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PETROGRAPHIC AND MINERALOGIC STUDIES OF THE LAYERED INTRUSIONS AT JABAL EL-EKEIM, SAUDI ARABIA

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ABSTRACT

Jabal El-Ekeim consists of two differently sized coalescing mafic-ultramafic layered intrusions. The large intrusion is divided into sixteen units, while the smaller one is divided into fourteen units. This classification depends on their cumulus crystals and post-cumulus material. Both intrusions consist of concentric layers dipping radially inwards and have a higher dip at the periphery. The large intrusion has a boat like shape elongated in a NW-SE direction, while the small one has a subcircular shape and is elongated in a NE-SW direction perpendicular to the elongation of the large one. It could be concluded that the elongations of the two intrusions are parallel to main structural trends in the investigated area.

Slump structure, igneous lamination, knobby texture and micro and macrorhythmic layering are the main internal structures distinguish the rocks of the area under inspection. Their formations could be attributed to the combination of different mechanisms of density gravitational stratification and crystal sorting by magnetic concvection currents.

El-Ekeim intrusions include seven rock types: olivine gabbro, troctolite, hornblende-olivine gabbro, olivine gabbronorite, gabbro, anorthosite and peridotite. The essential minerals of El-Ekeim rocks are: plagioclase, olivine, clinopyroxene, orthopyroxene and hornblende. These minerals occur as cumulus and intercumulus phases. The accessory minerals are: biotite, apatite and opaques. The latters consist principally of iron-titanium oxides as magnetite, chromomagnetite, ilmenite, hematite, spinel and hemoilmenite. Sulphides as chalcopyrite, pyrrhotite, pyrite and pentlandite are also present.

The mineral composition of both intrusions indicates that their parent magmas were similar and had a tholeiitic nature. The economic potential of these two intrusions at El-Ekeim is very poor with no signs for concentrations of ore minerals.

Keywords: El-Ekeim two mafic ultramafic layered intrusions. Cumulus and intercumulus, seven rock types, tholeiitic nature, poor economic potentials.

INTRODUCTION

Jabal El Ekeim is located in the Asir mountains in the SE part of the Arabian Shield. It is bounded by latitudes, 19°05' and 19°09' N, and longitudes 43°41' and 43°50' E (*Fig. 1*).

Jabal El Ekeim is a dark colored body enveloped by lighter colored rocks, displaying a notable contrast in color and shape. It actually consists of two coalescing mafic-ultramafic layered intrusions. Both intrusions and their enclosing rocks are included in the Hamdah Quadrangale sheet 19/43D, at the scale of 1:100.000 (ZUBEIR 1989).

Few authors were dealt with the geology of Jabal El Ekeim at reconnaissance level. BROWN and JACKSON (1959) mapped the area as layered gabbro with other ultramafic rocks. In the geological map of the Arabian Peninsula at scale 1:2.000.000, produced by USGS, ARAMCO and DGMR (1963) in ZUBEIR (1989), the area was mapped as layered

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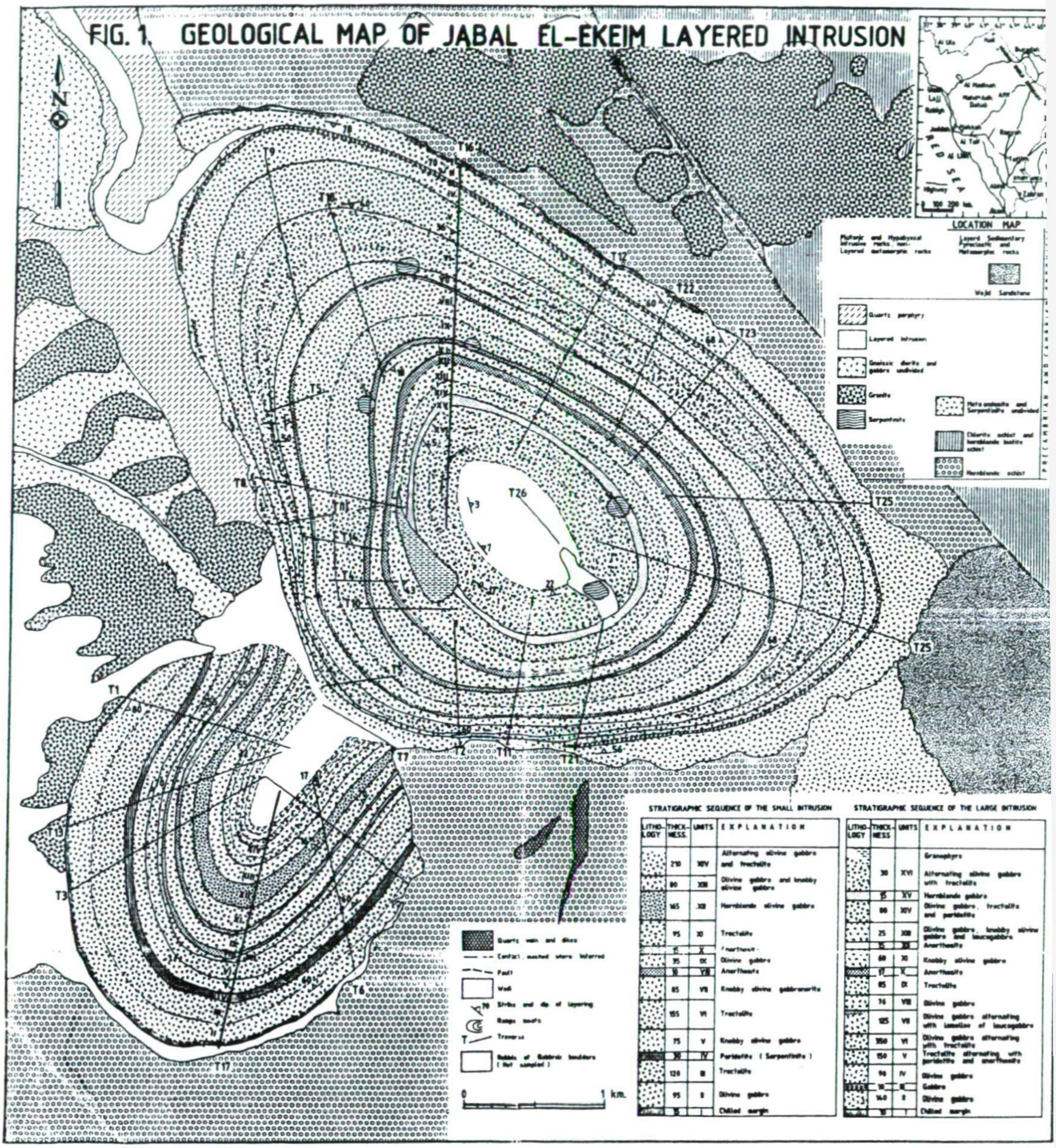


Fig. 1. Geological map of Jabal El-Ekeim layered intrusion

gabbro and basic flow rocks. COLEMAN et al. (1972) briefly identified Jabal El Ekeim along with six other layered gabbro intrusions. OVERSTREET (1978) described El Ekeim as layered gabbro and norite complex forming two ring-shaped bodies. LOWRENCE et al. (1978) explained Jabal El Ekeim as a mass of mafic rocks consisting mostly of gabbro. However, WHITE (1984) attributed El Ekeim to post-tectonic layered gabbroic pluton with three lobes, resulting from coalescence of two separate intrusions.

The objectives of the present work are:

1. To determine the configuration and geological setting of Jabal El Ekeim intrusions as well as their relationships with the country rocks.

2. To determine the petrographic and mineralogic characteristics and reveal any concentration of economic minerals.

3. To investigate the nature of their internal layering with the aim of understandig their mode of formation.

To fulfil the purpose of this study, field work of an area of about 14x20 km^2 including Jabal El Ekeim intrusions and its surroundings has been done by traversing the intrusions along 26 traverses (*Fig. 1*). Samples of four traverses are selected for petrographic and mineralogic investigations. In addition, the petrographic and mineralogic study is performed through about 200 thin and polished sections. Further publications will be produced by the same authors concerning the chemistry of the rocks of the two intrusions, as well as, the microprobe study of some mineral phases.

GEOLOGY OF JABAL EL EKEIM LAYERED INTRUSIONS

Jabal El Ekeim is composed of two coalescing mafic-ultramafic layered intrusions. The southwestern intrusion is smaller than the northeastern one.

A. Geology of the southwestern intrusion (small intrusion)

It has an elliptical shape, with plan dimensions of 2.6x2.4 km^2. The central part of the intrusion forms a high plateau, rising about 320 m above the surrounding wadis. This intrusion consists of layers of different composition and texture, expressed by ramp-moat topography (COLEMAN 1973). At the norheastern part of the intrusion, the layers are not continous due to truncation by the large intrusion. The ramps at the central plateu are generally low, ranging from 10-20 meters high. The concentric, elliptical layers have produced an extraordinary ramp-moat topography. Layers are very steeply dipping (80°-85°) inward at the periphery of the intrusion, and decrease in dip towards the centre to about 10° and less (*Fig. 1*). This disposition of layers is regular throughout the intrusion. The strike of layering swings around to give the general shape of the intrusion (*Fig. 1*).

A discontinous chilled margin with varying thickness against the country rocks was observed in many places. However, xenoliths of the country rocks within the intrusion were not observed. Several dikes of a dark colored basic rock crosscut the country rocks of the small intrusion at the mutual contact, particularly at Wadi Al-Ghabah. These dikes are believed to be offshoots from the intrusion into the country rocks, since they are very similar in many respects to the rock of the chilled margin.

Other dikes and sills occur within both the small intrusion and the country rocks. Three of them are regarded to represent progressively differentiated parts of the main gabbroic magma. They are composed of:

a. Fine-grained gabbroic dikes and sills,

b. Few trondhjemite sills,

c. Two pegmatite and several aplite dikes,

d. A fourth type of dikes is believed to be derived from later dioritic intrusions. These dikes are coarse-grained pegmatite dikes of dioritic composition.

According to the major relationship of the layered sequence, it was possible to divide this mass into fourteen units (I to XIV, *Fig. 1*). They have a total thickness of 1185 m from the margin to the centre of the intrusion.

B. Geology of the northeastern intrusion (large intrusion)

It is elongated and oval in plain view, with the major axis trending NW-SE for 8.3 km (*Fig. 1*). This intrusion is made up of uniformly alternating layers, except at the coalescing part with the small intrusion and at the northernmost part where it is cut by dikes. Dips are generally steep inwardly, 70°-50°at the borders, while at the central parts the dip decreases to few degrees, where the layers are nearly horizontal and the surface is covered by thick rubble of gabbroic boulders. Differential weathering of the concentric layers of this intrusion produced an extra-ordinary ramp-moat topography (*Fig. 2*).

In the northern and southern parts, the intrusion has sharp contacts with hornblende schist and gneiss. Off-shoots and dikes of fine grained gabbro are present and cut both country rocks and the layers of the intrusion. Few pegmatite and quartz veins cut across the layers perpendicularly at the northern and eastern edges of the intrusion.

Few isolated lenticular masses of various sizes of sheared and fractured ultramafic rocks crop out nearly at the central part of the large intrusion (*Fig. 1*). These masses are extensively serpentinized and slightly carbonatized. A large porphyritic granophyric body occurs at the southwestern side of the central part of the large intrusion. It is light in color and mostly fractured and jointed (*Fig. 3*). The layered sequence of the large intrusion is divided into sixteen units (*Fig. 1*). Total thickness of this sequence is 1778 m from the margin to the centre of the intrusion.

Characteristic structural features in both intrusions are recorded during the field work, they are the following:

a. Slumping folds which dominate in Unit III of the small intrusion, usually accompanied by rhythmic layering of thin laminae of anorthosite alternating with troctolite (*Fig. 4*).

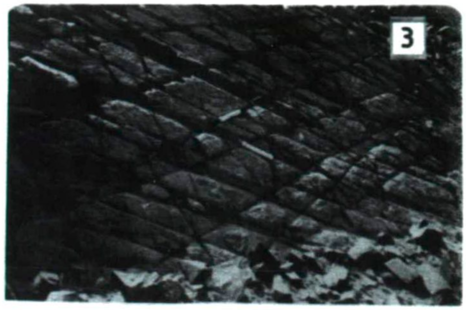
b. Knobby olivine gabbro of Unit V of small intrusion exhibits a characteristic outrcop appearance due to spheroidal weathering and differential weathering of the knobs. (*Fig. 5*).

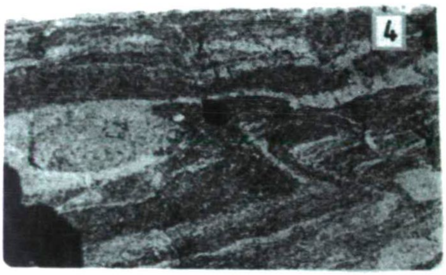
c. Fractures and joints dissect the porphyritic granophyric body at the central part of the large intrusion (*Fig. 3*).

d. Macrorhythmic layering of normal gabbro of Unit III of the large intrusion shows in few cases microrhythmic layering of troctolite and anorthosite. The exposed surface of this unit shows large angular boulders with very well developed igneous lamination and spheroidal weathering (*Fig. 6*).

e. Coarse-grained troctolite of Unit V in the large intrusion contains rthythmic layers of olivine-rich gabbro and peredotite (*Fig. 7*).

The layered sequences in the two intrusions do not show a definite upward pattern in the mineral composition of the layers, except the hornblende gabbro becomes more abundant towards the topmost parts. This may be suggest that the cumulate layering process was continuously interrupted by frequent introduction of fresh surges of magma.





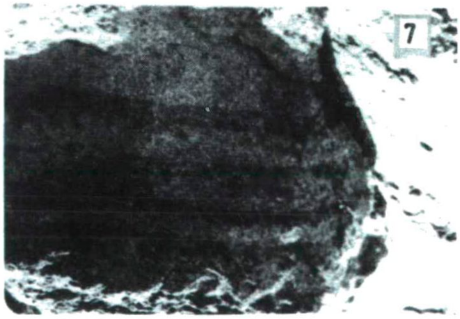


Fig. 2. Ramp-moat topography near the centre of the large intrusion.

Fig. 3. Fractured and jointed outcrop of granophyre at the central part of the large intrusion.

Fig. 4. Rhythmic layering of thin laminae of anorthosite alternating with troctolite slumping features are also observed (small intrusion).

Fig. 5. A large spheroidal boulder from unit V of the small intrusion, showing uniform distribution of large size knobs.

Fig. 6. A typical exposure of Unit III showing boulders with igneous lamination and spheroidal weathering.

Fig. 7. Rhythmic layers of olivine-rich gabbro and peridotite in the coarse-grained troctolite of Unit V in the large intrusion.

From the study of the outcrop pattern and attitude and compositon of layers of the two intrusions, it seems that they are most probably funnel shaped in three dimensions, which is a very common feature for the small layered intrusion, such as Rhum (WAGER and BROWN 1968); Muskox (IRVINE and SMITH 1967); Insizwa (LIGHTFOOT and NALDRETT 1984); Jabal Shayi (COLEMAN 1973) and Timberlana (CAMPBELL 1977). However, the large intrusion is much more elliptical than the small one. This suggests that the large intrusion could have a boat-like shape rather than a circular funnel shape. The small intrusion is slightly elongated in a NE-SW direction perpendicular to the elongation of the large one. It seems that the formation of the two intrusions was controlled by two major regional deep seated fracture zones. Layering of the small intrusion is truncated by the large one indicating that the large intrusion is the younger.

PETROGRAPHY OF THE PRINCIPAL CUMULATE ROCKS TYPES

The petrographic studies on about 150 thin sections showed that both intrusions are composed of the same rock types. Five essential cumulus minerals constitute the major part of these rocks. The minerals are, in decreasing abundance: plagioclase, olivine, clinopyroxene, orthopyroxene and hornblende. Accessory minerals are: biotite, apatite and opaques. Conventional petrographic terminology for the cumulus minerals which tackled by CAMPBELL (1987), IRVINE (1982), STRECKEISEN (1973) and WAGER et al. (1960), are also applied on the description of El Ekeim rocks. Determination of the modal composition of selected samples was carried out by a swift point-counter. The identified rock types of the present study are listed and briefly described below.

1. Cumulate rock types

a. Plagioclase – clinopyroxene – olivine cumulate (olivine gabbro).

b. Plagioclase – olivine cumulate (troctolite).

c. Plagioclase – clinopyroxene – olivine – hornblende cululate (hornblende – olivine gabbro).

d. Plagioclase – orthopyroxene – clinopyroxene – olivine cululate (olivine gabbronorite).

e. Plagioclase – clinopyroxene cumulate (gabbro).

f. Plagioclase cumulate (anorthosite).

g. Olivine – pyroxene cumulate (peridotite).

2. Non-cumulate rock types

h. Hornblende – olivine gabbro (chilled margin)

i. Granophyre.

a. Olivine gabbro

It is the most abundant rock type in both intrusions, and constitutes about 60% of the exposed rocks in the small intrusion, and about 75% in the large intrusion.

In the sections, the rock is medium-coarse grained, roughly equigranular, and consists of fresh plagioclase, pyroxene and olivine. The plagioclase makes up to 45-58% which are mostly labradorite. Pyroxene is the second most abundant cumulus mineral averaging from 52 to 35%. Subhedral olivine is the third most abundant cumulus mineral and froms 15-25%. The orthopyroxene and hornblende form less than 2%. The olivine gabbro of the lower and middle units is characterized by dissiminated opaques which constitute up to 5%. Orthocumulate to mesocumulate textures are dominant in the upper and middle units, while mesocumulate to adcumulate textures are more dominant in the lower unit.

b. Troctolite

It is the second most dominant rock type in both intrusions. It constitutes about 30% of the small intrusion and about 12% of the large intrusion. Microscopically, the rocks consist mainly of plagioclase and olivine, with subordinate amount of pyroxene, opaques, biotite and apatite as cumulus and intercumulus material. The plagioclase constitutes approximately 50-60% and is usually tabular. Euhedral to subhedral olivine crystals form 20-45% of the rock. In some samples, the olivine crystals are rimmed by a very thin veneer of orthopyrexene that occurs as an intercumulus phase. Serpentinization is so advanced in some thin sections. Mesh texture and igneous lamination are well developed. Troctolite is poor in cumulus opaques, but some intercumulus opaques were observed.

c. Hornblende – olivine gabbro

It makes about 15% of the exposed rocks in the small intrusion and about 5% of the large one. The main cumulus minerals are plagioclase, hornblende and olivine. The plagioclase and olivine crystals are moderately altered.

d. Olivine gabbronorite

It represents about 8% of the exposed rocks of the small intrusion. It is composed mainly of fine – medium grained cumulus plagioclase, orthopyroxene, clinopyroxene and olivine. Opaques and biotite occur as intercumulus phases.

e. Gabbro

It is less abundant than the previous types. The rocks consists mainly of plagioclase and clinopyroxene with minor olivine and hornblende as cumulus minerals. The intercumulus minerals are represented by minor amounts of hornblende and opaques.

f. Anorthosite

It consistutes the whole of Units VIII and X of the small intrusion, with thickness of 10 and 15 m respectively. It also constitutes Unit X with 17 m thickness of the large intrusion. Some thin layers of olivine gabbro and troctolite occasionally forming rhythmic layering in the anorthosite. The plagioclase cumulate crystals represent more than 90% of the whole rock. The rest is represented by intercumulus pyroxene and opaques. The intercumulus material is mostly less than 5%, therefore the rock is an adcumulate. Igneous lamination is well developed in this rock type due to the parallel alignment of plagioclase crystals.

g. Peridotite

It occurs as thick continous layer near the bottom of the small intrusion, and as three discontinous layers at the southern part of the large intrusion. Alternations of thin layers of olivine gabbro and troctolite are prevailed with peridotites. The microscopic study revealed that the main cumulus minerals are olivine (70-85%). Pyroxene, plagioclase and accessories form the rest of the rock.

h. Chilled margin

It forms a single discontinous layer at the outer border of the intrusions at the contact with the country rocks. It is characteristic that the most of the minerals are fine-grained, with non-cumulate texture. Plagioclase, hornblende, pyroxene and olivine are the dominant constituents. However, few opaques, biotite and apatite are also recorded.

i. Granophyre

It occurs as a large elongated body, with a small off-shoot at the top towards the centre of the large intrusion. It is composed of fine-grained potash feldspar, plagioclase, quartz, orthopyroxene, apatite, biotite, ilmenite and magnetite. Olivine crystals are found near the contact. Granophyre represents the late stage of crystallisation of the layered series of the large intrusion, such as Insizwa complex (LIGHTFOOT and NALDRETT 1984) and Jimberlana intrusion (CAMPBELL 1978).

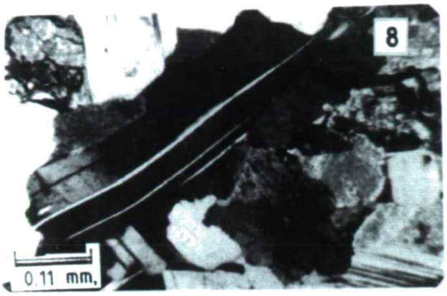
MINERALOGY OF EL EKEIM INTRUSIONS

The essential cumulus minerals of the investigated rock types, in order of abundance are: plagioclase, clinopyroxene, olivine, orthopyroxene and hornblende. However, the main accessory minerals are biotite, apatite and opaques. Some 70 polished sections are performed for the opaque mineral identification. The mineral constituents were examined microscopically in samples collected from four traverses, while two of them were examined by microprobe for further publication by the same authors.

a. Plagioclase

It is the most abundant cumulus mineral in most rocks of the two intrusions. It represents 50-60% by volume of the whole total composition of most rocks. However, some layers contain little or no plagioclase. The dominant plagioclase crystals are euhedral to subhedral, platy or lath-shaped. Their size variable is ranging from 0.2 to 1.8 mm in width and vary from 0.5 to more than 5 mm in length. Some of these crystals are slightly bent (*Fig. 8*) possibly due to accumulation of other crystals on their tops. Orientation or alignment of plagioclase crystals are clearly exhibited in some layers, which causes the prominent igneous lamination (*Fig. 9*). Primary normal zoning is well developed in some plagioclase crystals where some of them show three or more zones (*Fig. 10*). The boundary between the zones is always gradational indicating the gradual slow change of liquid composition and/or temperatures. Reverse and oscillatory zoning in plagioclase are also present indicating fluctuations in temperatures and liquid composition (SMITH and LOFGREN 1983).

Plagioclase also occurs as an intercumulus phase, that is lath-shaped or wedge shaped between the cumulus phases. It was crystallized from intersitial liquid in pores between crystal boundaries. Most plagioclase crystals are fresh, nevertheless some highly calcic plagioclases are altered to saussurite (zoisite, epidote and calcite). Some plagioclase crystals show radiating fractures due to the extensively alteration of the associated olivine (*Fig. 11*).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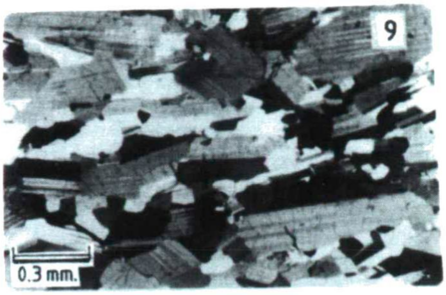
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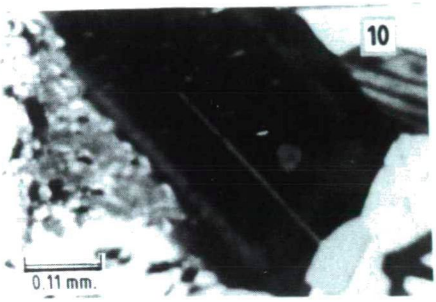
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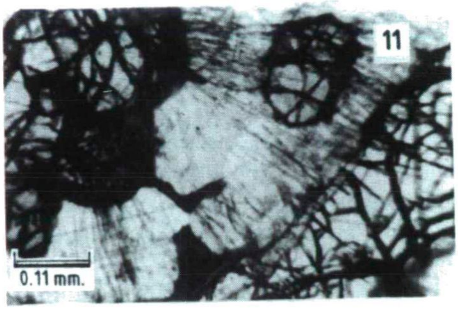
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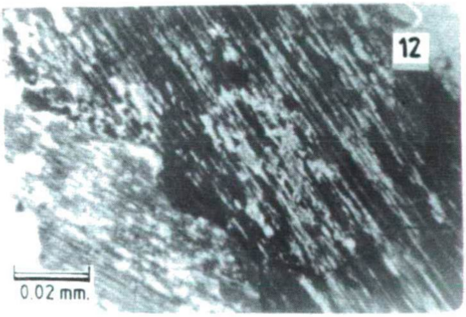
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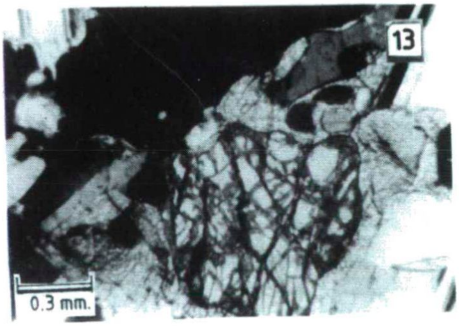
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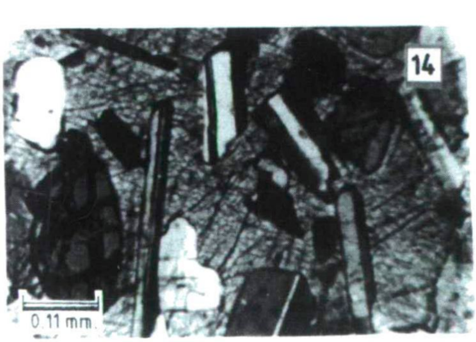
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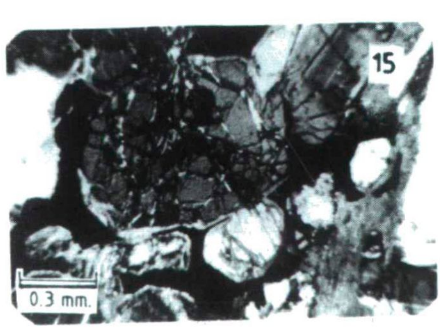
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Fig. 8. Elongated and bent adcumulate plagioclase crystal showing wavy extinction and without zoning. (Transmitted light, C. P.)

Fig. 9. Adcumulate plagioclase showing well development igneous lamination. (Transmitted light, C. P.)

Fig. 10. Zoned Plagioclase crystal exhibiting post-cumulus growth in olivine gabbro. (Transmitted light, C. P.)

Fig. 11. Radiating fractures in plagioclase due to the expansion of extensively altered olivine. (Transmitted light, P. L.)

Fig. 12. Exsolved lamellae of orthopyroxene in clinopyroxene. (Transmitted light, C. P.)

Fig. 13. An olivine crystal rimmed by intercumulus clinopyroxene, which also encloses intercumulus hornblende (dark brown) (Transmitted light, C. P.)

Fig. 14. Knobby olivine gabbro, showing olivine and plagioclase chadacrysts embedded in large anhedral plate of clino-pyroxene. (Transmitted light, C. P.)

Fig. 15. Large subhedral olivine crystal rimmed by thin veneer of clinopyroxene and biotite (corona texture). It is also poikilitically enclose some opaque minerals (Transmitted light, C. P.)

b. Clinopyroxene

It occurs as the second major cumulus mineral in both intrusions. Generally it represents about 20-30% of the whole mineral composition. It is an augite variety. It occurs as cumulus crystals aligned parallel to tabular plagioclase and clustered olivine grains. It is mostly fresh and apperas in euhedral to subhedral prismatic shape. The dimension varies from 0.8 to 1.4 mm in width and 1.2 mm to more than 2 mm in length. Some clinopyroxene crystals are extensively schillerized by tiny small inclusion of opaques. Some augites contain exsolved lamellae of orthopyroxene parallel to {100} plane (*Fig. 12*). These were interpretted as inverted pigeonites (WAGER and BROWN 1967) which is a common feature in differentiated gabbroic intrusions.

Clinopyroxene also occurs as an intercumulus phase in the form of wedge-shaped grains and partial thin rims, in places pseudomorphed by hornblende around olivine and plagioclase crystals (*Fig. 13*). Occasionally, the intercumulus clinopyroxene forms large poiklitic plates enclosing numerous grains of differently sized plagioclase and olivine (*Fig. 14*). This texture is only observed in knobby olivine gabbro.

c. Olivine

It occurs as an essential cumulus constituent in most rock types. It forms about 10-47% of the whole cumulus minerals. The olivine crystals are mostly medium to coarse grained, ranging from 0.7-3 mm in diameter. Most of them are clustered to form elongated thin laminae. The shape is usually subhedral and rarely euhedral. Some olivine crystals poikilitically enclose few grains of plagioclase and/or opaque minerals. Corona texture is common where olivine is uniformly rimmed by reaction rims of pyroxene and biotite (*Fig. 15*).

Olivine also occurs as intercumulus phase, filling the interstitial spaces between plagioclase (*Fig. 16*). Most crystals are fresh. However, some are slightly to extensively altered to serpentine iddingsite or bowlingite. During this alteration, mesh texture is well developed, in which iron is released, filling the fractures (*Fig. 17*).

d. Orthopyroxene

Hypersthene occurs as a cumulus phase in few layers of both intrusions. It mostly represents less than 15% of the whole mineral composition. It commonly forms thin rims surrounding olivine or plagioclase crystals (*Fig. 18*). In some cases, it occurs as a narrow zone between olivine and plagioclase. Occasionally, these zones or rims pass into intercumulus orthopyroxene. They could be interpreted as corona structure, which are mostly developed around the cores of olivine minerals, where the orthopyroxene shows a sharp boundary against an outer rim of amphibole.

e. Hornblende

It occurs as cumulus and intercumulus phases. The primary cumulus type is brownish in colour, and medium grained, ranging from 0.8 to 1.2 mm across. It mostly occurs in the olivine gabbro. The secondary hornblende is more common and mostly occurs as pseudomorphs after clinopyroxene. It represents less than 5% of the whole mineral composition.

f. Accessory and alteration minerals

They include; biotite, apatite, chlorite and actinolite, and zoisite. Biotite is persistently present as an accessory mineral especially in the olivine gabbro. It occurs as small ragged tabular flakes around the olivine and pyroxene crystals (*Fig. 15*). Possibly both cumulus and intercumulus biotite is present. It was formed after the bulk of the magma had solidified. Apatite is the most common accessory cumulate and intercumulate mineral throughout the intrusions. The large euhedral apatite crystals are inferred to have crystallized late in the magmatic history of the gabbroic rocks, probably from liquid trapped between plagioclase-ferromagnesian precipitates (COLEMAN et al. 1977). Apatite is a common minor orthocumulate phase in iron rich olivine gabbro as in Skaergaard and Bushveld intrusions (WAGER and BROWN 1967).

Chlorite and actinolite are rarely observed along fractures and rims. Zoisite is detected in very few thin sections, it is believed to be derived from alteration of the Ca-rich plagioclase.

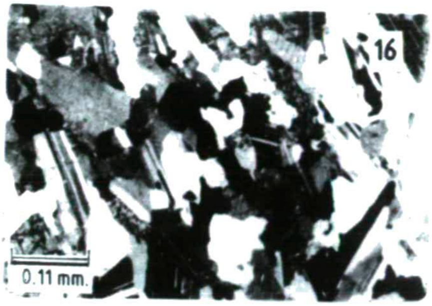
g. Opaque Minerals

Opaque sulphide and oxide minerals constitute between 0.2 and 5% by the volume of the mafic-ultramafic rocks of El Ekeim intrusions. These minerals occur either as cumulus or intercumulus phases similar to Duluth Complex (TYSON and CHANGE 1984).

Ore microscopic examination for some 70 polished sections of the various rock types was carried out. The cumulus opaques occur as euhedral-subhedral grains between the cumulus silicates, or enclosed by polikilitic plates of them. However, intercumulus opaques occur as irregular interstitial grains between the silicate minerals. In order of abundance; the sulphide minerals are: pyrrhotite, chalcopyrite, pyrite, pentlandite and covellite. Whilst, the oxides are: magnetite, titano-magnetite, ilmenite, rutile, hematite, ulvospinel and hemo-ilmenite, together with little chromite, goethite and spinel.

The most abundant sulphide mineral is the pyrrhotite which forms 70-80% of the whole opaques. It usually occurs as a cumulus mineral and also as intercumulus as interstitial anhedral grains filling the spaces between the silicate minerals (*Fig. 19*). It is also commonly present as composite grains in association with magnetite, chalcopyrite and pyrite (*Fig. 20*). Pentlandite is present in a relatively minor amount, mostly associated with pyrrhotite forming exsolution texture (*Fig. 21*). The exsolved pentlandite tends to diffuse rapidly to the grain boundaries and along the {0001} planes of pyrrhotite and precipitate as rims around these grains.

Chalcopyrite is the second most common sulphide mineral. It occurs as single anhedral intercumulus grains or as clustered cumulus composite grains of chalcopyrite, pyrite and magnetite. Pyrite occurs in very small amounts, always in association with one or more of pyrrhotite, chalcopyrite and magnetite forming cumulus composite grains. Covellite is rarely observed, it is secondary mineral being formed by alteration of chalcopyrite.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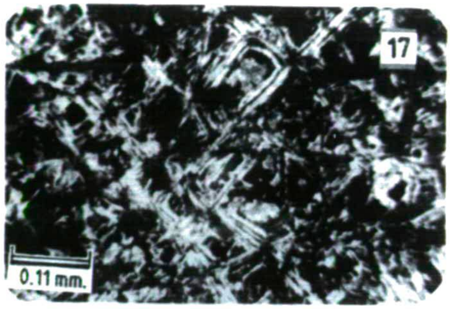
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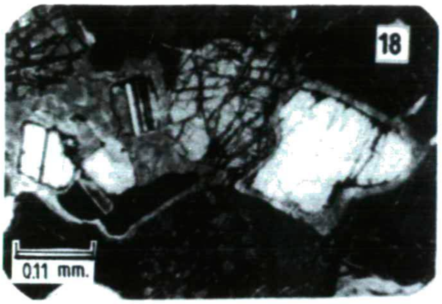
18
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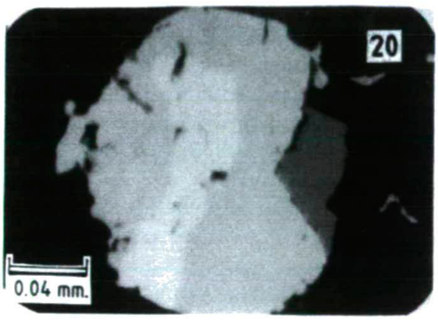
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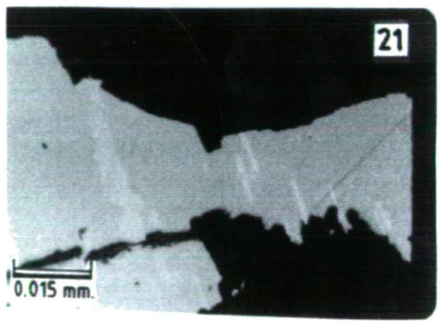
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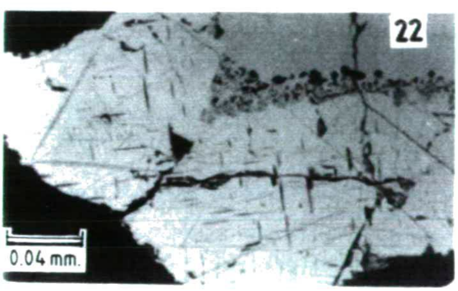
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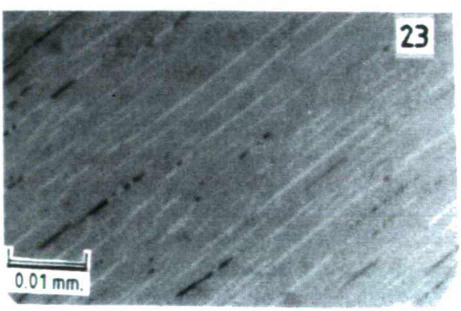
23
0.01 mm.

Fig. 16. Intercumulus olivine crystals occupying spaces between cumulus plagioclase (Transmitted light, C. P.)

Fig. 17. Serpentinized olivine in peridotite showing well developed mesh texture with some preserved relics (Transmitted light, C. P.)

Fig. 18. Thin rim of orthopyroxene surrounded by the olivine and plagioclase crystals. Some plagioclase crystals are embedded in clinopyroxene (Transmitted light, C. P.)

Fig. 19. Composite andhedral pyrrhotite – pentlandite and chalcopyrite filling the spaces between the silicate grains (Reflected light, oil imm.)

Fig. 20. Cumulus composite grains of magnetite, pyrrhotite and pyrite embedded in olivine (Reflected light, oil imm.)

Fig. 21. Pyyrhotite – pentlandite exsolution (Reflected light, oil imm.)

Fig. 22. A composite grain of ilmenite and magnetite. Magnetite contains spinel exsolution. Lamellae of ilmenite are oriented along the magnetite octahedral planes (Reflected light, oil. Imm.)

Fig. 23. Exsolution lamellae of hematite in ilmenite (hemo-ilmenite) (Reflected light, oil imm.)

Oxide minerals are less abundant than the sulphides. Their amount decreases gradually from the bottom to the top of the layered sequences. Magnetite occurs either as small intercumulus anhedral interstitial grains or as a cumulus phase with euhedral to subhedral shape. It forms frequently composite grains with ilmenite. The contact between magnetite and ilmenite grains is either rectilinear or highly curved, with the convexity towards the magnetite, and is often marked by specks fo translucent spinel. Magnetite commonly contains exsolution of ilmenite in various types of intergrowth, among which the fine ilmenite lamellae are oriented along the octahedral magnetite planes to form triangular networks (*Fig. 22*). Magnetite also shows common replacement by hematite as a result of martitization (RAMDOHR 1980). Hematite also occurs as exsolutions (hemo-ilmenite) representing by thin linear or thread-like lamellae in ilmenite (*Fig. 23*).

Chromite was observed in the peridotite, troctolite and olivine-rich layers of the present intrusions. Same results were recorded by (CAMERON 1980 and 1982). It is generally present in the form of rounded to oval shaped idiomorphic homogenous single grains or as clustered grains. Some are highly fractured and filled with either serpentinite or martitized magnetite.

Modal Analysis

Modal analysis was carried out on 59 samples representing the main rock types along the two main traverses in the two intrusions (T 17 in the small intrusion, and T 16 in the large one). The results are represented diagramatically in *Figures 24* and *25*. The obtained data indicate the following:

1. The two chilled margins of both intrusions are very similar in their modal compositon.
2. Both intrusions have the same mineral constituents, with slight difference in relative proportions.
3. Plagioclase seems to be slightly more abundant in T 16 than in T 17. On the other hand, olivine is clearly more abundant in T 17 than in T 16.
4. Orthopyroxene is more persistant with a greater proportion in T 16 than in T 17.
5. The variation in the content of the clinopyroxene in T 16 is clearly less than its variation in T 17, where it shows increase on the expense of olivine in the upper part of the traverse.

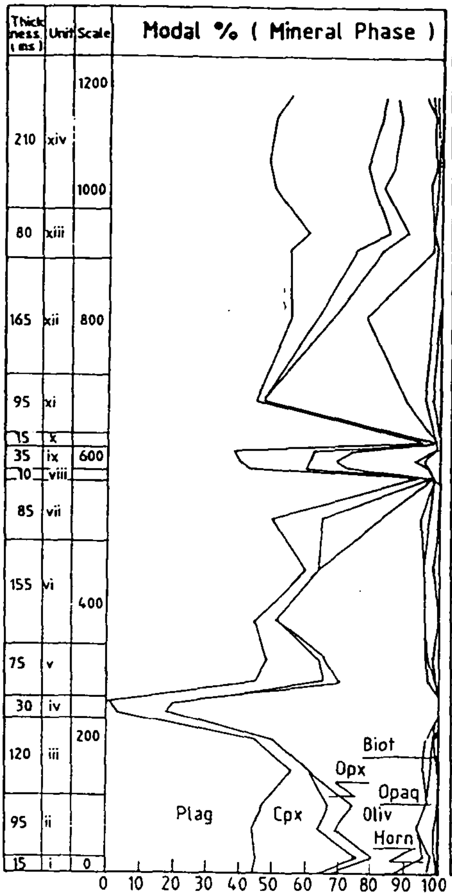

Fig. 24. Modal analysis along T17, small El Ekeim.

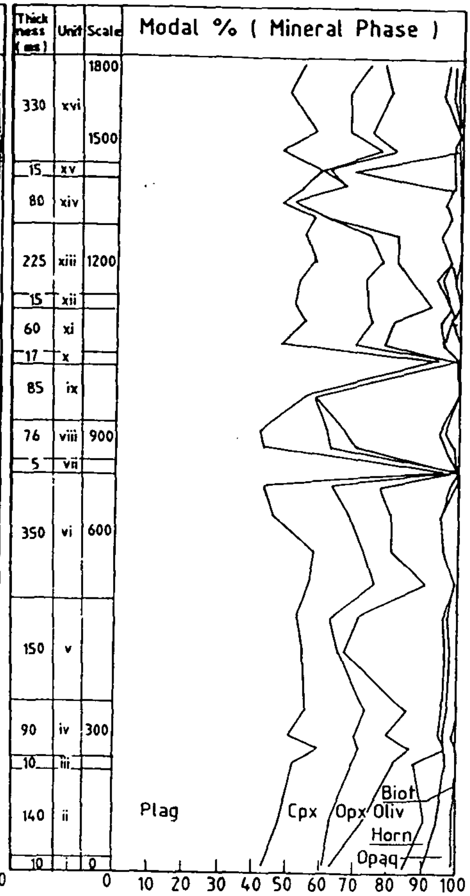

Fig. 25. Modal analysis along T16, large El Ekeim.

CONCLUSIONS

The overall conclusion of the petrographic and mineralogic study can be put in two main points to recognize the parental magma of the two intrusions:

1. The mineral composition of both intrusions indicates that their parent magma is the same and it had a tholeiitic nature.
2. Although the two intrusions are very close in their composition, the parent magma of the large intrusion seems to be slightly more evolved than that of the small intrusion.

Based on the current studies, some other conclusions are reached, they are following:

1. The presence of some internal structures characterizing the units and layers of the two intrusions as slump structures, igneous lamination, knobby texture and rhythmic layering could lead that they were formed by a combination of different mechanisms of density gravitational stratification and crystal sorting by magmatic convection currents.
2. The crystal sorting due to recurrent burts of nucleation, crystallization and gravitational settling (GOODE 1975) seems to have had a major role in the formation of layering of the two intrusions.
3. The layered sequences in the two intrusions do not show a definite upward pattern in the mineral composition of the layers, except the hornblende gabbro becomes more abundant towards the topmost parts. This may suggest that the cumulate layering process was continuously interrupted by frequent introduction of fresh patches of magma.
4. From the outcrop pattern, attitude and composition of layers of the two intrusions. It seems that the formation of the two intrusions was controlled by two major regional deep-seated fracture zone. Layering of the small intrusion are truncated by the large one indicating that the large intrusion is the younger.
5. Zoning in plagioclase is common, with oscillatory zoning more prevalent than normal and reverse zoning. The oscillations of anorthite content are primary, which indicate that minor pulses of fresh magma introduction was common. This feature may equally be due to minor variations in water vapour pressure causing undercooling at the same horizons (AL SHANTI 1974).

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