibolite rocks exposed within gneisses at Wadis Um Arta and Um Tenassib at the extreme northern Eastern Desert, 55 km northwest of Ras Gharib, to characterize and explore the parentage of these amphibolites as well as to elicit their tectonic environment. The defenition of a possible metamorphic grade is attempted for these amphibolites mainly on the basis of their amphibole chemistry. The estimation of the relative pressure and temperature conditions for the investigated amphibolites is based on their amphibole and plagioclase chemistry.

GEOLOGIC SET-UP AND PETROGRAPHY

The amphibolite rocks of the present study crop out to the south of Gabal Um Tenassib as well as at the northern tributary of Wadi Um Arta (Figs.1A&1B). South of Gabal Um Tenassib, the amphibolites are represented by pyroxene-, hornblende-, and biotite-amphibolites, they occur as thin layers (1-3 cm thick) intercalated and interveined by aplite granites and completely enclosed within K-feldspar biotite gneisses. They also occur as relatively thick layers (6 m thick) concordant with the foliation of the host gneisses as well as pockets and boats enclosed within gneisses and sometimes biotite hornblende granites. The foliation strikes nearly E-W and dips steaply (70° to 80°) to the north. At Wadi Um Arta, the amphibolites are mainly represented by biotite-amphibolites. They are of the amphibolites have relatively high Al_2O_3 and CaO, a feature characteristic of young arc basalts (Wilson, 1989) . The TiO_2 content increase from the pyroxene amphibolites to the hornblende-, and biotite-amphibolites. All the amphibolites show marked normalized enrichment in LIL elements, Sr, K, Rb and Ba and very slight enrichment in HFS elements Nb, Zr and Y relative to MORB (Fig.2), with the exception of the pyroxene amphibolite that show very slight depletion in HFS elements Nb, Zr, Ti and Y.

The samples fall within the sub-alkaline basalt field (Fig.3) of Winchester and Floyd (1977) and plot in the tholeiite field of Irvine and Baragar (1971) and Jensen (1976) (Figs.4&5). The latter diagram was used because the elements used in its construction (total iron and TiO_2, MgO and Al_2O_3) are, according to Elliot (1973), static during the metamorphic transition from basic igneous rocks to amphibolites. The amphibolites define a slight to moderate Fe enrichment trend (Fig.4) similar to that shown by basalts erupted within island arc or incipient back-arc basins (Whitford et al., 1979; Dupuy et al., 1982). A similar pattern of Fe enrichment has been described in the island-arc tholeiite series (Jakes and Gill, 1970), the transitional tholeiite series (Kay and Kay, 1985), and the low-pressure calk-alkaline series (Grove and Kinzler, 1986).

TECTONIC SETTING OF AMPHIBOLITES

Although the interpretation of whole-rock data from metamorphic rocks may be unreliable due to the potential mobility of some elements, the concentration of Ti, P, Zr, Y, Nb, Cr and Ni are considered to be relatively immobile during metamorphism (Thompson, 1973; Hart et al., 1974; Humphris and Thompson, 1978).

To discriminate between ortho- and para-amphibolites, the analysed samples are plotted on the MgO-CaO-FeO* diagram of Walker et al. (1960) and Zr vs MgO diagram of Geringer (1979). Most plots fall within the fields of igneous rocks and ortho-amphibolites (Figs.6&7) respectively. The studied amphibolites have relatively low Zr/MgO ratios which would be consistent with an igneous parentage (Geringer, 1979).

The studied amphibolites show systematic variation in Cr, Ni, Ti, P, Nb, Zr and Y values characteristic of a basaltic igneous rock suite. Leake

(1964) showed that the para-amphibolites exhibit a limited range in variation of Cr, Ni and Ti, relative to the ortho-amphibolites. Mehta (1976) stated that ortho-amphibolites are characterized by high concentrations of Cr, Co, Ni, V and Y and low Ba, Zr values in contrast with para-amphibolites derived from pelite-dolomite mixtures. The analysed amphibolites show relatively wide range in variation of Cr, Ni, Ti, V and Y and have relatively higher values of these elements than those observed from para-amphibolites in the literature.

In order to characterize the tectonic environment of the study amphibolites, trace element variation and chemical discrimination diagrams of basalts are used. Although chemical discrimination diagrams cannot uniquely distinguish tectonic environments (Morrison, 1978; Holm, 1982) they are widely applied, and when used with other geological evidence are valuable in determining palaeotectonic setting. The analysed samples plot in the field B on the Ti-Zr-Y discrimination diagram (Fig.8) of Pearce and Cann (1973). This field includes MORB, island-arc tholeiites and calc-alkaline basalts. To separate between these varieties, the discrimination diagram TiO_2-MnO-P_2O_5 of Mullen (1983) (Fig.9) was used where the studied amphibolites fall in the island arc tholeiite field (IAT).

MINERAL CHEMISTRY

Twelve chemical analyses of amphiboles and four analyses of plagioclases from amphibolite rock samples have been performed at the Polish Academy of Science (AGH) in Poland using JXA-840 A elecron microprobe operating with an accelerating voltage of 15 kv. Each of the mineral compositions presented in Tables 2&3 is the average of three or more spot analyses from different areas of the same grain. Minerals have been accepted for thermometric calculations only when the variations of individual analyses are within the bounds of the microprobe analytical error (approximately ± 2% for major elements).

The cation calculation and site assignment of the analysed amphiboles was made on the basis of 23 oxygen and 13 cations (Robenson, 1982) as recommended by Leake (1978). The values derived from the above calculations were used in a number of discrimination diagrams. In the rest of diagrams total cations were normalized on the basis of 23 oxygen and 16 cations with total iron as Fe^{2+} . The analysed amphiboles (Table 2) are all calcic according to the nomenclature of amphiboles

(Leake, 1978). They range from magnesiohornblende to tschermakite (Fig.10).

The relation of amphibole chemistry in the present study to metamorphic facies can be noticed from Figure 11A, B& C in which the amphiboles plot close to the region characterized by Laird and Albee (1981) as garnet zone. Only the plots in diagram B do not give good results since the Al^{vi} in the present amphiboles has lower values than those referred to by the above authors (0.3-1). However, Al^{iv} shows systematic variation within the amphibole compositional range. There is a marked increase in Al^{vi} and K content with the increase in Al^{iv} (Fig.11B&11C).

Laird et al. (1984) separated the calcic amphibole analyses into groups based on facies series. Plotting of the present data in their diagram (Fig.12) shows they all fall in the area of low pressure. Hynes (1982) suggested a discriminating diagram (Fig.13) between amphiboles from medium- and low-pressure terrains on the basis of Ti content. He (op.cit) concluded that amphiboles from low-pressure metabasites generally carry higher amounts of Ti than those from medium-pressure metabasites at the same Al level. The plots of the analysed amphiboles show that all samples exhibite Ti/Al ratios of low pressure amphiboles. The variation in Al^{vi} with Si (Raase, 1974) and Al^{iv}/Al^{vi} partitioning (Fleet & Barnett, 1978) in the analysed amphiboles also indicate low pressure (less than 5 kb) assembages (Fig.14).

Figure 15A, B, C and D present Um Arta amphibole analyses compared to the data for amphiboles from different world wide occurrences of mafic schist with similar mineral assemblage. These diagrams are used by Laird and Albee (1981) and the normalization used are equal so that the data can be compared. As it is obvious the Um Arta amphiboles fall in the area of overlap between the low- and medium-pressure facies series but very close to the low pressure facies (Fig.15C) represented by the Abukuma plateau terrane in Japan (Shido, 1958; Shido and Miyashiro, 1959).

A comparison is made of the amphiboles chemistry of the present study with those from other world metamorphic terrains belonging to various facies series type (Fig.16 A, B, C). Um Arta amphiboles plot in Figure15A (Al^{vi} vs Si) quite below the Leake's (1965) line of "maximum Al^{vi}". They occupy an area between the Abukuma and Aracena high-temperature, low- pressure metamorphic facies type with the same Si range from 6.3 to 7 but lower Al^{vi} values. In Figure16B (Na+K vs Al^{vi}) the Um Arta amphiboles cover the area between the Abukuma and Aracena amphiboles and a part of the epidote amphibolites. Finally, on the Mg vs Al^{vi} diagram (Fig. 16C) the amphiboles show a closer resemblance to the amphiboles described from the Abukuma (Shido, 1958) and Aracena plots (Bard, 1970).

The thermobarometric evaluation of metamorphism for the investigated amphibolites can be deduced by using the plagioclase-hornblende geothermobarometer diagram of Plyusnina (1982). The analysed plagioclase-hornblende pairs from Um Arta amphibolites give a temperature value of nearly 600° C and a pressure value of 2-3 kb (Fig.17).

CONCLUSIONS

The studied amphibolites are closely associated with gneisses. All the amphibolitic samples examined are characterized by the coexistence of plagiocalse and hornblende; this assemblage is typical of the amphibolite facies existing over a wide range of temperature, pressure and oxygen fugacity. The appearance of pyroxene coexisting with amphibole at Wadi Um Tenassib characterizes the upper limit of this assemblage. The beginning of the breakdown of hornblende to form pyroxene is experimentally determined at temperatures as high as 730°±12° C to 788°±8° C at pressures from 0.5 to 2 kbs for olivine tholeiite composition (Spear, 1981). The lower limit of the plagiocalse- hornblende assemblages in basaltic compositions is experimentally found at temperatures up to 550° C, P_{H2O} =3 kbs (Liou et al., 1974). On the assumption that the chemistry of hornblende is considered to be influenced by pressure during metamorphism, the amphiboles in the present study suggest P-T coditions at least as high as that for the Abukuma type metamorphism (Fig.16).

The mineral assemblages and composition confirm an amphibolite facies. A slight increase of the P-T conditions is deduced from the amphibolites in the Wadi Um Tenassib area due to the more calcic composition of the plagiocalse, their coarser grain size, and the more frequent occurrence of pericline twins, in the studied samples from this area. Besides, the appearance of diopside in this area is characteristic. In no case the metamorphism proceeded up to the granulite facies since hypersthene and the paragenesis calcite-anorthite are completely absent.

The analysed amphibolites are relatively high in Al_2O_3 and CaO, a feature characteristic of young arc basalts. The present whole rock analytical data indicate that the studied amphibolites are tholeiitic (Figs. 4&5) and have relatively low Zr/ MgO ratios (2.5 to 37.5 with an average of 14.5) which would be consistent with an igneous parentage (Geringger, 1979). Also, most plots fall within the fields of igneous rocks and ortho-amphibolites (Figs.6&7). It is concluded from the geochemical investigation that most of the analysed amphibolites are the metamorphosed equivalent of basalts with chemical characteristics most similar to island arc tholeiitic basalts.

The chemistry of the amphiboles revealed more informations about the P-T conditions of metamorphism of the amphibolitic rocks. Plotting the chemistry of amphiboles on relative discriminant diagrams shows in all cases that the studied samples fall mostly near the garnet zone and may extend down into the upper biotite zone. They reached in no case the staurolite-kyanite zone. They also plot always in the low-P fields resembling the Abukuma low-pressure, high-temperature metamorphic facies type. The analysed amphibole samples plot on the plagioclase-hornblende geothermobarometer diagram (Plyusnina, 1982) at temperature around 600° C and pressure of 2-3 kb which indicate the P-T conditions of metamorphism of the studied amphibolites.

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Table 1. Chemical composition of the studied amphibolites.

Serial	1	2	3	4	5	6	7	8	9	10	11	12
Sample	160	164	170	147	148	153	159	130	135	138	184	188
SiO_2	48.60	47.20	46.10	49.90	49.20	49.50	49.40	49.70	50.10	50.40	50.20	46.60
TiO_2	0.89	0.59	0.90	0.81	1.30	1.14	1.49	1.13	1.26	1.09	1.58	1.53
Al_2O_3	14.30	13.10	16.60	13.90	13.50	14.40	13.60	19.40	13.40	13.90	14.40	15.70
Fe_2O_3*	16.40	11.50	12.80	13.60	14.60	13.20	13.30	10.50	14.00	12.50	16.20	13.40
MnO	0.22	0.19	0.20	0.21	0.23	0.24	0.22	0.15	0.23	0.22	0.25	0.21
MgO	6.80	12.82	7.41	7.88	7.12	6.74	6.93	4.46	6.81	6.79	4.85	8.38
CaO	10.71	11.32	12.94	11.23	9.41	9.40	11.25	10.92	11.45	11.12	9.34	12.76
Na_2O	2.46	1.87	2.00	1.45	3.22	3.34	2.77	2.85	2.50	2.79	2.77	1.89
K_2O	0.11	0.39	0.09	0.37	0.14	1.24	0.24	0.72	0.16	0.25	0.24	0.25
P_2O_5	0.09	0.05	0.06	0.08	0.16	0.27	0.26	0.16	0.09	0.10	0.26	0.14
Rb	6	11	19	6	4	40	6	15	15	5	13	24
Sr	113	155	256	92	124	305	288	401	147	206	203	605
Ba	93	144	121	229	175	337	328	307	167	181	339	589
V	402	256	260	369	376	334	440	298	404	340	514	354
Cr	83	1183	334	117	31	78	134	94	57	120	59	19
Co	55	64	57	47	46	41	40	28	48	44	47	30
Ni	54	434	134	67	44	47	63	43	49	43	32	16
Sc	32	20	31	9	40	23	4	32	34	20	41	25
Ga	16	13	15	16	19	15	19	20	18	19	22	20
Y	19	16	28	17	39	24	34	29	28	25	36	35
Zr	49	32	47	40	88	94	96	76	81	69	99	147
Nb	2	3	3	3	4	12	6	4	3	6	7	9

Fe_2O_3* (Total iron as Fe_2O_3)

Columns: 1-3 Pyroxene amphibolite, 4-8 Hornblende amphibolite, 9-12 Biotite amphibolite.

Table 2. Chemical analyses and structural formulae of the studied amphiboles.

Sample	160	160	160	160	159	159	159	159	159	184	184	184
SiO_2	42.86	45.01	44.74	41.97	43.67	43.78	44.32	45.04	44.15	47.74	47.36	47.43
TiO_2	1.52	1.23	1.39	1.78	1.62	1.66	1.42	1.44	1.52	1.01	1.02	0.93
Al_2O_3	9.84	8.16	8.56	10.55	9.15	9.54	9.31	8.62	9.55	6.68	6.51	6.73
Cr_2O_3	0.10	0.04	0.09	0.09	0.09	0.01	0.07	0.00	0.00	0.04	0.06	0.20
FeO	16.83	15.40	16.33	17.39	16.00	16.30	15.81	15.63	16.26	14.62	15.02	14.66
MnO	0.34	0.41	0.37	0.39	0.26	0.19	0.23	0.31	0.41	0.35	0.39	0.37
MgO	10.73	11.96	11.81	10.22	11.32	11.10	11.74	12.11	11.50	13.54	13.29	13.69
CaO	12.43	12.55	12.56	12.56	12.30	12.49	12.46	12.27	12.28	12.61	12.72	12.69
Na_2O	1.17	0.96	1.23	1.38	1.31	1.56	1.33	1.37	1.43	0.99	1.04	1.08
K_2O	1.06	0.83	0.93	1.32	0.73	0.68	0.66	0.53	0.60	0.74	0.69	0.67
T Si	6.475	6.754	6.646	6.350	6.585	6.571	6.596	6.679	6.550	6.965	6.953	6.912
Al^{iv}	1.525	1.246	1.354	1.650	1.415	1.429	1.404	1.321	1.450	1.035	1.047	1.088
C Al^{vi}	0.229	0.198	0.146	0.233	0.212	0.259	0.232	0.186	0.220	0.114	0.080	0.070
Cr	0.012	0.005	0.011	0.010	0.010	0.001	0.008	0.000	0.000	0.004	0.007	0.023
Ti	0.172	0.139	0.155	0.202	0.183	0.188	0.159	0.161	0.170	0.111	0.113	0.101
Fe^{3+}	0.370	0.296	0.360	0.271	0.326	0.191	0.361	0.421	0.462	0.335	0.304	0.314
Mg	2.417	2.674	2.614	2.304	2.543	2.482	2.604	2.676	2.541	2.943	2.908	2.973
Fe^{2+}	1.757	1.637	1.668	1.930	1.692	1.855	1.607	1.517	1.554	1.449	1.539	1.474
Mn	0.044	0.052	0.046	0.050	0.033	0.024	0.029	0.039	0.052	0.043	0.048	0.045
B Ca	2.000	2.000	1.998	2.000	1.987	2.000	1.987	1.949	1.951	1.971	2.000	2.000
Na	0.000	0.000	0.002	0.000	0.013	0.000	0.013	0.051	0.049	0.029	0.000	0.000
A Ca	0.012	0.017	0.000	0.037	0.000	0.008	0.000	0.000	0.000	0.000	0.001	0.024
Na	0.342	0.279	0.352	0.404	0.371	0.455	0.371	0.343	0.364	0.251	0.297	0.306
K	0.204	0.158	0.176	0.254	0.141	0.130	0.125	0.100	0.114	0.138	0.130	0.124

Table 3. Chemical analyses and structural formulae of the analysed plagioclases.

Sample	160	159	184	184
SiO_2	58.97	59.20	58.35	58.90
TiO_2	0.03	0.06	0.04	-
Al_2O_3	25.52	25.74	25.72	25.81
Cr_2O_3	0.05	0.05	0.01	-
FeO	0.13	0.17	0.26	0.06
MnO	-	0.01	0.05	-
MgO	-	-	-	-
CaO	8.56	8.73	8.93	8.90
Na_2O	6.20	6.49	6.19	6.41
K_2O	0.28	0.20	0.21	0.24
Si	10.56	10.35	10.48	10.51
Ti	0.00	0.01	0.01	-
Al	5.39	5.39	5.44	5.43
Cr	0.01	0.01	0.00	-
Fe^{+2}	0.02	0.02	0.04	0.01
Mn	-	0.00	0.01	-
Mg	-	-	-	-
Ca	1.64	1.66	1.70	1.70
Na	2.15	2.24	2.22	2.22
K	0.06	0.05	0.06	0.06

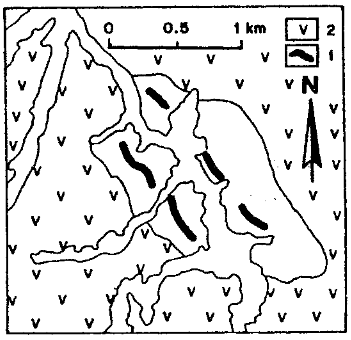
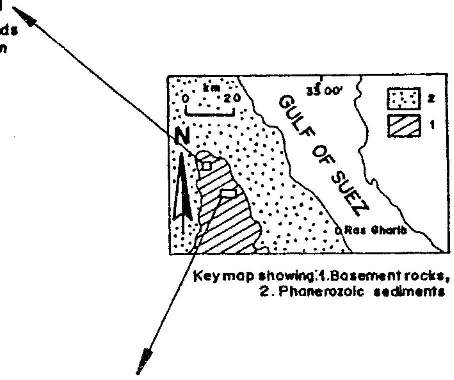


Fig.1B. Sketch-map showing: 1. Amphibolite bands in host gneisses, 2. Dokhan volcanics at northern tributary of W.Um Arta.



Keymap showing: 1. Basement rocks, 2. Phanerozoic sediments

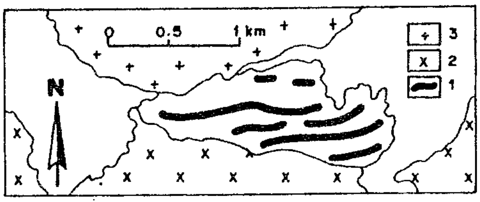


Fig.1A. Sketch-map showing: 1. Amphibolite bands in host gneisses, 2. Older granitoid, 3. Perthitic leucogranite at W.Um Tenassib, in the south of G.Um Tenassib.

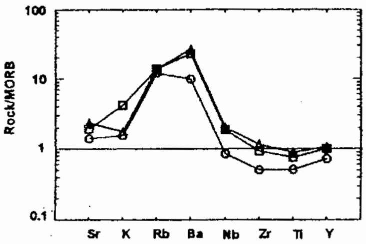


Fig.2. Multi-element diagram of the study amphibolites.

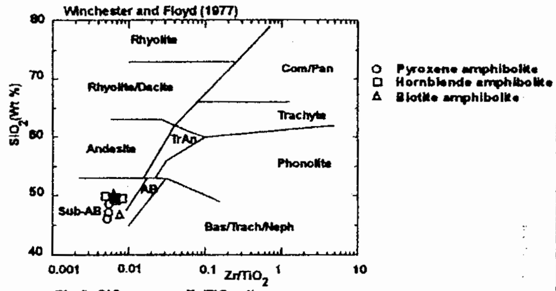


Fig.3. SiO_2 versus Zr/TiO_2 diagram.

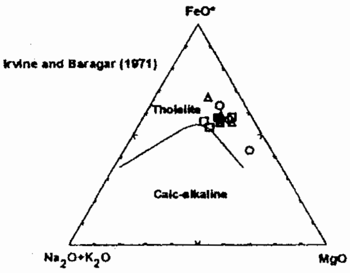


Fig.4. FeO^*-Na_2O+K_2O-MgO diagram.

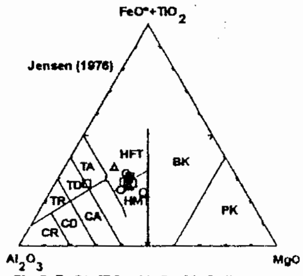


Fig.5. FeO^*+TiO_2-Al_2O_3-MgO diagram.

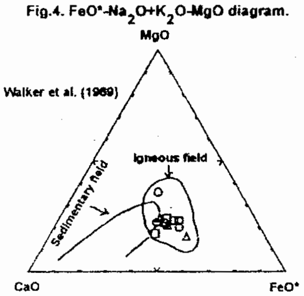


Fig.6. MgO-CaO-FeO^* diagram.

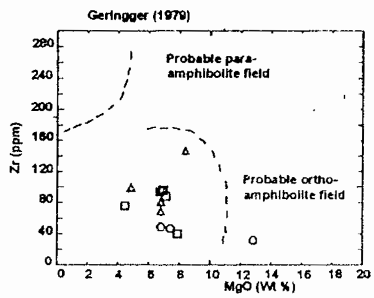


Fig.7. Zr-MgO diagram.

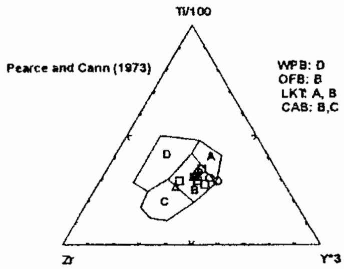


Fig.8. Ti-Zr-Y diagram.

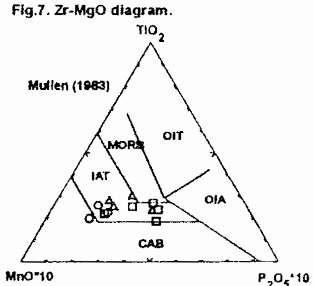


Fig.9. TiO_2-MnO-P_2O_5 diagram.

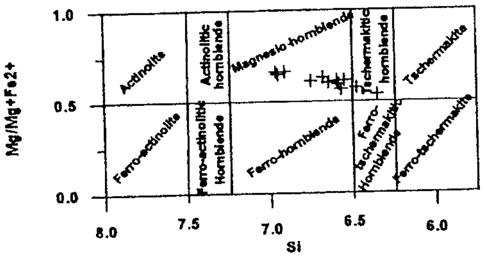


Fig.10. Plotting of the analysed amphiboles on the nomenclature diagram for calcic amphiboles from Leake (1978).

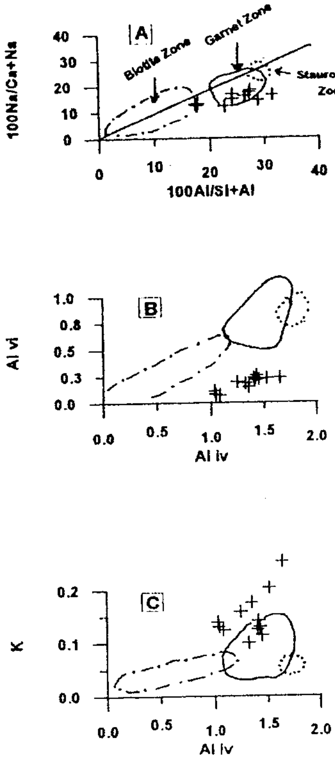


Fig.11. Amphiboles formula proportion variation diagrams of the study amphibolitic rocks in relation to Laird's and Albee's (1981) defined zones..

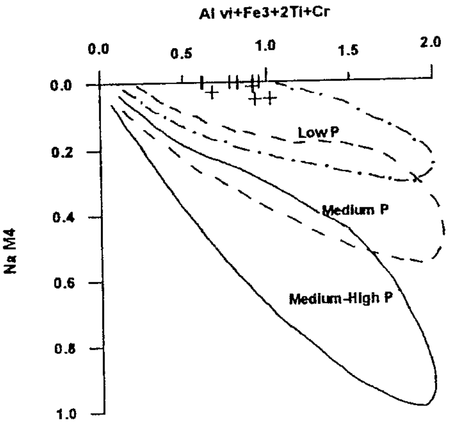


Fig.12. Plot of the analysed amphiboles in Laird's et al. (1984) formula proportion variation diagram.

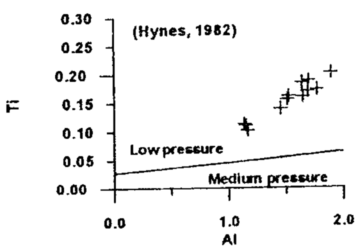


Fig.13. Total Ti versus total Al of the analysed amphiboles.

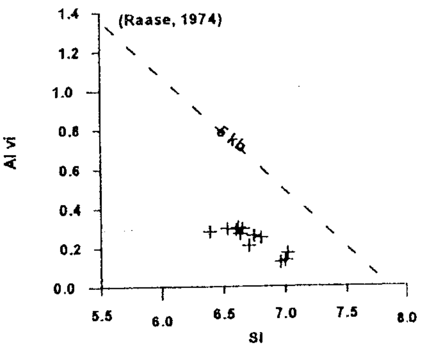


Fig.14. Relation between Alvi and Si of the analysed amphiboles.

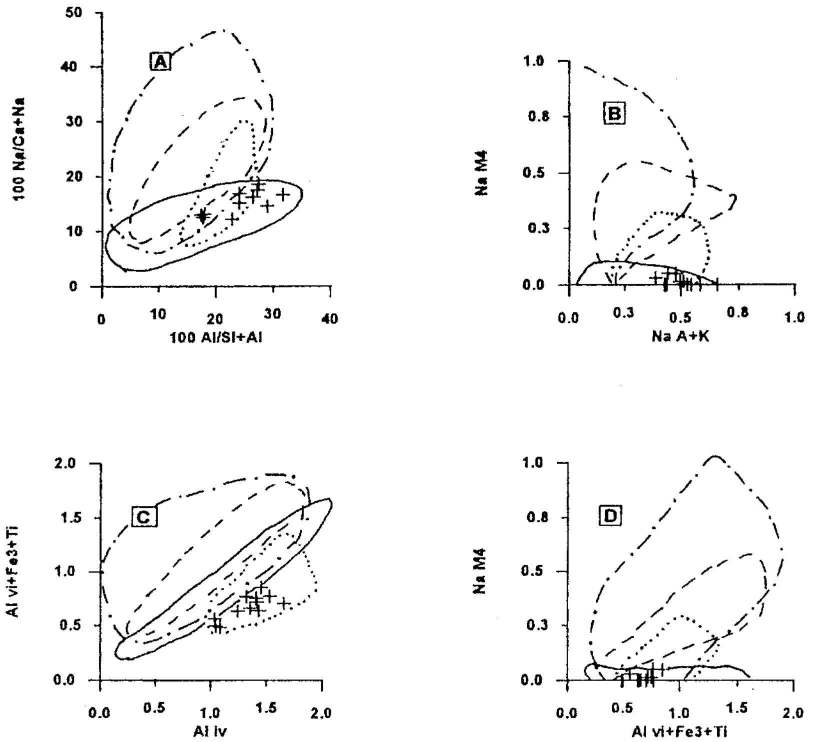


Fig.15. Formula proportion diagrams (after Laree and Albee, 1981) for the analysed amphiboles.

High pressure facies, Sanbagawa terrane in Japan and Franciscan terrane in California

Medium pressure, Dalradian terrane in southwestern Scotland

Medium pressure, Haast River in New Zealand

Low pressure, Abukuma terrane in Japan

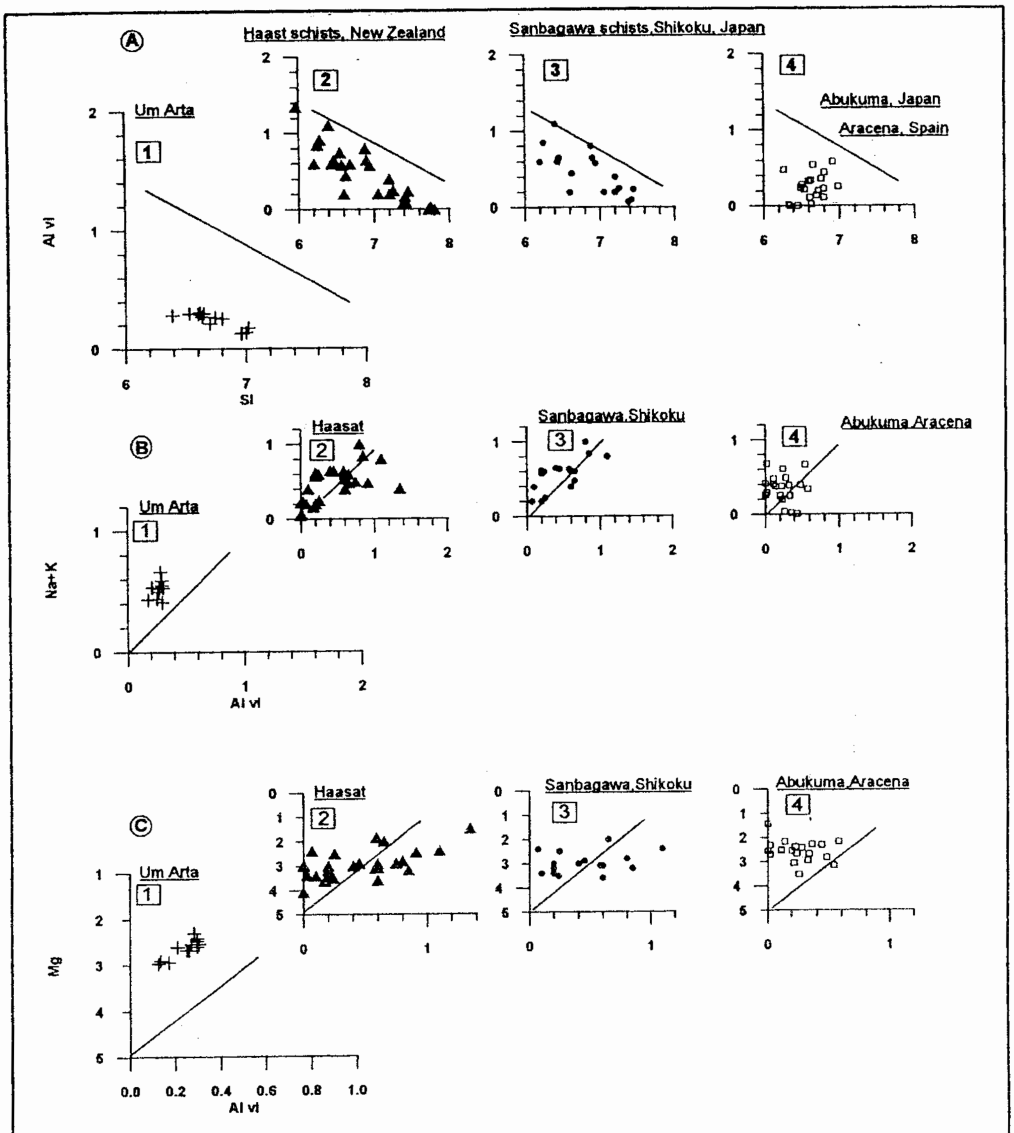


Fig.16. Si vs Alvi, Alvi vs (Na+K), and Alvi vs Mg for the studied amphiboles in comparison to corresponding diagrams from other areas. 16A1, B1, C1: Studied amphiboles plotting. 16A2, B2, C2: Metabasite amphiboles of Haast Shists, New Zealand (Cooper and Lovring, 1970). 16A3, B3, C3: Metabasite amphiboles of Sanbagawa Schists, Shikoku, Japan (Banno, 1964). 16A4, B4, C4: Metabasite amphiboles of high-temperature, low-pressure metamorphic facies series terrains; Abukuma, Japan (Shido, 1958); Aracena, SW Spain (Bard, 1970). Diagonal line represents line of maximum Alvi for a given Si (Leake, 1965).

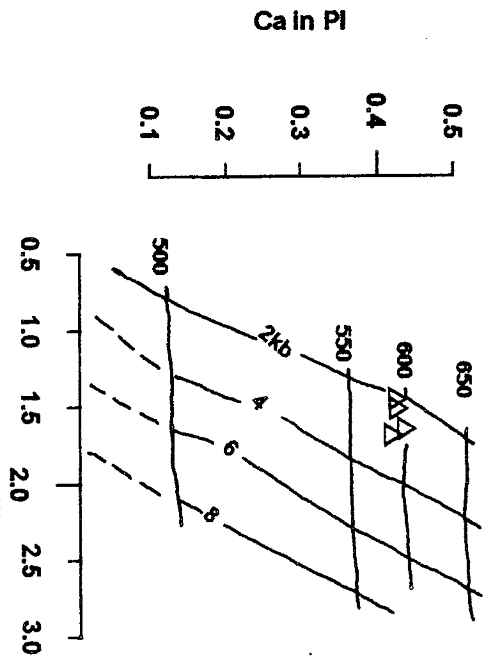


Fig.17. Pl-Hb geothermobarometer of the studied amphibolites (after Plyusnina, 1982).

كيميائية معادن ونشأة صخور الأمفيبولايت شمال غرب رأس غارب، شمال الصحراء الشرقية، مصر.

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ملخص

تتواجد صخور الأمفيبولايت على هيئة راقات وعدسات داخل صخور النايس شمال غرب رأس غارب. وقد أمكن تقسيم هذه الصخور بتروجرافيا إلى ثلاثة أنواع هى: بيروكسين أمفيبولايت- هورنبلند أمفيبولايت وبيوتايت أمفيبولايت.

وقد أظهرت التحاليل البتروكيميائية لإثنى عشر عينة من صخور الأمفيبولايت أنها ذوات أصل نارى وأن غالبية العينات لها طبيعة ثولييتية مثل الصخور البركانية التى تكونت فى أقواس الجزر.

وبتوقيع نتائج تحاليل معدن الهورنبلند فى عدة أشكال مختلفة أمكن التوصل الى أن صخور الأمفيبولايت قد تكونت تحت ضغط منخفض مماثل لصخور منطقتى أبكوما فى اليابان وأراسينا فى أسبانيا، والتى تتميز بسحن تحول ذات ضغط منخفض ودرجة حرارة عالية.

وقد بينت الحسابات الثرموبارومترية لظروف التحول احتمال تكون صخور الأمفيبولايت تحت ضغط يتراوح من ٢ الى٣ كيلوبار ودرجة حرارة ٦٠٠ درجة مئوية تقريبا.