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PHASE RELATIONS IN AL_2SIO_5 POLYMORPHS; LE CONQUET REGION, NORTH-WESTERN BRITTANY, FRANCE

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Three types of Al_2SiO_5-bearing aggregate are preserved in gneiss from the Le Conquet region of north-western Brittany. These aggregates display two sequences of Al_2SiO_5 polymorph growth. In pseudomorphs after garnet, and in matrix aggregates, the sequence kyanite - andalusite - fibrolite is preserved, and in andalusite porphyroblasts the sequence kyanite - coarse sillimanite - andalusite - fibrolite occurs. Four mechanisms are proposed to explain the apparent conflicting histories of metamorphic evolution suggested by these sequences. Metastable growth of Al_2SiO_5; reaction domains; production by continuous reaction; and the differing behaviour of Al_2SiO_5 polymorphs during syntectonic metamorphism.

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INTRODUCTION

The occurrence of metapelitic rocks containing the Al_2SiO_5 polymorphs kyanite, sillimanite and andalusite is always noteworthy, because of the continuing debate and conflicting experimental data regarding the positioning of the Al_2SiO_5 triple point (for a review see Kerrick, 1990), and its importance for metamorphic petrology. Only a few examples of true equilibrium triple point assemblages have been recorded (e.g. Grambling, 1981; Grambling and Williams, 1985). In the majority of cases rocks containing the Al_2SiO_5 polymorphs show clear textural relations indicating a sequence of mineral growth from which a common metamorphic history can be determined. An example is described here, from a single sample of gneiss, in which the textural relations amongst the Al_2SiO_5 polymorphs clearly indicates a progressive sequence of mineral growth, but within which the analysis of adjacent Al_2SiO_5 -bearing aggregates may give conflicting information concerning the metamorphic evolution of the sample in question. In this paper I propose several possible mechanisms to account for and reconcile the apparent disparity illustrated by these aggregates.

SAMPLE LOCATION AND GEOLOGY OF THE STUDY AREA

A single sample of gneiss containing Al_2SiO_5-bearing aggregates was collected from the Presqu'ile de Kermorvan in the vicinity of Le Conquet, Léon region, north-western Brittany, France (Figure 1).

The Léon region is situated in the north-west of the Armorican Massif (Figure la). It is bounded to the south-east by the Léon fault (Brun and Balé, 1990), and is dissected by a major dextral strike-slip fault, the North Armorican Shear Zone (NASZ) (Chauris, 1972; Hirbec, 1979; Watts and Williams, 1979). The Léon region (Figure lb) is composed of a sedimentary succession and a series of igneous complexes (Le Corre et al., 1989), which were metamorphosed during the period 440 to 385 Ma, and in which the metamorphic grade increases towards the north (Cabanis *et al.*, 1979). Three major units of contrasting character can be identified in the region (Figure 1b). A southern belt consisting of sediments metamorphosed in the greenschist to amphibolite facies, including the Quartzophyllades de L'Elorn and the Micaschists du Conquet, into which a foliated calcalkaline granodiorite, the Gneiss de Brest, was emplaced (Bishop *et al.*, 1969). The Gneiss de Brest has been imprecisely dated at 460 ± 70 Ma (U-Pb on zircon, Michot and Deutsch, 1970; see also Cabanis et al., 1977). An intermediate belt is composed of a series of upper amphibolite facies Para- and orthogneisses which are collectively

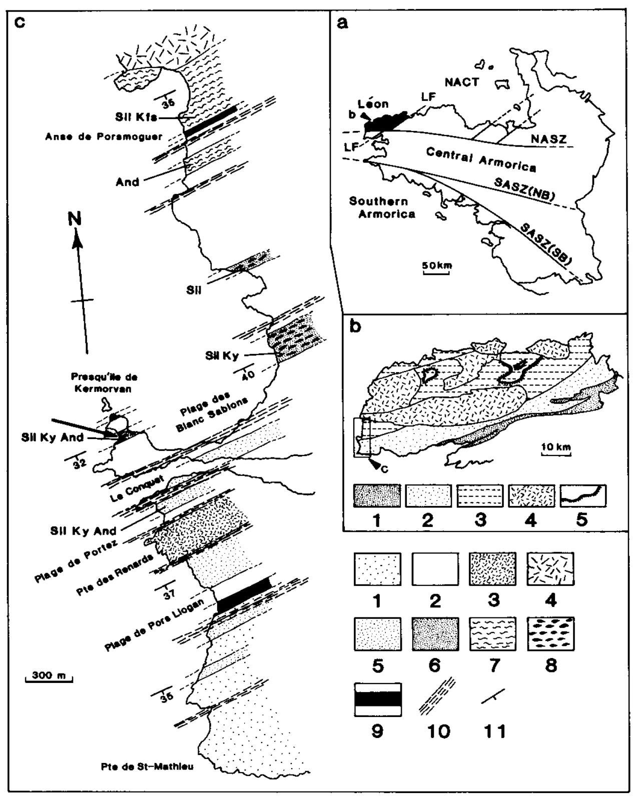

Figure 1: a) Geology of the Armorican Massif. NACT - North Armorican Composite Terrane. NASZ - North Armorican Shear zone. SASZ - South Armorican Shear Zone, (NB) - northern branch, (SB) - southern branch. LF - Léon Fault. Location of Fig 1b is indicated. b). Geology of the Léon Region (after Chauris, 1972). 1. Quartzophyllades de L'Elorn. 2. Gneiss de Brest. 3. Gneiss de Lesneven. 4. Variscan granites. 5. Mylonitic gneisses with eclogite boudins (after Cabanis and Godard, 1987). Location of Fig 1c is indicated. c) The Geology of the Le Conquet area (in part after Roper, 1980). 1. Gneiss de Brest. 2. Gneiss de Lesneven. 3. Pointe des Renards complex. 4. Variscan granite. 5. Garnet-staurolite schists. 6. Sillimanite gneisses. 7. Sillimanite - K feldspar migmatites. 8. Sillimanite bearing leucocratic segregations. 9. Amphibolite and metagabbro. 10. Mylonites. 11. Orientation of main foliation. Arrow indicates sample location.

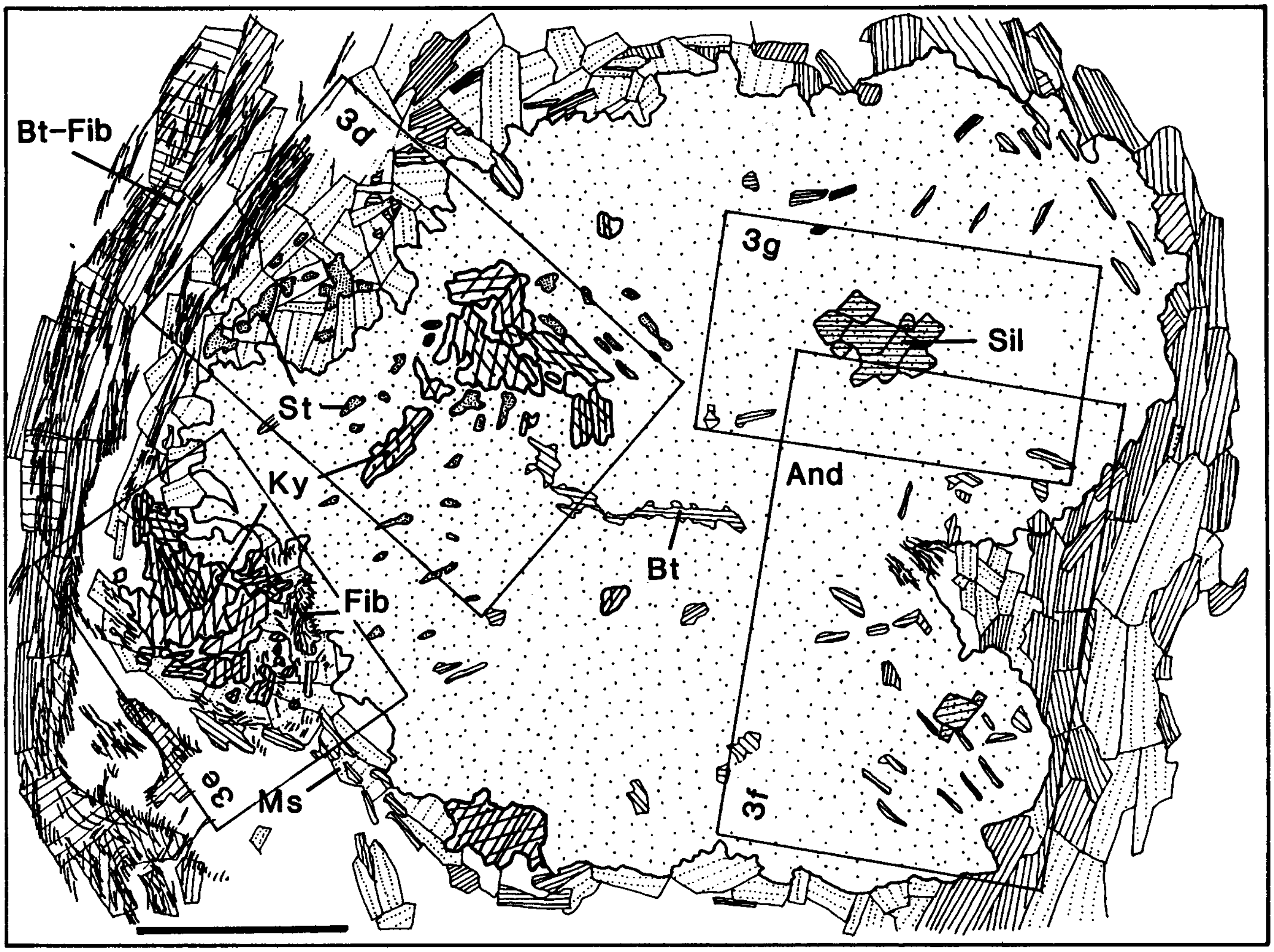

Figure 2: Textural relations within and surrounding an andalusite porphyroblast. Inset boxes indicate location of photomicrographs in figure 3d, e, f, and g. Sketch from photomicrograph composite and thin section. Scale bar 3 mm.

termed the Gneiss de Lesneven (Chauris, 1972). The age of metamorphism in these gneisses has been bracketed between 400 ± 40 Ma (U-Pb on zircons, Cabanis *et al.,* 1979) and 385 ± 8 Ma (Rb-Sr whole rock isochron, Cabanis *et al.,* 1979), an age interpreted as the metamorphic peak. A series of basic rocks which preserve an eclogite-facies metamorphic event (Godard and Cabanis, 1987), yields an age of 439 ±13 Ma (U-Pb on zircons, Paquette *et al.,* 1987), and was tectonically emplaced within the gneisses (Figure 1b). A northern belt (the Plougerneau Migmatite Complex) comprises acid to intermediate intrusives and migmatised sediments. Intruded into this sequence was a suite of Variscan granites. An early phase (330 to 340 Ma - Rb-Sr whole rock isochron and K-Ar mineral ages, Leutwein *et al.,* 1969) has been emplaced synchronous with an initial phase of strike-slip movements along the NASZ (Peucat *et al.,* 1984; Gore and Le Corre, 1987). A later phase (300 to 290 Ma - Rb-Sr whole rock isochrons, Georget *et al.,* 1986; Peucat *et al.,* 1984; Le Corre *et al.,* 1989) has been affected by subsequent strike-slip deformation along the NASZ. A series of late microgranite dykes (282 ± 5 Ma, Rb-Sr whole rock isochron) remain undeformed (Chauris *et al.,* 1977).

In a coastal section in the vicinity of Le Conquet, from Pointe de St. Mathieu in the south to Anse de Porsmoguer in the north, a sequence of tectonically emplaced metasedimentary `screens' occur within a series of orthogneisses collectively termed the Gneiss de Brest and Gneiss de Lesneven (Figure 1c). Power and Taylor (1988) and Jones (in press) have interpreted these rocks as a major crustal-scale shear zone. The metasedimentary screens and xenoliths within the gneisses preserve a Barrovian-type metamorphic sequence which exhibits a sharp increase in metamorphic grade from the south to the north. In the south are spectacular garnet-staurolite schists. North of Le Conquet on the Presqu'ile de Kermorvan, sillimanite-bearing gneisses contain sillimanite-rich leucocratic segregations. These segregations are intepreted as indicating the onset of partial melting. Further north in the region of Anse de Porsmoguer, stromatic migmatites contain sillimanite and K-feldspar (Figure 1c).

DISTRIBUTION OF THE AL_2SIO_5 POLYMORPHS

A thin section study by Jones (in press) has outlined the general relationships between the Al_2SiO_5 polymorphs. Al_2SiO_5 polymorphs have not been recorded south of the Pointe des Renards (Figure 1c). Sillimanite was first recorded by Taylor (1969) from the occurrence of veins of sillimanite and albite. Kyanite, sillimanite and andalusite have been recorded, in garnet- and staurolite-bearing schists at Plage de Portez. Kyanite occurs as a relict phase in biotite and quartz along with some staurolite in garnet-rich layers. The main foliation (S4; see Jones in press) is defined by an intergrowth of biotite and fibrolite. Intergrowths of biotite and fibrolite mantle and replace staurolite (see Figure 3a). Andalusite porphyroblasts contain rounded fragments of staurolite (occurring in optical continuity) and overgrow fibrolite foliae.

On the Presqu'ile de Kermorvan, sillimanite gneisses contain abundant relict kyanite and staurolite with biotite. The main foliation consists of an intergrowth of biotite and fibrolite. Andalusite occurs as large porphyroblasts enclosed in muscovite.

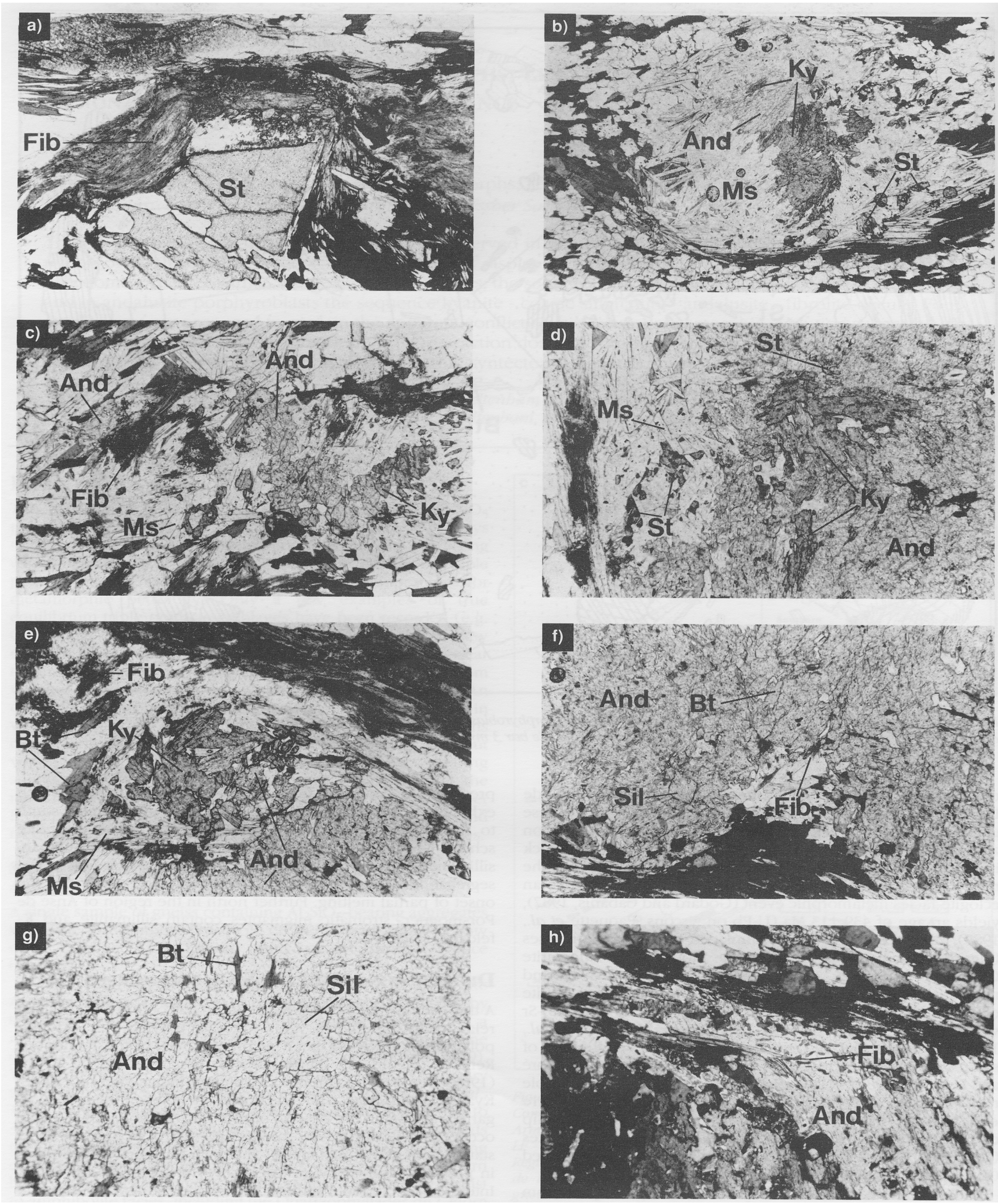

Figure 3. Textural relations in Al_2SiO_5 -bearing aggregates. a) Fibrolite replacing staurolite porphyroblast. Note the coarsening of fibrolite in low-strain area (microfold). b) Pseudomorph after garnet. Note the occurrence of staurolite surrounding the aggregate. c) Matrix aggregate. Kyanite is replaced by andausite (right centre) and muscovite containing fibrolite (centre). Note fibrolite replacing andalusite (left centre). d) Relict staurolite and kyanite in andalusite porphyroblast. Note intergrowth of staurolite and muscovite (centre left) replacing andalusite (see Figure 2 for location of photomicrographs d, e, f and g). e) Radiating kyanite partially replaced by andalusite, inturn replaced by muscovite containing fibrolite. Note the presence of an intergrowth offibrolite and biotite mantling the aggregate (see also Figure 2). f) Textural relations on an andalusite porphyroblast margin. Overgrowth of idioblastic coarse sillimanite. Andalusite contains biotite and is partially replaced by fibrolite. g) Coarse sillimanite in andalusite. h) Overgrowth of fibrolite on the margin of an andalusite porphyroblast. Width of field 3 mm in all cases. All photomicrographs are taken from the same gneiss with the exception of 3a.

Fibrolite-rich leucocratic segregations are interpreted as marking the initial stages of partial melting (for a more detailed description of these gneisses see below). In the gneisses and migmatites further to the north kyanite is no longer present. Relict staurolite, coarse sillimanite and fibrolite occur within muscovite plates. Andalusite porphyroblasts persist to the highest grades exposed. At Anse de Porsmoguer stromatic migmatites contain leucocratic segregations consisting of microcline, plagioclase, muscovite, sillimanite and quartz. Mafic selvages on the margins of these segregations contain biotite and fibrolite folia. Fibrolite, coarse sillimanite and rounded fragments of staurolite occur enclosed in coarse muscovite plates. Muscovite plates are replaced by fibrolite, which itself is pseudomorphed by muscovite. To the north of Le Conquet enclaves and xenoliths occurring in the orthogneisses contain coarse sillimanite and fibrolite enclosed in coarse muscovite plates. Bale and Brun (1986) have recorded an occurrence of kyanite, sillimanite and andalusite within enclaves occurring adjacent to the eclogites in the north of the massif.

FIELD OBSERVATIONS

The metasedimentary screen from the Presqu'ile de Kermorvan contains a compositional heterogeneity (bedding S0?). Pelitic horizons have developed a gneissose fabric which is characterised by a strong biotite-rich foliation within which discontinuous leucocratic segregations (1 to 5 cm in thickness) occur. These segregations consist of plagioclase and quartz and contain no mafic selvage unlike those at Anse de Porsmoguer. Gneiss layers up to 10 cm in thickness contain Al_2SiO_5 occurrences. Two types can be clearly distinguished in outcrop; randomly orientated andalusite porphyroblasts (up to 2 cm in length) occur partially replaced by muscovite; and polymineralic 'knots' of Al_2SiO_5 (up to 2 cm in diameter) which are interpreted as pseudomorphs after garnet. Rare examples of layers containing remnants of garnet and staurolite occur within adjacent layers (these garnets have been used for thermobarometry, see below). Semi-pelitic and psammitic layers up to 5 cm in thickness have developed a fine-grained gneissose fabric defined by biotite, in which discontinuous leucocratic segregations, up to 1 cm in thickness, occur. These leucocratic segregations consist of plagioclase and quartz and contain no mafic selvage. Psammitic layers contain no obvious Al_2SiO_5 occurrences. The sample described in detail below was collected from one of the pelitic gneiss layers.

PETROGRAPHY

The following description refers to a detailed petrographic study of a single sample of gneiss collected from the metasedimentary screen on the Presqu'ile de Kermorvan (Figure lc). In thin section, the gneiss sample contains the assemblage biotite + plagioclase (albite) + quartz + staurolite + coarse sillimanite + fibrolite + kyanite + andalusite + muscovite + ilmenite. The dominant foliation (mica-rich or M domains) consists of biotite alone and/or biotite intergrown with fibrolite and muscovite. Rare examples of relict kyanite and staurolite occur in these biotites. Quartz-rich or Q domains consist of quartz and plagioclase. Q domains contain rare intergrowths of kyanite and staurolite. Leucocratic segregations consist of quartz and plagioclase (albite) within which relict kyanite and 'swirling' foliae of fibrolite occur. Three types of Al_2SiO_5-bearing aggregates occur in the gneisses:-

1. Pseudomorphs after garnet

Polymineralic Al_2SiO_5-bearing aggregates, up to 1 cm in diameter, contain radiating aggregates of kyanite with biotite. These aggregates are interpreted as the replacement of garnet. Although no garnet has been found in the se Al_2SiO_5 aggregates, at lower grade both kyanite and fibrolite intergrown with biotite, mantle and partially replace garnet. Kyanite aggregates show all stages of replacement by andalusite (Figure 3b). Kyanite occurs as partially digested 'slivers' within andalusite. These aggregates are enclosed by a rim of coarse radiating muscovite, in which fragments of kyanite are preserved, and quartz. On the margins of these aggregates are rounded fragments of staurolite.

2. Matrix aggregates

Kyanite and staurolite occur in muscovite plates. These muscovites contain fibrolite and are surrounded by either quartz with fibrolite or an intergrowth of fibrolite and biotite. Fragments of kyanite occur partially enclosed in andalusite and muscovite. These are surrounded by fibrolite or an intergrowth of fibrolite and biotite. In these aggregates andalusite is partially replaced by late fibrolite (Figure *3c).* In some instances staurolite is absent from these aggregates.

3. Andalusite porphyroblasts

Andalusite porphyroblasts, up to 2 cm long, contain numerous included phases (Figure 2). Thin slivers of partially digested kyanite and rounded fragments of staurolite occur throughout the porphyroblasts (Figure 3d). Idioblastic coarse sillimanite occurs enclosed in andalusite (Figure 3f and g). In most cases, coarse sillimanite is randomly orientated and crystals are not found in optical continuity with one another. On the margins of these porphyroblasts fibrolite inclusions curve gently into and are continuous with the matrix foliation. In some instances, near the rim of the porphyroblasts, andalusite overgrows fibrolite of the matix (Figure 3h). These porphyroblasts are partially replaced by radiating muscovite plates and quartz within which aggregates of several types are preserved. Kyanite and andalusite are partially replaced by radiating aggregates of muscovite and quartz, which both contain fibrolite (Figure 3e). On occasion andalusite is absent from these aggregates.

Individual staurolites have crystallised between radiating muscovite plates (Figure 3d). Unlike the kyanite relicts these staurolites do not occur replaced or within the muscovite plates; this texture is interpreted as an intergrowth. Andalusite occurs partially replaced by late fibrolite. The andalusite porphyroblasts and related aggregates occur mantled by an intergrowth of fibrolite and biotite (Figures 2 and 3c).

METAMORPHIC REACTIONS

Kyanite and staurolite-forming reaction

The presence of kyanite intergrown with staurolite is interpreted as resulting from the reaction:

R1 Grt + Ms +Chl = Ky + St + Pl + Qtz + H_2O.

A similar reaction has been documented for such intergrowths by Yardley *et al.* (1980) in Fe-rich pelites from Connemara.

Garnet breakdown reaction

The mantling of garnet by kyanite and biotite and fibrolite intergrown with biotite is interpreted as resulting from:

R2 Grt + Ms = Bt + Ky + Qtz.

Staurolite breakdown reaction

The breakdown of staurolite is the major sillimanite (coarse sillimanite and fibrolite)-producing reaction in these gneisses and is interpreted to have resulted from:

R3 Ms + St + Qtz = Al_2SiO_5 + Bt + H_2O.

The replacement of staurolite and overgrowth of fibrolite by andalusite in the schists indicates that this reaction progressed into the stability field of andalusite.

The development of the Al_2SiO_5-bearing leucocratic segregations in the gneisses is interpreted as resulting from the reaction:

R4 Ms + Alb + Qtz = Al_2SiO_5 + L,

TABLE 1: Representative analyses of mineral compositions used in thermobarometry

	Garnet	Biotite
SiO_2	36.947	35.113
Al_2SiO_5	21.495	20.535
TiO_2	2.519	
FeO	35.487	21.333
MnO	2.098	—
MgO	2.922	7.800
CaO	0.984	—
K_2O	8.708	
Total	99.933	96.131
	(24 oxygens)	(22 oxygens)
Si	5.960	5.311
Al^4	0.040	2.689
Al^6	4.048	0.973
Ti	—	0.287
Fe	4.788	2.698
Mn	0.287	—
Mg	0.703	1.758
Ca	0.170	—
K	—	1.680

although in layers of appropriate composition partial melting would have occurred at the metapelite solidus. The above reaction may have initiated in the kyanite stability field and continued to operate in the stability field of sillimanite.

PHYSICAL CONDITIONS OF METAMORPHISM

An evaluation of the conditions of metamorphism attained by the gneisses is illustrated on Figure 4. Representative analyses of mineral compositions used in thermobarometry calculations are presented in Table 1. Temperatures have been estimated by application of the garnet-biotite thermometer of Perchuk and Lavrent'eva (1983) and are consistent with the assemblages present. An upper pressure limit for these samples is based on application of the GRAIL barometer of Bohlen *et al.* (1983). Application of garnet-plagioclase-Al_2SiO_5-quartz barometry to these samples has proven unsuccessful owing to the presence of albite (Jones, in press).

ORIGIN OF THE AL2SIO5 OCCURRENCES

Two sequences of Al_2SiO_5 growth occur within the aggregates. In the pseudomorphs after garnet and in the matrix aggregates:

kyanite — andalusite — fibrolite,

in the andalusite porphyroblasts;

kyanite — coarse sillimanite — andalusite — fibrolite.

Any attempt to reconcile the apparent disparity in the evolution exhibited by these aggregates has to assume that the sample studied must have attained the same physical conditions of metamorphism and be located on the same pressure-temperature (P-T) path. A P-T path for the evolution of the sample is illustrated in Figure 4. Four basic mechanisms are proposed to explain the origin of these aggregates.

1. Metastable growth of Al_2SiO_5

Pseudomorphs after garnet. Replacement of garnet by kyanite and biotite could have occurred through reaction R2 (see above and point 1, Figure 4). The direct replacement of kyanite by andalusite is interpreted as a 'volume for volume' replacement and a paramorphic transformation. Similar textures have been recorded by Kerrick (1988). In a sample which has clearly passed through the stability field of sillimanite, the replacement of kyanite by

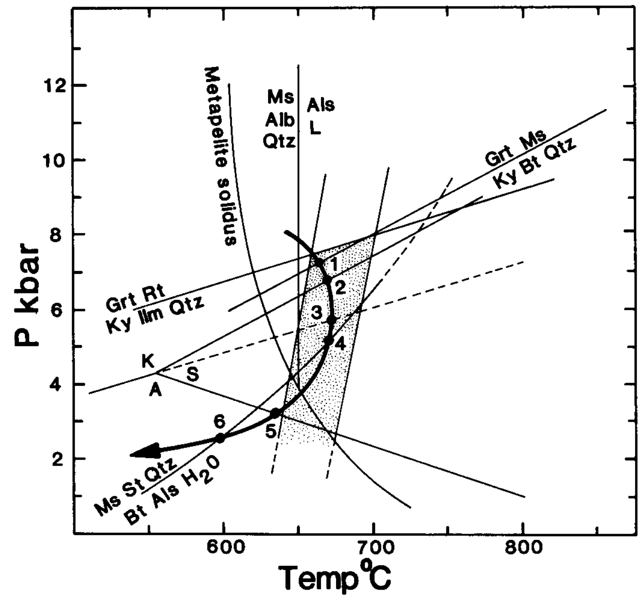

Figure 4: Conditions of metamorphism and P-T evolution of the Al_2SiO_5-bearing aggregates. Melting relations in metapelites from Thompson and Algor (1977). Grt + Rt = Ky + Ilm + Qtz calculated after Bohlen et al. (1983). Shaded area indicates temperature estimates calculated by application of the garnet-biotite thermometer of Perchuk and Lavrent'eva (1983). Inferred position of Grt + Ms = Ky + Bt + Qtz after Thompson (1982). Ms + St + Qtz = Bt + Als + H_2O after Hoschek (1969). Al_2SiO_5 triple point after Powell and Holland (1988). Dashed line indicates metastable extension of kyanite-andalusite reaction boundary. See text for discussion relating to points 1 to 6.

andalusite may have occurred at the metastable extension of the kyanite-andalusite reaction boundary (point 3, Figure 4). A similar mechanism proposed by Hollister (1969) involved the metastable transformation of andalusite to kyanite. This mechanism would imply the metastable persistence of kyanite and metastable growth of andalusite in the stability field of sillimanite. The metastable persistence of kyanite into the sillimanite field has been recorded by Grambling and Williams (1985) and the occurrence of andalusite in the sillimanite field has been noted by Wickham (1987) and Kerrick and Woodsworth (1989). Consequently both kyanite and andalusite are transformed to fibrolite at the staurolite-consuming - Al_2SiO_5-producing reaction R3 (point 4, Figure 4) which is the major sillimanite-producing reaction in these rocks (see also Hollister, 1969).

A second possible mechanism can be put forward to explain the features observed in the pseudomorphs after garnet and the matrix aggregates. Kyanite may have persisted metastably throughout the sillimanite stability field and been directly replaced by andalusite at the sillimanite-andalusite reaction boundary (point 5, Figure 4). McLellan (1985), based on observation in the Barrovian type area, has suggested that kyanite may have spent 'too little time' in the sillimanite stability field to have converted to sillimanite. The incomplete replacement of reactant phases may have resulted from reaction overstepping, indeed the presence of both the reactants and products of a reaction or transformation implies such a mechanism. Jones and Brown (1990) have suggested that the preservation of such delicate reaction textures, the product of reaction overstepping, may imply rapid near-isothermal decompression, a feature which is consistent with the proposed P-T path (Figure 4).

2. Reaction domains

The absence of relict staurolite and the inferred replacement of garnet within the pseudomorphs may be an important observation. If, as indicated above, sillimanite is the product of staurolite breakdown, then the absence of staurolite and sillimanite in these aggregates may be a direct result of the presence of reaction domains. In other words, different aggregates 'having seen' different reactions dependent upon the composition of the pre-existing phase. Hence the garnet aggregates have seen R2 during their evolution and the absence of sillimanite is a result of the absence of staurolite as a reactant for reaction R3.

3. Production by continuous reaction

Andalusite porphyroblasts. The presence of relict staurolite and kyanite along with idioblastic coarse sillimanite and biotite within the andalusite porphyroblasts needs a further explanation. Idioblastic coarse sillimanite occurs randomly orientated and crystals are not in optical continuity, a feature inconsistent with the replacement of andalusite by late sillmanite. Coarse sillimanite may have grown from kyanite breakdown at the kyanite-sillimanite breakdown reaction (point 2, Figure 4), although as has already been stated, sillimanite is primarily a product of staurolite breakdown. A more plausible explanation involves the operation of the staurolite breakdown reaction. The staurolite breakdown reaction (R3) is a continuous reaction which may have operated in the sillimanite field (point 4, Figure 4) and continued into the andalusite field. At the sillimanite-andalusite reaction boundary both polymorphs would coexist. Coexisting andalusite and sillimanite have been reported by Kerrick and Woodsworth (1989) and Kerrick and Speer (1988). These authors have also indicated the significant role which minor components may have on the stability relations of the polymorphs. At present no analytical data is available on the composition of the Al_2SiO_5 polymorphs in this sample to evaluate this effect.

The subsequent breakdown of kyanite and andalusite to fibrolite + muscovite + quartz could be explained by metastable growth of fibrolite in the stability field of andalusite. This mechanism would also apply to the matrix aggregates. A further possibility arises from the occurrence of the staurolite + muscovite intergrowths at the andalusite margin (see Figure 3d). The intergrowth of staurolite and muscovite replacing andalusite could be interpreted as resulting from crossing the staurolite breakdown reaction (R3) in a retrograde sense (point 6, Figure 4). The late-stage replacement of andalusite by fibrolite may have resulted from metastable growth of fibrolite or from a late stage increase in temperature resulting in a prograde recrossing of the sillimanite-andalusite reaction boundary (see Figure 4). Jones (in press) has indicated that regrowth of fibrolite in the migmatites may have such an origin.

4. The differing behaviour of the Al2SiO5 polymorphs during syntectonic growth

The Al_2SiO_5 polymorphs exhibit different growth habits and behaviour during syntectonic metamorphism (e.g. Vernon, 1987; Wintsch, 1981; Wintsch and Andrews, 1988). Fibrolite may occur in the foliation in high-grade rocks in place of mica (Vernon, 1987). Fibrolite has a preference for the foliation owing to its ability to deform and not undergo dissolution in these structural sites. Other phases such as garnet, staurolite, andalusite and kyanite have a tendency to form porphyroblasts. Bell (1981) and Bell *et al.* (1986) proposed a model for foliation development and porphyroblast growth, in which the rock consists of zones of progressive shearing (high-strain zones) in which minerals such as the micas and fibrolite may grow. Wintsch (1981) and Wintsch and Andrews (1988) have also indicated that fibrolite growth is deformation-induced and may preferentially grow in high-strain zones. In between these zones of progressive shearing, areas of bulk shortening occur (low-strain zones), and form the sites for nucleation and growth of porphyroblasts. Vernon (1975; 1987) has indicated that in low-strain areas fibrolite may coarsen, and such a mechanism may explain the occurrence of coarse sillimanite in the andalusite porphyroblasts (Figures 2, 3f and g) and in low- strain areas, e.g. replacing staurolite (Figure 3a). This model may apply to the aggregates and may explain the absence of fibrolite and presence of coarse sillimanite in the andalusite porphyroblasts and abundance of fibrolite with biotite in the matrix foliation and mantling porphyroblasts. Therefore the direct replacement of kyanite by andalusite may be an indirect result of the absence of fibrolite from these sites. In this instance kyanite is the only readily available source of aluminium for the growth of andalusite porphyroblasts. Although it should be noted that such a mechanism would also require the metastable persistence of kyanite.

Bell and Johnson (1989) and Bell and Hayward (1991) have indicated that once shearing has stopped, owing to the changing pattern of deformation partitioning, porphyroblasts may overgrow these zones. This may explain the overgrowth of fibrolite by andalusite porphyroblasts (Figure 3h).

CONCLUSIONS

Four mechanisms are proposed to explain the apparent conflicting metamorphic evolution in Al_2SiO_5-bearing aggregates. Metastable growth of Al_2SiO_5; reaction domains; production by continuous reaction; and, the differing behaviour of the Al_2SiO_5 polymorphs during syntectonic metamorphism. No one mechanism is favoured. It may be that the sequential growth of Al_2SiO_5 polymorphs occurred through different reactions and mechanisms at different times along a single P-T path as indicated in Figure 4. Textures are interpreted to have resulted from volume for volume replacement. The successive growth of Al_2SiO_5 polymorphs in restricted reaction domains may have implications for the limited mobility or migration of aluminium (see Carmichael, 1969; and Kerrick; 1988, 1990). Similar textures to those reported by Carmichael (1969), who advocated ionic-exchange reactions involving intermediate phases are here interpreted as resulting from recrossing of reactions during cooling, or late-stage metastable growth.

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