Amphibolite–granulite facies assemblages in southern Nyasaland.

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[Taken as read, 26 January 1961.]

Summary. The mineral assemblages developed in a variety of high-grade metamorphic rocks from southern Nyasaland are compared with standard metamorphic facies mineral assemblages proposed by some authors.

THE Middle Shire area of Nyasaland lies roughly midway between the southern tip of Lake Nyasa and the Zambezi river. It includes the western side of the Shire Highlands horst, the central section of the Shire rift, and the eastern face of the Kirk mountains scarp which here forms the watershed between the Nyasa and Zambezi troughs.

This area is occupied mainly by high-grade gneisses and granulites of the Mozambique Belt, which prior to their metamorphism were intruded by a series of pre-Cambrian plutonic rocks ranging from ultrabasic to syenitic in composition.

The gneisses and granulites can be divided into two groups on the basis of metamorphic grade. In the eastern part of the area gneisses and granulites of charnockitic type are prevalent whilst in the central and western parts amphibolites and hornblende-biotite gneisses are common. Horizons of marble, calc-silicate granulite and arenaceous schist are common to both groups, as are highly metamorphosed basic and ultrabasic intrusives (Morel, 1955, 1958).

Facies delineation. During the geological mapping of the Middle Shire area it was found that the gneisses changed in texture from lepidoblastic to granulitic in what was later described as the transition zone between the amphibolite and granulite facies (Morel, 1958, fig. 1). Later petrographic work showed that this textural change was accompanied by several mineralogical changes: hypersthene appeared in the granulitic rocks; the oligoclase feldspar of the lepidoblastic gneisses was replaced by andesine in the granulitic rocks; pale green augite became very common in the granulites; the bluish-green hornblende of the hornblende-biotite gneisses and amphibolites was replaced by an olivegreen hornblende in the basic charnockitic granulites; sphene disappeared; and biotite became less common and foxy-red in colour.

As hornblende-biotite-gneisses are the commonest rock type found in the central and western parts of the Middle Shire area, and charnockitic

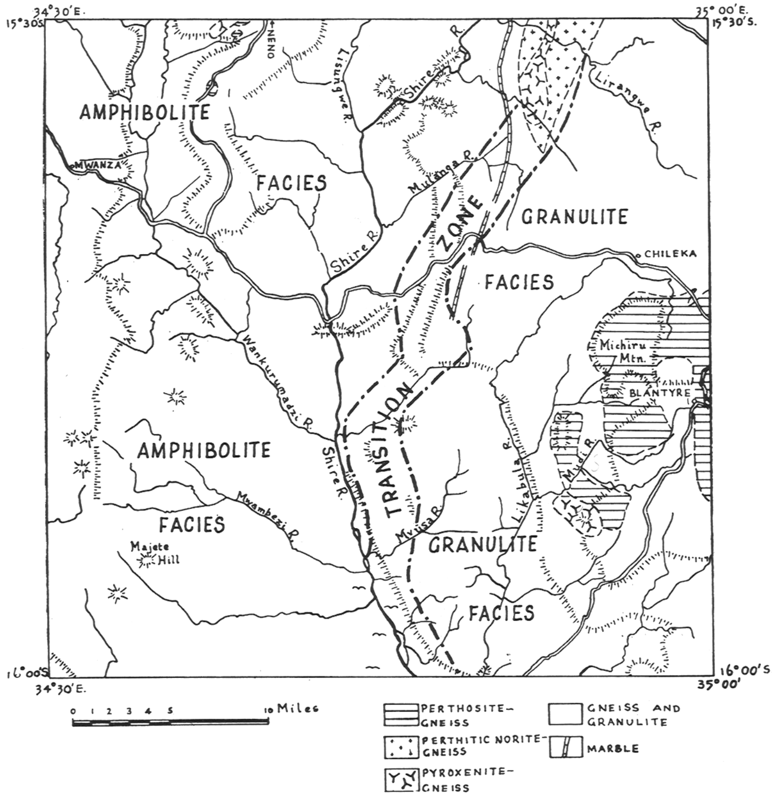

FIG. 1. Sketch map of the Middle Shire area showing metamorphic facies.

granulites form the country rocks of the eastern part, these two groups of rocks were utilized to delineate the boundaries between the amphibolite and granulite facies.

The assemblage hornblende–biotite–oligoclase was taken to be critical for the amphibolite facies and hypersthene–diopside–andesine as typical of the granulite facies (Turner and Verhoogen, 1951, p. 446).

It was found that a broad transition zone, up to two miles in width, was present in which assemblages common to both groups obtained. To the west of this transition zone hypersthene is rare and sphene is common, whilst to the east the reverse holds and sphene is only found in calc-silicate rocks (fig. 1).

Once the boundaries of the transition zone had been determined on the basis of the above assemblages it became possible to compare the mineral parageneses of the less abundant rock types with the standard assemblages as presented by Turner and Verhoogen (1951) and Ramberg (1952).

Amongst psammitic granulites it was found that muscovite occurs partially altered to sillimanite some seven to eight miles to the west of the transition zone. Ramberg (1952, p. 158) states that the muscovite→sillimanite reaction occurs abruptly at the amphibolite–granulite facies boundary. The evidence quoted above suggests that this reaction may take place before the appearance of hypersthene in rocks of appropriate composition that are undergoing increasing metamorphism.

In the magnesia-rich ultrabasic rocks the break-up of biotite to form orthoclase and anthophyllite has been detected in biotitites that lie a mile or more to the west of the transition zone. This reaction would appear to represent a stage in the reaction: Mg-phlogopite + silica→enstatite + orthoclase, which Ramberg (1952, p. 159) indicates as taking place at the boundary between the amphibolite and granulite facies. The metamorphosed ultrabasic intrusions are mainly biotitites and biotite-pyroxenites in the western and central parts of the Middle Shire area, whilst to the east, amongst the charnockitic rocks, they are largely websterites, and it appears likely that this difference may be a function of their metamorphic grade.

Calc-silicate Granulites. As the main mineral groups taking part in reactions at the amphibolite–granulite facies boundary are almost entirely members of mix-crystal series, it is not to be expected that this boundary can be represented on a geological map by other than a relatively broad transition zone. In view of this supposition it is of interest to compare the zonal relationships amongst calc-silicate granulites that Kennedy (1949, pp. 43–56) has described from the Scottish Highlands with those of southern Nyasaland.

Kennedy succeeded in delineating zonal relationships between members of the Moine Series to within a few hundred feet by using certain mineral assemblages that are present amongst the pelitic and arenaceous granulites of the Morar–Sunart area. He divided the accompanying calc-silicate rocks into four classes, which he correlated with Eskola's facies as shown in table I, where a correlation with the Middle Shire facies is also put forward.

Kennedy thought that the Scottish rocks belonged to a single isochemical series in which variations in chemical composition were due to changes brought about in the attainment of mineralogical equilibrium during the process of metamorphism.

TABLE I.

Eskola's facies	*Kennedy's facies*	*Middle Shire facies*
Epidote–amphibolite	*Group* 1. Quartz–calcite–zoisite–acid-plagioclase–hornblende–garnet	Absent
Epidote–amphibolite	*Group* 2. Quartz–zoisite–acid-plagioclase–hornblende–garnet	Absent
Amphibolite	*Group* 3. Quartz–bytownite–hornblende–garnet	Epidote–hornblende–calcic-plagioclase
Pyroxene hornfels	*Group* 4. Quartz–bytownite–pyroxene–garnet	*Granulite facies* Hedenbergite–calcic-plagioclase–calcite–garnet

The petrology of the Nyasaland calc-silicate granulites has been described elsewhere (Morel, 1958, pp. 26–29) and it is unlikely that these rocks represent an isochemical series, for they are strongly banded into alternating layers rich in pyroxene or garnet, which vary from a few millimetres to several centimetres in thickness. This banding appears to be due to compositional differences between the layers of the parent sediment.

The garnet of the Scottish rocks is found in each of Kennedy's groups but in Nyasaland this mineral is restricted to the upper part of the amphibolite facies and the granulite facies, where it appears to be replacing hedenbergite (Morel, 1958, fig. 5B). The garnet of the Nyasaland rocks is probably an andradite-grossular.

The pyroxene of the Scottish rocks is a colourless and apparently highly aluminous augite. That of Nyasaland is a deep emerald hedenbergite with strong pleochroism. In the amphibolite facies its place is taken by hornblende, in agreement with Kennedy's findings, but, considering their different compositions, it is unlikely that the two pyroxenes and their accompanying feldspars crystallized under strictly comparable conditions.

In the Middle Shire area epidote is common in the calc-silicate granulites of the amphibolite facies and the transition zone whilst Kennedy did not find it in rocks whose metamorphic grade exceeded that of the epidote-amphibolite facies. When calcite is present in the Nyasaland examples it is frequently accompanied by primary scapolite of a mizzonitic composition.

In a later paper von Knorring and Kennedy (1958) discussed the mineral paragenesis and metamorphic status of a garnet–hornblende–pyroxene–scapolite gneiss from the Shai Hills, Ghana. They published two chemical analyses of these rocks and stated that these indicate that they were formed from basic igneous rocks, and are comparable to some eclogite rocks. They considered that the petrographical uniformity of the formation and the absence of relict banding provide an indication of an original igneous character, and that these rocks formed under conditions transitional between those of the amphibolite and eclogite facies. They reached this conclusion from the association of hornblende and plagioclase with garnets and pyroxenes of eclogitic type in the Shai Hills rocks. Because of differences in mineral chemistry they did not assign these rocks to Turner's almandine–diopside–hornblende subfacies of the amphibolite facies (Turner and Verhoogen 1951, p. 458), and proposed an association garnet–pyroxene–hornblende, which they consider to be transitional between the amphibolite and eclogite facies, and to be chemically distinct from the almandine–diopside–hornblende subfacies.

From the point of view of facies delineation in the field it would be impractical to differentiate between the garnet–pyroxene–hornblende assemblage and Turner's almandine–diopside–hornblende subfacies, since chemical analyses are required to detect the jadeite component of the pyroxene.

In the Ncheu area of Nyasaland (Morel, 1956) garnet–hornblende–diopside gneisses are commonly interlayered with hypersthene-bearing charnockitic granulites. In this case there can be no difference in metamorphic grade between the two rock types, and the differing mineral parageneses can only represent original compositional differences. Howie and Subramaniam (1957, p. 582) have shown that the presence or absence of garnet is controlled only by the chemical composition of the rock.

It is apparent that the almandine–diopside–hornblende subfacies of the amphibolite facies overlaps into the granulite facies and one may ask whether any useful purpose will be served by further subdivisions of the imprecise but useful facies concept until more is known about the mineral parageneses of rocks of differing chemical compositions that have undergone the same degree of metamorphism.

Acknowledgement. The fieldwork upon which part of this paper is based was carried out whilst the writer was employed by the Nyasaland Government. The opinions expressed are those of the writer and not necessarily those of the Nyasaland Geological Survey.

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