Manganese-Silicate-Bearing Metamorphic Rocks from Central Tanzania

By *K. D. Meinhold**) and *Thomas Frisch***)

With 3 figures and 2 tables in the text

Abstract. The Precambrian Konse Series includes isolated bodies of manganese-rich metasedimentary rocks, which were formed under amphibolite facies conditions in the Usagaran orogeny. Piemontite is a member of a variety of parageneses, providing a further example of its stability in a facies of higher grade than the greenschist or glaucophane schist facies. In piemontite-hornblende rock the amphibole is an optically positive magnesio-hornblende. Viridine with 8.50% Mn_2O_3 is a major component of schist, in which it coexists with ferrian muscovite, manganoan phlogopite, spessartite, oligoclase An_{23-27}, quartz, hematite, minor piemontite and accessory minerals. The garnet has the composition $Spess_{76.0} Py_{20.2} Gross_{1.7} Alm_{1.6} Ti-Andr_{0.5}$ and, as far as is known, is the most magnesian spessartite yet described.

INTRODUCTION

The metamorphic manganese-silicate rocks described below were discovered in the course of mapping by the German Geological Mission Tanganyika of the "Bundesanstalt für Bodenforschung (Hannover)" during the period 1963 to 1965. A brief petrographic description of these rocks forms part of a detailed report on their geologic setting by MEINHOLD (1968 and in press). Chemical analysis of the chief minerals of these unusual rocks provides the basis of the following more comprehensive description.

The first-named author is responsible for the field, optical and X-ray work, the second author for electron microprobe analyses.

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GEOLOGIC SETTING

Manganese-silicate-bearing rocks comprise a part of the metasedimentary sequence of the Konse Series, which represents the base of the Precambrian Usagaran System in the area of Tanzania mapped by the German Geological Mission. The Konse Series is exposed in a curved belt, about 200 km long, extending from Rudi to Ruaha National Park, north of Iringa (Fig. 1). It lies unconformably on the migmatitic gneisses of the Archean Dodoman System, with the contact disturbed by a northwest-trending thrust fault.

The Konse Series begins with quartzites and conglomerates, which .are overlain, in irregular succession, by marbles, calc-silicate rocks, calcareous mica schists, quartzites, quartz schists, ferruginous quartzites, mica schists, graphite schists, paragneisses, and amphibolites. Concordantly above the Konse Series lie interbedded para- and orthogneisses and amphibolites ("Gneiss-Amphibolite Series" of MEINHOLD, in press). South of the Mbungu River, northeast of Ismani (Fig. 1), banded gneisses and massive garnet or cordierite-sillimanite gneisses (the "Amphibolite-free Gneiss Series") occur above the Gneiss-Amphibolite Series.

These three rock series are assigned to the Usagaran System (MEINHOLD, 1968 and in press). They were folded and metamorphosed together during the Usagaran orogeny, in which the amphibolite facies, locally even the granulite facies, was attained and migmatization occurred in places. The rocks of the Konse Series, the Gneiss-Amphibolite Series and the lower part of the Amphibolite-free Gneiss Series belong to the Barrovian facies series, whereas those of the upper parts of the Amphibolite-free Gneiss Series belong to the Abukuma type (cf. WINKLER, 1967).

Towards the end of the Usagaran orogeny, the Konse Series was faulted and thrust over the Dodoman Shield. The associated cataclasis coupled with invading hydrothermal solutions led to retrograde metamorphism of large parts of the Konse Series and smaller portions of the Gneiss-Amphibolite Series. Nevertheless, relics of the original high-grade metamorphism are everywhere preserved.

Manganese-silicate-bearing rocks have been observed in three places within the Konse Series (Fig. 1). The largest exposure, at Mwhana (Fig. 1, No. 1), is composed of quartz-viridine-mica schists and piemontite-quartz schists, in which lenses only a few meters thick of piemontite-amphibole rocks are intercalated. Interbeds of piemontite- and manganoan phlogopite-bearing marbles and of piemontite- and spessartite-bearing calc-silicate rocks occur locally. The exposure in the Mwhana Hills is about 130 m wide; to the northeast it wedges out rapidly, whereas to the southwest it splits into individual bodies 50 m thick, separated by marbles, calc-silicate rocks, quartzites, gneisses

Geological Sketchmap of Iringa Area (Tanzania)

Superficial deposits

Igneous rocks

Ndembera Series

Usagaran System

Dodoman System

① Occurrences of manganese silicate rocks

Index map

Kenya

Tanzania

Iringa

Zambia

U.

K.

M.

Dodoma

Chipogoro

Rudi

Luhomero

Mbungu

Mhwana

Kisigo

Mtera

Izazi

Ikengeza

Ismani

Dar-es-Salaam

IRINGA

Mbeya

North Road

Great

Little Ruaha

Mloa

Great Ruaha

Idodi

Tungamarenga

Mdonya

Mkwawa

Ruaha National Park

Mandweka

No. of Quarter Degree Sheet

197

198

197

215

214

213

30 km

0 10 20 30

Geology by
BRINCKMANN (1964),
VENZLAFF (1964, 1965),
and MEINHOLD (1968).
Simplified and modified
by MEINHOLD (1969)

7°00'

7°30'

8°00'

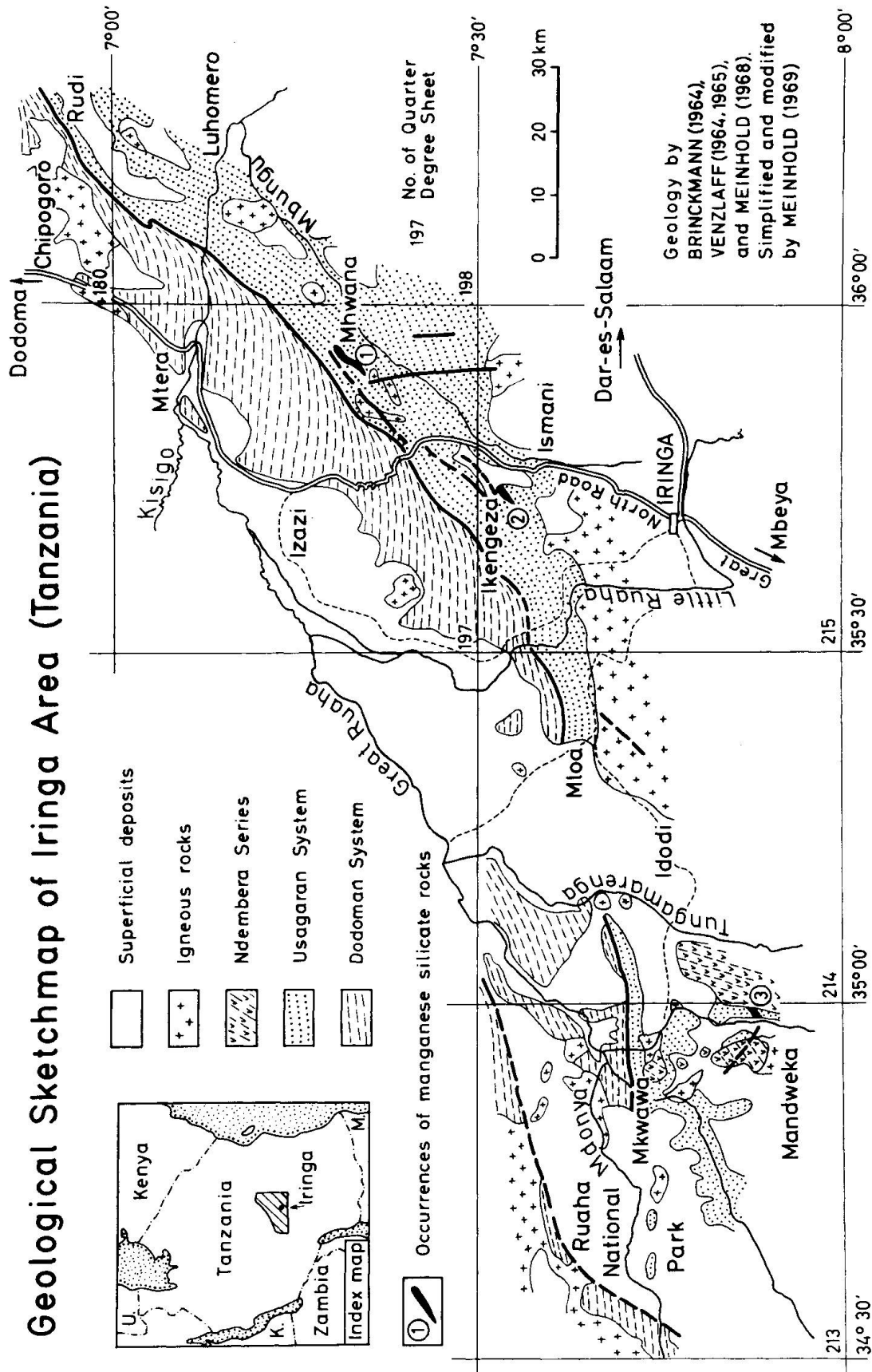36°00'

35°30'

35°00'

34°30'

Fig. 1. Geologic setting of the manganese-silicate-bearing metamorphic rocks of central Tanzania.

and mica schists. Seven kilometers farther southwest, the manganese-silicate rocks finally wedge out in the Mhumbirisa Hills.

The exposure of quartz-viridine-mica schists east of Ikengeza (Fig. 1, No. 2) is but a small lens with a maximum thickness of 10 m. The associated rocks comprise quartzite, calc-silicate rocks and paragneisses.

The Mandweka occurrence (Fig. 1, No. 3) was only cursorily examined. Here, piemontite-bearing quartz-viridine-mica schists are associated with metasedimentary rocks that may represent a facies repetition of the Konse Series within the Gneiss-Amphibolite Series or a saddle-type structure.

During the Usagaran orogeny, the rocks of all three occurrences were metamorphosed in the staurolite-almandine or the kyanite-almandine-muscovite subfacies of the almandine-amphibolite facies (Barrovian facies series) (cf. TURNER and VERHOOGEN, 1960; WINKLER, 1967). Retrograde metamorphism did not affect the rocks of the Mwhana occurrence but it is clearly evident at the other two localities.

ANALYTICAL PROCEDURE

Analyses of minerals were performed on separated grains mounted in "Araldite" embedded in plastic, except in the case of spessartite, for which a polished thin section was used. All samples were coated with beryllium to make them electrically conducting. The electron probe used was an A.R.L. EMX machine.

Analytical conditions were as follows: accelerating potential 15 kV, sample current 0.02 to 0.08 microampere, X-ray spot size 1 to 10 microns, integration time on scalers 10 to 40 sec. Pulse height discrimination was used for all elements. A minimum of four spot determinations was made on each of at least four grains of each mineral. Intensities so obtained were averaged and corrected for background and mass absorption, using the methods of SMITH (1965) and the absorption coefficients of HEINRICH (1966). When two standards were used for the same element in any one sample, the two "apparent" concentrations obtained never varied by more than ten per cent and their mean was used in the correction procedure.

A variety of natural and synthetic silicates was used as standards. For Si and Al in all minerals except spessartite, sillimanite (checked for minor element content and found to be essentially pure Al_2SiO_5). For Si, Ti, Al, Fe, Ca, and Mg in spessartite, natural pyrope (MASON, 1966, Tab. 1) and synthetic pyrope glass (prepared by M. J. O'Hara). For Ca, Fe and Mg in all minerals except spessartite and hematite, Ca-rich clinopyroxenes R 2397 (using microprobe values of SMITH, 1966, Tab. 3) and E-108 (AOKI and KUSHIRO, 1968, Tab. 3). For Fe, Ti and Mg in hematite, ilmenite K 13–131.8 (ANDERSON, 1968, Tab. 3). For Ti, Na and K in all minerals except spessartite and hematite, kaersutite with TiO_2 4.38%, Na_2O 2.60% and K_2O 2.05% (B. Mason, unpublished analysis). For Mn in all minerals, Mn-cummingtonite No. 4 (KLEIN, 1968, Tab. 1).

Accuracy is estimated at 2 to 4% of the amount present for major elements and 5 to 10% for the minor ones.

Table 1. *Microprobe analyses of minerals from the manganese-silicate-bearing rocks*

	1	2	3	4	5	6	7
SiO_2	38.1	52.1	35.8	38.8	38.5	45.1	n.d.
TiO_2	0.06	0.20	0.03	0.13	0.81	0.76	1.13
Al_2O_3	23.6	7.30	53.2	21.7	18.6	32.7	0.42
Fe_2O_3[a]	11.0	3.72	2.90		2.06	3.90	97.7
FeO[a]				0.69			
Mn_2O_3[b]	1.90		8.50				
MnO[b]		0.53		35.0	1.72	0.25	1.75
MgO	0.19	21.7	0.23	5.27	23.2	1.45	0.06
CaO	23.3	12.4	0.02	0.76	n.d.	0.02	n.d.
Na_2O	n.d.	0.97	n.d.	n.d.	0.43	1.44	n.d.
K_2O	n.d.	0.15	n.d.	n.d.	9.30	8.94	n.d.
Total	98.2	99.1	100.7	102.4	94.6	94.6	101.1

[a] total iron   [b] total manganese   n.d. = not detected

Structural formulae

Basis (0 =)	12	23	20	24	22	22
Si	3.018	7.104	4.000	6.002	5.438	6.085
Al^4		0.896			2.562	1.915
	3.02	8.00	4.00	6.00	8.00	8.00
Al^6	2.199	0.284	7.007	3.958	0.526	3.287
Ti	0.005	0.016	—	0.037	0.085	0.081
Fe^3	0.657	0.377	0.242		0.221	0.389
Fe^2				0.093		
Mn^3	0.114		0.725			
Mn^2		0.057		4.581	0.204	0.032
Mg	0.024	4.408	0.040	1.217	4.887	0.292
Ca	1.975	1.811		0.130		—
Na		0.262			0.119	0.373
K		0.032			1.680	1.540
	4.98	7.24	8.01	10.02	7.72	5.99

1 = Piemontite
2 = Amphibole } from piemontite-amphibole rock, Mwhana

3 = Viridine
4 = Garnet
5 = Mn-phlogopite } from quartz-viridine-mica schist, Mhwana
6 = Muscovite
7 = Hematite

MINERALOGY

The following mineral assemblages were observed in the manganese-silicate-bearing rocks of the Konse Series:

1. Quartz – Mn-phlogopite – muscovite – piemontite – ore (– tourmaline – zircon) (retrograde: scapolite – sphene).
2. Quartz – biotite – spessartite – piemontite – ore (– tremolite) (retrograde: tremolite – sphene).
3. Quartz – muscovite – piemontite – biotite (– ore – garnet) (retrograde: sericite-chlorite-clinozoisite).

Table 2. *X-ray powder data for piemontite, magnesio-hornblende, viridine and muscovite (cf. Tab. 1). Cu K_α radiation*

Piemontite d (Å)	I	Mg-Hornblende d (Å)	I	Viridine d (Å)	I	Muscovite d (Å)	I
5.0122	25	9.0175	10	6.1626	7	9.9051	95
4.1912	37	8.3860	81	5.5691	100	4.9676	34
4.1678	40	5.0748	4	4.5483	33	4.4622	4
3.4847	54	4.9130	4	4.2467	5	3.8734	3
3.4009	17	4.7410	6	3.9413	13	3.7200	3
3.2063	15	4.5071	8	3.7047	4	3.6656	5
3.0598	17	4.1990	14	3.7017	5	3.4820	5
2.9153	19	3.8834	3	3.5365	17	3.3285	12
2.9005	85	3.4502	5	3.5063	16	3.3091	100
2.8202	46	3.3731	12	3.3432	82	3.1951	5
2.6914	37	3.2663	25	3.0867	4	3.1839	6
2.6773	42	3.1142	100	2.7843	95	2.9857	7
2.6603	21	2.9340	14	2.6961	7	2.8589	5
2.5989	37	2.7978	26	2.5902	5	2.7910	4
2.5321	46	2.7313	9	2.5128	5	2.6977	9
2.4024	63	2.7009	16	2.4793	20	2.5931	3
2.2783	35	2.5916	15	2.4237	4	2.5643	6
2.1661	42	2.5432	6	2.3635	12	2.5169	6
2.1176	25	2.3791	5	2.2816	14	2.4859	8
2.0723	15	2.3386	11	2.2651	7	2.1984	3
1.8841	19	2.3224	8	2.1841	34	2.1721	3
1.8739	21	2.2973	4	1.9584	6	1.9868	33
1.6417	17	2.1591	7	1.8178	8	1.6570	2
1.6369	23	2.0420	5	1.8104	6	1.6423	3
1.6258	17	2.0136	8	1.7647	4	1.4347	3
1.5888	100	1.9968	5	1.6709	4	1.4211	3
1.5769	17	1.8878	12	1.6039	6	1.3489	6
1.4576	19	1.8433	3	1.5470	5	1.2422	3
1.4387	15	1.8104	5	1.5363	8		
1.4097	21	1.6857	4	1.4933	14		
1.3941	31	1.6466	7	1.4847	5		
		1.6342	5	1.3937	14		
		1.5813	54	1.3104	8		
		1.5466	3	1.3020	4		
		1.5154	4	1.2919	5		
		1.4999	3	1.2008	5		
		1.4666	3				
		1.4543	3				
		1.4351	27				
		1.3718	3				
		1.3523	3				
		1.3082	3				
		1.2940	2				

4. Quartz – viridine – muscovite – Mn-phlogopite – spessartite – plagioclase – hematite (– piemontite – tourmaline – apatite – zircon – zoisite) (retrograde: ore – sericite – serpentine – quartz – albite – epidote).

5. Piemontite – amphibole (– ore).

6. Carbonate – Mn-phlogopite – muscovite – tremolite – diopside (– piemontite – ore) (retrograde: tremolite – quartz – scapolite).

7. Quartz – diopside – tremolite – Mn-phlogopite – ore (– piemontite – tourmaline – apatite) (retrograde: tremolite – epidote – sphene – carbonate).

Rocks of this type have not previously been reported from Tanzania. In western Tanzania, rocks termed "gondites" (manganiferous ironstones) by McConnell (1950, p. 31) contain spessartite as the only Mn-silicate, as well as manganese ores.

Minerals investigated by optical, X-ray and/or chemical (electron probe) methods are: piemontite, viridine, spessartite, Mn-phlogopite, muscovite, hematite, amphibole, tourmaline, and plagioclase.

1. Piemontite

Piemontite was found in marbles, calc-silicate rocks, piemontite-quartz schists, quartz-chlorite-mica schists, quartz-viridine-mica schists, and piemontite-amphibole rocks. Only in the piemontite-quartz schists and in the piemontite-amphibole rocks does piemontite form a major constituent, in generally subhedral crystals, commonly stretched in "b". Pleochroism is intense: X = yellow, Y = pale violet pink, Z = red. Zonal structure, in which cores of crystals are paler than margins, is particularly common in the piedmontite-amphibole rocks. The piemontite of the calc-silicates has a paler colour than that of the other piemontite-bearing rocks.

Piemontite is optically positive in all the rocks studied. According to Tröger (1967, p. 311), this property would place the mineral in the Mn^3 – rich part of the piemontite series, but chemical analysis (Table 1, Col. 1) indicates a low content of trivalent Mn.

The piemontite is commonly closely intergrown with ore and mica (Mn-phlogopite and muscovite). In the quartz-viridine-mica schists it has in part grown along cleavage planes in muscovite, and in the piemontite-amphibole rocks it forms abundant inclusions in amphibole. Grains stretched in "b" display alignment with the schistosity and here and there are bent in small folds. In the same rocks piemontite may also occur in non-aligned crystals or in granular aggregates. Crystallization of the piemontite was evidently syn- to postkinematic with respect to the main deformation (Meinhold, in press).

The occurrence of diopside and, above all, the assemblage quartz-viridine-muscovite-oligoclase An_{23-27} are indicative of the almandine-amphibolite facies. In addition, the piemontite-bearing rocks are associated with rocks whose pre-retrograde mineralogy clearly indicates recrystallization in the amphibolite facies (Meinhold, in press). Textural relations show that the piemontite formed during the primary, amphibolite-facies metamorphism, not in the greenschist facies, which was reached during retrograde metamorphism. Whereas most piemontite previously reported belongs to the greenschist or glaucophane schist facies, piemontite in the amphibolite facies has recently been found in several other occurrences (Smith and Albee, 1967, Fuchs, 1968, Roy and Purkait, 1968).

In the piemontite analysis (Tab. 1, Col. 1), both the iron and the manganese are considered to be in the trivalent form. Microprobe wavelength scanning of the L_α and L_β peaks of Fe (cf. SMITH and ALBEE, 1967, p. 191) confirmed that at least the majority of the iron is present as Fe^3. Mn intensities in the L-spectrum were too low to provide unequivocal information as to the valence state of this ion.

Counts for manganese and iron varied antipathetically in some of the piemontite grains, doubtless reflecting the zoning that is visible optically. Maximum and minimum concentrations of Mn_2O_3 recorded were about 3% and 1%, of Fe_2O_3 about 11.5% and 9%. As a large number of spots were analyzed, the piemontite analysis given is considered to be a reliable bulk analysis.

The piemontite analyzed, from piemontite-amphibole rock at Mwhana, is characterized by a low Mn^3 content. MIYASHIRO and SEKI (1958, p. 427 ff.) contend that this feature is typical of piemontites "from low-grade schists and associated rocks from areas where the temperature of metamorphism was so low that biotite was not formed". However, the Tanzanian piemontite, as well as the piemontite from San Gorgonio Pass, California (SMITH and ALBEE, 1967), all of which formed in the amphibolite facies, fall in the low-temperature field of MIYASHIRO and SEKI's Al^3-Fe^3-Mn^3 diagram (Fig. 2). Temperatures prevailing in the amphibolite facies are well over 500° C, accord-
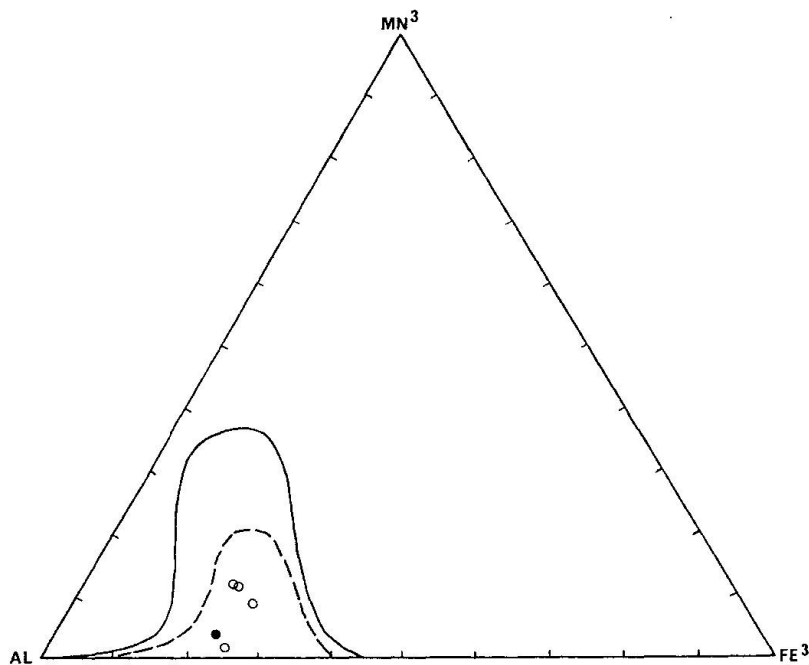

Fig. 2. Al-Mn^3-Fe^3 diagram of piemontites from Tanzania (this study) – solid circle – and San Gorgonio Pass, California (SMITH and ALBEE, 1967) – open circles. Composition fields after MIYASHIRO and SEKI (1958, Fig. 4): the broken line marks the upper limit of piemontites formed at low temperature, in the greenschist and glaucophane schist facies; the solid line demarcates the field of piemontite formed at higher temperature.

ing to WINKLER (1967, Fig. 40). It appears that piemontites of similar composition may form at various temperatures ranging from low to high.

2. Amphibole

Intercalated with the quartz-viridine-mica schists at Mwhana (Fig. 1, No. 1) are massive reddish rocks, composed entirely of piemontite, yellow amphibole and a little ore (Assemblage 5). The amphibole occurs interstitially and in schlier-like zones between piemontite-rich layers. The amphibole crystals are aligned in general but in places have grown parallel to the schistosity. Inclusions of piemontite in the 'amphibole are common. Growth of the amphibole is assigned to a postkinematic stage of recrystallization.

The amphibole exhibits weak pleochroism from colourless to pale yellow. On the basis of paragenesis and optical properties – $2V_X = 91°$ to $98°$, $Z \wedge c = 16°$ to $23°$, length slow – MEINHOLD (1968) considered the amphibole to be manganese cummingtonite (Fig. 3). Chemical analysis (Tab. 1, Col. 2) shows it to be magnesio-hornblende (classification of LEAKE, 1968, Fig. 2): Ca and Al are high, Mn is low, and Al takes the place of a silicon atom in the Z position. However, magnesio-hornblendes investigated up to now are optically negative.
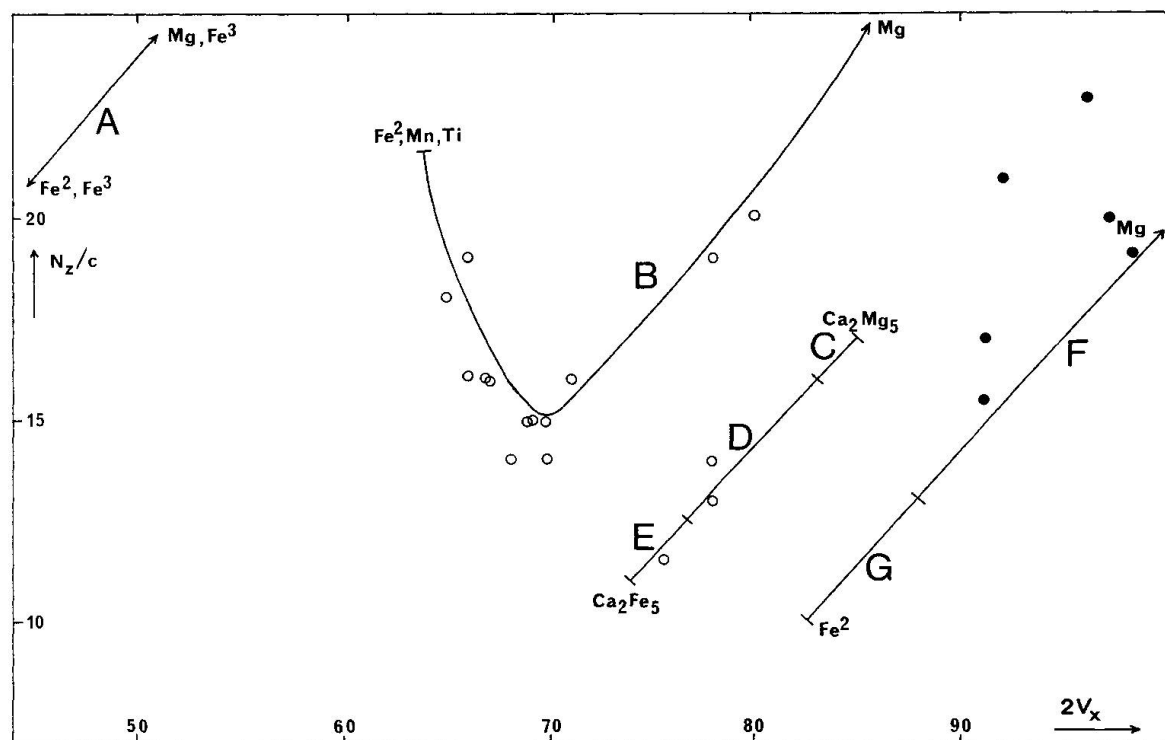

Fig. 3. Optical properties of amphiboles. Solid circles: amphiboles from piemontite-amphibole rocks, Mwhana; open circles: mean values of amphiboles from amphibolites of the Usagaran System. Determinative curves after TRÖGER (1956) and HELBIG (1969). A = Hastingsite series, B = Hornblende series, C = Tremolite, D = Actinolite, E = Fe-actinolite, F = Cummingtonite, and G = Grunerite.

Perhaps a solid solution series exists between the optically negative magnesio-hornblendes and the optically positive pargasites, An X-ray diffraction study of the Tanzanian amphibole (Tab. 2) did not aid in resolving the problem but, as there is a lack of X-ray data on such amphiboles, results are presented herein.

3. Viridine (manganandalusite)

Viridine, while limited to the quartz-viridine-mica schists (Assemblage 4), which are found in all three localities of the manganese-silicate rocks (Fig. 1), is a major constituent of these schists. Pleochroism is vivid: X = yellowish green, Y = grass green, Z = golden yellow. Isomorphous overgrowths on crystals are less intensely coloured than the primary viridine. HEINRICH and COREY (1959) state that the unusual pleochroism is the result of the copresence of Mn^3 and Fe^3.

The viridine porphyroblasts, which are green in hand specimen and up to fist size, grew largely synkinematically. They are anhedral and commonly deformed into s-shapes and may contain helicitic inclusions of quartz, hematite, Mn-phlogopite and muscovite. Small, rounded spessartites are also included in many viridine porphyroblasts. Deformation related to small folds suggests that crystallization of viridine began early in the deformation history. Quartz and mica have penetrated along fractures and in embayments. During retrograde metamorphism the viridines were granulated and partly to wholly replaced by sericite, with concomitant formation of ore.

The pattern of the "L" peaks of Fe and Mn in the viridine shows that these ions are trivalent. The Mn_2O_3 content, 8.50% (Tab. 1, Col. 3), is the highest yet reported for viridine, but it seems likely that the specimens from Yakutia, U.S.S.R. (SERDYUCHENKO, 1949, SHABYNIN, 1948), are richer still in trivalent Mn if, as HEINRICH and COREY (1959, p. 1268) suggest, they contain Mn^3 rather than Mn^2 as claimed by the Russian workers.

Substitution of aluminium by manganese and iron must obviously extend the stability field of andalusite. Andalusite is typically restricted to the high-temperature, low-pressure Abukuma-type facies series. Viridine, on the other hand, occurs not only in that facies series, alongside cordierite and sillimanite (SERDYUCHENKO, 1949, SHABYNIN, 1948), but also with kyanite in the almandine-amphibolite facies of Barrovian type (BACKSTRÖM, 1896, HEINRICH and COREY, 1959). The Tanzanian occurrence also belongs to the latter facies series.

The X-ray powder data of the analyzed viridine (Tab. 2) deviate from both the data of HEINRICH and COREY (1959, Tab. 2) and those given in the ASTM card 18–36. The discrepancy is probably due to differences in chemical composition.

4. Garnet

Small (up to 4 mm diameter), colourless garnets are abundant in some of the quartz-viridine-mica schists (Assemblage 4) at Mwhana and in the Mhumbirisa Hills (Fig. 1, No. 1). The garnets formed largely prekinematically and have been granulated and strung out along the foliation planes. They are very irregularly distributed as single crystals, commonly included in viridine, Mn-phlogopite and muscovite, and as aggregates of grains. Hematite and rutile occur as intergrowths with garnet. Beginning retrograde metamorphism in the Mhumbirisa Hills has caused brownish clouding of garnet centres.

Tectonically stretched, in part granulated and skeletal garnets occur in a biotite-garnet-tremolite-piemontite quartzite schist (Assemblage 2) in the Mhumbirisa Hills. These are colourless to pale yellow and generally closely intergrown with ore. Piemontite, along with sphene, replaces some of the garnet at its margins.

Chemical analysis of garnet from quartz-viridine-mica schist is given in Table 1, Col. 4. It is spessartite of unusual composition, $Spess_{76.0} \, Py_{20.2} \, Gross_{1.7} \, Alm_{1.6}Ti$-$Andr_{0.6}$ (mol per cent). MATTHES (1961, p. 266ff.) experimentally investigated the miscibility of pyrope in spessartite and found that spessartite took up no more than 15 mol per cent pyrope in solid solution and that incorporation of Mg in spessartite was favoured by high temperature. The compositions of natural spessartites support MATTHES' results. While a significant amount of magnesia might be expected in spessartite formed in the amphibolite facies, the Tanzanian example is anomalously high in MgO. The MgO in the spessartite was standardized against an homogeneous natural pyrope (with $MgO = 18.80\%$) and a synthetic pyrope glass ($MgO = 30.0\%$). The "apparent" (uncorrected except for background) Mg as MgO concentrations obtained were 4.60% and 4.30%. The mean of these two values after their correction for mass absorption is 5.27%. The analytical total for the analysis is slightly high, 102.4%, but the structural formula is very satisfactory. Thus there seems to be no compelling reason to reject the analysis and the Tanzanian spessartite may be considered to extend the known miscibility field of spessartite-pyrope garnets.

Total manganese in the spessartite has been calculated assuming all the Mn to be divalent but some of it may be present as Mn^3, replacing Mg, which has an identical ionic radius (0.66 Å).

5. Manganoan phlogopite

Manganese-rich phlogopite is a significant constituent of the piemontite-quartz schists and the quartz-viridine-mica schists (Assemblages 1 and 4). The mineral is also present in marble and calc-silicate rocks (Assemblages 6 and 7),

associated with the manganese-silicate rocks at Mwhana and in the Mhum-birisa Hills.

Nematoblastic Mn-phlogopite generally displays good parallel orientation in the schistosity planes, indicative of prekinematic crystallization. However, in the same specimens, Mn-phlogopite may occur as a synkinematic growth in pressure shadows around viridine and as postkinematic crystals that grew athwart the foliation. Muscovite has formed in cracks in the Mn-phlogopite.

The Mn-phlogopite is distinctly pleochroic, X = very light reddish yellow, Y = Z = orange to reddish brown. Chemically (Tab. 1, Col. 5), it compares well with the phlogopite of the piedmontite gneiss from Southern California (SMITH and ALBEE, 1967), except that the latter has up to nearly twice as much manganese as the Tanzanian specimen. In keeping with the findings of SMITH and ALBEE (1967, Tab. 1), we have assumed the manganese to be divalent. The manganese content of the Tanzanian phlogopite is higher than normal for phlogopite but not high enough for manganophyllite, which contains at least twice as much Mn (JAKOB, 1924).

6. Muscovite

Pink muscovite is the major component of the quartz-viridine-mica schists (Assemblage 4). It also occurs in the piemontite-quartz schists and in the metacalcareous rocks. As only the muscovite of Assemblage 4 was studied in detail, further discussion is confined to this variety.

Muscovite forms plates up to one centimeter in size in the quartz-viridine-mica schists. It is well aligned with the schistosity, and longer flakes are commonly bent in microfolds. Muscovite has also grown in pressure shadows around viridine and across the foliation. Like Mn-phlogopite, it appears to have begun crystallization prekinematically and ended it postkinematically, but textural relations indicate that it probably continued to form after the cessation of Mn-phlogopite growth. At Ikengeza and Mandweka (Fig. 1, Nos. 2 and 3) diaphthoretic deformation has caused crushing of muscovite and its replacement by sericite, whereby the original pink colour was lost.

The pink colour of the mica is suggestive of alurgite, but X-ray diffraction measurements (Table 2) revealed the 2 M structure of muscovite; alurgite has the 3 T structure (HEINRICH and LEVINSON, 1955).

The iron content – nearly 4% Fe_2O_3 (Tab. 1, Col. 6), assuming all the iron to be trivalent – is unusually high for muscovite and is almost twice as high as that of the coexisting Mn-phlogopite. High iron (more than 6% Fe_2O_3) in pink muscovite and a similar unusual partitioning of iron between coexisting muscovite and Mn-phlogopite was found by SMITH and ALBEE (1967) in the Southern Californian piemontite gneisses.

7. Hematite

Hematite is an abundant accessory mineral in many of the rocks, and grains are generally well aligned with the schistosity. The common presence of hematite included in viridine, mica, quartz and plagioclase attests to early growth of the hematite. Rims of rutile around hematite grains may be the result of exsolution.

Hematite included in viridine was analyzed (Tab. 1, Col. 7). Ti and Mn are significant but minor constituents.

8. Other minerals

Small, idiomorphic tourmalines with weak pleochroism (colourless to pale yellow to ochre) occur in the piemontite-quartz schists, quartz-viridine-mica schists and piemontite-bearing calc-silicate rocks (Assemblages 1, 4 and 7). The colour suggests dravite but the paragenesis makes the manganese variety, tsilaisite, a possibility.

Small, well-twinned (Albite law) crystals of plagioclase are fairly abundant in the quartz-viridine-mica schists. They are up to 0.3 mm in size, anhedral and have the composition An_{23-27}. During retrograde metamorphism, the plagioclase was partly replaced by clinozoisite, pistacite and sericite, resulting in a decrease in anorthite content to 18 to 20 mol per cent.

Some specimens of quartz-viridine-mica schists contain minor, fractured zoisite with the typical blue-grey interference colour. Small zircons are surrounded by pleochroic haloes in Mn-phlogopite. Apatite is also present in rounded, generally much-cracked grains.

ORIGIN OF THE ROCKS

The manganese-rich rocks of the Konse Series belong to a suite of metamorphic rocks of undoubted sedimentary origin. The probable parent material comprised clay-rich sandstones, greywackes and sandy clays with manganese contents considerably higher than normal. Sedimentation most likely took place in small, isolated bodies of water under more or less euxinic conditions. In the Usagaran orogeny these sediments recrystallized during regional metamorphism that attained amphibolite-facies grade.

REFERENCES

ANDERSON, A. T. (1968): The oxygen fugacity of alkaline basalt and related magmas, Tristan da Cunha. Amer. J. Sci. *266*, 704–727.

AOKI, K.-I., KUSHIRO, I. (1968): Some clinopyroxenes from ultramafic inclusions in Dreiser Weiher, Eifel. Contr. Mineral. Petrol. *18*, 326–337.

BACKSTRÖM, H. (1896): Manganandalusit fran Vestana. Geol. För. Stock. Förh. *18*, 386–389.

BRINCKMANN, J. (1964): Geological sketchmap of Iringa area. (Compiled from maps of the Geol. Surv. of Tanganyika and the German Geological Mission Tanganyika.) Unpubl. draft map, German Geol. Miss., Iringa.

FUCHS, H. (1968): Stratigraphische, tektonische und petrographische Untersuchungen in dem Zentralindischen Manganerz-Gürtel des südlichen Bawanthari-Flussgebietes unter besonderer Berücksichtigung des Verhaltens der Manganerze und Mangansilikate. Diss., Tech. Univ. Clausthal-Zellerfeld.

HEINRICH, E. W., COREY, A. F. (1959): Manganian andalusite from Kiawa Mountain, Rio Arriba County, New Mexico. Amer. Mineral. *44*, 1261–1271.

HEINRICH, E. W., LEVINSON, A. A. (1955): Studies in the mica group; polymorphism among the high-silica sericites. Amer. Mineral. *40*, 983–995.

HEINRICH, K. F. J. (1966): X-ray absorption uncertainty. In: The Electron Microprobe, 288–302. John Wiley & Sons, New York.

HELBIG, P. (1969): Petrographische und gefügekundliche Untersuchungen am Westende des Schneeberger Zuges (Südliches Ötztalkristallin). Diss., Tech. Hochsch. München.

JAKOB, J. (1924): Beiträge zur chemischen Konstitution der Glimmer. I. Mitteilung: Die schwedischen Manganophylle. Z. Krist. *61*, 155–163.

KLEIN, C. (1968): Coexisting amphiboles. J. Petrol. *9*, 281–330.

LEAKE, B. E. (1968): A catalog of analyzed calciferous and subcalciferous amphiboles together with their nomenclature and associated minerals. Geol. Soc. Amer. Spec. Paper *98*.

MASON, B. (1966): Pyrope, augite and hornblende from Kakanui, New Zealand, N.Z. J. Geol. and Geophys. *9*, 474–480.

MATTHES, S. (1961): Ergebnisse zur Granatsynthese und ihre Beziehungen zur natürlichen Granatbildung innerhalb der Pyralspit-Gruppe. Geochim. Cosmochim. Acta *23*, 233–294.

McCONNELL, R. B. (1950): Outline of the geology of Ufipa and Ubende. Bull. geol. Surv. Tanganyika *19*, 1–62.

MEINHOLD, K. D. (1968): Petrographie, Metamorphose und Tektonik der Konse-Serie in Zentral-Tanzania (Ostafrika). Diss., Tech. Hochsch. München.

—— (in press): Petrographie, Metamorphose, Tektonik und stratigraphische Stellung der Konse-Serie in Zentral-Tanzania (Ostafrika). Geol. Jb. Beih. *91*.

MIYASHIRO, A., SEKI, Y. (1958): Enlargement of the composition field of epidote and piemontite with rising temperature. Amer. J. Sci. *256*, 423–430.

Roy, S., Purkait, P. K. (1968): Mineralogy and genesis of the metamorphosed manganese silicate rocks (gondite) of Gowari Wadhona, Madhya Pradesh, India. Contr. Mineral. and Petrol. *20*, 86–114.

Serdyuchenko, D. P. (1949): The composition and chemical constitution of manganian andalusite (in Russian). Vsesoyuz. Miner. Obshch., Zap. (Mém. Soc. Russe Minéral.) *78*, 133–135. (Chem. Abstr. *43*, 6119, 1949.)

Shabynin, L. I. (1948): Viridine from Yakutia (in Russian). Vsesoyuz. Miner. Obshch., Zap. (Mém. Soc. Russe Minéral.) *77*, 203–214. (Chem. Abstr. *44*, 7721, 1950.)

Smith, D., Albee, A. L. (1967): Petrology of a piemontite-bearing gneiss, San Gorgonio Pass, California. Contr. Mineral. Petrol. *16*, 189–203.

Smith, J. V. (1965): X-ray emission microanalysis of rock-forming minerals. I. Experimental techniques, J. Geol. *73*, 830–864.

— (1966): X-ray emission microanalysis of rock-forming minerals. VI. Clinopyroxenes near the diopside-hedenbergite join. J. Geol. *74*, 463–477.

Tröger, W. E. (1956): Optische Bestimmung der gesteinsbildenden Minerale. Teil 1: Bestimmungstabellen. 2. Aufl. E. Schweizerbart'sche Verlag, Stuttgart.

— (1967): Optische Bestimmung der gesteinsbildenden Minerale. Teil 2: Textband. E. Schweizerbart'sche Verlag, Stuttgart.

Turner, F. J., Verhoogen, J. (1960): Igneous and metamorphic petrology, 2nd ed. McGraw-Hill, New York.

Venzlaff, H. (1964): Annual report of the German Geological Mission in Tanganyika for 1962/63. Iringa.

— (1965): Annual report of the German Geological Mission in Tanganyika for 1963/64. Iringa.

Winkler, H. G. F. (1967): Petrogenesis of metamorphic rocks. 2nd ed. Springer-Verlag, New York.