PETROGENESIS OF SOME ALKALINE LAMPROPHYRES FROM SHEIKH SALEM AREA, EGYPT: EVIDENCES FROM THE CHEMISTRY OF ZONED CLINOPYROXENES.

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Abstract: Alkaline volcanics in the form of dykes are present in Sheikh Salem area (Eastern Desert of Egypt) dissecting the Precambrian basement rocks. The latter comprise metagabbro-diorite, serpentine and younger granite. Two types of alkaline dykes in the area are distinguished, namely lamprophyre (camptonite) and trachyte. The present work contributes to the use of clinopyroxene in the petrogenesis of some lamprophyres in the Egyptian shield rocks. Petrographically, the studied camptonites are characterized by the presence of very peculiar titanaugite megacrysts. This pyroxene is commonly zoned with enrichment of both Fe and Ti towards the rims. Very few olivine (forsterite) phenocrysts are encountered in some dykes, whereas alkali amphibole phenocrysts are common in all samples. The finer groundmass is rich in feldspars, titanomagnetite, chlorite and carbonates. Microfabrics show two generations of secondary carbonates in both amygdals and wedged fractures. As indicated by the mineral chemistry of the clinopyroxenes, fractionation trend is similar to that of intraplate-type volcanics from alkaline and peralkaline suites. Tendency of the analyzed pyroxenes towards peralkalinity is indicated by the acmite component (up to 3.20 mole%). Cr-bearing cores of clinopyroxene suggest deep-seated magma generation at high-pressure conditions in the mantle. The presence of hydrous phases may indicate a primitive melt (with high PH2O and PCO2) that could be produced from phlogopite-bearing peridotite (i.e. metasomatized mantle).

Introduction

Lamprophyre dykes are common in the Egyptian shield rocks. In many of the known occurrences, these lamprophyres usually associate other alkaline dykes and
plugs (mostly bostonites and trachytes), all cutting the Precambrian basement rocks of the Eastern Desert and Sinai. Egyptian lamprophyres were recorded by many workers (e.g., Akaad, 1959; Kabesh and Shahin, 1968; El-Ramly et al., 1971; Mikhail, 1979; El-Mahallawi et al., 1992 & 1994; Ashmawy and Salem, 1993). Few of these works paid attention to the petrogenesis of lamprophyres. Basta et al. (1985) presented a collective and comprehensive study on the Egyptian lamprophyres from 14 different localities, and concluded that they are basic rocks belonging to the alkaline series. These authors (op. cit.) distinguished between two groups of Egyptian lamprophyres, one is mildly potassic (shoshonitic type, including kersantite, spessartite and kersantosspessartite) and the other is sodic (mainly represented by camptonite). It was believed that the melt from which lamprophyres crystallized might represent modified alkali basaltic magma. Similar conclusions were reached by El-Mahallawi et al. (1992, 1994) based on the REE composition of the rock.

The present paper contributes to the use of clinopyroxenes in the petrogenesis of camptonitic lamprophyres from Sheikh Salem area in order to follow the course of fractionation and its implication on the nature of the melt and its tectonic setting. The use of clinopyroxenes as petrogenetic indicators in the Egyptian volcanics was presented and discussed by some workers (e.g., Stern, 1979; Basta and Hafez, 1985). No data on the application of clinopyroxene chemistry in the magmatic evolution of Egyptian lamprophyres has yet been presented.

**GEOLOGICAL SETTING**

In Sheikh Salem area, both lamprophyres and associating trachytes occur in the form of dykes cutting the Precambrian basement rocks (Fig. 1). These country rocks are metasediments, serpentinites, metagabbro-diorite and the outer peripheries and apophyses of Sheikh Salem younger anorogenic granite. These dykes trend NW-SE, nearly vertical with cores more leucocratic than the outer peripheries. Field observations suggest that the studied dykes might have been formed during a crustal extensional event post-dating the emplacement of Sheikh Salem granite. Kamel et al. (1993) obtained the age of 463-518 M. a. for this granite based on K-Ar dating of K-feldspars. It is evident that the studied alkaline dykes intrude the so-called “post-granitic” dykes (mostly andesite and rhyolite in this occurrence). In some cases, the alkaline dykes...
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trend parallel to the older felsic dykes. Generally, the concerned camptonite dykes are of dark brownish green colour, fine-grained and exhibit megascopic crystals of pyroxene. The lamprophyres, in addition to the granites, are the least weathered staff among the lithologies in the area.

PETROGRAPHY

Microscopic investigation of the collected samples of lamprophyres indicates that they are mostly camptonite, but a single dyke of vogesite was also recorded. They are almost fresh, typically porphyritic and exhibit panidiomorphic texture. No silica as free quartz is present, whereas feldspathoids (nepheline) are common in the camptonite.

Mineralogically, the camptonite is characterized by peculiar coarse titanaugite crystals. Other primary minerals in order of decreasing abundance are intermediate to sodic plagioclase, alkali and calcic amphibole (barkevikite and kaersutite, respectively), titanomagnetite, olivine, nepheline and pyrite. Secondary minerals are represented by epidote, serpentines and chlorite. Late carbonate filling is common in both amygdales and fractures. Olivine is earlier than the clinopyroxene (Fig. 2a). This olivine occurs as rounded to sub-rounded crystals, extensively altered to serpentine and chlorite (Fig. 2b). The fibrous thin veinlets of both secondary minerals are associated with “iddingsite”. Sometimes, fresh olivine crystals present as inclusions in the pyroxene are also recorded. Wilkinson (1974) stated that in strong contrast to the nearly fresh co-existing clinopyroxene, olivine in alkaline volcanics is very susceptible to alteration due to either deuteric or weathering effects. Detailed opaque mineralogy indicates that olivine encloses some Fe-sulphide (pyrite).

Clinopyroxene is present as megacrysts embedded in a fine-grained groundmass composed of the other phases in addition to a finer clinopyroxene generation. Identification of the clinopyroxene species was based on the optical properties which was then verified by the electron microprobe analyses. The clinopyroxene megacrysts are in most cases nearly equant (dimension is about 3.5–4mm), either euhedral (Fig. 2c) or corroded by the components of the groundmass (Fig. 2d). They are commonly zoned, but few prismatic crystals (2mm x 3.7mm) exhibit only cryptic chemical zoning as indicated by the microprobe scans. Generally, the cores of the zoned clinopyroxene crystals are colourless augite followed by pinkish rims of titanaugite.
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forming typical concentric zoning. Dobosi et al. (1991) and Deer et al. (1992) mentioned that zoning is very common in Ti-bearing augite. Hourglass zoning which is common in some alkaline volcanics (e.g. Smith and Lindsley, 1971) is not observed in the dykes under investigation. On the other hand, clinopyroxene from tholeiitic volcanics is always unzoned, as the case of the Bushveld Igneous Complex in South Africa. In the present occurrence, both the optically and cryptically zoned crystals are highly cracked with the development of brownish green hornblende along the cross-cutting cracks in all zones, especially in the Ti-poor core. Combination of zoning and simple twinning is also detected in some clinopyroxene crystals. In such case, the twinning plane runs only through the core indicating splitting of the mineral before the final stages of crystallization and the accompanied enrichment of the magma in both Ti and Fe. Clinopyroxenes are completely absent in the single vogesite dyke in the occurrence of Sheikh Salem.

The feldspars in the studied lamprophyres comprise both plagioclase in camptonite and alkali feldspars in vogesite. On optical basis (e.g. extinction angles), two varieties of plagioclase are distinguished in camptonite, one is intermediate (oligoclase-ande) and the other is sodic (albite). The latter is the main constituent of the groundmass, in the form of laths, showing clear carlsbad twin lamellae and rare interpenetration twinning. Some crystals of intermediate plagioclase are zoned (Fig. 2e) and coarser than the more sodic laths of the groundmass. In all of the examined thin-sections, no ophitic or sub-ophitic textures are recorded indicating the cease of clinopyroxene crystallization prior to the separation of feldspars from the melt.

Barkevikite represents the common alkali amphibole in the studied lamprophyres. It occurs as perfect euhedral prismatic crystals (Fig. 2f) with imperfect cleavage. Some rhombic cross-sections are also present with altered rims to olive-green biotite. Such alteration was also reported in some other Egyptian lamprophyres (Basta et al., 1985). Generally, the recorded barkevikite is dark reddish brown in colour, with distinct pleochroism to brown (Y) and brownish yellow (Z). In some crystals, the rim is black which is typical of alkali amphibole such as barkevikite (Deer et al., 1992). Texturally, it is obvious that barkevikite post-dates the plagioclase. On the other hand, barkevikite encloses titanomagnetite. Calcic amphibole is represented by kaersutite in the
form of prisms. (Fig. 2f) varies in colour from pink to brick red, also post-dating the titanomagnetite.

Feldspathoids, when present, ranges from 4 to 6%. Nepheline is the sole identified foid mineral occurring as sub-rounded grains confined to the groundmass.

Ore-microscopic investigation revealed that opaque minerals (5-8%) are mainly represented by Ti-bearing magnetite and Fe-sulphide (pyrite). Titanomagnetite exhibits its diagnostic pinkish tint. It occurs either as inclusions in the outer zone of clinopyroxene megacrysts or in the groundmass as skeletal leaf-like crystals, fine cubes and octahedra. Magnetite in the clinopyroxenes is almost fresh, whereas it is highly altered in the groundmass to a mixture of goethite and anatase (Fig. 2g) due to low-temperature oxidation. The presence of anatase as an alteration product supports the titaniferous nature of this magnetite. Very few magnetite crystals are enclosed in the sodic plagioclase and barkevikite. Titanomagnetite is very common in the Phanerozoic alkaline volcanics of Egypt (Mikhail, 1979; Abdel Aal et al., 1988).

Pyrite is only confined to the spots rich in olivine or its ghost alteration. It is noticed that alteration of olivine to phyllosilicates is ac-

accompanied by goethite rim replacement of pyrite due to hydration. In some cases, isolated island-like relics of pyrite survive inside the goethite pseudomorph.

Calcite (Fig. 2h) is always interstitial. Secondary silicate minerals replacing the clinopyroxene crystals are mainly represented by chlorite. Different forms of chlorite are present. The first one replaces hornblende along the cracks of augite (Fig. 2i). The second exhibits fan-shaped crystals replacing augite in the groundmass (Fig. 2j). Chlorite also occurs in amygdals. In this case, the mineral forms a circular zone adjacent to the walls of vesicles, followed inward by successive zones of calcite and quartz. Sometimes, two generations of calcite are identified in wedged fractures, one forming perfect rhombheda growing on the walls, whereas the open space is filled by later coarser calcite (Fig. 2i). Some amygdals (wedge-shaped) in the augite crystals are composed of chlorite and calcite only (Fig. 2k). Others sometimes contain sub-idiomorphic quartz.
PYROXENE CHEMISTRY

Mineral chemistry of clinopyroxenes was carried out using an electron microprobe analyzer with five spectrometers (CAMECA SX50) housed at the Swiss Federal Institute of Technology, Zürich. The standards used were natural silicates and oxides. Operating conditions were 15 kV accelerating potential and 20 nA sample current.

i. Chemical composition and zoning:
Table 1 gives electron microprobe analyses of some selected clinopyroxene crystals from the studied camptonite dykes. This table includes analyses of some representative cores and rims of different crystals, as well as a chemical scan (profile) in one zoned megacryst. Analyses for the clinopyroxene in the groundmass are also given. Figure 3 shows that all analyses indicate augite composition with the increase of the ferrosilite component from cores to rims as a result of relative Fe enrichment with fractionation. Following the pyroxene classification of Morimoto (1988), the present clinopyroxenes are all augite even those in the groundmass.

A chemical profile in a zoned augite crystal (Fig. 4) illustrates that liquid enrichment in Fe with the advance of crystallization is also accompanied by the increase of Ti, Al and Ca towards the rims. The titaniferous nature of the rims (titanaugite) is obvious from the TiO₂ content (1.39-2.29 wt %) as compared to those from cores (1.12-1.27 wt %). Clinopyroxene from the groundmass has an intermediate TiO₂ content (1.75-1.78 wt %). In the Eastern Desert of Egypt, Stern (1979) and Basta and Hafez (1985) reported clinopyroxenes from some Precambrian alkaline volcanics with average TiO₂ contents of 1.77 wt % and 2.58 wt %, respectively. On the other hand, tholeiitic and calc-alkaline volcanics contain 0.16-0.36 wt % TiO₂. The TiO₂ ranges from 0.85 and 1.50 wt % in clinopyroxenes from the tholeiitic metavolcanics of the Eastern Desert (Abu El-Ela, 1991).

Figure 4 shows a clear decrease of Mg, Na and Cr from cores to rims in harmony with their analogy from other alkaline suites (e.g. Gibb, 1973; Embey-Isztin et al., 1993). In the present Egyptian example, it is believed that the Si⁴⁺ in the tetrahedral sites is gradually substituted by Al⁴⁺, Ti and probably Fe³⁺ along the course of magmatic fractionation. Using the arithmetic method of Vieten and Hamm (1978), Fe³⁺ in the analyzed clinopyroxenes ranges from 0.026 (core) to 0.058 (rim). Presence of Fe³⁺ in the structure of pyroxenes is also in-
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Fig. 3

○ CORES
● RIMS
△ IN THE GROUNDMASS

alkaline trend
tholeiitic trend

augite
ferroaugite
subcalcic augite
subcalcic ferroaugite

Wo

En Fs
ferred diagrammatically (Fig. 5) using the charge deficiency versus charge excess (Schweitzer et al., 1979). It is evident that all points of rims (except for one) and one representing the groundmass are located above the line Fe^{3+} = 0 indicating that the mineral bears some Fe^{3+} in its structure. As to Na, the 0.03–0.06 cations are much higher than the normal value of augite (0.005) indicating Na-substitution in M2 octahedral sites. Generally, variations of Si^{4+} and other substituting cations support the aspect of chemical zoning and not corona or reaction rim.

ii. Structural formulae of clinopyroxenes:

From the composition and chemical variation of the analyzed clinopyroxene crystals, the following average structural formulae are obtained, based on data in Table 1:

1) Clinopyroxene cores:  
\[ \begin{align*} &Ca^{44.81} \quad Mg^{44.80} \\ &Fe^{10.39} \end{align*} \]

2) Clinopyroxene rims:  
\[ \begin{align*} &Ca^{47.46} \quad Mg^{39.41} \\ &Fe^{13.40} \end{align*} \]

3) Clinopyroxene of the groundmass:  
\[ \begin{align*} &Ca^{46.11} \quad Mg^{42.39} \\ &Fe^{11.50} \end{align*} \]

iii. Mg-number:

The use of Mg-number (100 Mg/Mg + Fe) of clinopyroxenes is very important for the understanding of the magmatic evolution (in terms of magmatic differentiation) of basic magmas since this number shows very sensitive correlation with elements eliminated from the melt (Sinton and Byerly, 1980; Carman et al., 1984). Table 1 shows the decrease of Mg-number from about 81 in the core of the zoned crystal to about 74 in its rim. Considering this number as a good index of fractionation, the clinopyroxenes from the groundmass (Mg-number \( \approx 78 \)) are considered to have been crystallizing during the time interval separating the time of core formation and that of rim crystallization of the megacrysts. According to Carman et al., (1984), finer clinopyroxenes in the groundmass are termed as differentiated pyroxene. This is diagrammatically shown in Fig. 6, where the Mg-number shows positive correlation with Cr and negative correlation with Al^{IV} and Ti. No clear trend is obtained when this number is correlated with Na. Similar results were reached by Ohnenstetter and Brown (1992). In alkaline rocks, Gibb (1973) concluded that when the clinopyroxene attains a composition in which the Mg-number exceeds 65, titanates start to crystallize. This is proved by the present ore-microscopic investigation. Clino-
Fig. 5

![Graph](image)

Fig. 6

![Graphs](image)
Table 1: Electron microprobe analyses of clinopyroxenes.

<table>
<thead>
<tr>
<th>Ordiine with</th>
<th>Zoned Megacrysts</th>
<th>Rims of different crystals</th>
<th>Crystals in the groundmass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ocm intermediate</td>
<td>core intermediate</td>
<td>nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>core</td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>46.26</td>
<td>48.79</td>
<td>48.36</td>
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<td>TiO₂</td>
<td>2.28</td>
<td>1.24</td>
<td>1.27</td>
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<tr>
<td>Cr₂O₃</td>
<td>0.08</td>
<td>0.30</td>
<td>0.46</td>
</tr>
<tr>
<td>FeO*</td>
<td>7.28</td>
<td>6.03</td>
<td>6.06</td>
</tr>
<tr>
<td>MnO</td>
<td>0.13</td>
<td>0.15</td>
<td>0.14</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.52</td>
<td>0.77</td>
<td>0.82</td>
</tr>
<tr>
<td>Total</td>
<td>99.94</td>
<td>99.49</td>
<td>99.00</td>
</tr>
</tbody>
</table>

Structural formula on basis of 6 oxygens

|                |                  | 8.00                      | 8.00                      | 7.71                      | 8.00                      | 8.00                      | 8.00                      | 8.00                      | 8.00                      | 8.00                      | 8.00                      | 8.00                      | 8.00                      | 8.00                      |
|                |                  | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      |
|                |                  | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      |
|                |                  | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      |
|                |                  | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      | 0.00                      |

Endmembers

|                  | 46.80            | 45.05                     | 45.05                     | 44.56                     | 47.00                     | 44.94                     | 46.27                     | 46.27                     | 45.60                     | 46.28                     | 46.56                     | 45.45                     | 45.45                     |
|                  | 37.56            | 41.40                     | 41.50                     | 42.11                     | 37.67                     | 40.49                     | 38.83                     | 37.76                     | 38.32                     | 40.43                     | 39.68                     | 41.17                     | 41.09                     |
|                  | 12.48            | 10.42                     | 10.33                     | 10.23                     | 12.43                     | 11.43                     | 11.73                     | 12.77                     | 12.95                     | 11.88                     | 12.17                     | 11.23                     | 11.30                     |
|                  | 2.16             | 3.13                      | 3.12                      | 3.10                      | 2.90                      | 3.15                      | 3.17                      | 3.20                      | 3.11                      | 3.11                      | 3.17                      | 3.14                      | 3.16                      |
pyroxenes from tholeiitic basic volcanics have much lower Mg-number, e.g. 56-67 (Ernst and Bell, 1992; Bendarz and Schmincke, 1994).

**MAGMATIC EVOLUTION**

This section is devoted to the magmatic evolution or the igneous history of the concerning camptonites including magma type, tectonic setting and fractionation trend. Geothermobarometry and oxygen fugacity are also considered.

**i. Magma type and fractionation trend:**

Using the Ti-(Ca+Na) relation of Leterrier et al. (1982), all the analyzed clinopyroxenes from the Sheikh Salem camptonites plot in the alkaline field (Fig. 7a). Aluminium in the structure of clinopyroxenes is very important to obtain the possible magma type with respect to Ti and degree of silica saturation in volcanic lavas (Kushiro, 1960; Le Bas, 1962; Nisbet and Pearce, 1977). Plotting the available clinopyroxene analyses on the Al-Ti and Al2O3-SiO2 diagrams (Fig. 7b&c) indicates that the mineral is of peralkaline affinity. Although Na2O is more concentrated at cores, tendency to peralkalinity on this diagram appears to be controlled by the depletion of SiO2 in the mineral to-wards rim. Coombs and Wilkinson (1969) reported similar ranges for alkaline and even more undersaturated basic volcanics. Basta and Hafez (1985) reported that the Mohagara volcanics of Wadi Ghadir area contain some clinopyroxene megacrysts of alkaline affinity, whereas the clinopyroxene in the groundmass is of peralkaline composition with similar SiO2 contents to those from Sheikh Salem camptonites.

Figure 4 also suggests an alkaline fractionation trend for the present camptonites similar to that of the alkaline suites, and not that of the tholeiitic Skaergaard suite. Fractionation parameters (e.g. Mg-number) also support this conclusion.

**ii. Tectonic setting:**

The composition of clinopyroxene indicates non-orogenic affinity (Fig. 8) on the diagram of Leterrier et al. (1982). The enrichment of both Ti and Fe is common through the course of fractionation, which is in harmony with the data and concepts of Nisbet and Pearce (1977). These authors also agreed with Barberi et al. (1971) that such enrichment is very characteristic of clinopyroxenes from within-plate alkaline volcanics (WPA). Similar trends of enrichment are known in the clinopyroxenes from other Egyptian al-
Fig. 7

(a) Ti (cations) vs. Na+ Ca (cations)

(b) Al (cations) vs. Ti (cations)

(c) SiO2 wt% vs. Al2O3 wt%
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that the cores crystallize at highest pressure followed by clinopyroxene of the groundmass and finally the rims of megacrysts at the lowest pressure conditions, although they all still plot in the field of high-pressure clinopyroxenes. This conclusion is also in harmony with that given by Embey-Isztin et al. (1993). Such observation indicates that crystallization of clinopyroxenes took place in mantle conditions.

Values of Fe$^{3+}$ and variation of Mg-number in the clinopyroxene from core to rim indicate that the initial oxygen fugacity in the magma was low and increased rapidly in contrast to the tholeiitic magmas (Gibb, 1973). Crystallization of olivine, early intermediate plagioclase and clinopyroxene occurred at low $f^O_2$ and almost no Fe$^{3+}$ enters the clinopyroxene structure (Cameron and Papke, 1981). Consequently, and when the Mg-number is $\geq 65$, Fe$^{3+}$ incorporates Ti to form titanomagnetite. Restriction of this magnetite to the outermost rims of the clinopyroxene, as well as in the groundmass, supports the increase of $f^O_2$ with fractionation. At a given temperature ($\approx 1000-1050^\circ$ C), Ti-substitution in the amphibole structure takes place and hence calcic amphibole (kaersutite) starts to crystallize with the progress of fractionation (Sinton

alkaline to peralkaline volcanics (e.g. Basta and Hafez, 1985).

iii. Geothermobarometry and oxygen fugacity:

Using the geothermometric aspects of clinopyroxenes (Nickel et al., 1985), the studied augite cores reached equilibrium at temperature around 1050°C, augite in the groundmass at a temperature range of 850-1050°C, whereas it amounts 700-800°C for the titanaugeite rims (Fig. 9). Huckenholz (1966) concluded that sometimes the cores of clinopyroxene megacrysts in the alkaline suites represent high-pressure phases. He gave a clinopyroxene composition similar to that of the present Egyptian example and stated that Cr$^{3+}$ plays a significant role since the element is early captured in the mineral core. High-pressure clinopyroxene cores from the alkali olivine basalt of Eifel (Germany) contain 0.3 - 0.6 wt% Cr$_2$O$_3$. The cores of augite from the Sheikh Salem camptonites contain 0.48 - 0.50 wt% Cr$_2$O$_3$. Plot of Al$^{IV}$ vs. Al$^{VI}$ is an excellent pressure parameter in clinopyroxenes (Fig. 10). Values of Al$^{IV}$ and Al$^{VI}$ at cores are almost similar, whereas Al$^{IV}$ dominates at rims indicating drop in pressure. It is believed that at cores forming at higher pressure Al is substituted in the octahedral M1 site instead of tetrahedral sites. It is also evident
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and Byrely, 1980). Based on some experimental data, Helz (1973) agreed such conclusion, and he also correlated the increase of TiO₂ with the raise of $f^{32}$.

**DISCUSSION AND CONCLUSIONS**

The mineralogy of Sheikh Salem camptonites as well as the chemistry of their clinopyroxene indicate that they belong to the alkaline lamprophyses of *Joplin* (1966). The single vogesite dyke belongs to the shoshonitic type. Both types are also recorded in other localities in the Eastern Desert by Basta et al. (1985). The studied samples of camptonite are characterized by the presence of peculiar megacrysts of zoned titanaugite that follows forsteritic olivine (when present) and its associated pyrite in the paragenetic sequence. The sequence of crystallization is then continued with feldspars, titanomagnetite and barkevikite. Different generations of chlorite and carbonate are distinguished on textural basis. Vogesite has orthoclase instead of plagioclase with the complete absence of pyroxenes.

Detailed mineral chemistry of clinopyroxene supports the optically identified concentric zoning of the mineral. Cores are more enriched in Si, Cr and relatively in Mg and Ni, whereas the rims are Ti-rich with maximum Al⁴⁺ substitution for Si. The clinopyroxenes obey the trend of fractionation similar to that of alkaline rocks. This trend is typical of equilibrium crystallization (Smith and Lind-sley, 1971). Al⁴⁺/Al⁶⁺, Mg-number, in addition to Fe- and Ti-enrichment and depletion of Cr in the clinopyroxene from cores to rims suggest early high-pressure crystallization conditions at growing $f^{32}$. The latter appears to increase with fractionation resulting in the formation of titanomagnetite fine cubes in the outer rims of titanaugite as well as in the groundmass. On the other hand, pyrite is only confined to olivine suggesting a higher sulfur activity or reducing conditions at the beginning of crystallization deep in the mantle. Other chemical parameters of clinopyroxene in camptonite (e.g. FeO⁺/MgO ratio: 0.41-0.42 at cores and up to 0.62 at rims) suggest crystallization from primitive melt in deep-seated mantle conditions. The evolved magma of intraplate-type might then have produced the associating vogesite and trachyte. To test the primitive nature of the melt from which pyroxenes have been crystallized, FeO⁺/MgO(liquid) was calculated using the formula FeO⁺/MgO(cpx) over FeO⁺/MgO(liquid) is equal to 0.24 (Church and Riccio, 1977). Data
of Table 1 shows that the difference between cpx and liquid ratios is not very high and FeO'/MgO(cpx) never exceeds 0.6 which is very typical for primitive magmatic melts.

Mg-number of the clinopyroxene in the camptonites also indicates that this variety of lamprophyre represents the most primitive mantle melt. Green and Ringwood (1967) indicated that alkali basalt and undersaturated melts are generated deeper in the mantle than the silica saturated one. The high-pressure nature of the analyzed clinopyroxenes suggests primitive alkaline melt generated at depth ≥ 80 km equivalent to pressure ≥ 25-30 Kbar at temperature of 1200-1300°C in the garnet-peridotite mantle (Green, 1973; Ulmer et al., 1989). Many of the Egyptian lamprophyres are volatile-rich (Mikhail, 1979) suggesting that they might be also from a phlogopite-bearing peridotite patch within the garnet-peridotite mantle. According to Edgar et al. (1980), such magma could be produced from abnormal mineralogy of the patches (olivine + clinopyroxene + phlogopite + ilmenite). Accordingly, the melt is enriched in the constituents of phlogopite such as K and Ti. Nature of the phlogopite-bearing mantle patches in the past was a disputed question, either being residual from crystallization of basaltic melts (Beswick, 1976) or fertile (Menzies, 1978). Almost in all modern research on lamprophyres, it is suggested that the phlogopite-bearing peridotite patches are metasomatized mantle rocks giving a lamprophyre melt by very low degree of partial melting (e.g. Hall, 1982; Szabo et al., 1993; Wyman et al., 1995). More recent studies proved that continental lamprophyres are mostly derived from fossilized subducted oceanic lithosphere that becomes metasomatized and incorporated in the upper mantle (Owada et al., 1992; Thrope et al., 1993). This seems reasonable for the camptonites of Sheikh Salem area since the clinopyroxene cores as well as in the groundmass have the characteristics of volcanic-arc basalt (Fig. 9a). Slight peralkalinity of early clinopyroxene (acmite up to 3.15 mole%) in the Sheikh Salem camptonites, in addition to deficiency in silica expressed by the presence of foids and absence of any crustal xenoliths all together suggest that crustal contamination of the ascending potassic melt with silicic continental materials is either negligible or of very limited effect.

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REFERENCES


Petrogenesis of Some Alkaline...


Menzies, M. (1978): Comment on “Is phlogopite the key?” by A. E.
Surour, A. A.


Petrogenesis of Some Alkaline...


CAPTIONS TO FIGURES

Fig. 1: Geological map of Sheikh Salem area (after El-Ramly, 1972).

Fig. 2: Petrography of Sheikh Salem camptonites:
  a. Rounded olivine (extensively replaced by serpentines) enclosed by augite, crossed-nicols.
  b. Sub-rounded olivine crystal with alteration to chlorite and serpentine along fractures, polarized light.
  c. Euhehedral zoned augite in groundmass rich in sodic plagioclase and titanomagnetite, crossed-nicols.
  d. Zoned augite corroded by components of the groundmass, crossed nicols.
  e. Zoned plagioclase (andesine) phenocryst, crossed-nicols.
  f. Randomly oriented barkevikite (BK) and darker kaersutite (KR) crystals, polarized light.
  g. Euhehedral to sub-hedral titanomagnetite, mostly altered to a mixture of anatase and goethite-limonite. Notice the presence of some silicate inclusions, reflected light.
  h. Interstitial subhedral calcite with iron staining, polarized light.
  i. Hastingsitic hornblende (HHB) replaced by chlorite along cross-cutting cracks in zoned augite megacryst. Notice the presence of two late carbonate generations (CC1&CC2) in fractures, crossed-nicols.
  j. Fan-shaped chlorite replacing augite in the groundmass, crossed-nicols.
  k. Amygdal in fractured zoned augite. Notice the inner calcite zone and the outer chlorite zone, crossed-nicols.

Fig. 3: Composition of clinopyroxenes from the camptonites of Sheikh Salem. Notice that the mineral fractionation trend follows that of alkaline rocks (Charmichael et al., 1974). The tholeiitic trend of the Skaergaard intrusion is given by Wager and Brown (1967).

Fig. 4: Chemical profile in a zoned titaniferous augite crystal, based on electron microprobe data of Table 1. Symbols as in Fig. 3.

Fig. 5: Charge deficiency versus charge excess (after Schwartz et al., 1979).

Fig. 6: Correlation of the Mg-number with the number of cations of some elements in the clinopyroxene structure. Symbols as in Fig. 3.

Fig. 7: Magma-type based on the clinopyroxene composition. Symbols as in Fig. 3:
  a. after Leterrier et al. (1982)
  b. after Kushiro (1960)
  c. after Le Bas (1962)
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Fig. 8 Tectonic setting of the Sheikh Salem camptonites based on the composition of clinopyroxene (after Leterrier et al., 1982). Symbols as in Fig. 3.

Fig. 9: Geothermometric data of the clinopyroxenes (after Nickel et al., 1985). Symbols as in Fig. 3.

Fig. 10: High-pressure nature of clinopyroxenes from Sheikh Salem camptonites. Fields of low- and high-pressure cpx are from Aoki and Kushiro (1968) and Wass (1979). Symbols as in Fig. 3.
النشأة الصخرية لبعض الالامبروفيرات تقنية بمنطقة الشيخ سالم، مصر:

خلال عدده من كميات النيل البئري أثناء المقالات المتسلسلة.

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تتواجد بعض الصخور البركانية القليبية ومنطقة الشيخ سالم بالصحراء الشرقية المصرية على سبيل السدود من الامبروفيرات والترابية تقاطع صخور معقدة القاعدة والتابعة للنهر الكمبري. وقد أعطت الدراسة الحالية أن معظم هذه الالامبروفيرات عبارة عن كميات النيل البئري، وتمت الأبحاث الحالية أساساً على استخدام التركيب الكيميائي لمعدن الامبروفيرات للنيل البئري في دراسة نشأة هذه الصخور.

وعلى أساس نتروجاقي ا전문 أن صخور الكاميونات بمنطقة الشيخ سالم تميز بوجود بوتارات بوفرية كبيرة من معبد الأوريس النباتي الفائق والشامي، وتتميز صخور الكاميونات المثالية أيضاً بوجود بوتارات بوفرية من الأوريسين (إلى شمال) والكائيون القلي (باركيكية) وكرسونتي. وقبل من البلاياسوس كالتور، بينما تتميز الأوريسين بأنها دقيقة للتحذيب وغنية بالكاميونات الصيادي والبيشري، والموقيات النباتية. هذا بالإضافة إلى بعض بورات الكاميونات الأولية للنيل البئري، التي تميزها بوفرة الألماسات، وغنية بالكاميونات.

وقد أظهرت الدراسة الفقيقية النباتي في الكاميونات باستخدام المجسات الإلكترونية (أميبروتوبر وثناء) أن المعبد ذو خصائص فوق قلية ويرجع تكوينه إلى نشاط نباتي كتلة في بداية بداية بين نهريج ونهر النيل. كما أن لعب دور في تطور النباتات الغنية بالكلوروب ونافذة لعطلة عن نشأة هذه الصخور من مياه واسع واسع عميق على المواد الطنية تحت ضغوط كبيرة لكل من مياه للأincerely والثاني أكتي أن والكروين، ويعتقد أن هذا الوثناء قد أحدثه بعض التغيرات لمظامات النباتات (أميبروتوبر حاوي للكلوروب)