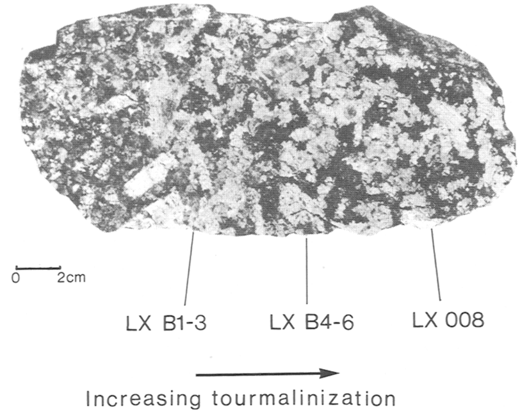

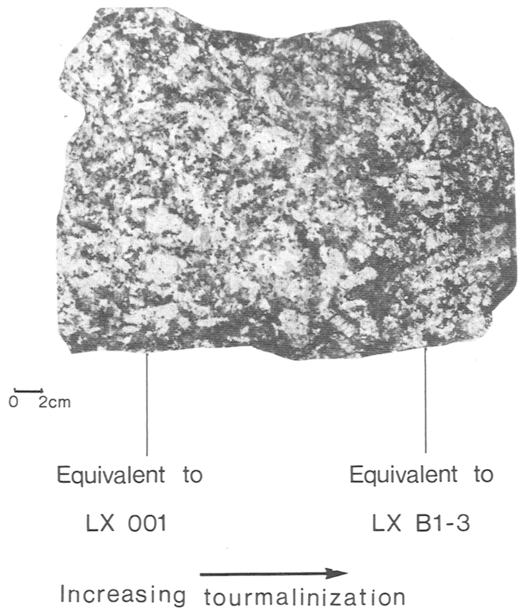

FIGS. 1 and 2: FIG. 1 (*left*). Transition zone from granite into luxullianite, showing megacrystic texture of both transitional material and luxullianite itself. There are no sharply defined zones of alteration such as Alderton illustrates. FIG. 2 (*right*). Transition zone from unaltered granite into the outer portion of a luxullianite vein, showing large K-feldspar megacrysts throughout.

agents of tourmalinization has evidently cancelled out any decrease in alkalis resulting from the replacement of micas (biotites) and feldspars.

It seems clear both from Alderton's remarks and from the present author's observations that luxullianite is not unique, and that a great variety of superficially similar rock types do occur in south-west England. Some examples are directly associated with metalliferous mineralization (e.g. as part of wall-rock assemblages), while others, including the veins at Luxulyan, occur in apparent isolation. Although the development of the characteristic luxullianite textures is relatively rare, the combination of tourmalinization and K-metasomatism would appear to be a fairly common one.

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The retrogressive breakdown of orthopyroxene in granulite-facies rocks, Sutherland

RETROGRESSION is extremely common in the acid granulite facies rocks of the Lewisian complex. In various mineralogical studies (Sutton and Watson, 1951; Beach, 1973; Sheraton *et al.*, 1973) it has usually been stated that biotite or biotite and hornblende are the replacement products after orthopyroxene. This paper shows that there is a sequential development of several minerals before these biotite and hornblende end-products.

In the freshest samples the acid granulites are composed of unzoned antiperthitic plagioclase (An_{30-45}), hypersthene (En_{41-48}), clinopyroxene, quartz, and ore, with greatly subordinate K-feldspar, apatite, zircon, and biotite.

The first indication of retrogression is a thin kelyphitic rim of granular blue-green hornblende around both pyroxenes. With increasing thickness this rim often has inclusions of quartz blebs together with a slight inward colour change to less pleochroic amphibole.

A serpentine-like mineral is frequently developed, inside this rim, around and through the orthopyroxene. It is variable in colour, being reddish, yellow, yellow-brown, greenish, brown, and greenish-brown. It is also pleochroic, platy or fibrous in habit, with parallel extinction, low interference colours (upper first order), length slow, and is biaxial negative. In other studies on similar rocks, a comparable mineral has been tentatively identified as chlorite (Howie, 1955; O'Hara, 1961), bowlingite (Nockolds, 1940), bastite or anthophyllite (Stewart, 1947), amphibole (O'Hara, 1961), serpophite or anthophyllite (Green and Jorde, 1971), serpentine (Groves, 1935; Beach, 1973), and a 'serpentinous-type' mineral (Himmelberg and Phinney, 1967). Some difficulty in identification was experienced in the present work but optical studies and qualitative scans using the electron microprobe indicate that serpentine is probable. Certainly the mineral is asbestiform in many samples and is mainly a Fe–Mg silicate. Frequently orthopyroxene is seen either with marginal alteration to serpentine or, more rarely, completely pseudomorphed by the latter. In both cases the

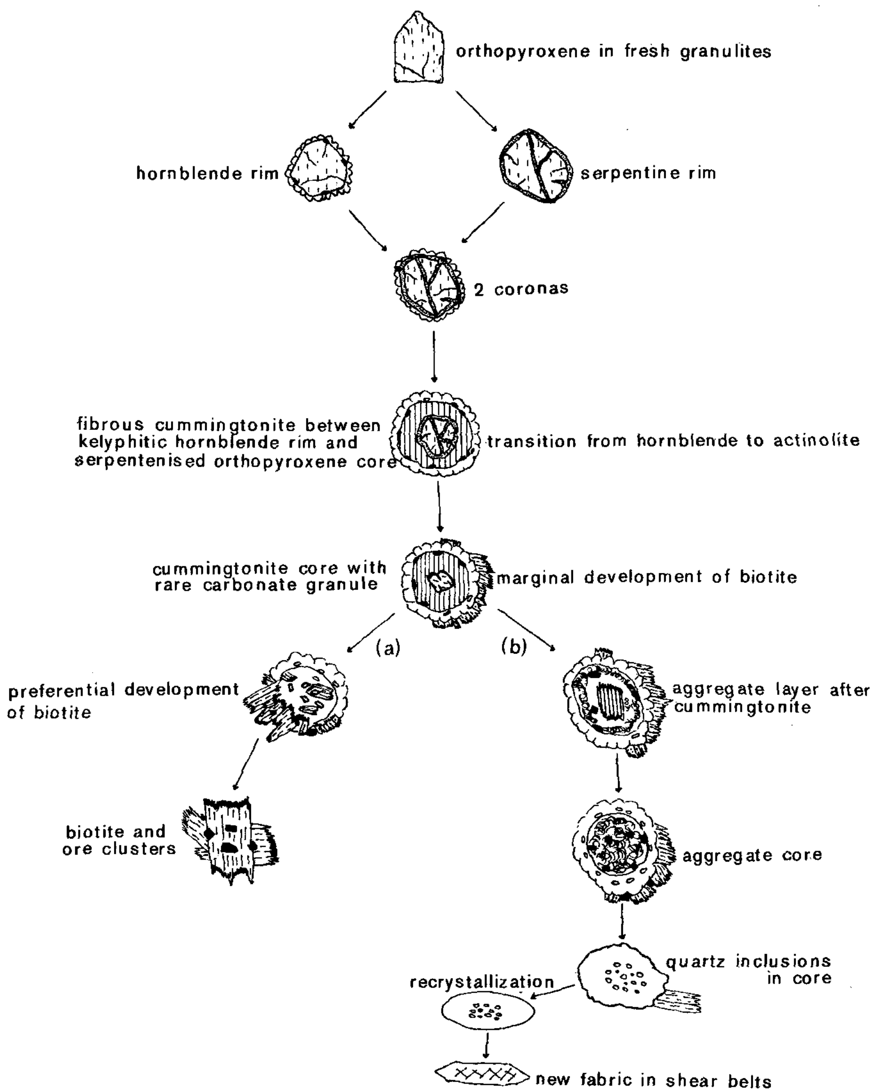

FIG. 1. Idealized diagram illustrating the retrogressive breakdown of orthopyroxene in Lewisian acid granulites showing the late divergence of the sequence into (*a*) biotite and (*b*) hornblende plus minor biotite end products.

kelyphitic hornblende rim may be absent. Read (1935) reported a similar phenomenon where some members of a pyroxene breakdown sequence were missing. In the present study it may indicate that serpentine predated the hornblende in some instances.

Next, there is the development of a third mineral between the marginal kelyphitic rim and the serpentine. This consists of felted mats of fibrous cummingtonite, oriented parallel to the original cleavage and around remnant orthopyroxene cores. It is also homoaxial to the hornblende granules on which it nucleates. Similar breakdown of orthopyroxene was noted by Deer (1935), Read (1935), and Himmelberg and Phinney (1967). Trails of small iron-ore granules can be seen parallel to the prismatic needles, and rare carbonate granules sometimes occur when serpentinized orthopyroxene is totally consumed.

The outer margins of the kelyphitic hornblende frequently show the subsequent development of a dull-brown biotite similar to that mantling ore granules but quite different from the reddish-brown primary biotite.

Next, cummingtonite grains, which now form the cores of many of these complex pseudomorphs, are gradually replaced by aggregates of extremely minute quartz, biotite, ore, epidote, calcite, hornblende, and possibly chlorite. This replacement occurs at the contact of cummingtonite with kelyphitic amphibole. Gradually these aggregates increase in volume until they alone exist as cores rimmed by kelyphitic hornblende.

The kelyphitic rim next increases at the expense of the aggregate layer and large poikiloblastic hornblendes with abundant quartz inclusions are the end result. In numerous shear belts that cut the acid granulites, the retrogressive sequence has proceeded furthest. Here a new mineral fabric, defined by a preferred orientation of recrystallized hornblende, is developed. An idealized diagram of the retrogressive sequence is shown in fig. 1.

Discussion. The initial breakdown of orthopyroxene was probably produced by reaction with plagioclase to give hornblende only, but this was quickly superseded by a reaction giving hornblende and quartz as products. With increasing thickness of the hornblende rim there was the development of Al-poor amphibole, with quartz inclusions, on the inner margin. This development of actinolitic amphibole is seen in the colour change within the rim. Possible reasons for this reaction change are either a decline in the available supply of constituents from anorthite or a change in the pressure-temperature conditions leading to a new amphibole composition.

The appearance of serpentine only requires hydration of orthopyroxene with decreasing temperature and gives quartz as a by-product. Later increasing temperature is needed to give cummingtonite from reaction between serpentine and quartz. The Fe/Mg ratio of cummingtonite is always less than that of the original orthopyroxene, which is consistent with the development of iron-ore granules within the cummingtonite.

If free diffusion of the anorthite constituents was still possible a further reaction, which would augment the hornblende rim, is that of cummingtonite, anorthite, and water.

The subsequent appearance of the 'aggregate' zone may be due to the breakdown of cummingtonite, possibly in the presence of a high CO_2 partial pressure, or to reaction between cummingtonite and the actinolitic inner part of the kelyphitic rim. The latter point may be unlikely since this rim eventually grows to replace all the other minerals. Finally, secondary biotite is the eventual end-product of retrogression. This is mainly produced by reaction between the orthopyroxene breakdown products and K feldspar from antiperthite. This biotite is usually subordinate to the poikiloblastic hornblende but in rare cases is the only mafic product of retrogression.

REFERENCES

Beach (A.), 1973. *J. Petrol.* **14**, 231–47.
Deer (W. A.), 1935. *Q. J. Geol. Soc.* **91**, 47–76.
Green (T. H.) and Jorde (K.), 1971. *Norges Geol. Unders.* **270**, 47–76.
Groves (A. W.), 1935. *Q. J. Geol. Soc.* **91**, 150–207.
Himmelberg (G. R.) and Phinney (W. C.), 1967. *J. Petrol.* **8**, 325–48.
Howie (R. A.), 1955. *Trans. R. Soc. Edin.* **62**, 725–68.
Nockolds (S. R.), 1940. *Q. J. Geol. Soc.* **96**, 451–510.
O'Hara (M. J.), 1961. *J. Petrol.* **2**, 248–76.
Read (H. H.), 1935. *Q. J. Geol. Soc.* **91**, 591–634.
Sheraton (J. W.), Skinner (A. C.), and Tarney (J.), 1973. *The Early Precambrian of Scotland and Related Rocks of Greenland*, eds. Park (R. G.) and Tarney (J.). University of Keele.
Stewart (F. H.), 1947. *Q. J. Geol. Soc.* **102**, 465.
Sutton (J.) and Watson (J.), 1951. Ibid. **106**, 241–308.

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