Kyanite produced in a granitic aureole

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Summary. An occurrence of kyanite in the inner aureole of a granodiorite intrusion is described from south-western Ghana. Greenschist facies phyllites have been elevated to the amphibolite facies and the regional strike of these country rocks has been disrupted by the intrusion, so that clear evidence is available of the time relationships. It is concluded that the kyanite crystallized as the result of the forceful intrusion of the granodiorite, probably under epizonal conditions.

The conditions under which kyanite crystallizes during metamorphism are open to some dispute (see, for example, the symposium on depth and tectonics as factors in regional metamorphism, Proc. Geol. Soc. London, No. 1594). Experimentally determined equilibrium relations (Clark, 1961) indicate that depths of burial of the order of 30 km are required before kyanite will crystallize, though the presence of tectonic overpressures may reduce this figure. Kyanite has been recorded from contact aureoles of granitic intrusions (e.g. McCall, 1954; Pitcher and Read, 1960), when forceful intrusion of the granitic body is regarded as the cause of the development of kyanite. Where the intrusion is of the high-level type, as in Donegal, the kyanite appears to be the result of high directed, not hydrostatic, pressure. The occurrence of kyanite described in the present paper, which is one of several reported in Ghana, is of this type and evidence is presented suggesting that the kyanite crystallized near the base of the epizone.

Geological setting. The granitic intrusion occurs near Bibiani in the Western Region of Ghana (Lobjoit, in press). The country rocks belong to the Birrimian System (Precambrian) and consist of geosynclinal sediments metamorphosed in the greenschist facies. The regional structural pattern is that of isoclinal folding and the strike of the near-vertical beds is NNE.–SSW. These rocks are predominantly argillaceous phyllites, with some metagreywackes, and rare chloritic and calcareous beds. Characteristic minerals are albite, sericite, and chlorite.

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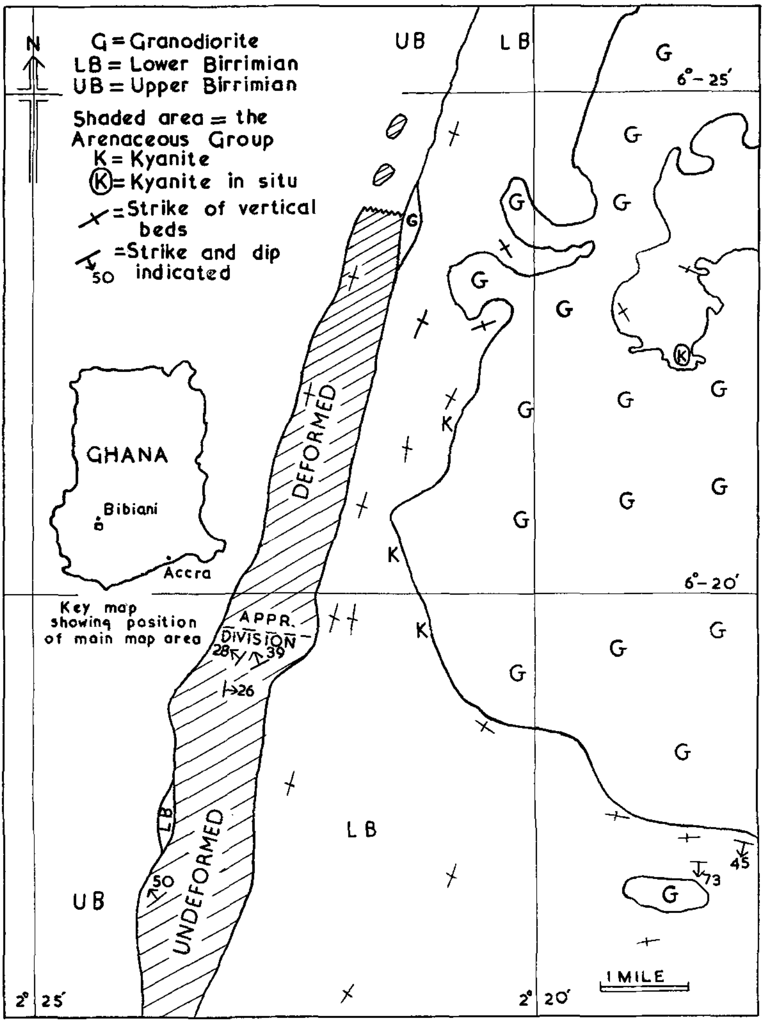

FIG. 1. Map showing the geological setting in which the kyanite is found.

The intrusion is a hornblende–biotite granodiorite and is the western part of a large body, the bulk of which has not been mapped in detail. The line of contact with the country rocks is tortuous and large schist 'pendants' occur within the intrusion. The present level of erosion would thus appear to be near the roof of this part of the granodiorite. The contact aureole is not more than half a mile in width, and generally less.

The outer extent of the aureole is marked by 'spotted phyllites' and phyllites with irregular micaceous patches, presumably after chiastolite, for this mineral in euhedral, shimmerized porphyroblasts is characteristic of the bulk of the aureole. These chiastolite or andalusite porphyroblasts are accompanied by similar euhedral pseudomorphs after staurolite, whose frequency increases towards the granodiorite. Cruciform twins and hexagonal sections reveal the identity of these pseudomorphs, which are now entirely mica plus opaque.[1] The 'groundmass of these rocks is still phyllite, but the increase in grade is shown also by the development of wisps of dirty brown biotite. In the inner part of the aureole, and in the pendants in their entirety, the phyllitic texture is lost and brown biotite, staurolite, garnet, and andalusite are the characteristic minerals, together with quartz, albite-oligoclase, and opaque. Staurolite, garnet, and andalusite form spongy porphyroblasts, the staurolite being by far the most common. In contrast to the outer aureole the staurolite and andalusite are almost unaltered. The kyanite-bearing rock, found exposed in only one place, where it lies within a hundred yards of the nearest granodiorite exposure, is a kyanite–garnet–biotite–muscovite schist with well-formed prisms of kyanite and many small garnets with dusty centres. Near this locality a calcareous rock contains zoisite and diopside. This occurrence is in one of the pendants, but evidence for a similar development of kyanite comes from the western margin of the granodiorite, where concentrates obtained from gravels immediately above bedrock contain, in order: staurolite and andalusite; staurolite, andalusite, and kyanite; highly pleochroic epidote and all three previous minerals, as the granodiorite contact is approached and passed. The epidote is characteristic of the granitic terrain and the metamorphic minerals have been 'smudged' downstream across the contact. Kyanite is again the nearest mineral to the granodiorite. All the other recorded occurrences of kyanite in the Birrimian in Ghana are in granitic aureoles (Geol. Surv. Ann. Reports, 1954, 1955, and 1961) and staurolite is common in this environment (Geol. Surv. Ann. Reports, 1954, 1955, 1957, and 1961).

The marginal parts of the granodiorite are not well exposed, but those outcrops seen suggest that locally the contacts are migmatitic, though these rocks are clearly distinguishable from the bulk of the granodiorite. Near the kyanite schist a fine-grained granodioritic rock with slender prisms of hornblende provides evidence for a liquid phase. It is interest-

[1] This is a retrograde effect, construed to be the result of a tail-off in the thermal effect of the intrusion, in the outer part of the aureole.

ing to note the juxtaposition of granodioritic liquid and the highest grade of metamorphism attained in the aureole.

The granodiorite does not appear to have imprinted a new schistosity on the country rocks, but the phyllites, etc., of the aureole have been bodily reorientated until their strikes lie parallel to the granodiorite contact, which is E.–W. in the south. This change of orientation is often accompanied by a lowering of the dip from near-vertical to as low as 45°. In view of the regularity of the regional strike these changes around the granodiorite are held to indicate its forceful emplacement.[1]

Along the foot of the Bibiani hill range, just to the west of the granodiorite, lies a group of rocks ranging from conglomerate to mudstone, but predominantly arenaceous. South of the southernmost extent of the granodiorite these rocks are undeformed and apparently only diagenetically altered (Dapples, 1962). Where these rocks lie opposite the granodiorite they are deformed, and low dips are replaced by high ones. But, beyond mechanical squeezing, the rocks are unmetamorphosed, as they lie outside the contact aureole. This so-called Arenaceous Group is considered to be a molasse type deposit as it clearly postdates the orogenic metamorphism of the Birrimian and, indeed, contains fragments of late-orogenic metasomatic rocks. It was thus deposited during the closing stages of the Birrimide orogeny and became partially deformed by the intrusion of the granodiorite, which is regarded as a late- or post-orogenic body. Thus at about the level of the top of this granodiorite, where the kyanite crystallized, there was the base of a non-metamorphic molasse deposit, now largely eroded away.

Discussion. The field evidence is clear that this granodiorite was emplaced by pushing aside the country rocks. The act of intrusion was thus forceful and it can be assumed that a shearing action was present. It is also reasonably certain that the superincumbent pile was little more than the thickness of the molasse deposits. Junner (1940) gives a maximum thickness of 10 000 feet for the Tarkwaian, a post-Birrimide continental accumulation with thick conglomerates at the base, which appears to be the representative of the molasse facies in this orogenic cycle. Thus, without considering the eroded sediments, the maximum is well on the way to the thickness given by Jung and Roques (1952) for the base of the non-metamorphic zone for pelitic rocks, namely 4 km. Because of the lack of metamorphism in the undeformed Arenaceous

[1] But compare Woodland (1963), who suggests a change in temperature, not pressure, when a granite is intruded after regional metamorphism to the greenschist facies.

Group rocks (coarse and fine) an original depth of not more than about 4 km is tentatively given for the present level of erosion. This is near the base of the epizone (Buddington, 1959).

The minerals developed in the aureole of the granodiorite are a mixture of 'contact' and 'regional' types, though the regional predominates. The grade of metamorphism rises from the muscovite–chlorite subfacies (the country phyllites), through the biotite–chlorite subfacies (the chiastolite–biotite phyllites) and epidote–amphibolite facies (staurolite–garnet pair), to the lower-grade part of the amphibolite facies (kyanite–garnet pair). This typical 'regional' metamorphism must be the result of the mechanical act of emplacement of the granodiorite, which is construed as a diapiric body and not the result of migmatization or metasomatism *in situ*. It is a high-level type of intrusion.

At the estimated depth of 4 km (identical to the depth given by Wenk, 1962, as that of the formation of kyanite in one part of the Swiss Alps) the pressure due to the superincumbent load is insufficient to cause the crystallization of kyanite. The high directed pressure must therefore be the cause, together with the necessary high temperature.

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References

BUDDINGTON (A. F.), 1959. Granite emplacement with special reference to North America. Bull. Geol. Soc. Amer., vol. 70, p. 671 [M.A. **14**–365].

CLARK (S. P.), 1961. A redetermination of the equilibrium relations between kyanite and sillimanite. Amer. Journ. Sci., vol. 259, p. 641 [M.A. **15**–437].

DAPPLES (E. C.), 1962. Stages of diagenesis in the development of sandstones. Bull. Geol. Soc. Amer., vol. 73, p. 913.

JUNG (J.) and ROQUES (M.), 1952. Introduction à l'étude zonéographique des formations crystallophylliennes. Services Carte géol. France, Bull. No. 235, t. 50.

JUNNER (N. R.), 1940. Geology of the Gold Coast and Western Togoland. Gold Coast Geol. Surv. Bull. No. 11.

LOBJOIT (W. M.) (in press). The petrology of two areas in the Birrimides of western Ghana, with a discussion of sedimentation, stratigraphy, and granite evolution. Geol. Surv. Ghana Bull.

McCALL (G. J. H.), 1954. The Dalradian geology of the Creeslough area, Co. Donegal. Quart. Journ. Geol. Soc. Lond., vol. 110, p. 153 [M.A. **12**–548].

PITCHER (W. S.) and READ (H. H.), 1960. The aureole of the Main Donegal Granite. Quart. Journ. Geol. Soc. Lond., vol. 116, p. 1 [M.A. **15**–376].

WENK (E.), 1962. In discussion on Symposium: Depth and tectonics as factors in regional metamorphism. Proc. Geol. Soc. Lond., no. 1594, p. 31.

WOODLAND (B. G.), 1963. A petrographic study of thermally metamorphosed pelitic rock in the Burke area, north-eastern Vermont. Amer. Journ. Sci., vol. 261, p. 354.