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Metamorphic assemblages and conditions in the Rombak basement window, Nordland

Norges geologiske undersøkelse
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Rombakvinduet har gjennomgått epidot-amfibolitt/amfibolitt-facies metamorfose (P > 6kb, T 575-600°C), som er tilsvarende den metamorfosen som det overliggende kaledonske dekkekomplekset har gjennomgått. En senere grønnskifer-facies retrogradering, muligens også ved moderat til høyt trykk, har påvirket vinduet i varierende grad. De fleste steder opptrer ingen eller bare utbetydelig regrograd reekvilibrering av mineralene. I et område langt øst i vinduet (Muohtaguobla) har imidlertid grønnskifer-facies retrogradering så godt som fullstendig utvisket tegnene til den tidligere høyere grads metamorfosen. Intensiteten av retrograderingen i Muohtaguobla-området kan muligens relateres til et større N-S-gående lineament i de østlige deler av vinduet.

Emneord

Berggrunnsgeologi

Metamorfose

INTRODUKSJON

av Are Korneliussen (prosjektleder)

Dette arbeidet er et ledd i USB-prosjektets undersøkelser i de sydlige deler av Rombakvinduet, som har hatt som formål å vurdere mulighetene for gullforekomster.

Mens denne rapporten omhandler den metamorfe utviklingen, vil en annen rapport av E. Sawyer (under utarbeidelse) ta for seg strukturgeologien.

En tredje rapport (Korneliussen og Sawyer 1986) beskriver den generelle geologiske utviklingen og diskuterer gullproblematikken.

Struktur- og metamorf-geologi tillegges stor betydning i den samlede vurdering av området. Dette fordi hydrotermale gullforekomster ofte vil være tilknyttet skjærsoner som har virket som kanaler for hydrotermale løsninger. Slike skjærsoner kan påvises gjennom et metamorf/strukturgeologisk studium. En slik situasjon er påvist i Muohtaguobla-området i de østlige deler av vinduet.

Skjærsonene i Muohtaguobla, som har virket som kanaler for H_2O-CO_2 rike løsninger som har retrogradert (hydrert) mineralselskaper i omkringliggende bergarter, er trolig assosiert med et større N-S-gående lineament i Rombakvinduet. De nærmere omstendigheter i denne sammenheng er ikke undersøkt.

METAMORPHIC ASSEMBLAGES AND CONDITIONS IN THE ROMBAK BASEMENT WINDOW.

E. W. SAWYER

LOCAL GEOLOGY

The Rombak window consists largely of early to middle Proterozoic granite, syenite and minor basic to intermediate plutons dated at 1780 Ma (Gunner, 1981). These ages are believed to reflect either crystallizaton or early Proterozoic metamorphism. These plutons intrude early Proterozoic volcano-sedimentary rocks that appear to form two distinct groups. The western part of the window (west of the north-trending lineament near the Norway-Sweden border Fig. 1) the supra crustals contain alkaline to subalkaline basic to acidic (but mostly intermediate) volcanics and low Al_2O_3, low K_2O graywackes and pelites. Some of the basic and intermediate rocks are pyroclastic or tuffaceous in origin. Marbles, conglomerates and quartzites are also present, but relatively uncommon. The eastern early Proterozoic supracrustal sequence contains marbles, graywackes and low-K subalkaline tholeiitic metabasalts and possible komatiites. These metabasites have a N-MORB type chemistry whereas those of the western supracrustals have alkaline affinities (Korneliussen, in prep).

Of uncertain age, but younger than the volcano-sedimentary sequences, is a group of quartzites and pelites and possible tillites (Torske, pers. comm.) in the Muotaguobla area. These rocks were considered to belong to the late Proterozoic-Cambrian Dividal Group by Birkeland (1976). The stratigraphic status of these rocks is uncertain (Fig. 1) but never the less they are crucial in determining the age of structural and metamorphic events

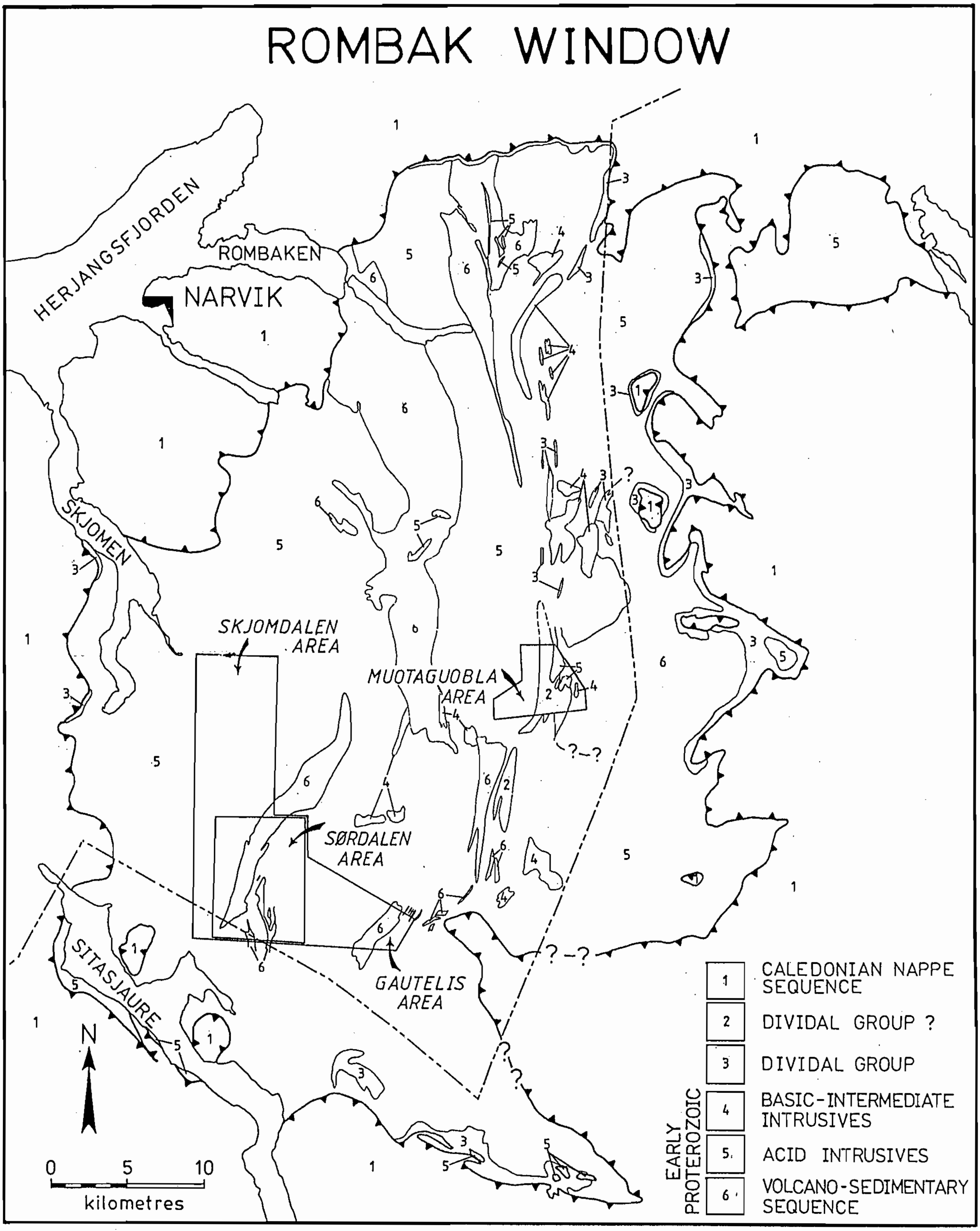


Figure 1 General geology of the Rombak Window showing the areas investigated in detail.

in the Rombak Window.

The areas investigated in detail are shown on Fiq. 1. In addition samples were also collected from the south side of Rombakbotn and in the Nordal area and between Muotaguobla and the Skjomdalen-Sordalen-Gautelis area.

BULK COMPOSITION

Many of the volcanic and plutonic rocks of the Rombak window are alkaline to subalkaline, and in general are potassic. For the more acid bulk compositions three K_2O-bearing phases, biotite, white mica and microcline are present. Intermediate to basic volcanics that are K_2O-rich contain microcline and biotite as the main potassic phases, but amphibole also contains minor amounts of K_2O. Even those intermediate to basic rocks that contain only biotite (+ amphibole) are sufficently potassic to have 20-30% modal biotite. In the western part of the window very few basic to intermediate rocks are of the low K-type containing less than 5 modal % biotite, however this type dominates in the eastern part of the window (e.g. Ruvssotoppen, Romer in prep.; Korneliussen, in prep.).

All rocks examined petrographically (except the marbles) contain quartz, sphene (or ilmenite), magnetite and a sodic plagioclase, thus the principal mineralogical changes in the plutonics, volcanics and metagraywackes can be shown in a tetrahedron with apices $(Al_2O_3+Fe_2O_3)$, (CaO), $(MgO+FeO+MnO)$, K_2O, Fig. 2. Chlorite, that on textural grounds is part of the prograde assemblage, has only been found in 3 out of 200 rocks, and coexists with albite and amphibole in intermediate volcanics. No prograde chlorite has been observed in the metagraywackes and metapelites. Garnet rich in spessartine (10-16 wt % MnO) occurs in a few rocks (granites, metagraywackes and sheared intermediate volcanics) and in each case coexists with oligioclase-andesine and biotite (not amphibole). The lack of garnet-amphibole assemblages may be due to either; a) inappropriate bulk compositions as the Rombak metabasites are low in (Al_2O_3 + Fe_2O_3) compared to garnet amphibolites (Laird, 1980) or, b) inappropriate metamorphic conditions.

MINERAL COMPOSITIONS

Biotites: Optically, in handspecimen and in thin section, the Rombak biotites are generally green in granites and the metavolcanics, only in the metagraywackes are they brown. However, plotted on the biotite composition space of Guidotti (1984) the Rombak biotites (Fig. 3) are typical of metamorphic biotites in general. Rombak biotites from granites and syenites have lower $Mg/(Mg+Fe_T)$ ratios than biotites from the intermediate and basic metavolcanics. Both biotite groups show a general trend of increasing Al^{VI} content with decrease in $Mg/(Mg+Fe_T)$ ratio implying a Tschermak-type exchange. Since all the biotites come from rocks lacking an Al_2SiO_5 polymorph, and in most cases coexist with magnetite it is to be expected that Rombak biotites contain significant Fe^{+3}. Typically the Rombak biotites contain about 0.2 atoms Ti per formula unit, and the data also follow the well known trend of increasing Ti content with decreasing $Mg/(Mg+Fe_T)$ ratio (Guidotti, 1984).

K-bearing white mica: Plotting microprobe analyses of Rombak K-white micas on the Al^{IV}-Al^{VI}-$(Mg+Fe_T)$ diagram of Guidotti (1984) shows a deviation from ideal muscovite (Fig. 4). Most of the samples fall close to, or on the muscovite-celadonite join implying a net $Fe^{+3} = Al^{VI}$ exchange. Since magnetite coexists with K-white mica in all the Rombak samples, the 15-20 mol % celadonite in these micas is not unexpected. Although bulk rock composition influences the celadonite content of K-white mica, the

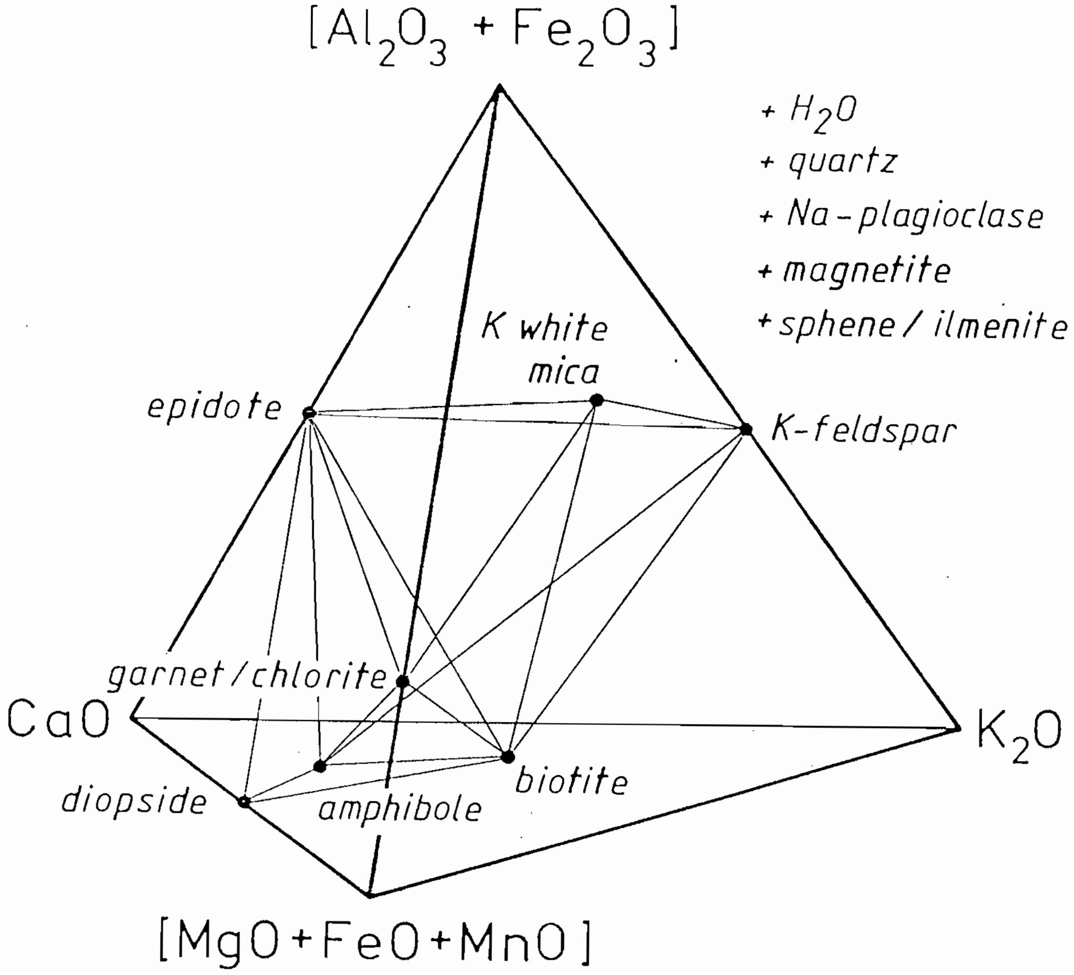


Figure 2 Composition terhedron showing the assemblages found in quartz-plagioclase-magnetite-sphene/ilmenite bearing rocks of the Rombak Window. The essential minerals in the Rombak rocks can be expressed in the 11 component system: K_2O-Na_2O-CaO-MgO-FeO-MnO-Al_2O_3-Fe_2O_3-TiO_2-SiO_2-H_2O. Since quartz, albite, sphene/ilmenite occur in all rocks SiO_2, Na_2O and TiO_2 can be regarded as excess components. The fluid phase present during metamorphism is treated as pure H_2O, enabling H_2O also to be treated as an excess component. This permits the number of components to be reduced to 4 i.e. (Al_2O_3-Fe_2O_3)-(K_2O)-(CaO)-(MgO+FeO+MnO).

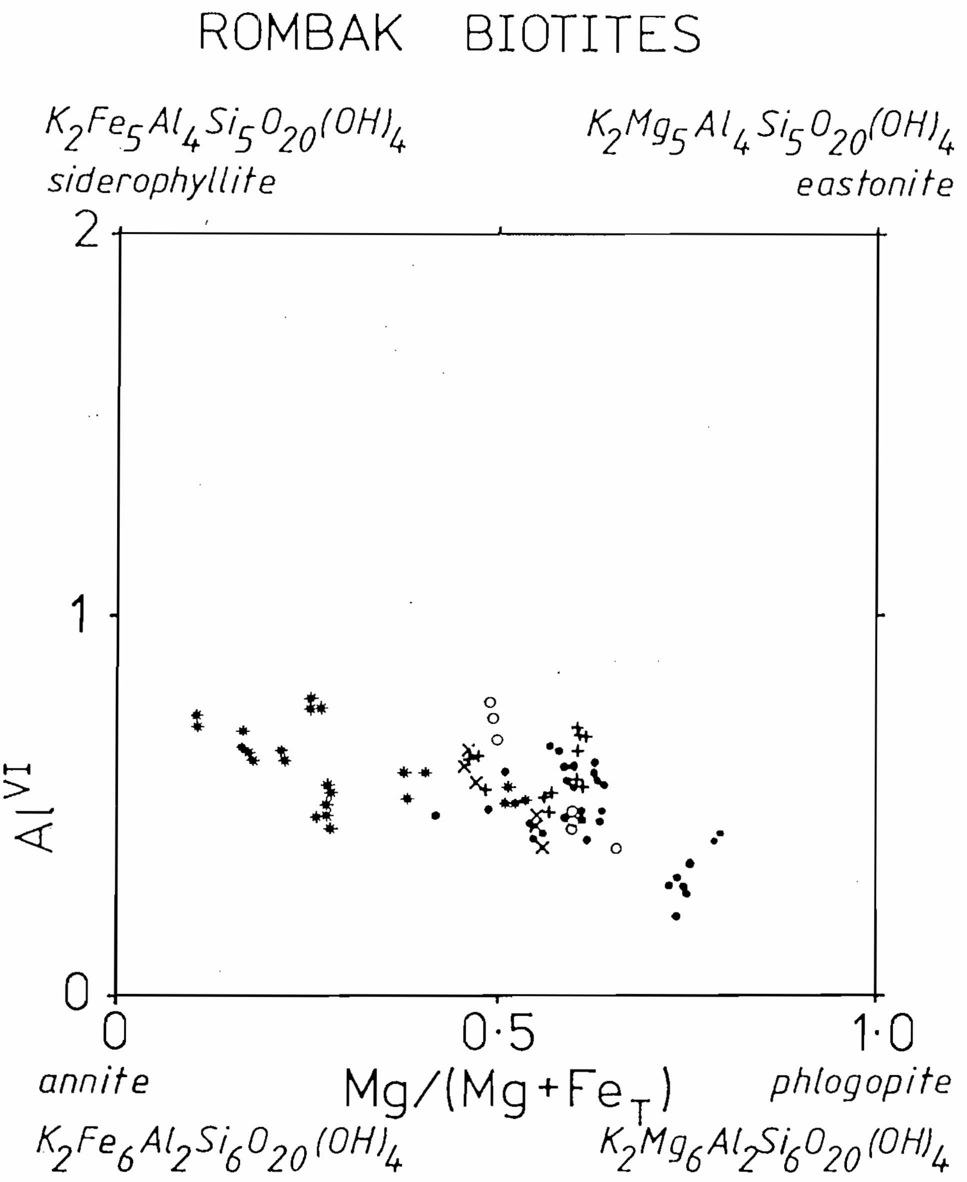


Figure 3 Composition of Rombak biotites plotted on the biotite composition space of Guidotti (1984), which treats all iron as Fe_T. Open symbols are from rocks containing ilmenite, all others from magnetite bearing assemblages.

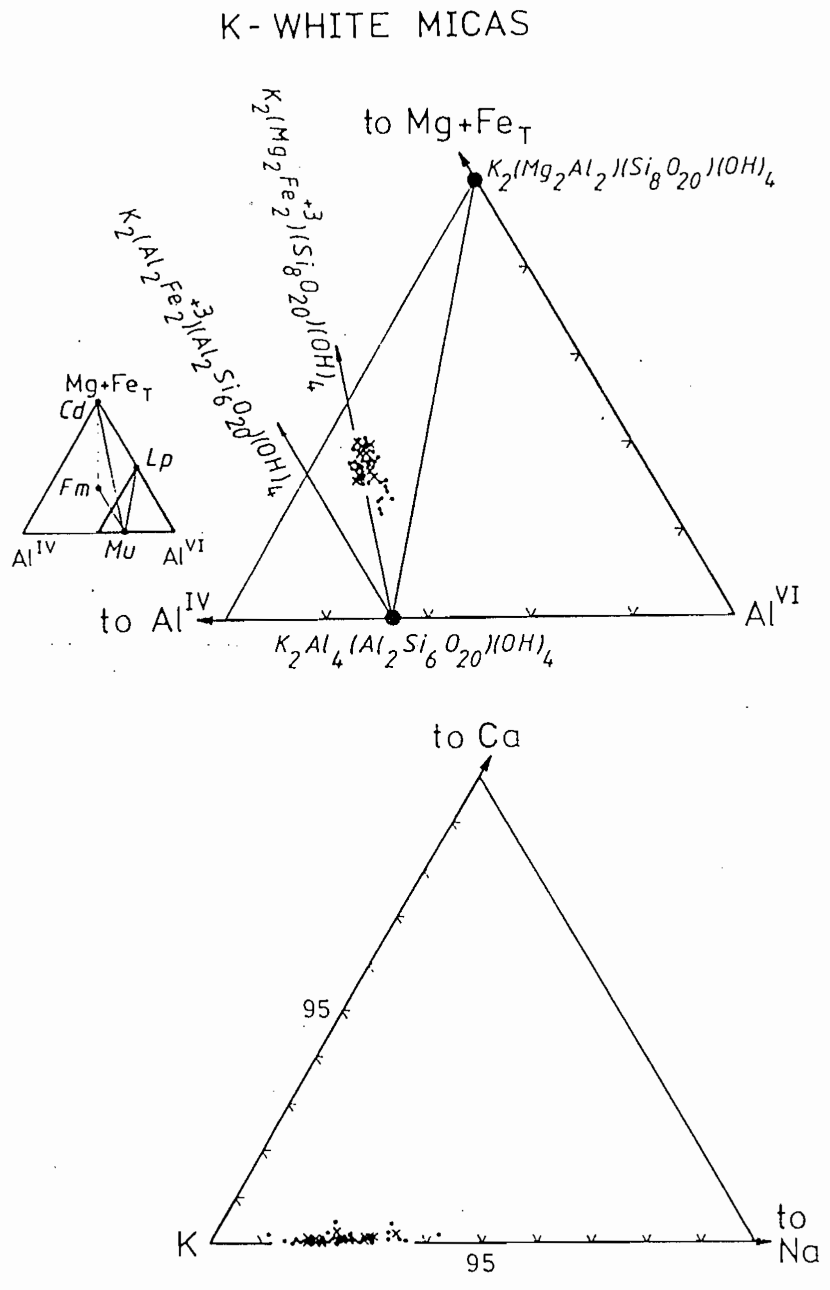


Figure 4 K-white micas plotted on the Al^{IV}-Al^{VI}-($Mg+Fe_T$) diagram of Guidotti (1984) showing end member compositions. Cd = celadonite, Lp = leucophyllite, Fm = ferrimuscovite, Mu = muscovite. Rombak white micas plot close to the muscovite-celadonite tie line with 15-20 mol % of celadonite. Lower diagram shows that the Rombak K-white micas have low margarite (Ca) and paragonite (Na) contents.

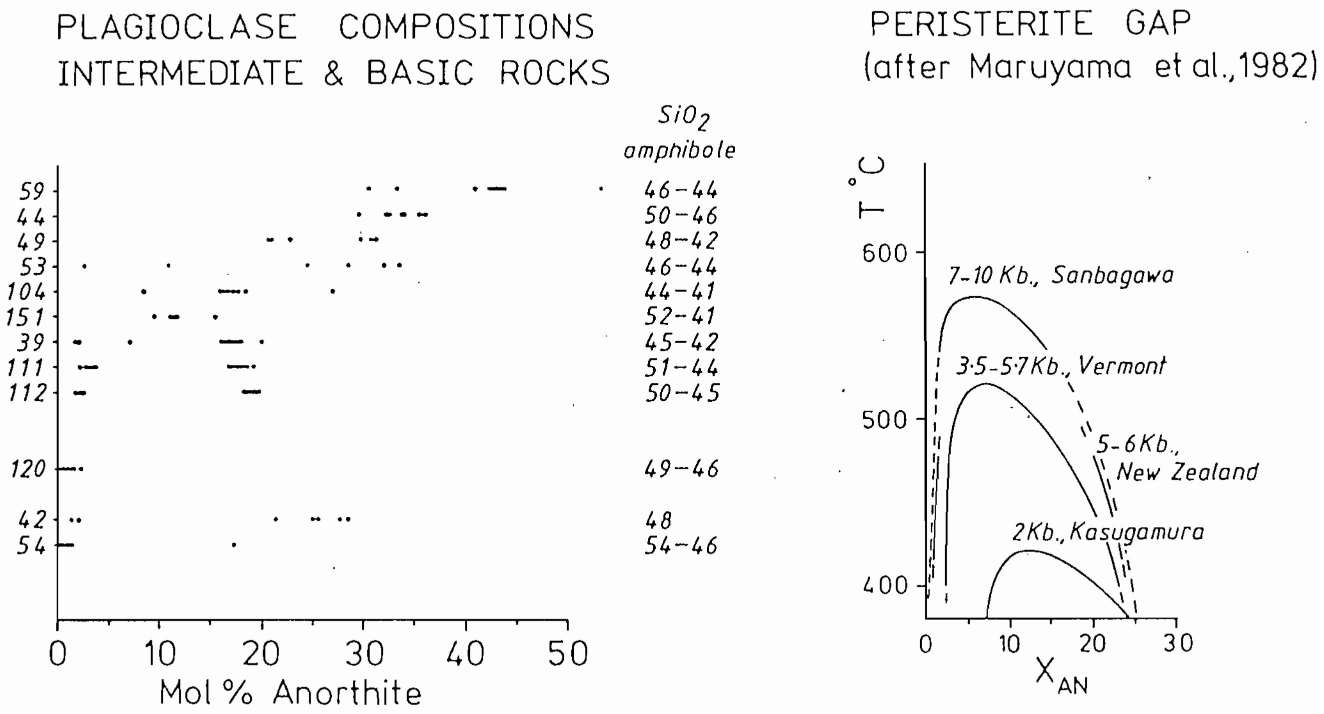


Figure 5 Composition of plagioclase in Rombak basic and intermediate rocks that contain only prograde zoning profiles. The sample ordering along the vertical axis is based upon SiO_2 contents of coexisting amphibole. Samples 42 and 54 contain K-feldspar and samples 111 and 112 contain chlorite. The peristerite gap present in the Rombak rocks is compared to those discussed by Maruyama et al., (1982).

substitution is also favoured by high pressure (Guidotti, 1984) and hence the Rombak K-white mica composition could also indicate growth at moderate to high pressures. All the Rombak K-white micas have the very low Na contents (Fig. 4) typical of muscovites with a high celadonite content.

Epidotes: Epidotes range in composition from Ps 0.19 to Ps 0.34 (where Ps = $Fe^{3+}/(Fe^{3+} + Al)$ and all iron is treated as Fe^{+3}). Although back scattered electron images often reveal an irregular zonation pattern in epidotes that can be related to cracks, it is never-the-less true that epidotes have more Fe^{+3}-rich cores. Epidotes enclosed within large plagioclase grains tend to be idioblastic and contain less (Ps = 0.2) Fe^{3+} than typically xenoblastic matrix epidotes (Ps = 0.28).

Plagioclase: On the basis of plagioclase compositions, four types of assemblages can be recognised in the Rombak metamorphic rocks:

a) Rocks with two seperate plagioclase phases, one an albite (An_{1-2}) and the other an oligoclase (An_{15-20}) (Fig. 5). Both plagioclases are weakly zoned; albite in contact with oligioclase has more calcic rims and oligioclase more sodic rims than their respective cores. This zonation is typicaly of prograde metabasites. (Maruyama et al., 1982).

b) Rocks with a single plagioclase, typically in the composition range An_{20-55} (Fig. 5).

c) Granites containing only albite; in these rocks a more calcic plagioclase has been extensively altered to epidote + albite, hence the presence of albite may be related to plagioclase sausseritization possibly as a retrograde feature.

d) A few rocks from the Sørdalen area, but many from the the Muotaquobla area contain albite and oligioclase, however, the zoning pattern in these suggest a retrograde formation.

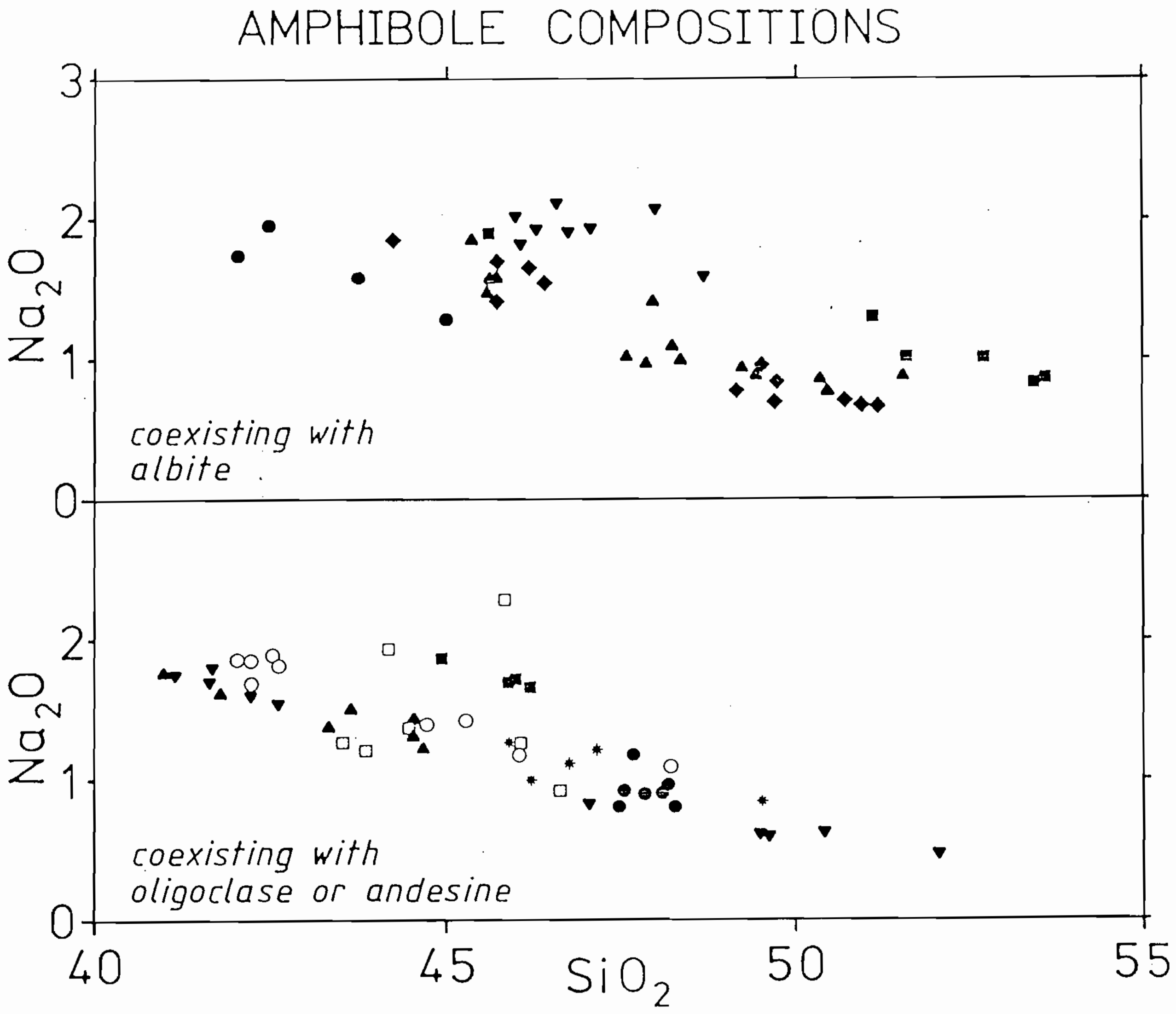


Figure 6 composition of Rombak amphiboles. Closed symbols indicate amphibole coexisting with magnetite, open symbols coexisting with ilmenite. Note that ilmenite only occurs in the oligoclase-andesine bearing samples (i.e. amphibole facies assemblages).

Recently Maruyama et al., (1982) have shown that the An content of albite is dependent upon the pressure at which the albites grew; higher pressures favour more sodic compositions. Comparing the Rombak prograde albites with data from Maruyama et al., (1982) suggests that they formed under medium to high pressures in the range 4-10 kb (Fig. 5).

Amphiboles: Amphiboles from the intermediate to basic volcanics range in composition from actinolite-tremolite to ferroan paragsite. Many rocks show two distinct, or more usually, a range of amphibole compositions. Zoned or mantled grains have cores that contain less Al, Fe and Na than the rims or mantles. Amphiboles that coexist with albite tend to contain more SiO_2 and less Na and Fe than those coexisting with more calcic plagioclase (Fig. 6). All the amphiboles come from rocks that contain a Ti saturating phase, either sphene or ilmenite, then the low Ti contents (<0.05 Ti per 23 oxygens) may reflect amphibole formation at medium metamorphic pressures (Hynes, 1982).

Clinopyroxene Diopside containing approximately 0.5 wt % Na_2O occurs in one subalkaline low-K metabasite. Weak zoning indicates that rims are slightly more ferroan than cores.

Magnetite: Magnetite is the opaque phase in most of the Rombak rocks. microprobe analyses indicate no ilmenite intergrowths; and a low Ti content. The only exception is a single sample which contained Ti magnetite containing 9.4 wt % TiO_2 in the cores and 3.5 wt % at the rims.

Ti-bearing phase: Most rocks contain sphene, however, a few oligioclase/andesine bearing intermediate to basic volcanics contain ilmenite often with magnetite. Ilmenite contains between 2 and 7 wt% MnO.

Garnet: Analysed garnets are small (<0.5 mm) and volumetrically (<0.1 wt %) minor constituents of the rocks in which they occur. All garnets are spessartine rich, especially in the cores. Typical garnet rim compositions are $Al_{0.39}$ $Spess_{0.31}$ $Py_{0.04}$ $Gross_{0.26}$.

PHASE RELATIONS

Mineral assemblages are more easily represented by projection from epidote onto the (Al_2O_3 + Fe_2O_3)-(K_2O)-(FeO + MgO + MnO) face of the tetrahedron shown in Fig. 2. Such a A^*-K-FM projection (Fig. 7) is suitable for most of the Rombak rocks, only the metagraywackes (no epidote) and marbles cannot be satisfactorily shown. Figure 7 clearly illustrates that K-white mica is confined to the bulk composition containing a large A^* component, whereas amphibole occurs in low A^* assemblages. The K-white mica-biotite and biotite-amphibole tie lines divide the Rombak rocks into two groups; those with high K_2O contents in which K-feldspar coexists with one or two other K_2O-bearing phases, and a low K_2O group in which biotite is the only K_2O phase and coexists with chlorite or garnet. Bulk compositions with low K and low Al and which contain a single plagioclase (oligioclase or andesine) (Fig. 8) may contain diopside, whilst more aluminous compositions contain garnet but not amphibole.

Although Fig. 7 and 8 show all the observed mineral assemblages in epidote-bearing rocks from the Rombak Window it is obvious that such a projection cannot show the Fe-Mg solid solution that affect all the phases except epidote and K-feldspar. Thus, a further projection is required for the K-feldspar bearing rocks onto the A^{**}-F-M plane (Fig. 9). For rocks lacking K-feldspar a projection from epidote onto A^*-F-M is used (Fig. 9), (this is analagous to the projection of Graham and Harte (1975)). Rocks lacking albite or microcline require a new projection from a more calcic

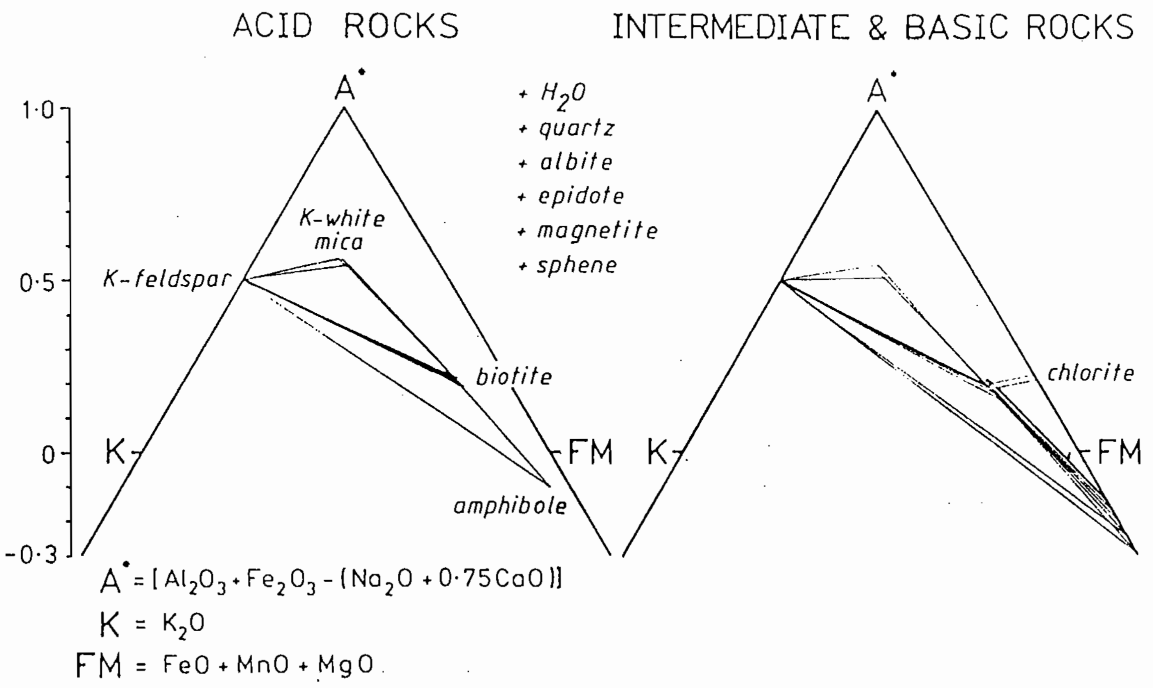


Figure 7 A^*-K-FM projection of mineral compositions for Rombak rocks containing albite ± K-feldspar.

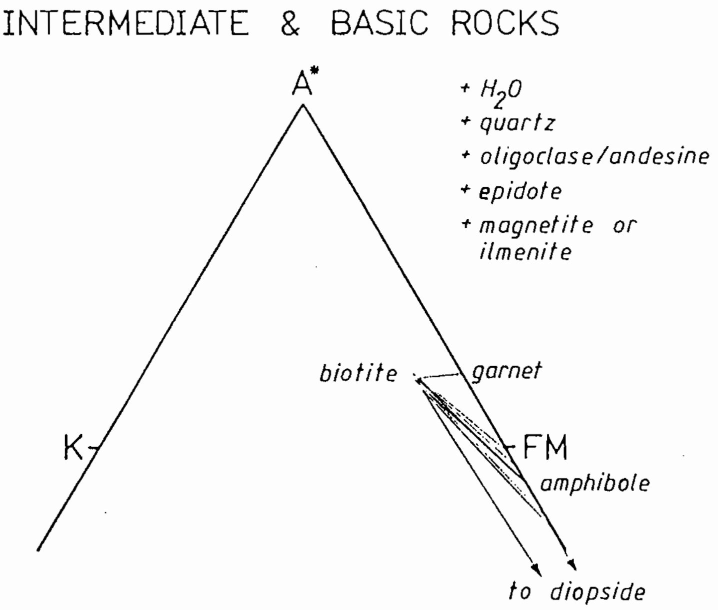


Figure 8 A^*-F-M projection for oligoclase/andesine bearing intermediate and basic rocks. Note apparent development of amphibolite facies assemblage in low K rocks only. This may be an artifact of sampling.

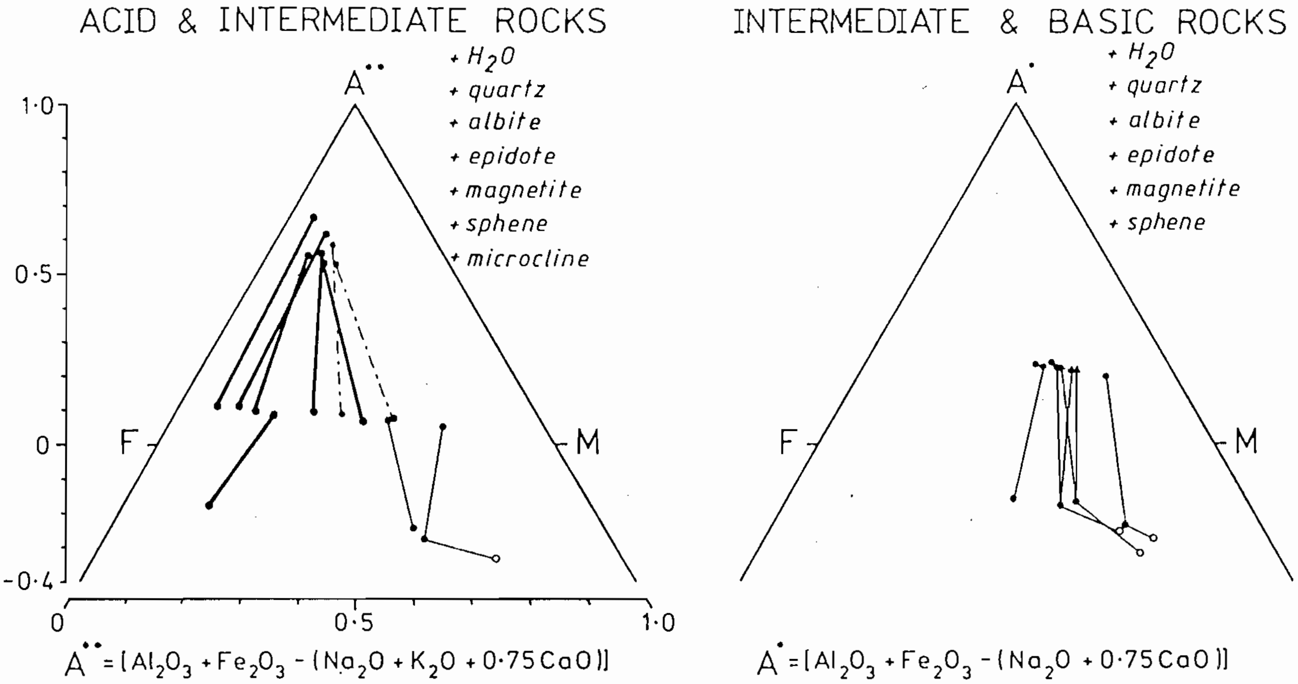


Figure 9 A**-F-M and A*-F-M projections for albite bearing rocks from the Rombak window. K-white micas plot at the top of the diagram, biotites and chlorites (triangles) in the centre and amphibole at the bottom. Open circles indicate amphibole cores. K-white micas, biotite and chlorites represent the average ofseveral analyses, but the range is smaller than the symbol used. Heavy lines = granites, light lines = intermediate and basic rocks, dashed lines = sheared intermediate and basic rocks.

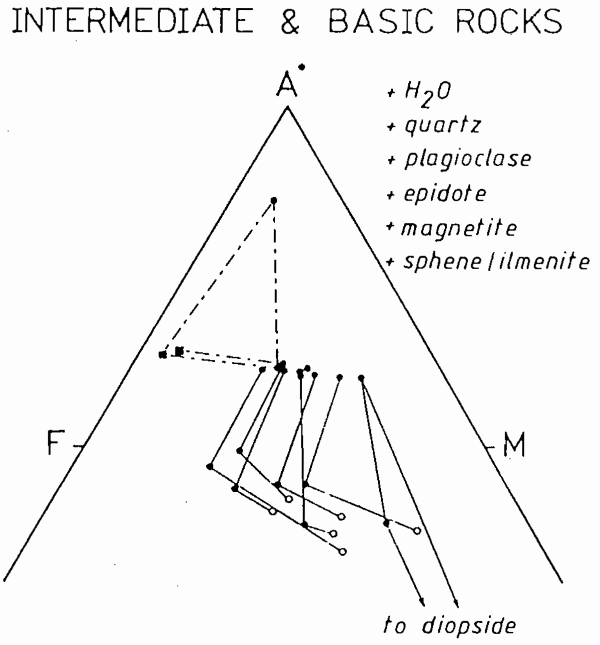


Figure 10 A*-F-M plot of amphibolite facies assemblages in intermediate to basic rocks. Squares = garnet, other symbols as on Fig. 9.

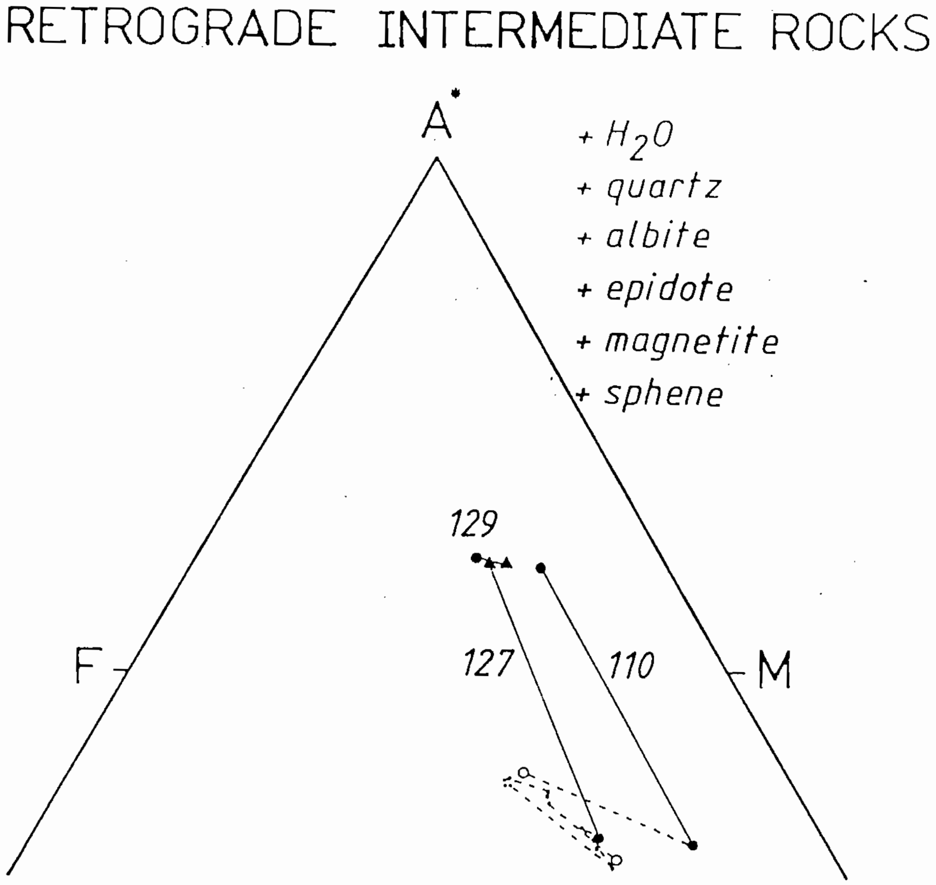
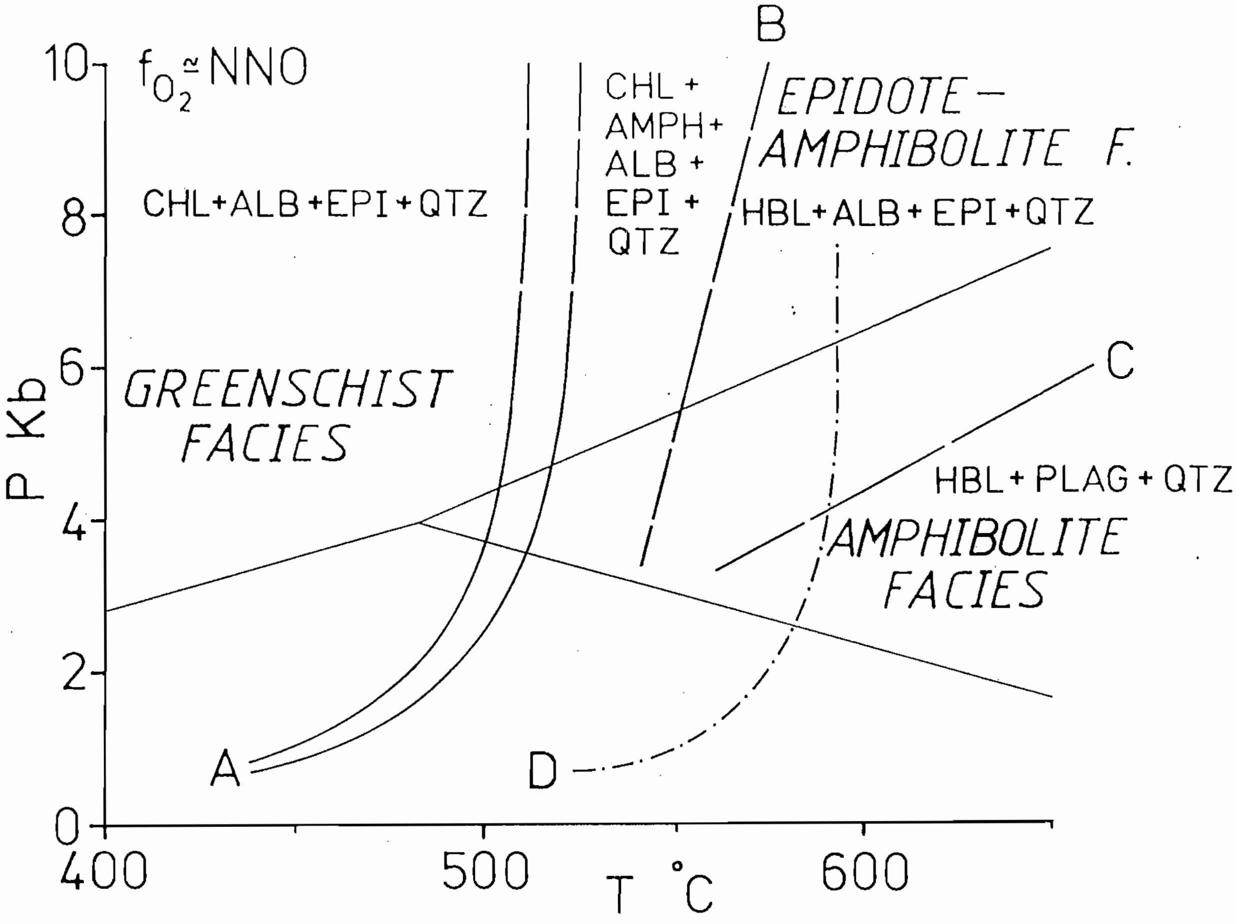


Figure 11 Retrograde zonation profiles in amphibole from Sørdalen (110) and Muotaguobla (127 & 129). Note the initial prograde zoning trend in the Muotaguola sample followed by the retrograde trend back to actinolite/tremolite. Sample with chlorite-biotite represents a completely retrogressed intermediate volcanic from Muotaguobla. Triangles = chlorite, open circles = amphibole cores.



<u>Figure 12</u> P-T diagram of relevant equilibria for basic rocks from Moody <u>et al.</u>, (1982) and Apted and Liou (1983). A = begining of chlorite breakdown, B = chlorite out boundary marking the begining of epidote-amphibolite facies. C = upper limit of epidote + albite stability marking the appearance of amphibolite facies assemblages. A, B and C at NNO. D boundary of amphibolite facies at fO_2 of IM buffer. Al_2O_3 triple point from data in Helgeson <u>et al.</u>, (1978). Region between A and B represents the transition region from greenschist to epidote-amphibolite facies.

plagioclase composition, however for the sake of simplicity they are also plotted on A^*-F-M, with the understanding that crossing tie lines could result (Fig. 10).

Figures 9 and 10 illustrate the principal change from albite-bearing to higher-grade oligoclase/andesine-bearing assemblages. In the basic and intermediate rocks the disappearance of chlorite accompanies an increase in the Al_2O_3 and FeO content of amphibole and a decrease in the Fe^{3+} content of epidote. The amphibole composition change can be seen in the swing of the amphibole rim-biotite tie lines from Fig. 9 to 10. These changes coincide with the Na_2O and SiO_2 changes shown on Fig. 6. The coexistence of aluminous amphibole (hornblende) with albite (Figs. 5, 6, 7 and 9) in some rocks is significant, and indicates the presence of the epidote-amphibolite facies. Thus although the Rombak rocks show the same mineralogical and compositional trends as reported by Miyashiro (1973), Laird (1980), Maruyuama _et al._, (1983) for the greenschist to amphibolite facies assemblages, they also include the intermediate epidote-amphibolite facies.

Breakdown of the greenschist facies assemblage to that of the epidote-amphibolite facies can be approximated by:

chlorite + albite + epidote + actinolite + quartz =

hornblende + albite + epidote + H_2O

(Apted and Liou, 1983), and subsequently amphibolite facies assemblages appear through the fO_2 dependent albite + epidote breakdown e.g.

hornblende_1 + albite + epidote + quartz = hornblende_2 + plagioclase + H_2O

(Apted and Liou, 1983).

When temperatures become high enough, diffusion within zoned, or mantled, amphiboles should yield hornblendes of the near uniform composition characteristic of amphibolite facies, Hornblende-biotite tie lines should then swing back somewhat towards MgO. The crossing tie line from the weakly zoned amphiboles in one sample on Figure 10 may indicate the begining of such an amphibole homogenisation.

It is also interesting to note that the K-feldspar bearing intermediate rocks (Fig. 9) show a similar amphibole composition change and biotite-amphibole rim tie line swing as the K-feldspar free rocks. However, Fig. 7 indicates that the K-feldspar bearing rocks cannot contain chlorite at these metamorphic grades. This, therefore implies that the increase in FeO, Na_2O and Al_2O_3 of the amphiboles arises soley by epidote and albite breakdown, or alternatively biotite breakdown occurs (analogous to chlorite disappearance in low K-rocks). A reaction similar to:

albite + epidote + actinolite + $biotite_1$ + quartz =

hornblende + albite + K-feldspar + $biotite_2$

may be applicable to the K-feldspar bearing intermediate volcanics in the transition from greenschist to higher metamorphic grades.

Figures 7, 9 and 10 show that the samples from ductile shear zones have experienced an increase in A^* component during deformation. The hornblende + K-feldspar + biotite or biotite + hornblende assemblages in massive intermediate metavolcanics are replaced by K-feldspar + K-white mica + biotite or garnet + K-white mica + biotite assemblages respectively in the foliated rocks of the ductile shear zones.

Although most of the Rombak rocks show zoning profiles in amphibole, epidote and plagioclase that is consistent with prograde metamorphism, some rocks, notably from the Muotaguobla area, contain textural and mineralogical evidence of retrogression.

Amphiboles in an intermediate metavolcanic from Sørdalen (110, Fig. 11) show a reverse zonation trend with aluminous amphibole cores and actinolite-tremolite rims. Texturally the Sørdalen rock does not appear retrogressed. However, the Muotaguobla area contains rocks that are often completely retrogressed to chlorite-biotite (29, Fig. 11). Nevertheless a few partially altered chlorite-amphibole samples (e.g. 127, Fig. 11) contain evidence of the earlier prograde metamorphic history in their zoning profiles. Thus the amphiboles of 127 have actinolite-tremolite cores, surrounded by aluminous amphibole (hornblende) mantles which are in turn mantled by actinolite tremolite. Albites from the retrogressed rocks are very sodic (An_{0-2}) and suggest that the greenschist retrogression occured at high pressure (>4 kb).

METAMORPHIC CONDITIONS

The mineralogical and compositional data from the basic to intermediate volcanic rocks of the Rombak window are characteristic of metamorphic conditions transitional form the greenschist facies to the epidote amphibolite and amphibolite facies. However, this transition occurs over a considerable temperature and pressure range because of the bulk compositional effects (especially fO_2), and the transition principally involves continuous reactions (Laird, 1980; Moody et al., 1982; Apted and Liou, 1983). The presence of the epidote-amphibolite assemblages precludes metamorphism at low pressures (< 3-4 kb). The composition of Rombak K-white micas and albites, together with the presence of kyanite in some quartz veins also suggest moderate to high pressures.

The breakdown of chlorite and epidote (A, Fig. 12) and the production of a more aluminous amphibole begins at about 500 - 525 °C (Moody et al., 1982; Apted and Liou, 1983) under fO_2 conditions suitable for magnetite stability. Since chlorite is present in only three of the Rombak rocks (and in those it coexists with aluminous amphibole) the chlorite-out reaction provides a lower estimate of temperature. From the 5 and 7 kb experiments of Apted and Liou (1983) carried out using a natural basalt starting material, the chlorite-out reactions (B, Fig. 12) occurs at 550 - 570 °C respectively at the NNO buffer. In the kyanite stability field the chlorite-out boundary marks the beginning of the epidote amphibolite facies.

The amphibolite facies begins with the development of hornblende of hornblende-oligoclase/andesine ± ilmenite assemblage (Miyashiro, 1973), resulting from the breakdown of epidote and sphene. This transition is also strongly dependent upon fO_2. At the NNO or HM buffers the epidote amphibolite facies presists to much higher temperatures than at fO_2 conditions of the IM buffer (compare C and D Fig. 12, Moody _et al._, 1982; Apted and Liou, 1983). The temperature difference can amount to as much as 100 °C (Fig. 12). Since, in the Rombak Window rocks containing transitional upper greenschist, epidote-amphibolite and amphibolite facies assemblages can occur within a few tens of meters it is unreasonable to propose local sharp temperature or pressure gradients. A more reasonable explanation for the close proximity of the three assemblages is variations in the bulk composition, especially fO_2 which stablized the three assemblages at similar P-T conditions. In support of this is the observation that magnetite is the opaque present in most rocks, but some rocks containing the amphibolite facies assemblage contain ilmenite.

The observed mineral assemblages in the basic and intermediate volcanic rocks of the Rombak Window is consistent with metamorphism at temperatures between 575-600 °C and pressures greater than 6 kb. The Proterozoic rocks in the Rombak Window were, therefore, metamorphosed under conditions not significantly different to those reported from the overlying Caledonian nappes.

AGE OF METAMORPHISM

If the rocks in the Muotagoubla area (Fig. 1) are in fact Dividal as Birkeland (1978) shows then the structures they contain, must be Caledonian in age. Therefore, it follows that the greenschist retrograde event so prevalent in these rocks must also be Caledonian. Structures in the supposed Dividalen rocks can be traced into adjacent Proterozoic intermediate volcanics, and the prograde epidote-amphibolite facies to amphibolite facies they contain post-date these structures, therefore the earlier prograde event must also be Caledonian. However, if the correlation of the Dividalen Group proves to be incorrect, then although the metamorphism may still be Caledonian in age, isotopic dating on mineral seperates will be required.

CONCLUSIONS

The Rombak Window, at least in its central, western and southwestern parts, has been metamorphosed to epidote-amphibolite/amphibolite facies grades (P > 6 kb, T 575 to 600°C). Evidence for this is widely preserved in the mineral zonation patterns found in the intermediate and basic volcanics. Thus basement metamorphism was of similar grade to that which affected the overlying Caledonian nappes. A later greenschist facies retrogression, possibly also of moderate to high pressure, has affected the window to varying degrees. In most places retrograde reequilibration of minerals is absent or minor. However, in the Muotaguobla area the greenschist retrogression has virtually obliterated evidence of the earlier higher grade metamorphism. The intensity of retrogression in the Muotaguobla area may be related to the existence of a major N-S trending structural lineament in the vicinity.

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