copper bearing solutions percolating through the specimen would have reacted to produce a more homogeneous torbernite.

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NOTE ON TWINNING AND PSEUDO-TWINNING IN DETRITAL QUARTZ GRAINS

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Detailed studies of etch figures and morphology have shown that with few exceptions single crystals of quartz are made up of more than one individual intimately grown together. The most common intergrowths are described by the Dauphiné, Brazil and combined Dauphiné-Brazil twin laws (Gordon, 1945; Gault, 1949). These types of twinning cannot be detected optically in thin sections of customary thickness. The purpose of the present note is to point out that a second group of intergrowths composed of sub-individuals whose c axes do not coincide are not uncommon, though hitherto they have seldom been recognized as such. A twin relationship can be demonstrated between members of some intergrowths of this second group, while in others the relation closely approximates one of the thirteen twin laws designated by Zyndel (1914). Because of the small but consistent departures from the laws of Zyndel, this type of intergrowth has been called pseudo-twinning by Hintze (1915, p. 1270).

Intergrowths of the second group are most conspicuous in individual grains of sandstones. They were repeatedly encountered by the writer in the course of a petrographic examination connected with the artificial deformation of the Asbury Park beach sand (Maxwell and Verrall, 1954; Borg and Maxwell, 1956). Although the crystallographic orientation of a twinned grain can be determined only on deformed material in which recognizable cleavage fractures have formed, twins and pseudo-twins are not themselves products of experimental deformation. They are equally common in the sand prior to deformation. Approximately $1\frac{1}{2}\%$ of the grains in the Asbury Park sand are intergrowths recognizable in thin section. Those that survive experimental deformation also contain minor fracturing controlled in large part by $r\{10\bar{1}1\}$, $z\{01\bar{1}1\}$, and $m\{10\bar{1}0\}$. Thus it is possible in favorable instances to describe the crystallographic relations between participating members of the intergrowths by measuring experimentally induced fractures, *c* axes and composition planes, if present, with a universal stage and by plotting the results on a stereographic projection.

Intergrowths cannot be seen in plane polarized light (Fig. 1*A*) unless foreign material has lodged along discontinuities bounding members of the intergrowth (Figs. 1*C* and 1*E*). Under crossed nicols the rounded grains appear to be made up of many sub-individuals of different orientation (Fig. 1*B*); however usually two and no more than three orientations may be recognized by measuring the exact position of the *c* axes in the various sub-individuals. The apparently large number of sub-individuals seen stems from overlap of portions of one individual on another resulting in areas of slightly different birefringence. The grain shown in Fig. 1*D* contains a nearly planar surface separating two members of the intergrowth in the manner of a composition plane. If this irregular surface were sub-parallel to the plane of the thin section, a grain of mottled extinction would be seen.

Twenty carefully measured intergrowths were found to be true twins on the Japanese law or pseudo-twins approximating the Esterel, Breithaupt, or Sardinian laws. The following is a résumé of the theoretical relations stipulated by these laws.

TABLE 1. PENETRATION TWINS OF QUARTZ

	Twin plane	$c \wedge c'$ angle*
1. Japanese law	ξ $\{11\bar{2}2\}$	84° 33′
2. Breithaupt law	s $\{11\bar{2}1\}$	48° 54′
3. Esterel law	r $\{10\bar{1}1\}$	76° 26′
4. Sardinian law	d $\{10\bar{1}2\}$	64° 50′

* The angle between the respective *c* axes of the two twinned sub-individuals.

Figure 2*A* is a stereographic projection of the *c* axes, fractures and approximate composition plane in a grain twinned by the Japanese law. Figure 2*B* is a similar projection of a grain whose sub-individuals nearly but not exactly conform to the Breithaupt law. The observed value of the angle $c \wedge c'$ in grains twinned on the Japanese law in no case depart from the ideal value by more than 2°, whereas deviations of 3°–6° were consistently recorded for pseudo-twins approximating the other three laws. In addition several grains were observed in which the *c* axes of the

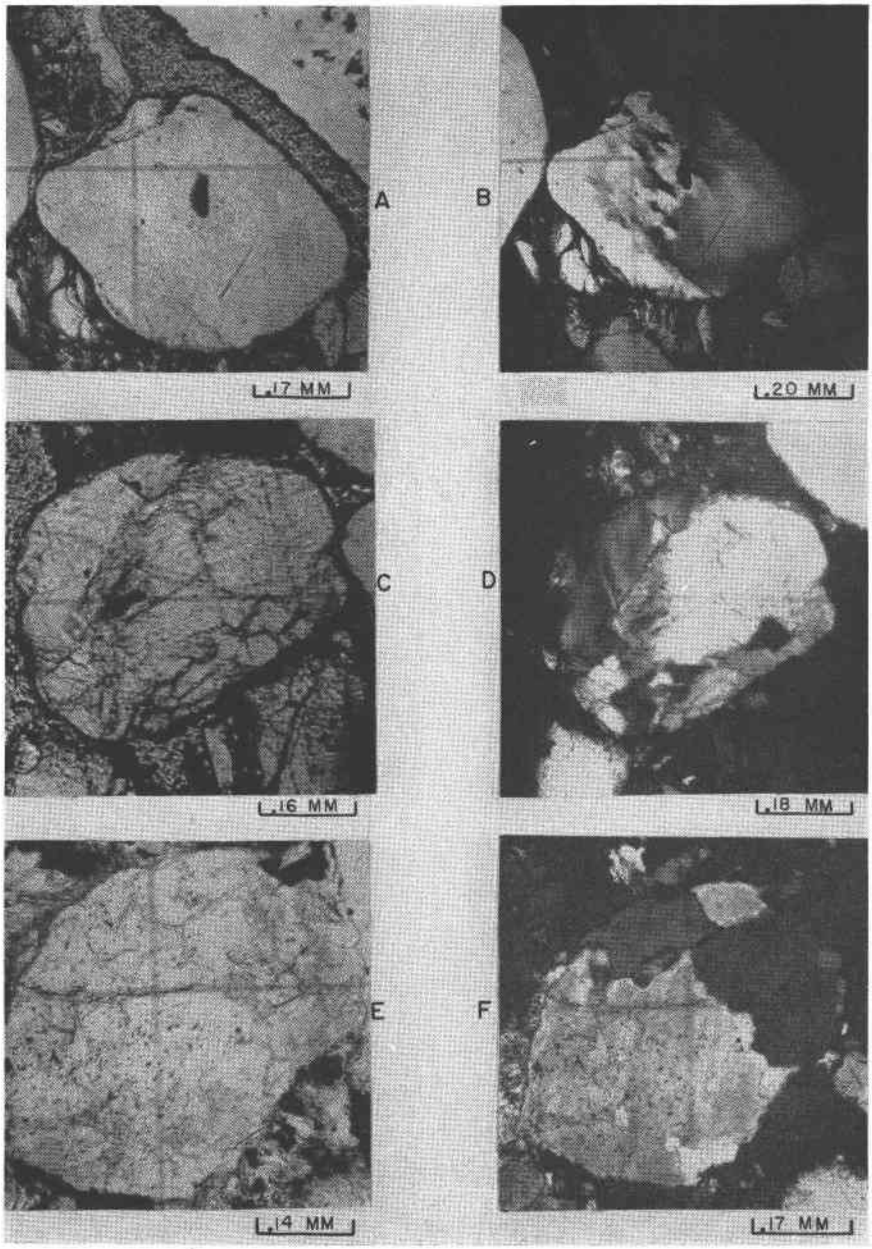

FIG. 1. Photomicrographs of intergrowths and twins. *A* and *B* are of a grain twinned by the Japanese law; the pairs *C* and *D*, and *E* and *F* are grains nearly conforming to the Esterel and Sardinian laws respectively. *A*. *C*, and *E* were taken with plane polarized light, *B*, *D*, and *F* under crossed nicols.

participating sub-individuals intersect at acute angles. Unfortunately fractures were not well enough developed in these grains to ascertain whether or not they conform to other "twin laws" or to intergrowths described by Zyndel and others.

An interesting feature of the intergrowths is the constant appearance of well developed undulatory extinction or "strain shadows" (Fig. 1*D*). Boehm or deformation lamellae are commonly developed also. The appearance of these features does not depend on experimental deforma-

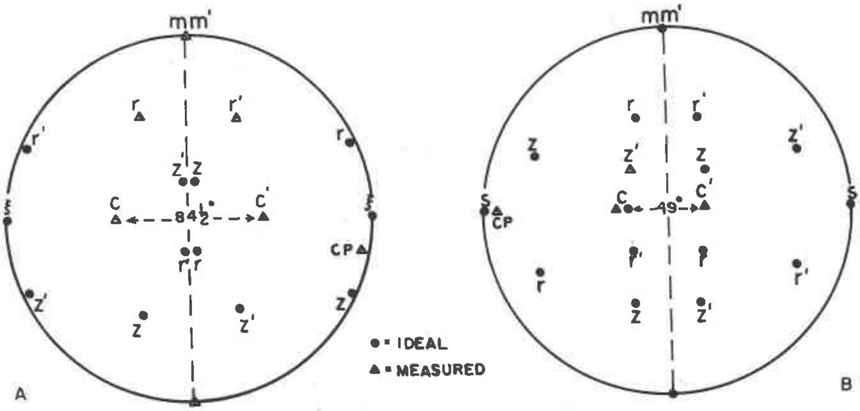

FIG. 2. Stereographic projection of intergrowths. *A*. Twinning according to the Japanese law, $\xi\{11\bar{2}2\}$. *B*. Pseudo-twinning approximating the Breithaupt law, $s\{11\bar{2}1\}$. Approximate position of the pole of the composition plane is indicated by *C.P.* Dotted line is twin plane.

tion, for they are seen in grains (intergrowths) in the loose sand subsequently used by Maxwell for his experiments. Most likely they reflect anisotropic contraction of the structure after formation of the intergrowths in response to falling temperature. It is also possible that some of the pseudo-twinning observed has been inherited in modified form from a higher temperature form of quartz, e.g. β quartz which twins by similar laws. Another explanation may be that the intergrowths are inversion twins subject to contraction upon further cooling, although to date only the Dauphiné law has been recognized to develop upon inversion of β to α quartz.

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NOTE ON LARGE CORDIERITE PORPHYROBLASTS, FREMONT COUNTY, COLORADO

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Cordierite occurs abundantly and, in places, conspicuously in metamorphic rocks of the Front Range, Colorado. It is most readily detected as porphyroblasts, although it is undoubtedly abundant as a more subtle constituent in granoblastic hornfelses; for example, cordierite-anthophyllite rocks, a few miles north of Salida, Colorado.

The purpose of this note is to draw attention to some unusually large porphyroblasts (four to five inches in greatest dimension) in a readily accessible exposure. This occurrence is 2.8 miles east of Texas Creek, on U. S. Highway 50 in Fremont County. At this point, a contact between Precambrian granitic rock and Precambrian metamorphic rock strikes across the highway and the Arkansas River (Fig. 1). Although the contact is generally well defined, it is complicated by abundant pegmatite dikes which thoroughly invade the metamorphic rocks giving them a sporadic distribution along the contact. Also, in some places, large masses of metamorphic rocks are included within the granitic rock at dozens, and even hundreds, of feet from the contact. Most of the metamorphic rock along the contact and within the granitic rock is cordierite-bearing schist.

Because of the pronounced, nearly vertical, foliation, the steep slopes on the highway side of the river are littered with large slabs of gray cordierite schist. The cordierite, in large black or dark gray porphyroblasts, stands out conspicuously against the gray or silvery gray groundmass (Figs. 2–4). The porphyroblasts range from $\frac{1}{8}$ inch to 5 inches in greatest dimension but commonly occur in two, and in some places, three sets of different sizes (Fig. 3). Most of them are blocky or prismatic but some are spheroidal, and in all, the greater dimensions are more or less

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