

Amphiboles in alkaline rocks of Koraput, Orissa

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Summary. The chemistry and optics of the amphiboles in alkaline rocks of Koraput, Orissa, India, are described. The variation in chemical characters of the amphiboles is consistent with the variation in rock composition. With progressive fractionation the mineral shows increasing replacement of magnesium by iron while Ca is not affected by such replacement. The trend in variation is comparable to that in pyroxenes of alkaline basaltic magmas. The entry of Ti into the structure of amphibole appears to be favoured by alumina activity and concentration of Ti in the magma. Optical characters vary with the iron : magnesium ratio and titanium content of the mineral. The water content of the magma had an important influence on the composition of the mafic minerals in the rocks.

AMPHIBOLE is developed in variable amount in different members of the igneous rock series of Koraput, Orissa. The oldest member of the series is a meta-gabbro, in which an amphibole comparable to common hornblende, though with high titania, is developed in subordinate amount. The present note, however, embraces the observations on amphiboles occurring in genetically related more alkaline members of the series, namely alkali-gabbro, calc-alkali-syenite, and nepheline-syenite. The alkali-gabbro, rimmed by the syenites, form an inclined lens of composite intrusion within the high-grade parametamorphics.

Petrographic summary. The alkali-gabbro is a coarse-grained, heavy melanocratic rock. The mafic silicates in order of abundance are: brown amphibole, titanian sahlite, and titaniferous reddish-brown biotite. Olivine is only occasionally developed in the assemblages towards the base of the body. Olivine, however, lacks any noticeable reaction relation with pyroxene. Amphibole readily replaces pyroxene and the latter is almost absent towards the top of the gabbro lens. Plagioclase (andesine) occurs with inequigranular habit, the coarse, subtabular grains with complex twinning coexist with smaller, anhedral polygonal grains. There is, however, no notable compositional difference in the two types of plagioclase. The mineral is frequently clouded by bright green rods oriented along (010) plane of the host. Apatite is a common accessory; of the opaque oxides, ilmenite dominates over ilmeno-

magnetite. The rock has been named alkali-gabbro on a chemical basis as it develops normative nepheline (Yoder and Tilley, 1962, p. 352) in the composition.

The calc-alkali-syenite is a medium-grained mesocratic rock with faint to well-developed foliation defined by the mafic constituents. The dominant constituent is an alkali feldspar (Or_{50-56}) with limited unmixing. The mineral occasionally develops coarse tabular phenocrysts set in an equigranular mosaic of micropertthite and plagioclase (oligoclase). The dominant mafic constituent is an amphibole, which occasionally coexists with an iron-rich sahlite and titaniferous dark-brown biotite. The common accessory opaque oxide mineral is ilmenomagnetite with variable amounts of unmixing. The calc-alkali-syenite locally grades into perthite-syenite and even to perthosite.

The nepheline syenite is a mesocratic coarse-grained rock with well-marked foliation defined by the mafic silicates and occasionally by feldspar tablets and is a hypersolvus syenite. The alkali-feldspar ($Or_{38}Ab_{62}$) shows variable degrees of unmixing. The intergrown albite lamellae in the perthite grow coarser and less rigid in orientation with increasing unmixing and occasionally the perthite grades almost to an antiperthite. Albite rims, in optical continuity with intergrown lamellae, are frequently developed along perthite-nepheline contacts. These albite rims and occasional fine, discrete albites possibly resulted during subsolvus cooling of the rock. Nepheline, subordinate to feldspar, occurs in aggregates of anhedral grains. Inter-nepheline contacts are typically straight while nepheline-perthite contacts are almost always curved and smooth. The composition of the nepheline shows slight deviation from the Morozewicz convergence field (Tilley, 1958). The common mafic silicates are biotite and amphibole, developed in subhedral to irregular blades that occasionally wedge into the adjoining felsic constituents. Calcite is frequently developed in close association with nepheline. Rare ilmenomagnetite shows a high degree of unmixing.

Amphibole in alkali-gabbro. The amphibole, the common dominant constituent of the gabbro, has a distinctive deep-brown absorption (table I). The other important but subordinate constituent in the rock is andesine, occurring in inequigranular grains. A common associate of the brown amphibole is a pyroxene varying in character from titanaugite to sahlite with a high alumina content (11.96 %). The pyroxene diminishes towards the upper part of the body, being replaced by coarse platy amphibole. Olivine is only occasionally developed, in the rocks towards the base of the body. A deep-brown titanian biotite almost always

accompanies the amphibole. The accessory opaque oxides are ilmenite and ilmenomagnetite. Hematite develops towards the upper part of the body and probably owing to the high water content in this part. Apatite is a frequent accessory.

TABLE I

	Chemical analyses			Atomic ratio to (O,OH) = 2400			
	1	2	3	1	2	3	
SiO ₂	41.48	36.95	38.84	Si	637	574	638
TiO ₂	3.92	6.25	2.56	Al ⁴	163	226	162
Al ₂ O ₃	10.05	15.02	11.81	Al ⁶	18	48	58
Fe ₂ O ₃	4.06	3.62	3.24	Ti	45	73	31
FeO	14.93	19.40	24.14	Fe ³	47	42	34
MnO	0.16	—	—	Fe ²	191	251	330
MgO	8.58	4.34	0.92	Mg	198	100	22
CaO	10.78	10.25	9.80	Mn	2		
Na ₂ O	2.89	1.34	4.13	Ca	177	184	172
K ₂ O	1.94	1.33	3.15	Na	86	40	131
H ₂ O ⁺	1.35	1.26	0.85	K	38	26	66
H ₂ O ⁻	—	0.19	0.17	OH	138	130	111
	100.14	99.98	99.61	1: (Ca,Na,K) _{3.0}			
FeO:MgO	0.97	2.54	14.56	(Fe,Mg,Mn,Ti,Al) _{5.0}			
(Mol. ratio.)				(Si,Al) ₈ O _{22.6} (OH) _{1.4}			
	Barke- vikite	Ferro- hastingsite	Alkali ferro- hastingsite	2: (Ca,Na,K) _{2.5}			
				(Fe,Mg,Ti,Al) _{5.1}			
				(Si,Al) ₈ O _{22.7} (OH) _{1.3}			
				3: (Ca,Na,K) _{3.7}			
				(Fe,Mg,Ti,Al) _{4.8}			
				(Si,Al) ₈ O ₂₃ (OH)			
γ	1.705	1.709	1.718				
α	1.678	1.677	1.695				
$\gamma-\alpha$	0.026	0.032	0.023				
2V _{α}	76°	72°	44°				
γ : [001]	12°	9°	14°				
α	Yellow	Yellow	Greenish yellow				
β	Brown	Dirty green	Green				
γ	Deep brown	Greenish brown	Deep green.				

1. Brown amphibole (barkevikite) from alkali-gabbro. Analyst: W. H. Herdsman.
2. Titaniferous amphibole from calc-alkali-syenite. Analyst: M. K. Bose.
3. Alkali ferrohastingsite from nepheline-syenite. Analyst: Mitra, S.K.P. Ltd.

A classification of brown amphiboles on optical data alone is not possible as there is considerable overlap in the optical properties of barkevikite, kaersutite, and the oxyhornblendes (Wilkinson 1961); on the basis of chemical and optical data (table I) the brown amphibole in the alkali-gabbro should be named barkevikite though it approaches kaersutite very closely in magnesium content.

Amphibole in calc-alkali-syenite. The calc-alkali-syenite grading to hypersolvus syenite is a product of fractionation of the basic magma.

Though poorer in mafic constituents, the ratio $(\text{FeO} + \text{Fe}_2\text{O}_3) : (\text{FeO} + \text{Fe}_2\text{O}_3 + \text{MgO})$, in this rock is higher than in the alkali-gabbro. Amphibole is dominant amongst the mafics in the syenite with subordinate sahlite and biotite. The syenite magma was possibly very rich in water as is indicated by high $\text{Fe}_2\text{O}_3 : \text{FeO}$ ratio of the rock, though magnetite still persists as an opaque accessory.

Like the host rock, the amphibole also shows advanced replacement of magnesium by iron. The calcium content of the mineral is not affected and the mineral is still a calciferous type. Titanium enters the composition in higher proportion than in barkevikite and this can be attributed to entry of aluminium in increasing amount in the structure (Verhoogen, 1962); the titania content of the mineral is comparable to that in many kaersutites. The ratio $\text{FeO} : \text{MgO}$ (molecular proportion) is higher than in the barkevikite of the alkali-gabbro and thus the femaghastingsite of the alkali-gabbro is followed by ferro-hastingsite in the syenite (Billings, 1928).

Amphibole in nepheline syenite. In the still younger member, the nepheline syenite, the amphibole is dominated by biotite, both the minerals are characterized by high iron with respect to magnesia. Magnesium is replaced by iron to a still greater amount than in the amphibole of the calc-alkali-syenite, but it is still a calciferous type. The optics and chemistry of the mineral suggest an alkali-ferrohastingsite (Billings, 1928). Compared to the earlier amphibole the titania content decreases, which may be related to lower aluminium in the structure and to lower concentration of titanium in the magma. Scarcity of ilmenite in the rocks supports the latter contention. Amphibole in the rock often coexists with magnetite, suggesting a relatively low oxygen pressure. Both these minerals, however, disappear towards the upper part of the body, where biotite persists as the only mafic mineral. This indicates that high water at magmatic temperature, causing an increase in oxygen pressure, is unfavourable for such alkali amphiboles.

Optical characters. Table I shows the principal optical characters of the amphiboles. The optic axial angle decreases with increasing value of the $\text{FeO} : \text{MgO}$ ratio (fig. 1). The refringence and birefringence appear to vary with titania, and possibly also with iron. The relative role of iron, titania, and soda on the colour of amphiboles is uncertain. The amphibole with highest titania content shows a greenish-brown rather than deep-brown colour, as in barkevikite. The alkaliferrohastingsite has a deep-green absorption, which may be due to both high ferrous iron and alkalis.

Discussion. Crystallization of the anhydrous phases enriches the basic magma (an early fraction of which is represented by the older gabbro) in water, together with other volatiles. Increasing water shifts

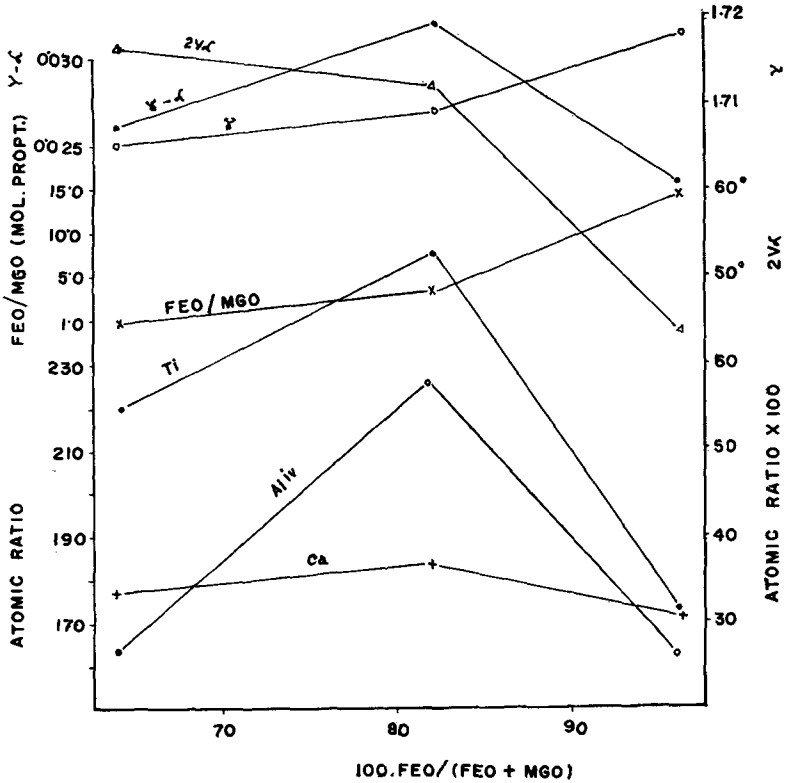


FIG. 1. Variation of some optical and chemical characters with iron:magnesia ratio in the amphiboles. Note constancy of calcium content and sympathetic relation between Al, Ti, and birefringence. 2V decreases and refringence increases with increasing iron. FeO:MgO in the mineral increases with decreasing age of the host rock.

the cotectic line towards anorthite in Ab-An-Di system and crystallization of plagioclase in the magma is thus inhibited. Inability of Al and Ca to enter the composition of plagioclase induce them to enter the structure of pyroxene and amphibole. Thus both the mafics become appreciably rich in alumina, lime, and soda. Aluminium replacing silicon in the structure promotes entry of titanium in the amphibole when it is available in abundance in the magma. Fractionation of the

magma increases the Fe:Mg ratio though the absolute amount of both decreases. This magmatic composition is reflected in the syenites in which the colour index falls with respect to alkali-gabbro but FeO:MgO (mol. proportion) increases as compared with barkevikite in the alkali-gabbro (fig. 1). Calcium, which accumulated appreciably in the magma, continues to enter the structure of the amphiboles and its entry in the structure of amphiboles is not affected by increasing diadochic replacement of magnesium by iron (fig. 1). Such a trend in compositional variation is noticed in the pyroxenes of alkali-olivine-basalt magma, where the pyroxene composition moves towards hedenbergite, remaining essentially parallel to the diopside-hedenbergite line. Possibly because of the absence of reaction relation with early formed olivine, the pyroxene in such rocks becomes relatively calcic (Wilkinson, 1956) and the amphibole, which follows the pyroxene, borrows the same character. Besides, as pointed out earlier, increasing water favours accumulation of calcium and aluminium in the magma and ultimately induces amphibole to crystallize (Ringwood, 1959). Limited crystallization of plagioclase also causes an indirect enrichment of sodium in the magma. All the three elements find high solubility in the amphiboles and promote crystallization of aluminous sodi-calcic amphiboles. A reaction between early formed pyroxene and plagioclase may also be stimulated by water, to develop rocks extremely rich in amphiboles. In some cases the process can proceed further to develop almost a mono-mineralic assemblage.

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