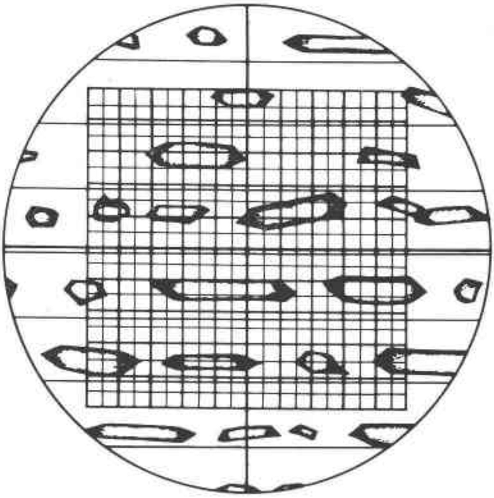

FIG. 2. Orthoscopic view of aligned minerals ready for measurement.

alcohols, benzene, acetone, or carbon tetrachloride for cleaning because they will soften the plexiglass surface.

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CALCIFEROUS BROWN AMPHIBOLE IN ALKALIC GABBRO OF KORAPUT, ORISSA, INDIA

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INTRODUCTION

Mineralogical interest associated with brown amphibole is out of all proportion to its frequency of occurrence. The limited occurrence of such amphiboles obviously reflects restricted conditions for their development. The recent significant contribution by Wilkinson (1961) furnishes the long needed comparative study of the calciferous brown amphiboles and offers a quantitative basis for distinguishing barkevikite from kaersutite—the latter was so long vaguely defined as a titaniferous brown amphibole.

OCCURRENCE

Brown amphibole occurs as the dominant constituent in an alkali gabbro sheet at Koraput, Orissa. The other significant coexisting mafic silicate is a titaniferous salite—a characteristic pyroxene of alkali olivine-basaltic magma (Wilkinson 1956). The constituent plagioclase in the rock is intermediate andesine commonly clouded with minute inclusions.

The accessory opaque oxides are chiefly ilmenite and subordinate magnetite, the latter showing exsolved ilmenite bands along octahedral planes. Absence of ulvospinel and presence of some modal hematite indicate a comparatively high oxygen pressure, possibly consequent on high water content of the magma. The chemical composition of the gabbro from Koraput, containing the brown amphibole (Table I) gives it an alkalic stamp in the development of nepheline in the norm (Poldervaart 1962). The detailed petrology and mineralogy of the alkali-gabbro will be described elsewhere.

INTER-RELATION BETWEEN KAERSUTITE-BARKEVIKITE AND THE INVESTIGATED AMPHIBOLE

Wilkinson (1961) demonstrated a pertinent distinction between kaersutite and barkevikite on the basis of magnesium content in the structure, the magnesium atoms in the formula of kaersutite being greater than two. Actually there is a gap in the values of magnesium atoms in the formulae of barkevikites and kaersutites, described by Wilkinson

TABLE I. ANALYSES OF BROWN AMPHIBOLE AND HOST ROCK, KORAPUT, INDIA

1		2				3	4	
SiO_2	41.48	Ca	177			45.44	Or	11.67
Al_2O_3	10.05	Na	86	W	3.01	14.17	Ab	23.05
Fe_2O_3	4.05	K	38			3.64	An	15.01
FeO	14.93	Fe_2	191			11.55	Ne	5.68
MnO	0.16	Mg	198	X	3.91	—	Di	14.25
MgO	8.58	Mn	2			5.70	Ol	15.92
CaO	10.78	Al^6	18			9.10	Mt	5.33
Na_2O	2.89	Ti_3	45	Y	1.10	3.94	Il	4.25
K_2O	1.94	Fe	47			1.94	Ap	4.70
H_2O	1.35	Si	637			0.23	H_2O	0.23
				Z	8.00			
TiO_2	3.92	Al^4	163			2.23		
P_2O_5	—			H	1.38	1·97		
Total	100.14					99.91		100.09

$\alpha=1.672$

$\gamma=1.705$

$\gamma-\alpha=0.033$

$Z\wedge C=12°$

$2V_x=76°$

X = brown yellow

Y = deep brown

Z = deep brown

1. Brown amphibole from Koraput. Analyst, W. H. Herdsman.
2. Atomic ratio of 1 for (O-OH) = 2400.
3. Alkali-gabbro from Koraput containing the brown amphibole. Analyst S. K. Mitra (P) Ltd.
4. Norm of 3 (note nepheline in norm).

(1961). (Note that No. 2 in Table 4 is a kaersutite rather than a barkevikite as stated by Wilkinson, 1961, p. 347). It is, however expected that there may be a gradation in iron-magnesium diadochic replacement in such sodic-calcic brown amphiboles, analogous to compositional variation: magnesiohastingsite→ferrohastingsite, suggested by Billings (1928). It is quite likely that brown amphiboles showing gradations in this fundamental chemical character and consequent optical properteis (Billings 1928) could be developed in igneous rocks under favorable conditions. The limiting number of magnesium atoms in the formula, separating barkevikite from kaersutite could be arbitrarily fixed at two.

The investigated amphibole from Koraput is a calciferous type (Miyashiro 1957). Strictly on the basis of magnesium atom in the formula (Table II) the present amphibole falls within the barkevikite range but approaches very closely that of kaersutite. Virtually on the kaersutite-barkevikite border, the present amphibole may be considered as a transitional phase between the two. A comparative analysis of the available chemical and optical characters of barkevikite and kaersutite (Wilkinson, 1961) along with those for the investigated amphibole may be significant in this respect (Table II). The scheme of absorption is comparable in all the three types and is not included in Table II. The refringence of the investigated amphibole is within the range for both kaersutite and barkevikite whereas the birefringence is higher than in barkevikite. The optic axial angle in the present amphibole is lower than in kaersutite and is consistent with its magnesia content (Billings 1928) in comparison to average kaersutite. The FeO/MgO proportion is intermediate between that in kaersutite and barkevikite. The value of the W group attains a saturation value as in barkevikite although the sodium content is comparable to that of average kaersutite. Table II suggests that there is a transition in the important chemical and optical characters of kaersutite and barkevikite, and the present amphibole is a link between the two species in many respects.

DISCUSSION

On the basis of FeO/MgO ratio, kaersutite is expected to form at an earlier stage of crystallization and at higher temperature than barkevikite. Although the titania content is not a valid criterion for distinguishing the two amphiboles, the frequent high titania content of kaersutite (Wilkinson 1961, Table 3) may be related to its higher temperature of crystallization often in volcanic association or in ultramafic rocks (see Wilkinson 1961 Table 3 for host rocks of kaersutites). The other important factor that strongly influences the entry of Ti in the structure of amphiboles is low silica activity or high alumina activity

TABLE II. COMPARISON OF KAERSUTITE, BARKEVIKITE AND THE INVESTIGATED AMPHIBOLE

	Kaersutite[1]	Barkevikite[1]	Amphibole in alkali gabbro of Koraput
range, γ average, γ	1.701–1.760 1.707	1.701–1.710 1.707	1.702–1.706 1.705
range, γ-α average, γ-α	0.029–0.068 0.038	0.014–0.021 0.017	0.019–0.033 0.028
2Vx average	80°		75°
$Z\wedge C$ (average)	7°	15°	12°
FeO/MgO Mol. Proportion (average)	0.37	1.60	0.97
Billings' classification	Magnesio hastingsite	Femaghastingsite	Femaghastingsite
FeO/MgO (range)	0.2–0.6	0.7–5.0	—
Mg atom in formula (range)	2.4–2.8	0.60–1.4	1.98
(Ca+Na+K) in formula (range)	2.7–2.9	3.0–3.1	3.02
Na atom in formula (average)	0.8	1.24	0.8

[1] Data from Wilkinson (1961).

(Verhoogen 1961). Consequently such amphiboles develop in rocks showing a wide range in bulk composition but commonly characteristically undersaturated in silica. The Ti content in the barkevikite-kaersutite group of amphiboles may vary over a wide range, depending on the degree of low silica activity or high alumina activity and temperature of crystallization.

The saturation of the W group in the formula (as in the present amphibole) is considered to be characteristic of barkevikite (Wilkinson 1961). This value depends on the entry of Ca and alkali metals into the amphibole structure. At later stages of crystallization the alkali concentration increases in the magma, although lime concentration is expected to fall, according to the normal reaction principle. However, increased water pressure inhibits crystallization of plagioclase (Ringwood 1959) and thus can cause a concentration of Ca in the basic alkali magma and its derivatives, as observed at Koraput. All these accumulating elements, namely Ca, Na and K, enrich the crystallizing amphibole, which then approaches barkevikite. It is thus expected that the value of the W group may show a variation in these sodic-calcic amphiboles, depending on the stage of crystallization and the water content of the magma. Barkevikite is expected to develop under more hydrous conditions, in a plutonic association (see Wilkinson, 1961, Table 4, for mode of occurrence of barkevikite. One in essexite, *i.e.* No. 2, is possibly a kaersutite). This is consistent with its crystallization later, than kaersutite. The common characteristics of coexisting pyroxene and amphiboles in alkali basaltic magma controlled by the same physico-chemical conditions will be described elsewhere.

CONCLUSION

From observational data there appears to be a remarkable gradation in optical and chemical properties in the two species of brown amphiboles, barkevikite and kaersutite. The brown amphibole in alkali gabbro of Koraput, is intermediate between the two in many respects. The physico-chemical conditions—the temperature of crystallization, degree of silica and alumina activity and water pressure are some of the important factors that determine the exact phase that will crystallize in the kaersutite-barkevikite series.

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REFERENCES

BILLINGS, M. P. (1928) The chemistry, opitics and genesis of the hastingsite group of amphiboles. *Am. Mineral.* **13,** 287–296.

MIYASHIRO, A. (1957) The chemistry, optics and genesis of the alkali amphiboles. *Jour. Fac. Sic. Tokyo Univ. II*, Sec II, 57–83.

POLDERVAART, A. (1962) Aspects of basalt petrology. *Jour. Geol. Soc. Ind.* **3,** 1–14.

RINGWOOD, A. E. (1959) Genesis of basalt trachyte association. *Beitr. Mineral. Petrogr.* **6,** 346–351.

VERHOOGEN, J. (1962) Distribution of titanium between silicates and oxides in igneous rocks. *Am. Jour. Sci.* **260,** 211–220.

WILKINSON, J. F. C. (1956) Clinopyroxenes of alkali olivine-basalt magma. *Am. Mineral.* 41, 724–743.

——— (1961) Some aspects of calciferous amphiboles, oxyhornblende, kaersutite and barkevikite. *Am. Mineral.* **46,** 340–354.