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Metamorphic Zones in the Southern Alps of New Zealand

BY BRIAN MASON[1]

During a reconnaissance of the district between the Franz Josef Glacier and the Copland Valley (Lillie and Mason, 1955) it was necessary to establish criteria for mapping the rocks in the field. As the rocks are largely greywackes and their metamorphosed equivalents, the criteria selected were based on those established by Turner and Hutton on similar rocks in Otago and South Westland (Turner, 1933; Hutton, 1940). The zones recognized in the field and the criteria therefor are as follows:

Chlorite 1: Unaltered greywacke
Chlorite 2: Sheared greywacke
Chlorite 3: Phyllonites, i.e., schistose and fissile rocks derived from greywacke, fine-grained by crushing and largely recrystallized, but not foliated
Chlorite 4: Foliated schists without biotite (the term foliation signifies aggregation of quartz and feldspar, and of muscovite and chlorite, into alternate lenticles or streaks or inconstant bands)
Biotite: Presence of biotite
Almandine: Presence of almandine garnet (and/or hornblende)

It has been found that the macroscopic criteria for the Chlorite 1, 2, 3, and 4 zones correspond closely with those established by Turner and Hutton for these zones and are readily applied in the field.

Further work in other parts of the Alps, from the Haast River to the Maruia River, has shown the general applicability of this scheme as a

[1] Curator of Physical Geology and Mineralogy, the American Museum of Natural History.

system of field mapping. Originally it was feared that the use of biotite as a field indicator might be complicated by the presence of the biotite-like mineral stilpnomelane, which occurs in many Otago rocks of the Chlorite zones. However, stilpnomelane has proved to be rare in the alpine rocks and confined to the Chlorite 2 and 3 zones. The incoming of biotite is readily mapped in most places, as the biotite generally appears as prominent porphyroblasts about a millimeter in diameter in an otherwise fine-grained rock. Some difficulty has been experienced in a few places, especially north of the Taramakau River, by the absence of a Chlorite 4 zone, Chlorite 3 rocks passing directly into Biotite zone rocks. Another difficulty in the above scheme is the sporadic occurrence of almandine. Biotite always appears where the conditions of metamorphism became sufficiently intense for its formation; almandine appears at a higher grade of metamorphism, and then only if the particular rock contains an excess of iron and aluminum over that which will combine with the potassium in the rock to form biotite. This explains why Turner did not recognize an Almandine zone in the Haast Valley, although the grade of metamorphism is sufficient for its formation (and it does occur in a few rocks); the Biotite zone on his map also includes rocks of the Almandine zone as defined here. He foresaw this, as is indicated by the table (1933, p. 248) in which he equates his Biotite zone with the Biotite zone *and* the outer part of the Almandine zone as recognized in the Scottish Highlands. During the course of the present work it has been found that in rocks of suitable composition (probably metamorphosed basic lavas and tuffs) hornblende appears at about the same grade of metamorphism as almandine.

Subsequent laboratory examination has shown that the Almandine zone can be divided into two distinct zones, one of lower grade in which the feldspar is albite, and one of higher grade in which the feldspar is more calcic. This was discovered by Turner in South Westland, where he distinguished an Oligoclase zone of higher grade than the zone characterized by albite. Unfortunately this distinction cannot be readily applied in the field, as the character of the feldspar can be determined only by microscope techniques, most readily by determination of refractive index by the immersion method. It has been observed, however, that coarsely foliated "gneissic" schists generally belong to the Oligoclase zone. This criterion must be applied with discrimination, because even some Chlorite 4-zone rocks may have a gneissic structure (as at Clarke Bluff, at the Clarke-Haast River junction, for example).

The resultant classification of metamorphic zones is demonstrated in table 1.

TABLE 1

METAMORPHIC ZONES AND CORRELATION WITH THE FACIES CLASSIFICATION OF METAMORPHIC ROCKS

Zone	Sub-facies	Facies
Chlorite 1	Muscovite-chlorite	Greenschist
Chlorite 2		
Chlorite 3		
Chlorite 4		
Biotite	Biotite-chlorite	
Almandine	Chloritoid-almandine	Albite-epidote Amphibolite
Oligoclase	Staurolite-kyanite	Amphibolite

Wellman, Grindley, and Munden (1952) mapped the following zones in the Harpers Pass district:

Upper subschist
Middle subschist
Lower subschist
Non-foliated mica schists
Foliated mica schists

Some difficulty exists in correlating their scheme with that set out in this paper, because of the complete absence of mineralogical data on their rocks. A rapid examination of that part of their area along the Ahaura River has shown a further complication—the absence of the Chlorite 4 zone, Chlorite 3-zone rocks passing directly into Biotite zone rocks. In this section their foliated mica schists fall entirely within the Biotite zone, as do the non-foliated mica schists and part of the lower subschist. The remainder of the lower subschist is probably equivalent to the Chlorite 3 zone, the middle subschist to the Chlorite 2 zone, and the upper subschist to the Chlorite 1 zone. It is desirable to emphasize here the utility and significance of biotite as an indicator of metamorphic grade; its presence is generally readily observable to the naked eye, and its appearance is a reliable indicator of increasing metamorphic grade.

Table 1 also gives the relationship of the metamorphic zones here recognized to the facies classification of metamorphic rocks as presented by Turner and Verhoogen (1951). The highest grade of metamorphism does not go beyond the staurolite-kyanite subfacies, as the next higher subfacies is characterized by the appearance of sillimanite, which has not been found in the alpine schists.

The occurrence of individual minerals in relation to the metamorphic zones is illustrated in table 2. The Chlorite 1 zone is omitted, because little reconstitution of detrital minerals takes place in this zone. Some brief notes on the individual minerals follow.

QUARTZ: Can occur in rocks of all zones. It is an essential mineral in all rocks of greywacke composition and is also present in hornblende

TABLE 2

OCCURRENCE OF THE MORE COMMON MINERALS OF THE ALPINE SCHISTS IN RELATIONSHIP TO METAMORPHIC ZONES

	Chlorite 2	Chlorite 3	Chlorite 4	Biotite	Almandine	Oligoclase
Quartz	——	——	——	——	——	——
Calcite	——	——	——	——	——	——
Muscovite	——	——	——	——	——	——
Chlorite	——	——	——	——	——	——
Biotite				——	——	——
Almandine					——	——
Albite	——	——	——	——	——	
Oligoclase-andesine						——
Tremolite-actinolite				——		
Hornblende					——	——
Clinozoisite-epidote	——	——	——	——	——	——

schists derived from basic igneous rocks and tuffs. The only rocks in which it does not occur are magnesium-rich types such as serpentine, talc-serpentine, and tremolite-actinolite rocks.

CALCITE: Can occur in rocks of all zones. It is absent or present only as an accessory in derivatives of greywackes or argillites, but may be fairly abundant in derivatives of basic igneous rocks. Narrow bands consisting essentially of calcite interbedded with normal schists have been observed (Mason and Taylor, 1955).

MUSCOVITE: Can occur in rocks of all zones and is omnipresent in rocks derived from greywackes and argillites. Some argillites of the Chlorite 2 zone have been shown by X-ray examination to consist almost entirely of fine-grained muscovite.

CHLORITE: As implied in the classification, chlorite is characteristic of Chlorite zone rocks. Nevertheless, it may occur, evidently as a stable phase, in rocks of higher metamorphic grade and has been observed even in Oligoclase zone rocks. Thus the Chlorite zones are characterized not alone by the presence of chlorite, but also by the absence of minerals of related composition but of higher metamorphic grade, viz., biotite and almandine. Preliminary examination of chlorite from greywacke-composition rocks has shown that it apparently becomes more magnesian in higher-grade rocks, chlorite from oligoclase-bearing rocks being lower in refractive index than that from Chlorite zone rocks.

BIOTITE: The incoming of biotite indicates that the boundary between Chlorite-zone and Biotite-zone rocks has been passed. Beyond this boundary biotite is always present in rocks of greywacke and argillite composition and generally in metamorphosed basic igneous rocks also. Biotite is a common and abundant mineral in the Almandine and Oligoclase zones also.

FELDSPAR: Albite is the only feldspar in all grades of metamorphism except the highest. In the highest grade of metamorphism the feldspar is oligoclase or occasionally andesine. An interesting point, not yet elucidated, is whether the plagioclase increases continuously in anorthite content as metamorphic grade increases, or whether this increase takes place in discontinuous increments. Preliminary observations suggest the latter; in the albite-bearing rocks the anorthite content is 0–5 per cent and in the oligoclase-bearing rocks 20 per cent or greater, feldspars of intermediate composition not having been observed. Further work is necessary to show whether this is universal in these rocks.

TREMOLITE-ACTINOLITE: These minerals are quite rare, having been observed only in North Westland and then only in Biotite-zone rocks. At lower metamorphic grade they are probably replaced by the association chlorite-calcite; at higher grade the amphibole is hornblende.

HORNBLENDE: Hornblende-bearing schists are not uncommon in the Almandine and Oligoclase zones. Hornblende does not form in derivatives of greywacke and argillite (evidently because of the low calcium content of these rocks), and its presence indicates derivation from basic igneous rocks or tuffs. Hornblende appears at about the same grade of metamorphism as almandine and is thus a useful zone indictor.

GARNET: The garnet in these rocks is an almandine of fairly uniform composition, judging from its fairly constant refractive index (1.80) and unit cell dimensions (11.58–11.62A). No garnet has been found in Chlorite zone rocks, although spessartite has been observed in some of these rocks in Otago (Hutton, 1940).

CLINOZOISITE-EPIDOTE: A mineral of this series is present in minor amounts (5%–10%) in rocks of greywacke or argillite composition. Its amount reflects the calcium content of the original rock. Some rocks of the Oligoclase zone contain little or no clinozoisite or epidote, the calcium having been taken up in the plagioclase.

A number of other minerals have been observed in these rocks, but usually only as accessories. The occurrence of cummingtonite and piedmontite has been mentioned in a previous paper (Mason, 1955). Stilpnomelane has been observed in a few rocks of the Chlorite 2 and 3 zones, as has pumpellyite. Kyanite has not been observed *in situ;* nevertheless detrital kyanite has been recorded from South Westland (Hutton, 1950), and recently N. E. Odell (private communication) observed large blocks of kyanite schist in moraine at Hunt's Beach, between Bruce Bay and the Paringa River. The composition of the associated feldspar in a sample provided by Odell is about $Ab_{65}An_{35}$, indicating a provenance in the Oligoclase zone. This suggests that the block of kyanite schist in the Canterbury Museum labeled "Moorehouse Range" was probably collected by Haast on his journey down the South Westland coast in 1868, and was later mislabeled as to locality.

Table 2 and the above discussion serve to emphasize that more than one criterion may be necessary to assign a rock to a specific metamorphic zone. The only mineral specific to a single zone is oligoclase or andesine. A rock may belong to the Almandine zone, yet its composition may be such that garnet will not form. On the whole, however, the application of zonal criteria on a regional scale is generally feasible. Fortunately, mapping in the central and northern parts of the Alps (from the Copland Valley north) is expedited by the over-all simplicity of structure, the grade of metamorphism increasing uniformly from the Main Divide westward, so that the individual zones follow one another in regular sequence. South of the Copland Valley this is no longer so; post-metamorphism folding has resulted in a repetition of individual zones.

The highest grade of metamorphism reached is that illustrated by the Oligoclase zone. The Oligoclase zone is a rather wide one in comparison with the other zones, but no criteria for its division have yet been observed. There is a complete absence of minerals which might indicate a higher grade of metamorphism. Such minerals are sillimanite and orthoclase, which would be formed by the breakdown of muscovite. A Sillimanite zone often occurs in areas of high-grade regional metamorphism, and the breakdown of muscovite to give orthoclase and sillimanite has been observed to take place at about 650° C. (Yoder and Eugster, 1955). Similarly the association of quartz and calcite in the highest-grade rocks, and the absence of wollastonite, shows that the temperature was never high enough (about 600°–650° C., according to Harker and Tuttle, 1956) for the reaction quartz + calcite → wollastonite + carbon dioxide to take place. The implication is that metamorphic conditions in the Southern Alps never reached this intensity, the maximum temperature of metamorphism in the Oligoclase zone probably having been between 500° C. and 600° C.

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