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X-RAY AND ELECTRON MICROPROBE ANALYSIS OF SOME PLAGIOCLASES FROM THE JABAL ABU SAFIYAH INTRUSION

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التحليل بواسطة المجس الألكتروني والأشعة السينية لبعض البلاجيوكليزات من جبل أبو صفية بالمملكة العربية السعودية

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إن جبل أبو صفية هو متداخل ناري متطبق وقد تداخل خلال الصخور البركانية الرسوبية . ويمتد على شكل قوس طوله حوالي ١٥ كيلو متراً ويبدي تطبقاً واضحاً . ولقد درست البلاجيوكليزات التابعة للنطاق السفلي للتداخل بواسطة تقنية المجس الألكتروني بالأضافة إلى تقنية حيود الأشعة السينية وذلك لدراسة كيمياء هذه المعادن والحالة البنائية لها .

ويكون البلاجيوكليز المتراكم الطور الغالب في جميع القطاعات الرقيقة المدروسة ما عدا في صخور الكلاينوبايروكسينايت الأمفيبولي . وتتميز البلاجيوكليزات المتراكمة من النطاق الأسفل لجبل أبو صفية بحالة بنائية منتظمة قليلاً . ويقترح هنا أن الحالة البنائية لهذه البلاجيوكليزات قد تكونت خلال التبلور تحت التجمد عند درجة حرارة متوسطة . إن الحالة البنائية المنتظمة قليلاً لهذه البلاجيوكليزات تتفق بشكل جيد مع المميزات البتروجرافية للقطاعات الرقيقة التي تحتوي على البلاجيوكليزات المدروسة .

Key Words: Plagioclases, Electron microprobe, x-ray diffraction, Structural state, Layered intrusion.

ABSTRACT

The Jabal Abu Safiyah is a layered intrusion, which was emplaced within volcanosedimentary rocks. It extends in an arc for about 15 km and displays clear layering. The lower zone plagioclases were studied by electron microprobe and X-ray diffraction techniques to investigate their chemistry and structural state.

Cumulus plagioclase forms the dominant phase in all thin sections studied, except in the amphibolized clinopyroxenite. Cumulus plagioclases from the lower zone of the Jabal Abu Safiyah intrusion have a slightly ordered structural state. It is suggested that the structural state of these plagioclases was formed during sub-solidus crystallization at intermediate temperature. The slightly ordered structural state is in good agreement with the petrographic characteristics of the plagioclases studied.

INTRODUCTION

The Jabal Abu Safiyah intrusion was first studied by Hadley, (1972). Hadley identified three units on his 1:100,00-scale map; namely layered gabbro, layered diorite and granodiorite, and granophyre. These three units crop out in more-or-less continuous fashion within a rectangle bounded by the following coordinates; lat 25° 50′ to 26° 00′ N., Long 38° 50′ E. The largest body in the area is that of Jabal Abu Safiyah, which extends in an arc for about 15 km (Chevremont & Johan, 1981).

The purpose of this paper is to investigate the chemistry and structural state of some plagioclases from the lower zone of the intrusion. This is part of a reconnaissance study on some of the layered basic intrusions in Saudi Arabian Shield.

GEOLOGICAL SETTING

Fig. (1) shows the Jabal Abu Safiyah intrusion which was emplaced within Volcanosedimentary rocks. Hadley, 1972 divided the Volcanosedimentary rocks into two formations of the Halaban cycle:

1. The Jizl Formation which is composed of rhyolite, dacite and

pyroclastic rocks and is between 800 and 1000 m thick.

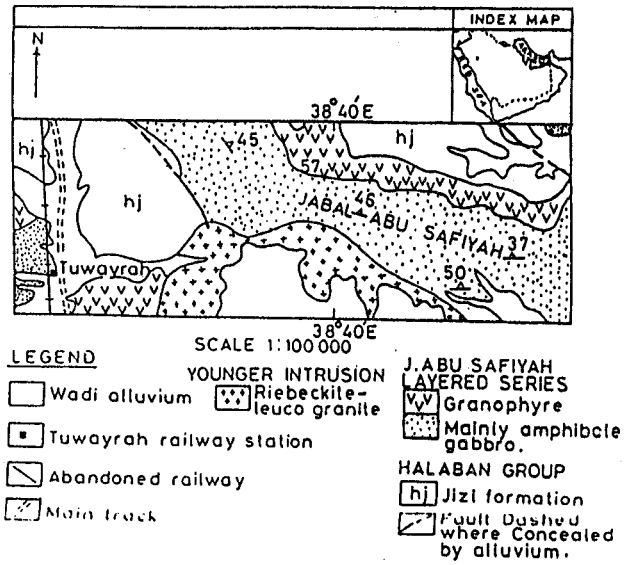

Fig. 1: Geological map of the Jabal Abu Safiyah layered intrusion, Saudi, Arabia. (Modified after Chevremont and Johan, 1981).

2. The Matran Formation which is composed of basalt, andesite and tuff and locally is more than 5,000 m in thickness.

The two formations are partially covered by Tertiary and Quaternary basalt flows and alluvial deposits.

Radiometric dating of the Jabal Abu Safiyah granophyre, using Rb/Sr method, gave an age of 705 ± 34 m.y. (Kemp *et al*, 1980). The Jabal Abu Safiyah is intruded by riebeckite granite, which is about 586 ± 5 m.y.

Three zones were identified in the Jabal Abu Safiyah intrusion (Chevremont & Johan, 1981), these are:

a. The lower zone, which is located close to the recognized base of the intrusion and composed of ultramafic cumulates.

b. The gabbro zone, which forms the central part of the intrusion.

c. The upper zone, which is formed of gabbro rich in magnetite-ilmenite and capped by granophyre.

The intrusion displays clear layering. Its visible thickness is about 2,200 m, while the thickness of the individual layers ranges form 10 cm. to 10 m. The various units of the intrusion are symmetrically distributed in relation to an approximately N 125° striking axis.

The thickness of the lower zone is about 400 m. This zone is composed of ultramafic cumulates; mainly clinopyroxenite, clinopyroxene gabbro, olivine gabbro and anorthosite are well developed within the ultramafic cumulates (Chevremont & Johan, 1981).

METHODS OF STUDY

Five rock samples were collected from the intrusion according to their stratigraphic position and lithologic variations. All samples were from the lower zone of the Jabal Abu Safiyah intrusion. Two from the clinopyroxene gabbro, and one each from the amphibolized clinopyroxenite, the anorthosite and amphibolized gabbro.

Five polished thin sections of the Jabal Abu Safiyah rocks were analysed with an ARL-SEMQ electron microprobe at the Department of Mineral Sciences, Smithsonian Institution, Washington, D.C., U.S.A. The analyses were carried out on plagioclase grains using an operating voltage of 15 kv and a sample current of 0.15 mA; aboard beam (approximately 0.05 mm diameter) was used to counter the local inhomogeneities. The data were corrected by an on-line computer using the method of Bence & Albee, (1968). Most of the analyses of the spots were made in the centre of plagioclase grains. The composition of plagioclase was determined in terms of the end members.

Plagioclase grains were separated, using the isodynamic magnetic separator. Repeated runs by magnetic separator removed most of the ferromagnesian minerals, as verified by careful examination of grains under microscope, using Refractive Index liquids. The well-separated grains were then crushed finer in agate pestle and mortar. The powder of the crushed grains were examined by X-ray technique. X-ray diffraction of the plagioclase samples was carried out using Philips PW 1050 diffractometer with CuK α_1 radiation. The goniometer was set at a speed of one degree 2θ / min. between 2θ5° and 2θ35°, with a chart speed on the recorder equivalent to 1 cm/min. All XRD analyses were carried out at the Physics Department, King Saud University.

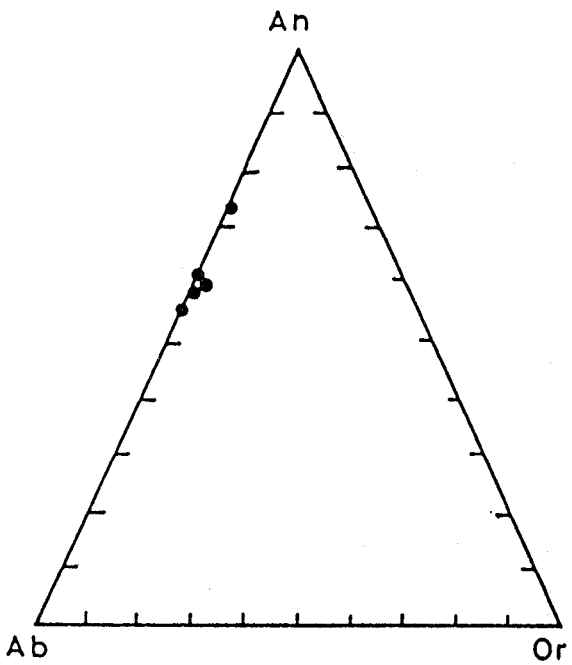

Fig. 2: Normative feldspar composition for the Jabal Abu Safiyah plagioclases based on microprobe analyses.

PETROGRAPHIC DESCRIPTION

The lower zone rocks of the Jabal Abu Safiyah intrusion are generally composed of large aligned laths of plagioclase and

uralitized clinopyroxene. Olivine is rare. Opaque minerals are present between slicates, and they commonly associated with amphiboles.

Plagioclase forms the dominant phase in all thin sections studied except in the amphibolized clinopyroxenite. It persists throughout the exposed layered series Cumulus plagioclases are lath-like in form flattened parallel to the side pinacoid (010). The average grain size is about 2 mm. Plagioclases are slightly zoned except in the amphibolized clinopyroxenite, where the plagioclase is an intercumulus mineral. No evidence of reversed or oscillatory zoning was seen. Most plagioclase crystals are twinned according to the albite law but combined carlsbad and albite twins can be seen in some thin sections.

CHEMISTRY OF PLAGIOCLASES

The results of microprobe analyses for Jabal Abu Safiyah plagioclases are presented in (Table 1). Original data is

Table 1

Electron microprobe analyses of plagioclases from the Jabal Abu Safiyah intrusion.

Rock Type	CPX-Gabbro	CPX-Gabbro	Anorthosite	HB-Gabbro	HB-Clinopyroxenite
Specimen No.	AS-77	AS-78	AS-79	AS-80	AS-81
SiO_2	52.88	54.10	55.00	54.60	49.71
TiO_2	0.09	0.05	0.03	0.03	0.03
Al_2O_3	28.50	29.03	29.20	28.13	31.32
Fe_2O_3	—	—	—	—	—
FeO	0.55	0.43	0.12	0.27	0.26
MnO	0.01	0.01	0.03	0.01	0.26
MgO	0.10	0.01	—	0.04	0.10
CaO	11.52	11.46	10.77	10.79	14.00
Na_2O	4.50	4.21	4.55	5.09	2.95
K_2O	0.13	0.02	0.09	0.03	0.12
P_2O_5	—	—	—	—	—
Total	98.28	99.32	99.79	98.99	98.52
	Original data (Wt. %) converted to elements (Wt. %)				
Rock Type	CPX-Gabbro	CPX-Gabbro	Anorthosite	HB-Gabbro	HB-Clinopyroxenite
Specimen No.	AS-77	AS-78	AS-79	AS-80	AS-81
Si·4	24.72	25.29	25.71	25.52	23.24
Ti·4	0.05	0.03	0.02	0.02	0.02
Al·3	15.08	15.36	15.45	14.89	16.58
Fe·3	—	—	—	—	—
Fe·2	0.43	0.33	0.09	0.21	0.20
Mn·2	0.01	0.01	0.02	0.01	0.02
Mg·2	0.06	0.01	—	0.02	0.06
Ca·2	8.23	8.19	7.70	7.71	10.01
Na·1	3.34	3.12	3.38	3.78	2.19
K·1	0.11	0.02	0.07	0.02	0.10
P·5	—	—	—	—	—
Total	52.03	52.36	52.45	52.18	52.41
	Cations/unit cell				
Rock Type	CPX-Gabbro	CPX-Gabbro	Anorthosite	HB-Gabbro	HB-Clinopyroxenite
Specimen No.	AS-77	AS-78	AS-79	AS-80	AS-81
Si·4	9.74	9.82	9.90	9.94	9.19
Ti·4	0.01	0.01	0.00	0.00	0.00
Al·3	6.19	6.21	6.19	6.04	6.82
Fe·3	—	—	—	—	—
Fe·2	0.08	0.07	0.02	0.04	0.04
Mn·2	0.00	0.00	0.00	0.00	0.00
Mg·2	0.03	0.00	—	0.01	0.03
Ca·2	2.27	2.23	2.08	2.10	2.77
Na·1	1.61	1.48	1.59	1.80	1.06
K·1	0.11	0.02	0.07	0.02	0.10
P·5	0.03	0.00	0.00	0.01	0.03
Total	19.97	19.82	19.80	19.94	19.94

converted to elements (Wt. %) and unit cell using a micro-computer program for storage and manipulation of chemical data on minerals (Afifi & Essene, 1988). Using the same program, (Table 2) shows the analyses recalculated to weight

Table 2
Electron microprobe analyses of plagioclases from the Jabal Abu Safiyah intrusion.

Rock Type	CPX-Gabbro	CPX-Gabbro	Anorthosite	HB-Gabbro	HB-Clinopyroxenite
Specimen No.	AS-77	AS-78	AS-79	AS-80	AS-81
SiO_2	48.83	49.57	49.99	49.87	46.09
TiO_2	0.06	0.03	0.02	0.02	—
Al_2O_3	31.01	31.35	31.28	30.28	34.23
Fe_2O_3	0.34	0.27	0.07	0.17	0.16
FeO	—	—	—	—	—
MnO	0.01	0.01	0.02	0.01	0.02
MgO	0.14	0.01	—	0.05	0.14
CaO	11.40	11.25	10.49	10.56	13.91
Na_2O	8.06	7.48	8.02	9.01	5.30
K_2O	0.15	0.02	0.10	0.03	0.14
P_2O_5	—	—	—	—	—
Total	100.00	100.00	100.00	100.00	100.00

Analyses recalculated to weight percent feldspar molecules

Rock Type	CPX-Gabbro	CPX-Gabbro	Anorthosite	HB-Gabbro	HB-Clinopyroxenite
Specimen No.	AS-77	AS-78	AS-79	AS-80	AS-81
Il	0.02	0.02	0.06	0.02	—
Mt	—	—	0.01	—	0.10
Or	0.77	0.12	0.52	0.18	0.70
Ab	38.12	35.19	37.73	43.05	24.76
An	57.23	56.17	52.36	53.51	68.91
Hy	0.16	0.02	—	0.07	0.16
C	0.02	2.47	3.99	0.21	1.75
Q	1.38	4.91	5.01	1.70	1.93
Hm	0.50	0.38	0.10	0.24	0.17
Ru	0.08	0.04	—	0.02	—
Total	98.28	99.32	99.79	98.99	98.49

percent feldspar molecules. These two tables show that the CaO and K_2O is higher in the amphibolized clinopyroxenite than other samples, while Na_2O is the lowest. K_2O is very low, which reflects the basic nature of the Jabal Abu Safiyah plagioclases.

Fig. (3) shows the normative feldspar composition for the Jabal Abu Safiyah plagioclases.

The plagioclase with maximum anorthite content was found in the amphibolized clinopyroxenite, while the plagioclase with minimum anorthite content was found in the amphibolized gabbro.

There is a general increase in SiO_2 and decrease of Al_2O_3 with decrease in CaO content of the plagioclases.

STRUCTURAL STATE OF PLAGIOCLASES

Tuttle & Bowen, (1950) first demonstrated that x-ray powder patterns could be used to distinguish high and low plagioclase series, and since then there have been many attempts to discover which of the lattice parameter are most sensitive to structural state (Ribbe, 1972). Several workers including (Goodyear & Duffin, 1955; Smith & Yoder, 1956; Smith & Gay, 1958 and Bambauer *et al*, 1967) have studied X-ray powder diffraction

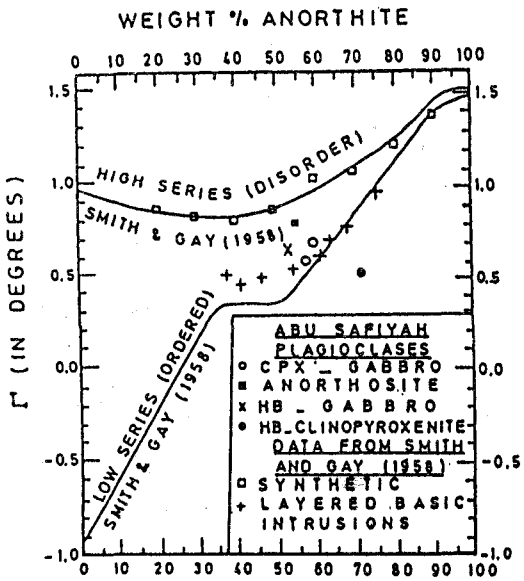

Fig. 3: Diagram modified from (Smith & Gay, 1958) showing the X-ray spacing parameter (degrees in $2\theta K \alpha_1$ radiation) Vs. Composition of plagioclases from the Jabal Abu Safiyah intrusion.

Table 3
X-Ray data and anorthite content of plagioclases from the Jabal Abu Safiyah intrusion.

Specimen No.	$2\theta_{131}$ (in degrees)	$2\theta_{220}$ (in degrees)	$4\theta_{131}$ (in degrees)	An %
AS-77	31.70	28.70	59.80	58.04
AS-78	31.79	29.46	60.58	60.08
AS-79	31.73	28.72	59.64	56.09
AS-80	31.60	28.70	59.66	53.89
AS-81	3.42	28.37	59.32	71.92

lines to find dependable pairs of reflections, sensitive to the variation in the structural state with the anorthite content of plagioclases.

Smith & Gay, (1958) gave two series of plagioclase structures, the 'high series' corresponding to the most disordered series, that is, the rapidly cooled rocks, and the 'low series' corresponding to the sturctures with the highest degree of order and thus smooth cooling. The Γ function of (Smith & Gay, 1958) obtained mainly from the measurements of reflections depends on angle γ (Smith, 1974) and is expressed in the angle 2θ (131) + 2θ (220) − 4θ (131).

Table (2) shows x-ray data and the anorthite contents of Jabal Abu Safiyah plagioclases. (Fig. 3) shows the plotting of Γ separation calculated in the present work from the x-ray diffraction patterns.

In general, two categories of plagioclases can be distinguished on the basis of degree of ordering (Fig. 3). The first is plagioclases of CPX-gabbro, amphiblized gabbro and anorthosite which is moderately ordered. The second is plagioclases of the amphibolized clinopyroxenite, which is very well-ordered. Plagioclases from other layered basic rocks, such as Bushveld, Stillwater and Skaergaard, are plotted also in the field of moderately ordered and the curve of ordered plagioclases of (Smith and Gay, 1958).

DISCUSSION

Tuttle & Bowen, (1958) have shown that the extent of solid solution among anorthite, albite and potassium feldspars depends upon the temperature of crystallization and the composition of the parental liquid from which the feldspar crystallized. (Chevremont & Johan, 1981) concluded that Jabal Abu Safiyah rocks when plotted in the AFM diagram, they are located on a curve with a very clear tholeiitic affinity. This may reflect the composition of the parental liquid from which the plagioclase feldspars crystallized. The small amount of k-feldspar in the Jabal Abu Safiyah plagioclase reflect also the basic nature of the parental liquid. Petrographic evidence shows that only one feldspar, a plagioclase crystallized throughout the entire crystallization history of the Jabal Abu Safiyah layered intrusion. Electron microprobe analyses revealed that the cumulus plagioclase in the gabbro of the lower zone of the intrusion is mainly labradorite. The anorthite content of which varies irregularly from An_{54} to An_{60}.

Cumulus plagioclases from the lower zone of the Jabal Abu Safiyah intrusion have a slightly ordered structural state, which presumably was formed during sub-solidus crystallization at intermediate temperature. However, plagioclases from the amphibolized clinopyroxenite from the lower zone possess an ordered structural state, which presumably was formed during sub-solidus crystallization at low temperature.

The structural state here is an indication of the thermal conditions which prevailed through the rock solidification, although the temperature recorded by the plagioclases could be much lower than the highest temperature to which the rock was exposed (Barth, 1962). Gay & Muir, (1962) have confirmed, from their investigation on the Skaergaard plagioclases, the presence of several transitional states. This may suggest that the plagioclases, even from slowly cooled mafic intrusions to plot on a single curve, applicable to a particular structural state (Brown, 1967).

The slightly ordered structural state of the Jabal Abu Safiyah plagioclases is in good agreement with the petrographic characteristics of the plagioclases studied. The interpretation that for a certain composition, the plagioclase with the lowest Γ is more ordered, is also in good agreement with the crystallization history of the Jabal Abu Safiyah basic rocks.

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