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RUTILE-SILICATE INTERGROWTHS FROM THE KIMBERLITE FORMATIONS AT MBUJI-MAYI (BAKWANGA, ZAIRE)

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ABSTRACT. - Rutile-silicate intergrowths as well as discrete rutile nodules have been found in the kimberlite of Mbuji-Mayi. The textures are described and compared to those of pyroxene-ilmenite intergrowths. The chromium, niobium and zirconium content of the rutile was determined. The problem of the origin of these intergrowths is discussed.

INTRODUCTION.

The kimberlites of Mbuji-Mayi differ from other kimberlites in many respects : their diamond content is the highest presently known; the individual diamonds exhibit a large variation of types and indicate a complicated crystallization history (POLINARD, 1931).

Rutile, which is rarely mentioned in kimberlites from other locations, occurs here as discrete crystals up to 30 mm, or as rutile-silicate xenoliths. Similar nodules have to our knowledge never been described before elsewhere.

The textural resemblance of these rutile-silicate nodules with the pyroxene-ilmenite intergrowths, described in other kimberlites, is remarkable.

The purpose of this paper is to establish the primary nature of the rutile and to trace the origin of the silicate phase.

PETROGRAPHY.

The rutile-silicate intergrowths occur as nodules, up to 45 mm, of elliptical to subspherical shape. The elliptical nodules are generally composed of slender rutile columns with a parallel or subparallel arrangement. In the subspherical nodules the rutile columns are more randomly oriented. One large nodule consists of

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two parts, each composed of a group of parallel rutile crystals, that are oriented towards each other under an angle approximating that of rutile elbow twins (photo 1).

Cross sections of the nodules invariably exhibit a graphic texture consisting of rutile (60 to 70 %) intergrown with a white, very fine grained material (photo 2).

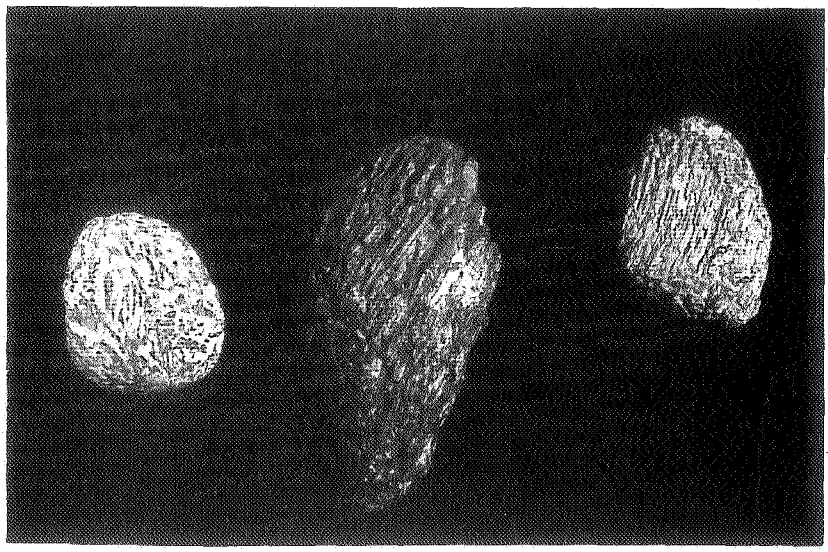

Photo 1 : real size.
Three types of rutile-silicate nodules.
Dark columns are rutile, white areas are silicate phases.

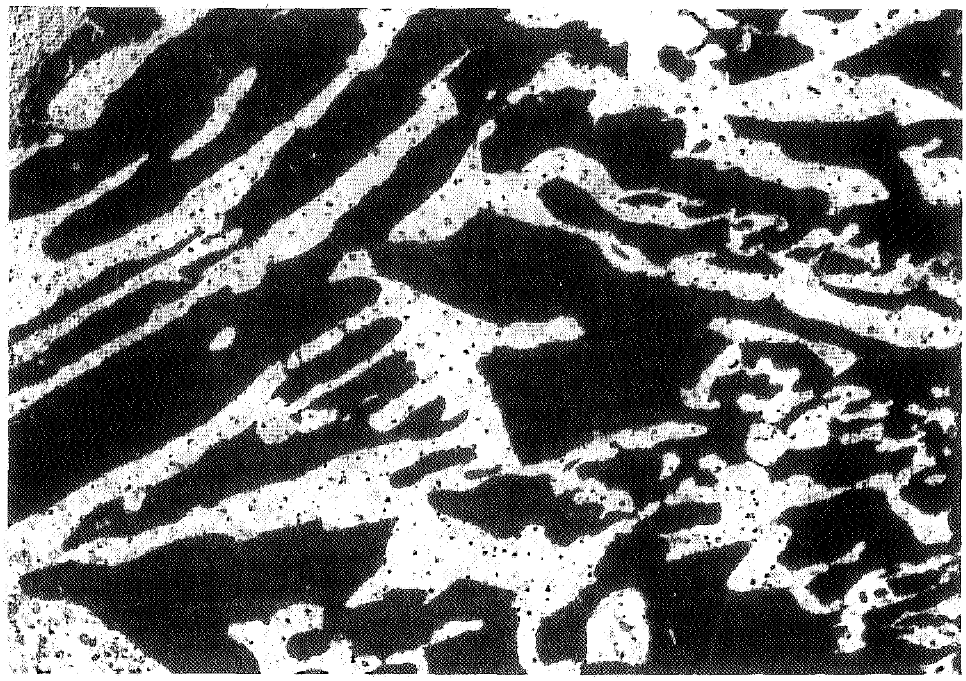

Photo 2 : 15 x
Graphic texture of rutile-silicate intergrowths.

Under the microscope the rutile, which exhibits strong yellow brown internal reflections, occurs as an aggregate of small rounded grains. Euhedral cross sections of the rutile columns are rare, as are twin lamellae. Small pits, oriented along two perpendicular directions in each rutile crystal probably represent cleavage traces.

Fresh looking ilmenite inclusions occur as spots located at the cleavage intersections, or are oriented parallel to them. Ilmenite may also show up as narrow discontinuous rims around rutile. The total ilmenite content never exceeds 5 volume percent.

In two nodules we observed a few small spinel crystals occuring either at the borders of rutile grains or growing across the oriented ilmenite inclusions.

Narrow fractures cutting both the rutile columns and the silicate matrix are filled with late quartz. Beside some larger grains of quartz, the silicates consist of an intricate network of fine grained quartz enclosing phyllosilicates, which are difficult to identify under the microscope. By means of X-ray diffraction they were identified as antigorite, palygorskite- attapulgite and sepiolite.

TRACE ELEMENT CHEMISTRY.

We analysed the rutile of seven nodules and the ilmenite of several others by means of X-ray fluorescence spectrometry, according to the "spiking" technique. The results are presented in Tables 1 and 2. It was impossible to eliminate the ilmenite inclusions in the rutile from the rutile-silicate intergrowths, which has to be taken into account when evaluating the analyses.

TABLE 1 : Results of trace element analyses for rutile. Samples 1-6 represent rutile separated from rutile-silicate intergrowths. Sample 7 was made on a single rutile crystal devoid of inclusions under the microscope.

Nr	sample code	% wt Cr_2O_3	% wt Nb_2O_5	% wt ZrO_2
1	rutile A	4.32	1.06	0.11
2	rutile VI	4.13	1.27	0.04
3	rutile VII	2.00	0.30	0.10
4	rutile VIII	4.04	1.00	0.04
5	rutile X	4.24	1.12	0.06
6	rutile XI	3.98	1.22	0.05
7	discrete rutile	0.08	0.41	0.06

Since similar rutile-silicate nodules have to our knowledge not been mentioned before, a comparison can not be made. But there exist a few data on the Cr_2O_3 content of rutiles from other occurrences. They were in large part summarized by SMITH and DAWSON (1975). The fairly constant Cr_2O_3 content of the rutile intergrowths (average 4 wt %) is much higher than the Cr_2O_3 values given for rutiles from eclogites (normally $<$ 0.3 wt %), while that for rutiles from lherzolites can vary between 1 and 7 wt % Cr_2O_3. The ZrO_2 content of Mbuji-Mayi rutiles resembles that of rutiles in eclogites from New Guinea, Tasmania, California (WHITE and TAYLOR, 1973), and from the Müncherberger Gneisgebietes (KNAUER et al., 1970), but the Nb_2O_5 content of Mbuji-Mayi rutiles is four to five times higher. The Nb_2O_5 content of the rutile intergrowths is comparable to that of perovskites ($CaTiO_3$) from South African kimberlites (0.59 to 1.45 % wt Nb_2O_5) (MITCHELL, 1972) and from Lesotho (0.45 to 0.91 % wt Nb_2O_5) (BOCTOR and BOYD, 1978). Perovskite was not found at Mbuji-

Mayi (C. FIEREMANS, personal communication).

Ilmenite-silicate nodules with textures resembling those of the rutile-silicate intergrowths have often been described from other kimberlite deposits. Their trace-element compositions are presented in Table 2.

TABLE 2 : Results of trace element analyses for ilmenite. The results from Mbuji-Mayi were obtained on a single crystal (first value) and on a composite sample of 5 single grains (second value).

Locality	type	N	% wt Cr_2O_3	% wt Nb_2O_5	% wt ZrO_2
Mbuji-Mayi	discrete	2	2.9-2.5	0.26-0.24	0.05-0.04
	discrete (4)	3	3.0-3.9-4.1	-	-
Lesotho	discrete (1)	20	0.11-1.07	0.14-0.37	0.11-0.28
	discrete (2)	2	0.13-0.53	-	-
	lamellar (3)	1	0.14	-	-
South Africa	discrete (1)	10	0.00-0.88	0.07-0.22	0.06-0.13
	lamellar (1)	9	0.05-0.10	-	-
	lamellar (2)	1	0.38	-	-
	lamellar (3)	1	0.13	-	-

N = number of samples analysed; (1) MITCHELL, 1977; (2) BOYD and NIXON, 1973; (3) BOYD and NIXON, 1975; (4) OKITAUDJI, 1971; C. FIEREMANS, 1966; C. MEYER de STADELHOFEN, 1963.

The Cr_2O_3 content of rutile from intergrowths is much higher than that of lamellar ilmenite. Discrete ilmenite nodules from Mbuji-Mayi display a much higher Cr_2O_3 content than similar ilmenites from other kimberlites; the Nb_2O_5 and ZrO_2 contents are more or less comparable. The discrete rutile crystal from Mbuji-Mayi compared to discrete ilmenite nodules is low in Cr_2O_3, relatively high in Nb_2O_5 and rather low in ZrO_2.

DISCUSSION.

The textural resemblance of the rutile-silicate nodules with the pyroxene-ilmenite intergrowths, and the trace element data are considered while discussing the nature of the rutile.

RAMDOHR (1969) writes that an exsolution out of rutile seldom occurs, and the almost complete absence of twin lamellar in rutile would point to a secondary origin after ilmenite.

We consider however this rutile as a primary phase, because of the complete lack of iron oxides in these intergrowths, the euhedral form of rutile in some cross sections, the relatively constant size of the oriented ilmenite (and spinel) inclusions, and the high Nb_2O_5 content of the rutile.

Beside quartz, the silicate component of the intergrowths invariably consists of Mg-rich alteration phases : antigorite $Mg_6Si_4O_{10}(OH)_8$, palygorskite-attapulgite

$(Mg, Al)_5(Si, Al)_8O_{20}(OH)_2.8aq.$, and sepiolite $Mg_2Si_3O_8.2H_2O$.

Kulbicki (1959), studying high temperature phases in sepiolite, attapulgite and saponite, demonstrated that these minerals are easily transformed to enstatite above 800°C, because of a close relationship between their crystal structures. Antigorite replacing pyroxene was described from "pyroxene"-ilmenite xenoliths from the Stockdale Pipe, Kansas (Mc CALLISTER et al, 1975). BOYD and NIXON (1973), and MITCHELL (1977) describe fresh enstatite-ilmenite nodules in kimberlites.

We think enstatite is the most obvious, primari mineral of the silicate phase and conclude to the original nature of the nodules as a rutile-enstatite rock. Opposed to the pyroxene-ilmenite intergrowths (HAGGERTY, 1977) the modal proportion of rutile to silicate is always greater than 1.

Most of what is known about the genesis of rutile in kimberlites is based on its occurrence in association with perovskite, picroilmenite or armalcolite, where rutile occurs in reaction rims, in intergrowths, as an exsolution phase or as a decomposition product.

ELTHON and RIDLEY (1977) also describe rutile as inclusions in kimberlitic phlogopites. The different occurrences must be the reflection of the multiplicity and the fluctuations of the physicochemical conditions, prevailing during the crystallization of the different phases in the kimberlitic magma.

Since the nodules we dealt with here merely consist of intergrowths of rutile with an altered silicate phase, our considerations on the genesis of these rocks will be based on current theories explaining the formation of pyroxene- ilmenite nodules with similar textures.

GURNEY et al (1973) and WYATT et al (1975) considered the pyroxene-ilmenite intergrowths to be products of crystallization from a kimberlitic magma with eutectic composition, while others did not exclude other possibilities, such as eutectoid transformation, discontinuous precipitation (Mc CALLISTER et al, 1975), simultaneous crystallization depending upon epitaxial kinetic factors (MITCHELL, 1977) or replacement and exsolution (HAGGERTY et al, 1977).

The rutile-enstatite intergrowths are not considered to be the result of exsolution, because of the high TiO_2 content (60 to 70 % rutile) of these nodules. Pyroxenes in equilibrium with rutile or ilmenite contain at most 1.5 wt % TiO_2 in solid solution; this amount decreases with increasing pressure (AKELLA and BOYD, 1972). Since it has been experimentally proved (WYATT, 1977) that pyroxene-ilmenite intergrowths are produced by cooling of Ti-rich liquids, rather than by exsolution from earlier high pressure phases, we like to propose a similar genesis for the rutile-pyroxene nodules. The Fe content of the liquid at that time had to be low, to make rutile the stable Ti-rich phase. WYATT (1977) defined also experimentally that Cr-bearing rutile is a stable phase in the Cr-rich "picroilmenite-clinopyroxene-Cr_2O_3" system at high temperature and pressure, whereas Cr-ilmenite would be a stable phase in the Cr_2O_3-poor system.

While some authors (BOYD and NIXON, 1973; 1975) consider the pyroxene-ilmenite nodules as "xenocrysts" originating from melt in the low velocity zone of the mantle, that have been sampled later by the kimberlitic magma, others (GURNEY et al, 1973; WYATT et al, 1975) regard them as early products from the kimberlitic magma itself.

A cogenetic origin for discrete ilmenite and pyroxene-ilmenite intergrowths was proposed by HAGGERTY et al (1977). We consider by analogy that the discrete rutile crystals and the rutile-pyroxene nodules both crystallized from the same Ti-rich magma, from which ultimately the kimberlite also derived, for the following reasons :

- the discrete rutile crystals were formed in this magma and later on, the rutile-pyroxene nodules crystallized from a Ti-depleted magmatic liquid with eutectic composition;
- the Cr, Nb and Zr content of this magma is supposed to have been high in view of the high values for these elements in the rutile (see Table 1). It is assumed that these abnormally high values resulted from partial melting of upper mantle material, since no known rock is by itself rich enough in all these elements.

A possible source for the Cr, Nb and Zr may be phlogopite, since phlogopite has been found in xenoliths of unaltered garnet-peridotite blocks ejected from the Lashaine volcano in northern Tanzania (DAWSON, 1971). This primary phlogopite contains up to 9.13 wt % TiO_2, 0.71 wt % Cr_2O_3 and only 3.57 wt % FeO (Nb was not analysed) (REID et al, 1975).

We like to propose that the rutile and rutile-pyroxene nodules originated from partial melting of a phlogopite-garnet peridotite. Rutile and enstatite are stable phases at the high temperature and pressure conditions prevailing during kimberlite genesis; the Fe content of this magma was low at that time, explaining thus also the absence of ilmenite.

The discrete MgO-rich ilmenite nodules (11.3 to 12.4 wt % MgO) (FIEREMANS C.; MEYER de STADELHOFEN; OKITAUDJI) present at Mbuji-Mayi (see Table 2) have been formed from a similar Ti-rich liquid richer in or enriched in iron.

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REFERENCES.

AKELLA, J. and BOYD, F. R. (1972) - Partitioning of Ti and Al between pyroxenes, garnets, and oxides. *Carnegie Inst. Wash. Yearb. 71, p. 378-384.*

BOCTOR, N. Z. and BOYD, F. R. (1978) - Oxide minerals in Liqhobong Kimberlite, Lesotho. *Geophys. Lab. Ann. Rep. 1977-78, p. 870-876.*

BOYD, F. R. and NIXON, P. H. (1973) - Origin of the ilmenite-silicate nodules in kimberlites from Lesotho and South Africa. *Lesotho Kimberlites, ed. P. H. Nixon, p. 254-268.*

BOYD, F. R. and NIXON, P. H. (1975) - Origins of the ultramafic nodules from some kimberlites of Northern Lesotho and the monastery Mine, South Africa. *Physics and Chemistry of the Earth, vol. 9, pp. 431-454.*

DAWSON, J. B. (1971) - Advances in Kimberlite Geology. *Earth Sci. Reviews, 7, p. 187-214.*

ELTHON Don and RIDLEY, W. Y. (1977) - Mineral chemistry of the Premier Mine Kimberlite. *2nd Int. Kimb. Conf., extended abstracts.*

FIEREMANS, C. (1966) - Contribution à l'étude pétrographique de la brèche kimberlitique de Bakwanga. *Mémoires de l'Inst. Géol. de l'Université de Louvain, XXIV, fasc. 1, p. 33.*

GURNEY, J. J., FESQ, H. W. and KABLE, E. J. D. (1973) - Clinopyroxene-ilmenite intergrowths from Lesotho kimberlites : a reappraisal. *Lesotho Kimberlites, p. 238-253, ed. Nixon P. H., Lesotho Nat. Develop.Corp.*

HAGGERTY, S. E. (1975) - The chemistry and genesis of opaque minerals in kimberlites. *Phys. and Chem. of the Earth, vol. 9, p. 295-307.*

HAGGERTY, S. E., HARDIE III R. B. and Mc MAHON, B. M. (1977) - The mineral chemistry of ilmenite nodule associations from the Monastery diatreme. *Extended Abstracts, 2nd Int. Kimb. Conf., Santa Fe.*

KNAUER, E. and MATTHES, S. (1970) - Die Eklogitvorkommen des kristallinen Grundgebirges in NE Bayern. V. Die opakminerale und Rutil der Eklogite und Eklogit-Amphibolite des Müncherberger Gneisgebietes. *Neues Jahrb. Min. Abhdl. 114, p. 1-17.*

KULBICKI, G. (1959) - High temperature Phases in Sepiolite, Attapulgite and Saponite. *Am. Mineral., vol.44, p. 752-764.*

Mc. CALLISTER, R. H., MEYER, H.O.A. and BROOKINS, D. G. (1975) - Pyroxene-ilmenite xenoliths from the Stockdale pipe, Kansas : chemistry, crystallography and origin. *Phys. and Chem. Earth, vol. 9, p. 287-293.*

MEYER de STADELHOFEN, C. (1963) - Les Brèches kimberlitiques du territoire de Bakwanga (Congo). *Archives des Sciences, Soc. Phys. et Hist. Nat. de Genève, vol. 16, fasc. 1, pp. 87-132.*

MITCHELL, R. H. (1972) - Composition of perovskite in kimberlite. *Am. Mineral., 57, p. 1748-1753.*

MITCHELL, R. H. (1973) - Magnesian ilmenite and its role in kimberlite Petrogenesis. *Journal of Geology, vol. 81, p. 301-311.*

MITCHELL, R. H. (1977) - Geochemistry of Mg-ilmenites from kimberlites in South Africa and Lesotho. *Lithos, 10, p. 29-37.*

OKITAUDJI, R. (1971) - Contribution à l'étude des minéraux opaques de la brèche kimberlitique diamantifère de Mbuji-Mayi (Bakwanga). *Thesis U.L.B.*

POLINARD (1931) - Les déformations extérieures, les propriétés internes et les modalités de la cristallisation des diamants de la Bushimaie. *Bull. Ac. Royale de Belg., 5e série, T. 17, n°2, pp. 137-162.*

RAMDOHR, P. (1969) - The Ore minerals and their Intergrowths. *Pergamon Press.*

REID, A. M., DONALDSON, C. H., BROWN, R. W., RIDLEY, W. I. and DAWSON, J. B. (1975) - Mineral chemistry of peridotite xenoliths from the Lashaine volcano, Tanzania. *Physics and Chemistry of the Earth, vol. 9, p. 525-543.*

SMITH, J. V. and DAWSON, J. B. (1975) - Chemistry of Ti-poor spinels, ilmenites and rutiles form peridotite and eclogite xenoliths. *Physics and Chemistry of the Earth, vol. 9, pp. 309-322.*

WHITE, A. J. R. and TAYLOR, S. R. (1973) - Some trace elements in rutile from eclogites and their implications. *First Intern. Kimb. Confer. Rep., p. 309-311.*

WYATT, B., Mc. CALLISTER, R. H., BOYD, F. R., OHASI, Y. (1975) - An experimentally produced clinopyroxene-ilmenite intergrowth. *Carnegie Inst. Wash. Yearbook 74, p. 536-539.*

WYATT, B. (1977) - The melting and crystallization behaviour of a natural clinopyroxene-ilmenite intergrowth. *Contrib. Min. Petrol., 61, p. 1-9.*

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