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THE GRANITES OF TRANCOSO (PORTUGAL): A STUDY IN MICROCLINIZATION

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ABSTRACT. At Trancoso, Portugal a massif of medium-fine granite is embedded in a younger coarsely porphyritic granite. The microcline megacrysts of the porphyritic granite exhibit zoning, orientation of inclusions, and hourglass structure. The older granite consists of a granodiorite which in many places has been extensively microclinized to granite under the influence of the porphyritic granite. Textural and quantitative evidence is given. All plagioclase in both granites and in xenoliths is albite-oligoclase. This seems to be due to secondary decalcification of originally more calcic plagioclase. The plagioclase shows albitic outer zones where in contact with microcline. Both granites carry abundant muscovite and occasional sillimanite as metasomatic minerals.

INTRODUCTION

Coarsely porphyritic granite has by far the greatest distribution among the granites of northern Portugal. Fine- to medium-grained granites of various types make up the remainder.

The area around the ancient walled town of Trancoso permits study of the relations between an older granodiorite and the encasing younger, porphyritic granite. The composition of the older rock, the Trancoso granite, ranges from granodioritic to granitic, under the influence of microclinization by the porphyritic granite. A special feature of the two granites contact is a profusion of pegmatites.

A much-weathered quartz schist crops out about 3 km southeast of Trancoso, most probably belonging to the pre-Ordovician Complex, a monotonous formation of generally metamorphic pelites and psammites unconformably underlying the Ordovician of northern Portugal. The schistosity of these rocks strikes 60° east of north, with approximately vertical dip. The porphyritic granite to the north occasionally carries angular hornfels inclusions derived from the schist.

Mafic dikes, varying in width from less than 10 cm to 5 meters are rather common. They consist of a very fine grayish-green rock with occasional feldspar phenocrysts. The dikes are perpendicular or nearly so and strike predominantly NNE-SSW or about NW-SE.

Important NNE-SSW faults cross the area.

The accompanying sketch map (fig. 1) roughly indicates the distribution of the various rock types.

Optic axial angles given were obtained by direct measurement on the universal stage; anorthite contents of plagioclase were determined by means of Fedorov migration curves.

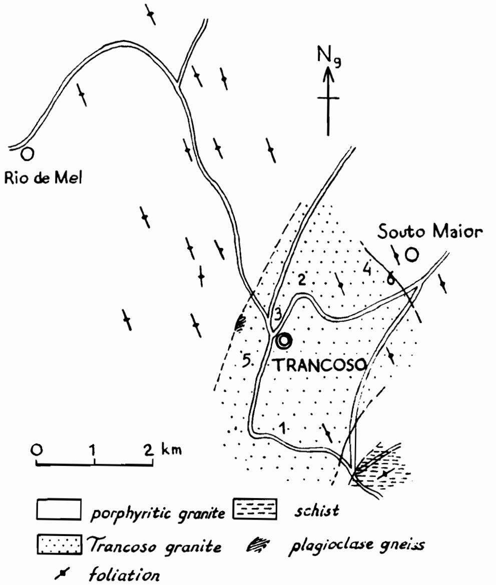


Fig. 1. Geological sketch map of the Trancoso area. The numbers indicate the localities of the specimens of which modal analyses are given in table 1.

THE PORPHYRITIC GRANITE

The porphyritic granite is to serve as reference unit, both petrographically and geologically. Its influence on the older granodiorite has been profound. The emplacement of the porphyritic granite took place after the second Hercynian phase in northern Portugal which sharply compressed the open folds of the first phase in which the upper Carboniferous was deposited. This granite may be observed crosscutting and metamorphosing Stephanian psammites northeast of Sátão, 33 km due west of Trancoso. Between the metasediments of Sátão and the Trancoso granite all is porphyritic granite. The block-faulted nature of this area is brought out by alternating stretches of deeply weathered plains and rocky uplands, divided by northeasterly- to north-northeasterly-striking faults. The porphyritic granite typically weathers into enormous rounded boulders or woolsacks (fig. 2), from which the more resistent microcline megacrysts protrude. The rock consists of abundant potash feldspar megacrysts (tabular on 010 and displaying the forms {010}, {001}, {110} and {$10\bar{1}$}) in a coarse matrix of feldspar, quartz, biotite, and white mica. The megacrysts may reach 4 cm in length by 1 cm across. Biotite and silvery-white mica frequently form six-sided flakes up to 4 mm in diameter. The quartz is in round and irregular grains which attain 10 mm in size. The granite may carry more muscovite than biotite. Although the texture of the rock is uniform throughout the area shown in the map, the dimensions of the constituents may vary somewhat. The coarsely porphyritic granite west of Trancoso grades into a less coarse variety towards Rio de Mel in the northwest. The passage is continuous and very gradual. In the latter variety the sizes of the constituents are somewhat reduced, on a scale of about 3:4 (compare fig. 3).

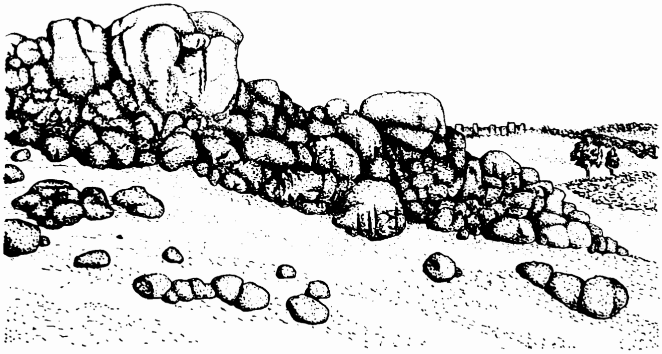


Fig. 2. Woolsacks of porphyritic granite, northwest of Trancoso. In the background the walls of Trancoso.

The porphyritic granite generally shows a planar parallelism, or *foliation*, of the megacrysts. The inclination of the foliation is always about vertical (± 10°); the strike varies between N 140 and N 180 (azimuthal reading), averaging N 160. In places a faint *lineation* is shown, a linear parallelism of the longest dimensions (c-axes) of the megacrysts. It is about vertical (± 20°). Foliation and lineation are considered due to regional stress after emplacement, since the megacrysts developed in a more or less stationary environment after intrusion was completed. This is more fully discussed in Schermerhorn (1956), in which the petrogenesis of a porphyritic granite at Cete, a hundred kilometers to the northwest, is described.

The primary accessories consist predominantly of *zircon*, *apatite*, and *ilmenite* (frequently replaced by leucoxene). They are idiomorphic and occur chiefly in biotite (preferential distribution). Some apatite crystals may reach diameters of over 0.5 mm.

There is a slight amount of what seems to be *early muscovite*, in small idiomorphic flakes included in biotite.

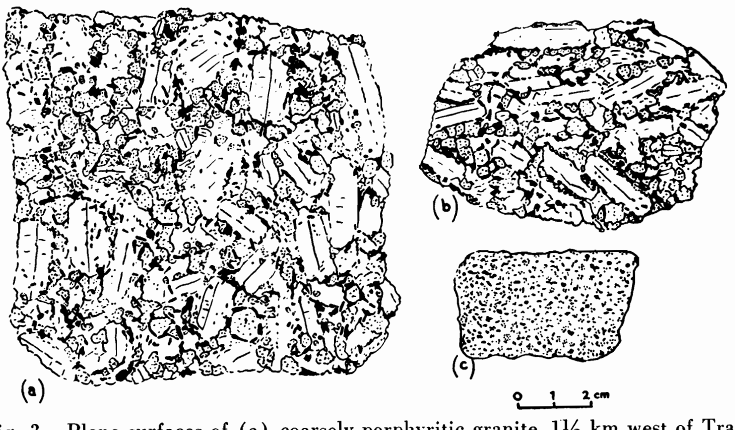


Fig. 3. Plane surfaces of (a) coarsely porphyritic granite, 1½ km west of Trancoso; (b) less coarse porphyritic granite, halfway between Trancoso and Rio de Mel; (c) granodiorite, 200 meters north of Trancoso. White: feldspar; black: mica; stippled: quartz.

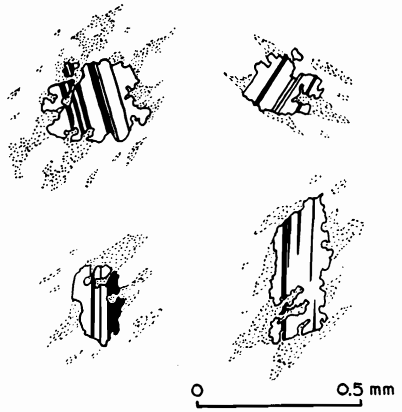
Biotite is pleochroic from deep red brown to straw yellow and carries abundant pleochroic haloes around zircon, sphene, or granules too small to identify, and occasionally around apatite. Biotite was the earliest of the main constituents to separate; it may be enclosed and/or corroded by plagioclase, microcline, quartz, and late muscovite. Preferential distribution of the primary accessories in the biotite points to its magmatic growth. The theory of this is given in Schermerhorn (1956); briefly, it is argued that since the primary accessories largely separated prior to biotite, their concentration in the mica was effected during the latter's crystallization period, in a fluid environment. It is thought that this concentration was made possible by internal motion of the intruding magma so that most of the earlier accessory minerals came successively into contact with growing biotite flakes, adhered to their surfaces (surface tension), and were incorporated. The latest biotite to form is represented by minute rounded flakes in quartz III (main quartz), which do not carry accessories. The biotite may be altered into a penninite-like chlorite, with anomalous blue interference colors. An intermediate stage is frequently represented by a green mica with somewhat lower birefringence than biotite. Both the green mica and the chlorite may show development of sagenite. Decomposition of biotite is often accompanied by segregation of sphene granules and aggregates (along the cleavage of the mica) with pleochroic haloes.

Quartz displays the following six different habits: quartz I—bipyramids; quartz II—inclusions in microcline megacrysts with concave or partly straight boundaries; quartz III—main quartz, forming the large grains in the matrix; quartz IV—drop-quartz; quartz V—small irregular bodies; quartz VI—garlands. Quartz I is a separate generation; quartz II, III and IV are considered a single generation, starting separation in the magmatic stage and continuing into the metasomatic stage; quartz V and VI seem to be still later (compare Schermerhorn, 1956).

Quartz I forms small bipyramids of original high quartz in feldspar. The other quartz varieties are posterior to feldspar.

Plagioclase builds hypidiomorphic, generally albite-twinned crystals, many of which are sericitized and kaolinized. A little fluorite is present among the alteration products. Plagioclase is corroded by microcline (fig. 4), quartz, and white mica. The large crystals in the matrix (up to 8 mm in length) consist of *albite-oligoclase* (An_{9-15}, averaging An_{12}). The plagioclase inclusions in microcline megacrysts (up to 2.5 mm in length) are slightly zoned, showing albitic rims (An_{0-5}) grading into somewhat more calcic cores (up to albite-oligoclase (An_{12}) in grains longer than about 1 mm). The cores are sericitized, the albitic rims are clear. Where the albite-oligoclase of the groundmass is in contact with microcline, it also shows a gradual decalcification of the outer zones, up to albite. These albitic rims follow corrosion outlines and are absent against adjacent minerals other than microcline. Myrmekite is occasionally developed in plagioclase corroded by microcline.

The potash feldspar is *microcline microperthite*, building roughly euhedral megacrysts and irregular grains in the matrix. $2V\alpha$ varies from 78° to 86°. Extinction angles are 15°-16° on 001 and 6°-7° on 010. Cross-hatch twinning is often present. It may be coarse and patchily distributed in un-



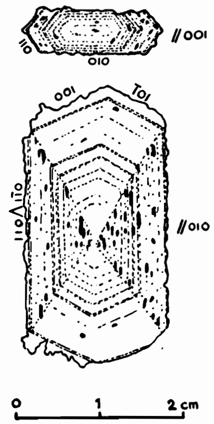


Fig. 4. Corroded unoriented plagioclase inclusions in microcline megacrysts. Perthitic plagioclase is stippled.

Fig. 5. Microcline megacryst in porphyritic granite. Above, section parallel to 001; below, section parallel to 010. Note euhedral zoning (narrow white opaque bands alternating with wider translucent zones), irregular border and hourglass structure of biotite inclusions (plagioclase and quartz inclusions not shown). The flakes of biotite are mostly parallel to microcline {110}; some are oriented on {001} or {10$\bar{1}$} in the upper and lower parts of the hourglass pattern.

twinned undulant microcline. Perthite is mainly of the vein and patch type; film perthite may also be present. The perthitic plagioclase may reach An_{10} in the patches but is generally more sodic in composition.

The *orientation of inclusions* of older minerals in microcline is definitely a magmatic texture. Orientation is in three types: on structural directions in the host, in zones, and in hourglass pattern. The three types are frequently combined. The oriented inclusions, up to a few millimeters in size, consist of the tabular minerals, biotite, and plagioclase. These are older than the microcline as proved by corrosion relations (compare figs. 4, 6). Any distinct orientation of these inclusions with respect to the structure of their host is therefore due to influences exerted by the host during its crystallization, and must of necessity have occurred in a fluid environment permitting rotation of existing crystals. The biotite and plagioclase inclusions are generally oriented on the {010}, {001}, {110}, and {10$\bar{1}$} planes of the microcline megacrysts in which they occur. {110} seems to exert the strongest orientational control in the porphyritic granite in question, since most of the inclusions exhibit 110-orientation (parallelism of biotite 001 and plagioclase 010 to microcline {110}). This is a dimensional orientation; the plagioclase inclusions may in addition show a structural orientation. In this case they exhibit parallelism not only of the 010-planes to a crystallographic direction in the microcline but also of some structural direction, generally the c-axis, to a direction in the host. Oriented plagioclases are in general less corroded than unoriented ones. Figure 6 shows part of a megacryst, cut parallel to 010, with oriented inclusions. One set of plagioclase inclusions in this megacryst is oriented on microcline 001; these show sharp 010-twinning lamellae. The other set is oriented on microcline $1\bar{1}0$, exhibiting undefined boundaries between the lamellae, cut at a low angle. The biotite flakes are also oriented. Fourteen measurements on plagioclases of the first set yielded $010_{plag} \wedge 001_{micr}$ angles varying from 1 to 9°; 19 measurements on the second set indicated $010_{plag} \wedge 1\bar{1}0_{micr}$ angles between 0 and 10°.

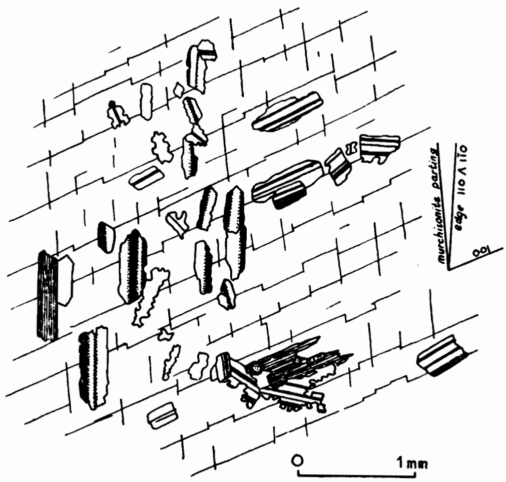


Fig. 6. Oriented albite inclusions in a microcline megacryst cut parallel to 010. There are two directions of orientation: plagioclase 010 parallel to microcline 001, or $1\bar{1}0$. Note the two oriented biotite flakes, one with apatite inclusions.

The oriented plagioclases and biotites frequently display a distinct zonal arrangement. A related directional intergrowth is formed by an *hourglass structure*, as far as I am aware hitherto unrecorded from feldspar. It combines the orientational arrangement of inclusions described in the preceding paragraph with a distribution in an hourglass pattern. This is illustrated in figure 5, where the orientation of the biotite and plagioclase inclusions is principally on {110} in the microcline megacryst. The section parallel to 010 passes approximately through the center of the megacryst. In the figure only the biotite flakes have been drawn, for the sake of clearness; most of them lie parallel to the nearest {110} plane (compare the 001-section, in fig. 5). The hourglass structure is evidenced by concentration of the biotites in two triangular areas between the megacryst center and respectively the 110-$1\bar{1}0$ and $\bar{1}10$-$\bar{1}\bar{1}0$ edges. It is also shown by the microcline being less translucent in these areas. The 001-section passes at some distance from the megacryst center so that it does not exhibit the pattern to most advantage. The spaces containing the biotite are shaped as two pyramids along the a-axis, with their apices facing in the center (evidently the crystallization nucleus) of the microcline host. The structure, which I have often observed in northern Portuguese granites, is rather well developed in the porphyritic granite around Trancoso.

The orientation of the inclusions is inferred to have been effected by crowding aside of tabular older minerals by the successive growth surfaces of the microcline megacrysts. The hourglass structure moreover depends obviously on variations in the crystallization force (or rather ability to crowd aside older crystals) of the potash feldspar according to the different directions in its lattice. In 010 it seems to have been greater parallel to c than normal to c, so that pre-existing crystals were pushed aside, to the 110 planes of the growing megacrysts, clearing the area of the c-axis (along which the megacrysts are invariably longest). Incidentally, these orientational textures bear out the primary nature of the zoning displayed by the same megacrysts. The *zonal structure* of the megacrysts is best observed macroscopically (fig. 5). Under the microscope it is vaguely evidenced by narrow bands somewhat richer in perthitic plagioclase and more kaolinized than the wider zones with which they alternate. It may be regarded as a kind of oscillatory zoning brought out by alternate shells of different behavior, possibly on account of somewhat varying sodium content. This zoning is a primary structure, its idiomorphism indicating development by zonal accretion in a magmatic environment.

The features described indicate growth in a fluid environment.

The potash feldspar megacrysts are thus shown to have largely crystallized from a magmatic fluid. They ended crystallization by a final metasomatic stage, as shown by their irregular corrosive borders.

An exhaustive study of potash feldspar features indicating magmatic growth has recently been published by Frasl (1954), concerning the potash feldspar megacrysts of some porphyritic granites and gneisses in Austria. According to Frasl, both orientation of inclusions and zoning (he does not mention hourglass structure although his figure 3 seems to exhibit it) may be taken to prove growth from magmatic fluids at high temperatures. He also discusses the evidence presented by habit, twinning, alteration, red coloration by hematite, optical orientation and type of perthitic structure; their value as yet seems relative. In my opinion it seems necessary to add that to the possibility of rotation of inclusions in a fluid phase it is irrelevant whether this fluid is truly magmatic or has formed, by anatexis, in and from solid rock. It will be shown below that orientation of biotite and plagioclase may occur in the new microcline of the Trancoso granite which developed in originally solid rock.

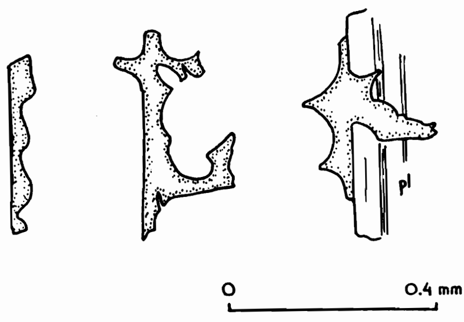


Fig. 7. Shapes of quartz II inclusions in microcline megacrysts.

Quartz II forms occasional inclusions in microcline megacrysts, with concave or partly straight outlines (fig. 7). Its straight boundaries are molded on plagioclase or biotite inclusions in the megacrysts or follow structural planes in the microcline (ancient growth surfaces). Quartz II is therefore considered to have crystallized, together with that part of the surrounding microcline towards which it is concave, from occasional pockets of residual magma enclosed by the growing megacrysts.

Quartz III is abundant, in large grains corroding biotite, plagioclase, and microcline. Its formation started in the magmatic stage to continue into the metasomatic stage. Magmatic crystallization is suggested by textures such as may be discerned in figures 3a and b, in which flakes of biotite are tangentially arranged around large rounded grains of quartz. Since biotite is older than quartz III, as borne out by corrosion relations, this texture may be inferred to have originated by a crowding aside of the mica flakes by growing quartz, until they abutted against surrounding minerals. Slightly bent plates of biotite, appressed between quartz III and feldspar, are occasionally observed. Thus the quartz crystallized interstitially in a rather loose mesh of biotite, plagioclase, and microcline. It continued metasomatically, as indicated by its replacive attitude toward the older minerals. It is concluded that after quartz III had separated, the magma had entirely solidified, except for a certain amount of rest-fluids present in, or introduced into, the intergranular spaces. Minerals posterior to quartz III and transecting grain boundaries are therefore metasomatic. The quartz commonly exhibits undulatory extinction, often with some granulation. This is thought to be due to the post-granitic block-faulting of the area.

Quartz IV, or drop-quartz, is sparingly present as small rounded bodies metasomatically formed in feldspar crystals near the margins. Quartz IV grains tend to occur in groups, frequently in optical continuity, mutually and with quartz III crystals nearby.

Quartz V is occasionally found in plagioclase, as small irregular bodies which frequently show stepped or frayed outlines oriented on the host structure.

Quartz VI is sparse. It forms narrow veinlets or garlands in microcline, following the cleavage directions of the host.

Sillimanite is uncommon. It has been encountered in a few slices, at the contact with Trancoso granite. The sillimanite is associated with late muscovite in which it occurs as bundles of needles. It generally shows fibrolite habit, but may build crystals up to 0.15 mm in width. Fibrolite trains in muscovite may in places continue into adjacent quartz III crystals. They are therefore posterior to quartz III and metasomatic. Sillimanite may attack biotite, starting at the borders of the mica and replacing it by a mat of felted fibrolite in which biotite is reduced to vague still pleochroic remnants before disappearing altogether. Figure 8 shows fibrolite developed at the expense of biotite, surrounded by late muscovite.

Muscovite is a late metasomatic mineral, apart from a slight amount of early white mica included in biotite. It forms irregular crystals, in places with a tendency to idioblastic outlines, but generally with ragged borders. It replaces biotite, plagioclase, microcline and, to less extent, quartz. The mineral has $-2V$ about 37° and a birefringence of 0.033-0.035.

Attention may be drawn to some differences between this granite and the Cete granite which probably belongs to the same batholith (Schermerhorn, 1956). Apart from the occasional presence of sillimanite the most important

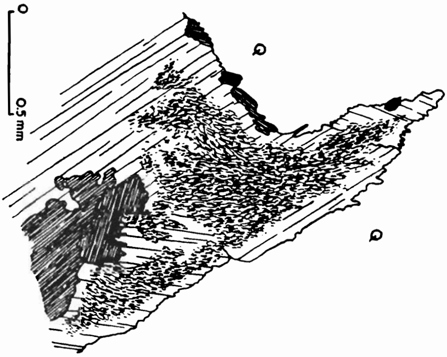


Fig. 8. A felted mass of fibrolite resulting from near-complete replacement of biotite, surrounded by muscovite. Porphyritic granite.

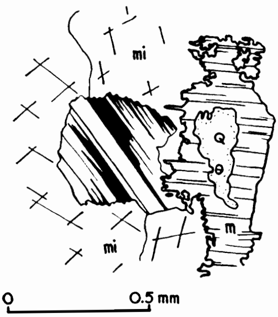


Fig. 9. Plagioclase corroded by microcline and muscovite. Note stepped corrosion outlines and tapering twin lamellae. Trancoso granodiorite.

difference is the uniform albite-oligoclase composition of the plagioclase. It will be argued below that this feature is secondary. Minor differences lie in the relative amounts of the late-stage minerals. In the granite in question there is more secondary muscovite and less late quartz than in the granite at Cete (there seems to be more quartz III). These differences originated in the metasomatic stage. The magmatic crystallization of both granites is considered to have been very similar, if not identical, slight divergences developing afterwards.

THE TRANCOSO GRANITE

The massif of Trancoso, a few kilometers across, consists of a medium-fine granite to granodiorite (fig. 3c). The difference in weathering between the huge woolsacks of the porphyritic granite and the small angular blocks of the granodiorite is conspicuous.

The rock is non-porphyritic except for occasional disseminated microcline megacrysts near the contacts with porphyritic granite or with pegmatites. It consists of white feldspar and quartz, with scattered small plates of biotite and very irregular flakes of white mica. Subparallel arrangement of biotite may occasionally lend a faintly gneissose appearance to the granodioritic varieties; it is probably a primary directional texture, destroyed during the subsequent microclinization of the rock. The muscovite does not exhibit any orientation. Where the rock shows extensive development of new microcline, in tabular grains with euhedral tendencies, these may display a foliation (planar parallelism) of the same north-northwesterly strike and vertical dip as the foliation in the porphyritic granite. Also, the amount of this microcline and of disseminated megacrysts increases conspicuously toward the porphyritic granite or around pegmatites. Thus a microclinization conditioned by the porphyritic granite and under the same stress is already evidenced in the field.

The primary accessories, *zircon* and *apatite,* are present in smaller amount than in the porphyritic granite. There is little or no ore (leucoxene, presumably pseudomorphic after ilmenite). Zircon builds minute prisms. preferentially distributed in biotite, or in muscovite replacing biotite. Apatite (up to 0.8 mm long) occurs mainly in biotite but may also be met with in other constituents.

Biotite is pleochroic from dark reddish-brown to straw yellow and carries abundant pleochroic haloes. It is corroded by all subsequent minerals. Chloritization, with sagenite and/or sphene release, is of the same type as in the porphyritic granite.

Plagioclase is in grains up to 2.3 mm in length, invariably showing multiple twinning (apparently Albite Law twinning), occasionally combined with Carlsbad twinning. Rarely a few pericline lamellae occur. The plagioclase generally carries fine alteration products consisting of sericite and kaolinite. The plagioclase is not zoned; its composition is very constantly that of albite-oligoclase ($An_{9\text{-}14}$, averaging An_{11}). In the granodioritic varieties a very narrow border zone (max. 0.05 mm) is generally decalcified to albite ($An_{2\text{-}5}$) at contacts with potash feldspar. This thin sodic zone closely follows the plagioclase outlines as corroded by microcline, abruptly ceasing where the plagioclase no longer adjoins microcline. These decalcified rims have therefore formed by a secondary process connected with corrosion by potash feldspar. In the Trancoso granodiorite it is characterized by a very abrupt change of extinction when passing from the albite-oligoclase into its albitic border zone. In the more granitic varieties the sodic rims widen concomitantly with increasing microclinization, and pass into gradual borders such as occur in the porphyritic granite. This also illustrates the presumably genetic connection between this secondary decalcification to albite and the development of microcline.

Plagioclase is replaced by later quartz (figs. 10, 11), microcline (figs. 9, 10, 12, 13), and muscovite (fig. 9). Frayed and stepped corrosion outlines, following plagioclase structure, are not uncommon (fig. 9). It is occasionally

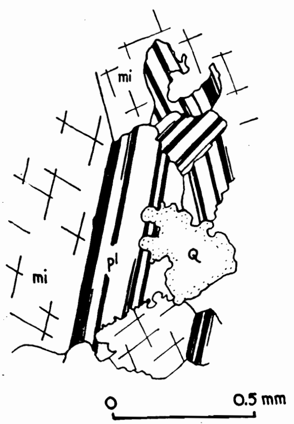


Fig. 10. Microcline corroding and molding plagioclase. Note lobate quartz. Trancoso granodiorite.

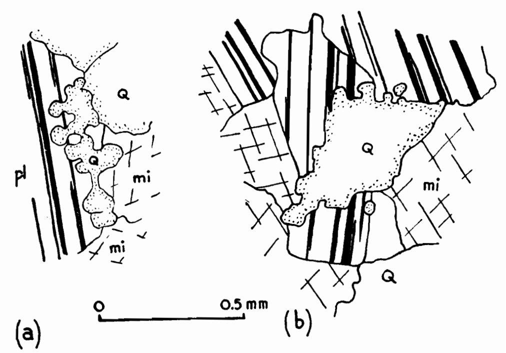


Fig. 11. Lobate quartz, corroding plagioclase and microcline. Note interstitial attitude of quartz in (*a*). Trancoso granodiorite.

observed that the polysynthetic 010-lamellae of plagioclase widen towards corrosion boundaries. This may indicate that the twinning of the plagioclase, at least in these cases, took place after corrosion. Myrmekite is occasionally developed in plagioclase corroded by microcline. Cataclastic effects are noted in places (fig. 12). Grains of plagioclase may be broken and the fragments slightly displaced. The twinning lamellae may vary in the fragments which points to twinning as a secondary process.

TABLE 1
Modes of Trancoso Granite (vol %)

	1	2	3	4	5	6
Microcline-perthite	12.5	24.5	22.9	29.3	27.9	29.9
Plagioclase	44.0	34.2	29.8	25.7	21.1	20.0
Quartz	29.0	31.3	27.9	31.6	33.4	33.0
Muscovite	9.5	5.2	11.8	5.6	10.0	9.9
Biotite, accessories	5.0	4.8	6.6	7.8	7.6	5.1
Sillimanite	—	—	1.0	tr.	—	2.1

Location of specimens given in figure 1.

Microcline occurs in varying amounts. The rock grades from granodiorite through adamellite to granite, according to Johannsen's classification (1932). This is caused by the development of microcline, principally at the expense of plagioclase, as shown in the modes in the accompanying table. The modal analyses were made by means of a Chayes point counter (Chayes, 1949). The modes are meant to demonstrate the variability of the plagioclase: microcline ratio in the massif as a whole. The microclinization is considered a secondary process brought about by contact action of the younger porphyritic granite, as stated below; it is most extensively developed near the contacts with the younger granite or with its pegmatites. Occasional disseminated microcline megacrysts occur near these contacts; here they may reach a density of one per square decimeter outcropping Trancoso granite.

In the non-porphyritic microcline two transitional varieties may be distinguished by means of perthitization and optic axial angle. They will be called "old" and "new" microcline. The former occurs in the more granodioritic types, giving way to the latter in the granitic types. The porphyritic microcline belongs to the latter variety.

The old microcline forms anhedral grains up to 2 mm in size in granodiorite. It may mold itself on euhedral outlines of biotite and plagioclase (without replacement) or may corrode them (fig. 10). It is itself attacked by quartz and muscovite. A shadowy undulatory extinction is common. The optic axial angle, $2V\alpha$, in old microcline is about 65° (mean of 22 determinations, from 60° to 69°).Film perthite is abundant and always present. It is formed by extremely thin films of albitic plagioclase (up to 0.0008 mm in width and reaching 0.05 mm in diameter) oriented on the murchisonite direction in the potash feldspar host. The film perthite does not grade into

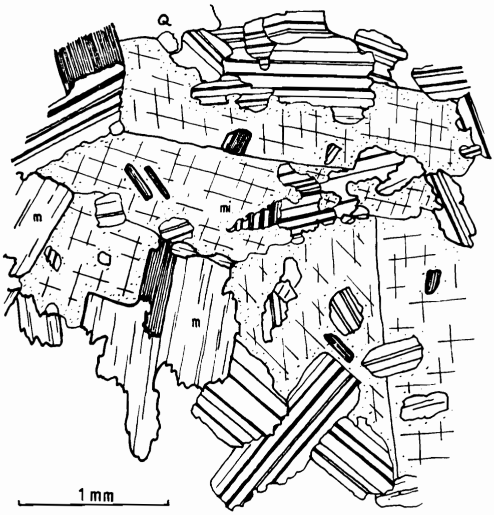


Fig. 12. Fabric of microclinized granodiorite, showing two crystals of new microcline (mi) corroding plagioclase, with flakes of muscovite (m). Note cataclastic plagioclase above. Trancoso granite.

vein or bleb perthite. Where albitic blebs or veins appear, the film perthite around them disappears.

The new microcline has an optic axial angle of about 75° (mean of 17 determinations, from 70 to 80°). It is slightly perthitic, exhibiting small irregular albitic blebs and veins.

Cross-hatch twinning is but faintly developed in both varieties of microcline, as a wavy indistinct grid, and is frequently absent, especially in the old microcline. The microcline is generally but slightly kaolinized, much less so than primary or perthitic plagioclase.

The development of the new microcline may be observed in hand specimens, since it tends to form roughly euhedral grains which may occasionally reach 8 mm in length. Carlsbad twinning is almost invariably present. The new microcline replaces biotite and plagioclase and is corroded by quartz and muscovite. All transitions occur, from microcline interstitial to biotite and plagioclase grains, or partly surrounding and corroding plagioclase, to large more or less euhedral plates of microcline. Biotite and plagioclase inclusions in new microcline crystals may show an orientational arrangement, parallel to microcline {010} and {110}, as shown in figure 13. The occasional megacrysts also exhibit orientational control over their inclusions.

In comparing the modes of occurrence of the *quartz* in the Trancoso granite with those in the porphyritic granite it is noted that the quartz in the Trancoso rock is largely of quartz III type, with a little quartz I and IV, and sparingly some quartz V and VI. Bipyramids of original high quartz are scarce. They reach 0.25 mm in diameter and are found only in plagioclase (which in places has slightly corroded them). Since most quartz appears to have recrystallized, it is inferred that these bipyramids are armored relics protected by a coat of plagioclase. The main quartz is in irregular grains

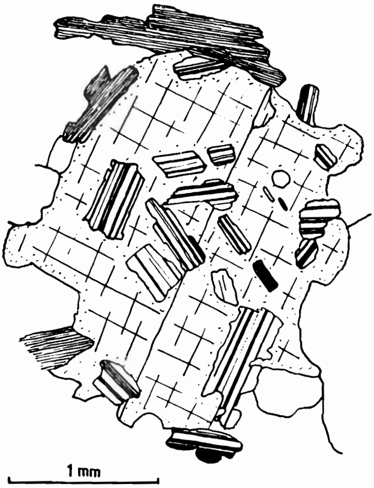


Fig. 13. Oriented plagioclase and biotite inclusions in new microcline. Trancoso granite.

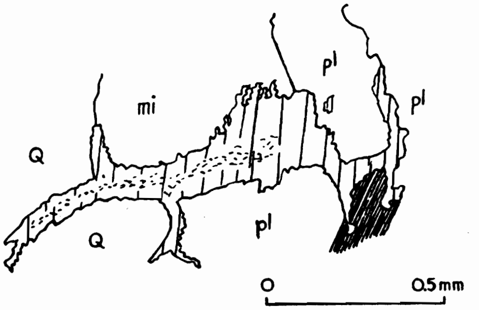
which corrode biotite, plagioclase, and microcline, and show lobate boundaries (figs. 10, 11) in the granodioritic varieties. In these latter the quartz may also mold plagioclase without replacement. Drop-quartz is found in feldspar. Part of it may owe its isolated appearance to favorable section of lobed outgrowths of the main quartz grains. The lobes seem to be late metasomatic growths. The lobate quartz in figure 11a may have originated by coalescence of quartz drops metasomatically formed along an intergranular surface. In the more granitic specimens the quartz is irregular, still replacive in habit, but not lobate or but little so.

The quartz is generally undulatory. It is to be noted that cataclastic plagioclase may be associated with but slightly undulatory quartz. This points to recrystallization of the quartz after dislocation of plagioclase took place, with subsequent development of undulance.

Sillimanite has been observed in adamellitic specimens and also at the contact with the porphyritic granite northeast of Trancoso. It occurs chiefly in muscovite, rarely in quartz, and may replace biotite in the same way as in the porphyritic granite. In rock slices cut across the contact between the two granites trains of fibrolite may transect the contact, as does muscovite. This indicates that both minerals belong to the paragenesis of the younger granite.

Muscovite is latest among the rock components. It shows the same properties as in the porphyritic granite ($-2V = 35°$-$39°$, averaging $36.5°$; birefringence 0.033-0.035) and builds ragged plates (up to 4 mm in size), frequently grading into irregular vein-like forms penetrating between the older minerals. The cleavage of this interstitial muscovite lies at a large angle to the direction of the vein (fig. 14).

The history of the rock may be summarized as follows: crystallization of a hypidiomorphic granodiorite—slight deformation prior to or possibly contemporaneous with the intrusion of the porphyritic granite—extensive re-



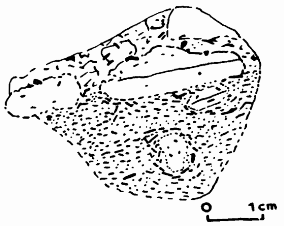


Fig. 14. (left). A train of fibrolite in late muscovite. Note interstitial attitude of muscovite. Trancoso granite.

Fig. 15. (right). Contact between porphyritic granite and gneissose xenolith. Note parallelism of biotite flakes, wrapping around microcline megacrysts.

crystallization and metasomatism, resulting in albite-oligoclase, microcline, quartz, sillimanite, and muscovite.

CONTACT RELATIONS

Although the contact between the two granites is generally obscured by superficial deposits, an intrusive relationship was established. Where observed, the contact is sharp. West of Trancoso the porphyritic granite carries a few inclusions of older granite near the contact. Near Souto Maior, northeast of Trancoso, the porphyritic granite sends out veins into the Trancoso granite. Three veins were observed, varying in width from 2 to 4 meters and dipping into the porphyritic granite at angles of 30° to 50°. These appear to be infillings of marginal fractures in the granodiorite caused by the rising magma of the younger granite. That the porphyritic granite is the younger is also proved by the extensive modification the granodiorite has undergone.

XENOLITHS

Inclusions or xenoliths are extremely rare in the younger granite and absent in the Trancoso granite. Near contacts, the porphyritic granite may carry a few angular inclusions of the adjacent rock. About 1 km WNW of Trancoso a large xenolithic mass, perhaps a hundred meters across, lies between the two granites. The contact with Trancoso granite is not exposed. The contact with porphyritic granite is sharp and dips 55° ESE. Here many pegmatite veins occur, chiefly in the xenolith. This large inclusion consists of a gray speckled rock with thin biotite layers and quartzofeldspathic bands, with gneissosity striking 45°-50° east of north, and vertical dip.

The rock is a fine-grained biotite-rich gneiss, mainly consisting of granoblastic quartz and plagioclase and idioblastic biotite plates (in subparallel orientation). The accessories are formed by minute zircon and zircon-like crystals, with little apatite and no ore, distributed indifferently within quartz, feldspar, and mica. Abundant quartz forms both rounded and irregular grains (up to 1 mm); the latter embay the plagioclase, occasionally in lobate forms. Plagioclase consists of albite-oligoclase (An_{9-12}). Muscovite occurs in a few small flakes intergrown with biotite or irregularly surrounding and corroding biotite. The absence of sillimanite is to be noted. In the center of the mass there is no microcline; this is developed only near the contact with the porphyritic granite. This plagioclase gneiss is probably of sedimentary origin.

Up to about 80 meters west of this large xenolith, the porphyritic granite contains occasionally a few small xenoliths of microclinized plagioclase gneiss, along with some much larger angular inclusions of Trancoso granite (up to 2 or 3 meters across). The gneiss inclusions are rounded and disk-shaped, in sizes up to 40 cm. Although the porphyritic granite contains abundant muscovite, these xenoliths are very poor in it. They show the same texture as the large gneiss mass but carry microcline in addition. The composition of the plagioclase is albite-oligoclase (An_{7-13}). The microcline is in irregular grains (up to 0.5 mm in size) which embay the plagioclase. The microcline shows undulance and coarse cross-hatch twinning, and occasionally exhibits a little vein perthite or, rarely, some film perthite. The quartz and the plagioclase are undulatory also. There is in addition a development of sporadic microcline megacrysts within the xenoliths (fig. 15). At the microcline stage of the surrounding porphyritic granite these xenoliths seem to have been pervaded by the late granitic fluids separating potash feldspar. Local accumulation may have formed megacrysts. The xenoliths were reduced to a plastic, part-fluid condition at this stage and consisted of a mash of biotite, plagioclase and possibly some quartz, permeated by late fluids. This is indicated by the biotite foliation wrapping around microcline megacrysts in the xenoliths and around megacrysts projecting from granite into xenolith (fig. 15). A relatively high degree of plasticity is indicated hereby, so that the mica flakes were pushed aside by the growing megacrysts. When microcline had separated, the xenoliths apparently became almost impervious to the fluids of the metasomatic stage in the granite, so that they contain but little muscovite.

THE PEGMATITES

Pegmatites are abundant around Trancoso. Their greatest concentration is found in the older granite along the two granites contact. Aplite has been observed only locally, in porphyritic granite northwest of Trancoso, in thin veins (1-5 cm) apparently on cross-joints, striking about N 55 with vertical inclination.

The pegmatites generally form irregular, pinching and swelling veins, lenses, and sheets, varying in width from a few centimeters up to 3 meters. They consist of coarse irregular quartz, potash feldspar (up to 20 cm in size) and muscovite (up to 6 cm). There is frequently also some biotite. The mica crystals often display six-sided outlines. The biotite is frequently surrounded and corroded by muscovite. Black tourmaline is occasionally met with, while pale green beryl has been noted in places (west of Trancoso). The beryl is euhedral against quartz and molded on potash feldspar. The quartz is generally milky. Small euhedral crystals of smoky quartz, lining cavities, occur here and there. The potash feldspar is in general euhedral. It is tabular on 010 and displays the forms {010}, {001}, {110} and $\{10\bar{1}\}$. It is corroded by quartz and muscovite and carries unoriented albite inclusions. The potash feldspar is perthitic (chiefly vein perthite grading into patch perthite; a little film perthite is occasionally present). It consists in the main of untwinned microcline ($2V\alpha = 80°\text{-}85°$). Orthoclase has also been noted ($2V\alpha$ about 60°).

The boundaries of the pegmatites are vague, merging into the surrounding granite. Relatively sharp borders may occur against Trancoso granite. In this granite many of the pegmatites are in sheets with low dips toward the porphyritic granite. The interior of the Trancoso massif which is most granodioritic in composition appears to contain few or no pegmatites.

The pegmatites seem to have formed from the rest-fluids of the porphyritic granite.

MICROCLINIZATION OF TRANCOSO GRANODIORITE

The increase in microcline content in the Trancoso granite from the interior of the body towards the periphery (compare the locations of the modally analyzed specimens in figure 1) is not due to initial variability in composition. It is a secondary feature brought about by extensive development of new microcline near the porphyritic granite. The old microcline in the granodiorite, with smaller optic axial angle, may represent the original potash feldspar of the rock, most probably entirely recrystallized. It may be pseudomorphic after the original potash feldspar, just as the albite-oligoclase is considered to be pseudomorphic after more calcic primary plagioclase (see below). It is thought that the granodiorite is not a microclinized earlier trondhjemite.

The increase in microcline content toward the porphyritic granite points to an influx of potash feldspar material from the younger granite, which is confirmed by the replacive habit of the microcline. Concomitant with the increase in microcline, the old microcline disappears, recrystallizing as new microcline. The new microcline is thus in part metamorphic and in part introduced. The same relationship probably holds for the quartz. Although it would appear from the modal analyses that the new microcline developed wholly at the expense of plagioclase (and by recrystallization of old microcline), this is not entirely true. On considering the fabric it becomes clear that the original granodiorite, a hypidiomorphic biotite-plagioclase-potash feldspar-quartz rock, became microclinized through the introduction of material replacing both plagioclase and original quartz. The new microcline made room for itself by replacing granodiorite minerals, quartz not excluded. Afterward quartz crystallized, partly replacing both plagioclase and microcline. The granodiorite was solid when the younger granite was emplaced. This follows from the sharp contacts. Apparently the metasomatic, crystalloblastic process by which the new microcline developed led to a partly fluid state, since orientation of its tabular biotite and plagioclase inclusions may be observed.

The microclinization is considered to have been a metasomatic contact effect of the porphyritic granite. The microclinized granodiorite may be regarded as a regional reaction rim between the porphyritic granite and the granodiorite proper. The process seems to have been effected by an emanation of mobile substances into the predominantly solid, recrystallizing granodiorite. The presence of late muscovite in large quantities indicates a high degree of fluxing by hydroxyl which possibly was instrumental in bringing about the metasomatic processes transforming the original granodiorite. The interstitial attitude of the new minerals in their early stages strongly suggests that the influx took place along intergranular surfaces, in fluid form. The deformation which is locally evidenced by cataclastic plagioclase probably also effected as a less intense but more extensive process of dislocation a general loosening of the grains of granodiorite minerals. This may have facilitated imbibition with fluids soaking in from the porphyritic granite magma along the loosened intergranular spaces of the slightly dislocated granodiorite fabric. Thus the impregnation of the rock gave rise to new microcline, quartz, and muscovite. Though this process, as a kind of palingenesis, may have started before the younger granite magma had completed intrusion, its activity must have taken place largely after emplacement of the younger granite since its mineral facies are mainly those of the later magmatic and the metasomatic stages of the porphyritic granite. The development of microcline is probably an early phase of the process. The replacement of older minerals seems to have given rise, at least locally, to pockets of fluid in which inclusions were oriented by the separating microcline. Larger pockets of fluid permitted the formation of megacrysts, also with oriented inclusions. This fluidization, probably due to fluxing, correlates this stage with the magmatic stage of the porphyritic granite. A process in which a new mineral begins crystallization by blastesis, to continue separation in and from a partly or entirely fluid environment, might perhaps be designated by the term *ultrablastesis.* It is not ultrametamorphic, because new material was metasomatically introduced. Just as the stage of microcline formation in the porphyritic granite was reached under falling temperature in a consolidating magma, so the new microcline in the granodiorite developed under rising temperature, leading to partial fluidization of the rock. Afterward, when the temperature was declining again, quartz and muscovite crystallized. The optic axial angle of the granodiorite microcline is smaller than in the microcline of the porphyritic granite. This may perhaps point to its having formed at somewhat higher temperatures. The persistence of smaller axial angles may indicate incomplete adjustment to the conditions of later stages.

DECALCIFICATION OF PLAGIOCLASE

The uniform albite-oligoclase composition of the plagioclase in all plagioclase-bearing rocks in the area appears to be due to an extensive process of decalcification.

The large plagioclase crystals in the Portuguese porphyritic granites I have examined (such as the Cete granite) frequently display normal zoning with cores as calcic as andesine. The texture of the porphyritic granite around Trancoso closely resembles the texture of the other porphyritic granites. It is therefore inferred that the primary plagioclase in this granite also exhibited a composition more calcic than albite-oligoclase, but was afterwards decalcified.

Persistent zonation in the plagioclase of igneous rocks, denoting internal disequilibrium, may be considered not to be due to lack of reactivity but to lack of time to effect readjustment in response to changing conditions. In the granite in question the temperature may be assumed to have decreased sufficiently slowly to allow the reaction from more calcic to more sodic plagioclase to proceed to completion. If the rock was kept for a considerable period at the pt-conditions of the albite-oligoclase stage in its crystallization history, the primary plagioclase could have been entirely decalcified to homogeneous albite-oligoclase pseudomorphs. This may conceivably be attributed to a slow rate of cooling. The porphyritic granite around Trancoso is situated in the center of an enormous batholith. Such a pseudomorphic process would act in the solid, most probably by ionic diffusion in the plagioclase framework.

In view of this, it also seems likely that the plagioclases of the granodiorite and of the gneiss xenoliths, whatever their original composition, were metasomatically changed into albite-oligoclase, since they may be considered to have been raised to the same mineral facies as obtaining in the huge surrounding mass of porphyritic granite. The restricted range of anorthite content in the three types of rocks is too similar to be fortuitous. In the granodiorite and the gneiss inclusions, albite-oligoclase formation is therefore considered a contact effect of the younger porphyritic granite.

Where the plagioclase is in contact with microcline it has albitic outer zones. The transition is abrupt in the granodiorite, gradual in the other granites. This seems to be due to a decalcifying process of essentially the same nature as the homogenization to albite-oligoclase, but not run to completion since it is zonal. It is curious that these albite rims occur only in contact with microcline. Since they are absent against adjacent quartz III which corrodes microcline, they were probably formed posterior to the separation of potash feldspar. In the porphyritic granite the formation of the albite rims may be assigned to the metasomatic stage. Albite is not a magmatic mineral in these rocks (Schermerhorn, 1956, where it has been shown that the magmatic passed into the metasomatic stage approximately at the transition from the conditions of the hornblende gabbro facies to those of the albite-epidote amphibolite facies). It is thus indicated that after microcline had formed, albite-oligoclase was no longer the stable phase of plagioclase in the metasomatic stage and was supplanted by albite. The abrupt narrow zones of decalcification in the granodiorite indicate that here the readjustment possibilities were much more restricted than in the porphyritic granite and in the more microclinized varieties of Trancoso granite.

Concerning decalcification, it may be remarked that the plagioclase in the rocks of the area under consideration carries few or no zoisite-epidote minerals. It is concluded that the decalcifying process consisted not only of the release of Ca and Al (as commonly in the decomposition of calcic plagioclase to sodic plagioclase and zoisite-epidote) but also of their removal. We may infer that the amount of Ca and Al set free during decalcification passed into the rest-fluids which yielded Na and Si to replace Ca and Al. Part of the Al released may immediately have gone toward formation of sericite and other alteration products of plagioclase. Furthermore, it seems logical to correlate the sphene replacing ilmenite and biotite with the decalcification of plagioclase. It may be conceived that owing to the calcium content of the rest-fluids, sphene was formed from Ti (or sagenite) released by biotite or derived from ilmenite. In the Cete granite (Schermerhorn, 1956) on the other hand, exhibiting a much lower degree of decalcification, there is but little late sphene. The aluminum in the rest-fluids went toward crystallization of sillimanite and late muscovite.

METASOMATIC SILLIMANITE AND MUSCOVITE

Sillimanite is rarely encountered in igneous rocks, where it is currently considered due to contamination by pelitic material. As a late mineral it is occasionally noted in granites and pegmatites. Hills (1938) lists a few occurrences of sillimanite-bearing igneous rocks assumed to have crystallized from uncontaminated magmas. Read (1931, p. 162-163) describes sillimanite-bearing muscovite granites in Sutherland. Read considers that the excess alumina needed to form sillimanite was contained in the granitic fluids and was not the result of assimilation: "The sillimanite and the replacing or late muscovite . . . are genetically connected, and both most likely arise by the break-up of aluminum halides, alkali aluminates, and similar compounds contained in the residual portions of the granitic magma." Watson (1948) further investigated sillimanite occurrences in the Central Sutherland injection complex, both in country rock and in pegmatitic and aplitic veins. This sillimanite is convincingly shown to have formed under the influence of pegmatitic solutions, at a late stage, as a metasomatic, not a metamorphic mineral.

The mode of occurrence of sillimanite in the two granites of Trancoso is indicative of late origin. The occasional vein-like habit of the muscovite with which it is associated and the interstitial attitude of sillimanite trains suggest permeation of fluids along intergranular spaces. It is thought that the muscovite was largely introduced from the porphyritic granite, although part of it may have been derived from an initial muscovite content of the granodiorite, in veins following the boundaries of feldspar and quartz grains, and starting replacement from between the older crystals. The muscovite grew at a high angle to the intergranular spaces as evidenced by cleavage attitudes. The sillimanite seems to have formed prior to muscovite. Possibly it is only locally present owing to local alumina excess or rather potash shortage in the late fluids. Sillimanite and muscovite are both late, metasomatic minerals that crystallized from the residual fluids given off by the porphyritic granite. It is most unlikely that the sillimanite was derived from assimilated country rock, since the sparse xenoliths do not carry alumino-silicates. Nor are there any indications of contamination in the granites. The relatively large quantity of secondary muscovite, on the other hand, points to the existence of peralumious rest-fluids of magmatic derivation. Relative alumina enrichment, to separate sillimanite before muscovite formed, might have been caused by local disturbances of the K-Al balance. The alumina that went to form sillimanite in the Trancoso granite may have formed as a consequence of decalcification of plagioclase. This sillimanite has nothing to do with metamorphic sillimanite as an index mineral for high grade schists or hornfelses. In the crystallization history of the Trancoso rocks it is posterior to quartz III. The sillimanite here was therefore formed in a late stage in their evolution, as a metasomatic mineral.

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