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Variation of Ferrous-Ferric Ratios in the Plutonic Rocks of Aswan, Egypt, and Their Significance

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ABSTRACT. The oxidation ratio $((2Fe_2O_3 \times 100)/(2Fe_2O_3 + FeO))$ of the granitic rocks of the Aswan batholith range from 8 to 90 and increase with the increase of differentiation index from older to younger rocks. The batholith was formed by crystallization of magma under buffered conditions with respect to oxygen. The buffer was magnetite, lower levels of oxygen pressure were maintained during the formation of the earlier phases of the batholith, and higher pressures of oxygen prevailed during the generation of the later phases. The earlier phases were probably produced by melting of parental mantle-derived anhydrous material and crustal rocks. The later phases were probably formed entirely by melting crustal materials of sialic composition. The initial Sr^{87}/Sr^{86} ratios of the earlier phases range from 0.7052 to 0.7352 and may support this view.

A small batholith of late Precambrian age is exposed around the town of Aswan in the Nile valley (Fig. 1). It is composed of different phases of rocks that range from quartz-diorite to granite. The Aswan quarries have been worked in these granitic rocks since ancient times (> 5000 years ago). Their products were used by the ancient Egyptians for ornamental portions of temples and other structures such as obelisks, statues and coffins. At present, the coarse-grained granites and granodiorites are widely used for ornamental purposes in Egypt and other countries.

Opinions differ widely on the origin and mode of formation of this batholith. Ball (1907), Barthoux (1922), Hume (1935), Gindy (1974), Meneisy *et al.* (1979) and Soliman (1980) considered the different phases of the batholith as successive products of a differentiating magma of basic to intermediate composition. El-Shazly (1954), Gindy (1954, 1956), Higazy and Wasfy (1955) and Zaghloul and Khafagy (1965) assumed that the earlier phases of the batholith originated metasomatically.

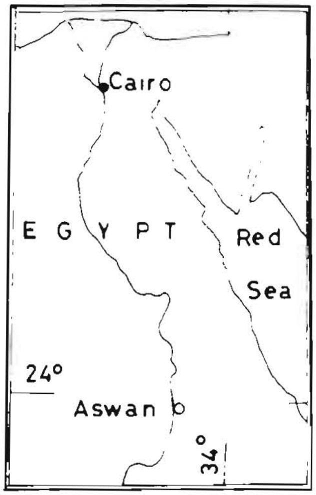

Fig. 1. Location map of Aswan area.

Osborn (1959, 1962) and Dodge (1972) have shown that the oxidation state of iron in the plutonic rocks and consequently the behaviour of oxygen during magmatic processes are indicative of the conditions of generation and evolution of igneous rock series.

Here, published geochemical data are reinterpreted and used to explain the role played by oxygen during the generation and evolution of the Aswan batholith.

Geological Background and Tectonics

The Aswan batholith covers an area of about 35 km^2 and is intruded into schists and gneisses of the Proterozoic basement (Fig. 2). It is a composite body consisting of quartz-diorites, diorites, granodiorites, coarse-grained granites, fine-grained granites and pegmatites. The diorites, quartz-diorites and granodiorites are mixed together with a total absence of distinct contact phenomena, while gradational contacts exist between the granodiorites and the coarse-grained granites. The latter are usually traversed by the fine-grained granites with sharp contacts, whereas all these rocks are cut by pegmatite bodies with obvious contacts. The granodiorites and their associated diorite and quartz-diorite masses and the coarse-grained granites are generally mafic, medium to coarse-grained rocks, locally porphyritic, foliated and show gneissose and rapakivi textures. The fine-grained granites occur in the form of scheets, dykes and elongated masses cutting mainly the coarse-grained granites. They are more felsic, leucocratic, fine-grained, non-porphyritic and locally aplitic. The pegmatites are widely distributed, and usually occur in the form of dyke-like bodies cutting the batholith and its country rocks. They are coarse-grained and simple in composition (non-zoned).

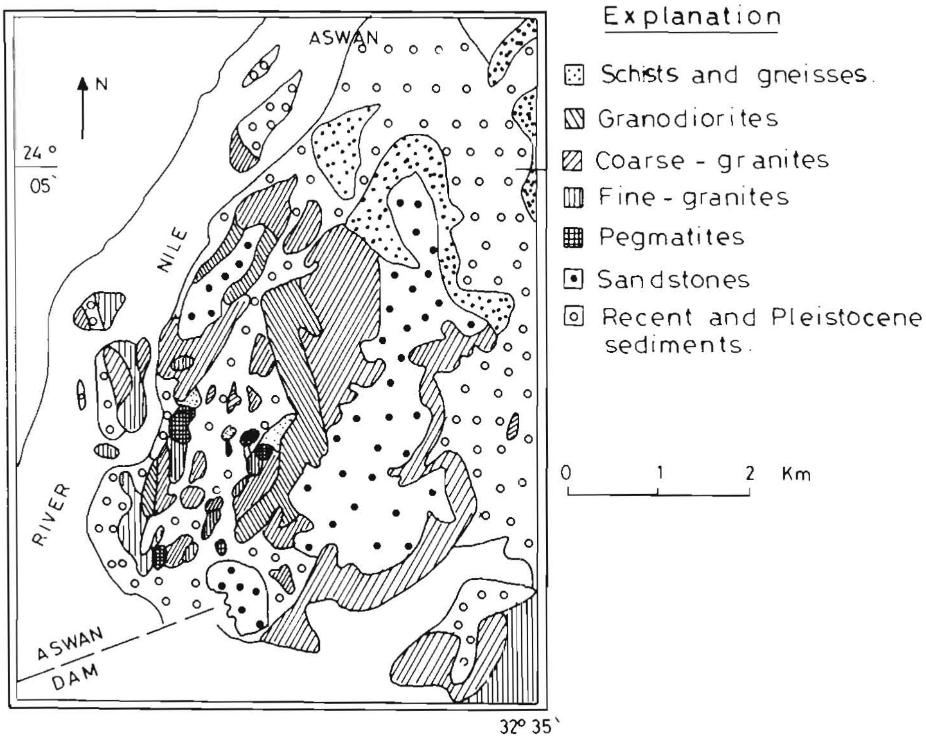

Fig. 2. Geologic map of Aswan area (after Attia 1955).

Quartz, microcline, microcline-perthite, orthoclase, plagioclase, biotite and sometimes hornblende are the main rock-forming minerals of the different phases of the batholith. Apatite, zircon, sphene, allanite and magnetite are common accessory minerals. The plagioclase is occasionally zoned. Graphic, perthitic, rapakivi and mayrmekitic textures are common, especially in the intermediate phases.

The batholith and its country rocks are cut by several faults striking in different directions. The NNW-SSE direction (almost parallel to the Red Sea rift) and ENE-WSW direction (nearly parallel to the gulf of Aqaba rift) are predominant. This diagonal system of faults is common in the basement complex of the Eastern Desert of Egypt (including the Aswan batholith) suggesting that this area has been under the influence of tectonic elements leading to the development of the Red Sea and Gulf of Aqaba.

Iron in the Plutonic Rocks

The chemical analyses of 79 samples from the quartz diorites-diorite-granodiorite association, coarse-grained granites, fine-grained granites and pegmatites of the

Aswan batholith were reported by Soliman (1980), Meneisy *et al.* (1979), Schurmann (1967) and Higazy and Wasfy (1955).

In order to define the variation in the oxidation state of iron, the oxidation ratio ((2 Fe_2O_3 × 100)/(2 Fe_2O_3 + FeO)) of Chinner (1960) is calculated for these analyses. Table 1 shows the range and average values of oxidation ratio, differentiation index (normative quartz + orthoclase + albite; Thornton and Tuttle, 1960) and total iron (as Fe_2O_3) for the Aswan batholith. A rock in which iron is present only as FeO would have a ratio of zero, whereas a rock containing only Fe_2O_3 would have a ratio of 100. A rock containing magnetite as the sole iron-bearing mineral would have an oxidation ratio of 66.6 (Dodge 1972).

Table 1 illustrates the wide range of oxidation ratios within the batholith as a whole, as well as within each rock type. It reflects the different oxidation state of iron, and indicates that the physico-chemical conditions prevailing during the formation and evolution of these rocks were variable. This is in harmony with the idea of the multiphase nature of each rock type within the batholith (*i.e.*, each rock is formed of more than one phase) as reported by Soliman (1980).

When total iron is plotted against the differentiation index (Fig. 3) it correlates inversely with the differentiation index. This is similar to data obtained for calc-alkaline batholiths elsewhere (Dodge 1972, Nockolds and Allen 1953, Bateman *et al.* 1963, Condie 1969). Osborn (1959, 1962) postulated two possible paths for differentiating magmas; a) where oxygen pressure remains at a high level during fractional crystallization, magnetite coprecipitates with the other rockforming minerals and consequently the late differentiates are relatively depleted in iron, and b) where oxygen pressure is much lower, iron goes into the silicates (to form iron-olivine, for example) rather than forming magnetite, consequently the late differentiates will be iron-rich. It is clear here that the Aswan batholith followed the first path (Fig. 3).

Table 1. Mean values and range of oxidation ratios, differentiation indices and total iron of the Aswan batholith.

	Granodiorites (18 samples)	**Coarse-granites (30 samples)**	**Fine-granites (25 samples)**	**Pegmatites (5 samples)**
Oxidation ratio	25.2 (8-49)	28.5 (10-76)	44 (18-83)	75 (63-90)
Differentiation index	55.3 (4.54-72.3)	84.3 (77-94)	86 (83-94.8)	91 (87-98.7)
Fe_2O_3	8.9 (4.8-13.7)	4.1 (2-6.9)	2.4 (1-3.5)	0.8 (0.3-2.3)

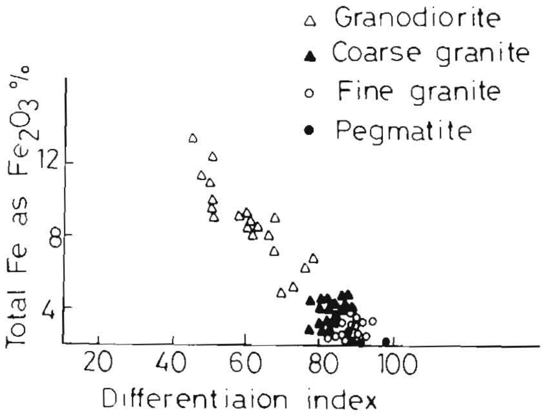

Fig. 3. Total iron relative to differentiation index.

Similarly, when the oxidation ratios are plotted against differentiation indices (Fig. 4), a considerable scatter is observed, nevertheless, it is clear that oxidation ratios increase with differentiation indices. This can be attributed to the continuous decrease of iron and increase of oxygen pressure with differentiation.

Biotite, hornblende and magnetite are the main iron-bearing minerals in the different phases of the Aswan batholith. Iron is also contained in substantial amounts in epidote, chlorite, sphene and allanite (El-Shazly 1954, Higazy and Wasfy 1955, Meneisy *et al.* 1979), but these minerals are too minor to cause any significant variations in the oxidation ratios.

Figure 5 is a plot of the volume percent of opaque minerals (assumed to be all magnetite) to the total volume of the mafic minerals against the oxidation ratios. Again, considerable scatter is obtained but still the plot illustrates the posi-

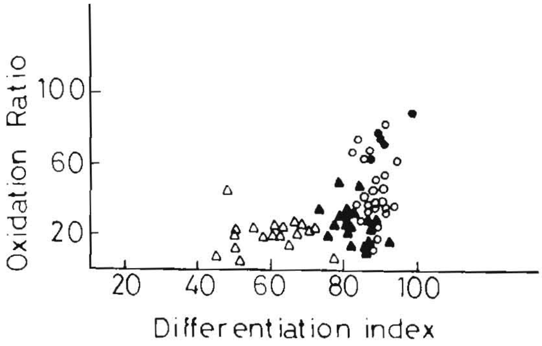

Fig. 4 Oxidation ratio relative to differentiation index. Symbols as in Fig. 3.

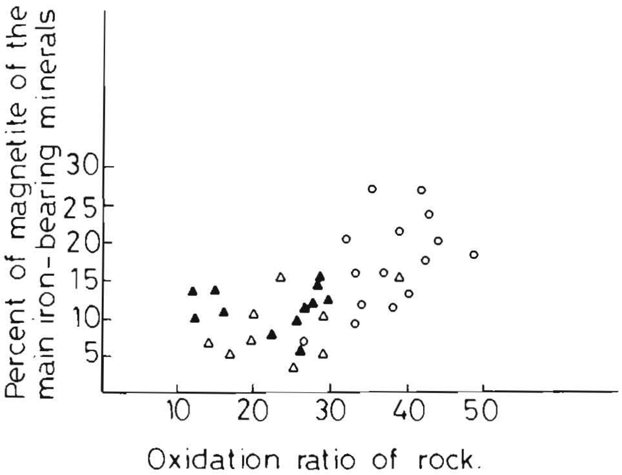

Fig. 5. Magnetite content (volume %) of the main iron-bearing minerals relative to oxidation ratio of the host rock. Symbols as in Fig. 3.

tive correlation between the oxidation ratio of the whole rock and its content of magnetite. The scatter here is probably due to estimation of opaque mineral percents from thin-section modes. These results are in good agreement with those of the Sierra Nevada batholith (Dodge 1972).

Iron in the Biotites

Twenty biotite samples representing the coarse-grained and fine-grained phases of the Aswan batholith as well as the pegmatites were analysed by Ragab *et al.* (1978), and seven additional biotites are analysed. Inspection of their data indicates that the amount of magnesium, ferrous and ferric iron in the biotites is higher in the granites than in the pegmatites. In general, the biotites of the Aswan batholith are compositionally similar to those from calc-alkaline plutonic rocks elsewhere (*e.g.*, Kabesh and Ragab 1974, Deer *et al.* 1965, Dodge *et al.* 1969).

Plot of Fe^{3+}/Fe total in the biotites against the oxidation ratios of the rocks from which they are obtained is presented in Fig. 6. The plot suggests a general increase of ferric to total iron ratios of biotites with the increase in the oxidation ratios up to a point (oxidation ratio = 32) past which little change is observed. This suggests that the composition of biotites is an important factor of variation of the wholerock oxidation ratios at lower values and becomes less important at higher ratios. A similar explanation was suggested by Dodge (1972).

On relating compositions of the Aswan biotites to positions estimated by Wones and Eugster (1965) for biotite solid solutions in the ternary system K Fe_3^{+3}

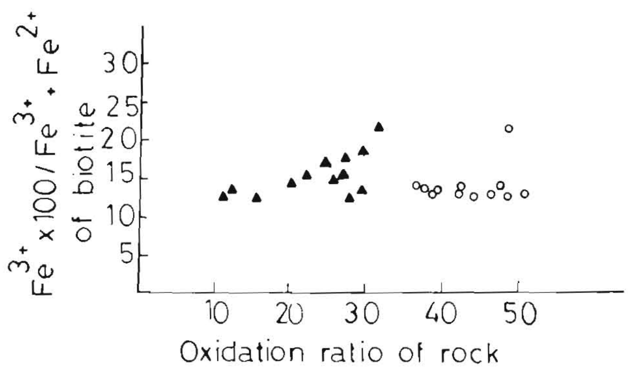

Fig. 6. Ferric total iron ratio of biotite relative to oxidation ratio of host rock. Symbols as in Fig. 3.

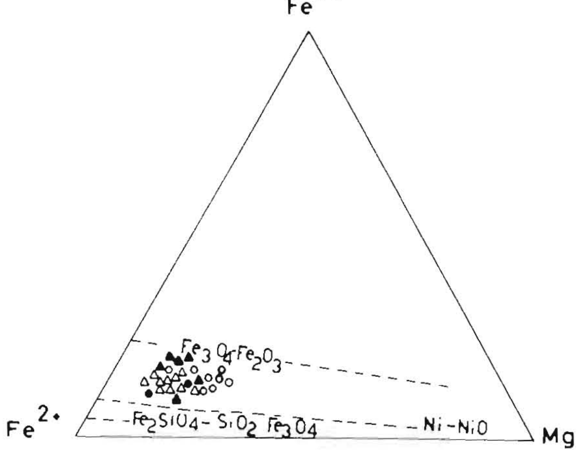

Fig. .7 Relation of Fe^{3+} — Fe^{2+}-Mg contents of biotites in granitic rocks from Aswan. Dashed lines represent compositions of buffered biotites in the ternary system depicted by Wones and Eugster (1965). Symbols as in Fig. 3.

Al Si_3O_{12} H_{-1}-K Fe_3^{+2} Al Si_3O_{10} $(OH)_2$ – KMg_3 Al Si_3O_{10} $(OH)_2$, Fig. 7 is obtained. It suggests that oxygen fugacities in the Aswan magma during biotite crystallization were slightly higher than those defined by the Ni-NiO buffer, and that the magma was buffered with respect to oxygen by oxides coprecipitating with the other rock-forming minerals (magnetite). These buffred crystallization conditions generally prevail in undisturbed (primary) plutonic environment as reported by Dodge and Ross (1971).

Causes of Variation of Oxidation Ratios

The earlier phases of the Aswan batholith are mafic varieties and have the lowest oxidation ratios (Table 1). Dodge (1972) reported that the decrease in the oxidation ratios of some rocks of the Sierra Nevada batholith is due to diminution of water content at the inception of crystallization of the magma, which had formed by melting of sedimentary rocks interfingered with anhydrous mantle-derived materials. The initial Sr^{87}/Sr^{86} ratios of four samples from the earlier phases of the Aswan batholith, including granodiorites and coarse-grained granites range from 0.7052 to 0.7352 (Ragab *et al.* 1978) and reflect compositional differences in the magma source. Kistler & Peterman (1973) believe that rocks in the California batholiths with initial Sr^{87}/Sr^{86} ratios between 0.704 and 0.7060 originated in the upper mantle, whereas those with ratios > 0.7060 were derived by melting of rocks in the lower crust. This suggests that the lower oxidation ratios of the earlier phases of the Aswan batholith reflect diminution of water content at the inception of crystallization of magma formed at deep levels by melting of parental mantle-derived anhydrous materials mixed with crustal rocks. The very coarse-grained nature, porphyritic and rapakivi textures of these rocks (granodiorites and coarse-granites) can tentatively be attributed to these physico-chemical conditions. The later phases of the magma were probably formed at higher levels in the crust by melting of materials of sialic composition.

Conclusion

The results suggest that the Aswan batholith formed by crystallization of magmas under buffered conditions with respect to oxygen. The buffer was magnetite. The earlier magma phases were formed at deep levels in the crust under low oxygen pressures, probably through the melting of crustal rocks interfingered with anhydrous mantle-derived materials. The later phases of the magma were formed at higher levels in the crust under higher oxygen pressures by melting crustal materials of sialic composition. The very coarse-grained nature, porphyritic and rapakivi textures of the earlier phases (granodiorites and coarse-grained granites) and the fine-grained nature of the later phases (fine-grained granites) can tentatively be attributed to these physico-chemical conditions.

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دراسة عن تغير نسبة الحديدوز/ حديديك ودلالتها فى الصخور الجوفية بأسوان - مصر.

مصطفى محمود سليمان

قسم الجيولوجيا - جامعة الزقازيق - مصر

يقدم هذا البحث دراسة عن تغير نسبة الحديدوز/حديديك والتى تعرف بنسبة الأكسدة فى مختلف الصخور الجوفية بكتلة أسوان العميقة. وقد وجد أن الصخور الأكثر مافيّة والأقدم عمراً تحتوى على نسبة أكسدة منخفضة بالمقارنة بالصخور الأكثر حامضية والأحدث عمراً. وقد عزى انخفاض نسبة الأكسدة فى الصخور القديمة إلى تكون تلك الصخور فى أعماق بعيدة نتيجة انصهار جزئى لصخور فقيرة فى الماء ومشتقة من الستارة الأرضية العليا مع بعض صخور القشرة الأرضية.

كما عزى ارتفاع نسبة الأكسدة فى الصخور الفاتحة اللون والأحدث عمراً إلى تكون تلك الصخور فى أعماق متوسطة نتيجة انصهار جزئى لمواد من القشرة الأرضية.