Quartz after tridymite in an acid intrusion from Mull.

By R. R. SKELHORN, B.Sc., Ph.D., F.G.S.[1]

King's College, London, W.C. 2.

[Read 2 November 1961.]

Summary. The occurrence of tridymite, now inverted to quartz, in a craignurite (allied to granophyre) from Craignure, Mull, is described. An account of the field occurrence and petrology and a new analysis of the craignurite are given. The significance of the occurrence of tridymite is discussed in the light of recent experimental studies.

WHILST studying a Tertiary composite intrusion at Craignure, Mull, it was found that the central acid component, named a craignurite by the Geological Survey (Mull Memoir, p. 225), contained tridymite, now, of course, inverted to quartz.

Field occurrence.

The composite intrusion is a cone-sheet forming an arc a mile long, and consists of thin basic margins of dolerite flanking a thicker central acid component. It forms the south-west part of Craignure Bay and is well exposed on the shore opposite the now disused United Free Church Manse. The upper part of the cone-sheet is not exposed here as it is obscured by the badly drained ground, which forms part of a raised beach. On the shore, north of the United Free Church Manse, this intrusion cuts across folded, sheared, and crushed Trias and Lower Lias without itself being sheared. Westwards from Craignure Bay it is intruded into Tertiary basalt lavas, and the exposures are poor except in the Allt a' Chladha where a complete cross section of the intrusion is available for study.

The basic margins are 2 ft 6 in. to 3 ft thick, discontinuous, and possess a sharp, straight contact with the central acid component. These basic margins, which consist of plagioclase (An 54), clinopyroxene, iron ore, chlorite, and a little olivine, are tholeiites of the Salen type (Mull Memoir, p. 285). A grey craignurite, 100 ft thick, forms the central acid component. A characteristic feature in the field is the flow banding, which is found throughout most of the intrusion. This flow banding

[1] *Present address*: Sir John Cass College, London, E.C. 3.

consists of alternate light and dark bands, which are usually about ½ in. wide although some reach 2 in. Individual bands may be traced several yards before tapering off; the junction between the bands is sharp. In thin section it is seen that the flow banding is an expression of textural variation, and is not due to differences in mineralogy. The dark bands have a uniform texture whereas in the light bands the quartz and feldspar occur concentrated in round or elongate aggregates that are surrounded by dark rims, the latter being glass flecked with iron ore and altered pyroxene.

This cone-sheet belongs to the Early Acid and Intermediate Cone-sheets, which are connected to the Beinn Chaisgirdle Centre, the first centre of igneous activity in Mull.

Petrology.

The main points of the Survey definition of craignurite (Mull Memoir, p. 227) are:

> The craignurites range in silica percentage from about 55–70 and their most characteristic representatives have about 65 per cent SiO_2. In the field, they are grey, moderately fine grained rocks, characterised by an acicular development of their chief constituents. Microscopically, they consist essentially of columnar and acicular aluminous augite and elongated skeletal crystals of a zoned andesine and oligoclase, in a matrix that appears to be the rapidly crystallised representative of a glassy base. The matrix usually shows an intricate network of slender and skeletal acid plagioclase crystals, set in the ultimate products of crystallization which are patches of microperthitic and microgranophyric material with minute areas of free quartz.

The Craignure craignurite, which is closely allied to a granophyre, consists of skeletal plagioclase (oligoclase-andesine), acicular pyroxenes, now altered to chlorite, and plates of quartz after tridymite, all lying in a brown devitrified acid groundmass of quartz and alkali feldspar. The alkali feldspar is considered to be a cryptoperthite as it has a lower general refractive index than the quartz. Also present are a few small albitized plagioclase (oligoclase-andesine) phenocrysts, which show combinations of Carlsbad, albite, and pericline twins.

An analysis, by the author, of the craignurite from opposite the disused United Free Church Manse gave: SiO_2 71·80, TiO_2 0·72, Al_2O_3 11·82, Fe_2O_3 1·48, FeO 2·70, MnO 0·07, MgO 0·73, CaO 1·57, Na_2O 3·44, K_2O 4·63, H_2O^+ 1·10, P_2O_5 0·21: total 100·27. This analysis shows that the Craignure craignurite lies at the acid end of the craignurite series as defined by the Survey.

The best specimens for showing quartz after tridymite are to be

collected on the coast just south of the disused United Free Church Manse. The tridymites exhibit their characteristic platy habit (figs. 1, 2). In a thin slice these now inverted tridymites appear as very narrow rectangular sections, the maximum length being 0·5 mm. The length: breadth ratio is often as high as 20 to 1. These sections show clearly that the tridymite has been replaced by 1 to 12 quartz individuals. The long sides of the former tridymites are distinct and straight whereas the faces that form the ends of the crystals are ill defined, implying that the basal pinacoid form of the tridymite was well developed in comparison with the faces in the prismatic zone. Where the tridymite has inverted to just one quartz individual, the section does not give straight extinction, showing that the optic axis is not perpendicular to the former basal pinacoids of the tridymite. This feature was also noticed by L. L. Ray (1946) and by L. R. Wager *et al.* (1953). The new quartz individuals do not usually have their edges perpendicular to the original basal pinacoid and may be likened to wedges in which the thin end has been truncated (fig. 1). The basal sections of the pseudomorphs now form irregular areas made up of many individual quartz units and, as such, are not easily identified as former tridymite units. But upon careful observation it is seen that the recognizable pseudomorphs after tridymite join with and are in optical continuity with one of the quartz units in such an irregular area (fig. 1). It is only by such evidence as this that one is able to show that these irregular areas, now made up of many individual quartz units, were once a tridymite crystal.

It is most noticeable that the former tridymite is more commonly to be found in the finer-grained parts of the craignurite, and this is even evident in the same thin section. Where a granophyric texture is present no evidence of the former presence of tridymite is to be found. Whether this distribution is a result of later recrystallization of a glass in which the tridymites were set is not known.

One thin section of craignurite showed a small xenolith of sandstone $\frac{1}{8}$ in. across; metamorphism resulted in the production of a fringe of tridymite now inverted to quartz. The 'tridymite' appears as lath-like sections, which give oblique extinction and are in optical continuity with the original quartz grains of the xenolith. In the Tertiary volcanics most of the recorded occurrences of tridymite in siliceous xenoliths or country rocks are to be found in association with basic igneous rocks. Other than the present example the only recorded occurrence of tridymite due to metamorphism by an acid intrusion is that of the Loch Uisg granophyre (Mull Memoir, p. 198).

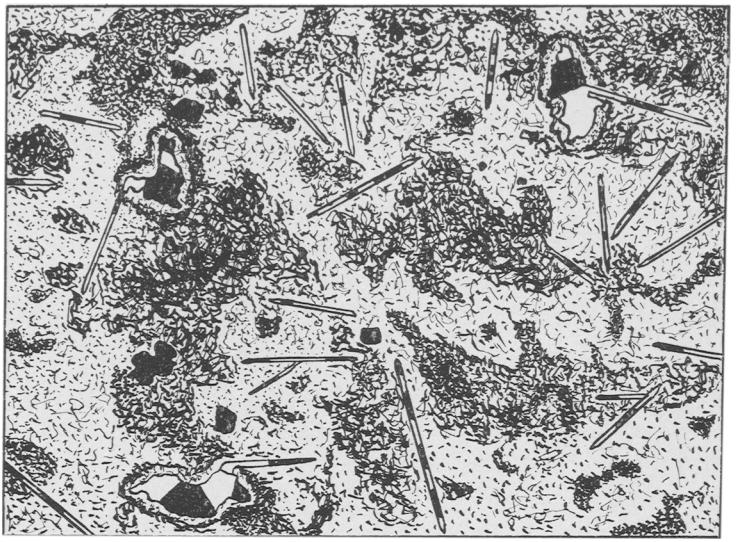

FIG. 1. Diagram showing tridymite crystals, now inverted to quartz, in a cryptocrystalline groundmass. Note the former basal sections of tridymite. Crossed nicols, ×42.

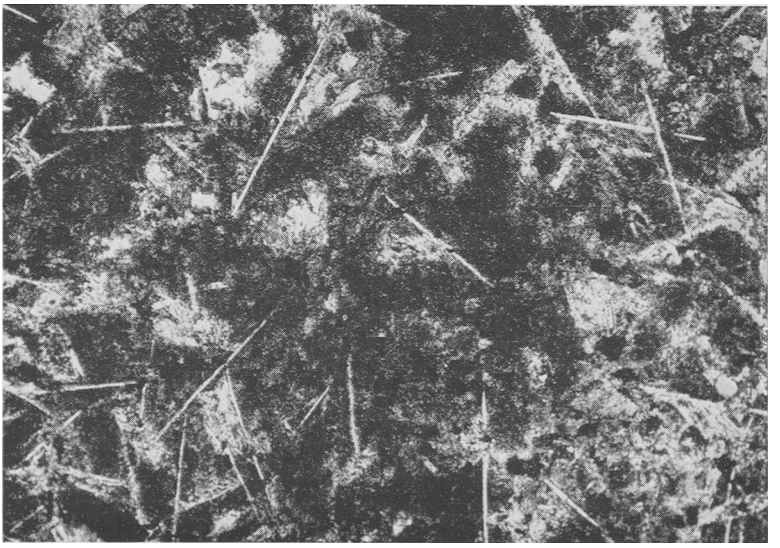

FIG. 2. Microphotograph showing tridymite crystals, now inverted to quartz, in a cryptocrystalline groundmass. Ordinary light, ×42.

Occurrence of tridymite.

This occurrence of phenocrysts of tridymite pseudomorphs is only the second to be described from an intrusive acid igneous rock in the Tertiary Thulean Province. Certain other examples of tridymite in igneous rocks in this province are associated with lavas: liparites (Hawkes, 1916) and rhyolites (Walker, 1959) from Iceland and the Tardree rhyolite, where the mineral occurs in fissures and cavities.

Although this is only the second such occurrence to be described from an intrusive acid igneous rock, the writer is of the opinion that it is of more common occurrence than this. For instance, the craignurite that outcrops at Scallastle Bay, Mull, exhibits in places under the microscope a very delicate criss-cross texture of thin quartz lamellae ('acicular quartz' of some authors), which were presumably tridymite crystals that have since inverted.

In 1953 Wager, Weedon, and Vincent described quartz paramorphs after tridymite from the Coire Uaigneich granophyre, Skye. The present writer has specimens of this granophyre and has studied it in thin section. The tridymite phenocrysts now inverted to quartz show the same features as the ones in the craignurite except that in the Skye rock each tridymite is represented by many more individual quartz units.

Significance of tridymite.

The presence of tridymite in a rock was considered by G. P. Black (1954) not only to indicate high temperature but also low pressures; he used the thermodynamic data of Mosesman and Pitzer (1941), who determined for various forms of silica the rates of variation of the inversion temperature with pressure. From this data one sees that the maximum pressure for tridymite to form is 930 atmospheres, but Mosesman and Pitzer considered that in fact it is probably not more than 640 atmospheres. Later work by Tuttle and England (reported in Morey, 1958, p. 61; see also Tuttle and Bowen, 1958) in which direct determinations were carried out, shows that the stability field of tridymite in the dry system is considerably larger than Mosesman and Pitzer's estimate. Work on the system SiO_2–H_2O by Tuttle and England (1955) has shown that the stability of tridymite under water-vapour pressure is greatly contracted by displacement of the liquidus. These authors state that the effect of only moderate pressures of water vapour on the silica liquidus was greater than expected. Fig. 3 shows the stability relationships of the various forms of SiO_2 for the dry system, the liquidus under water-

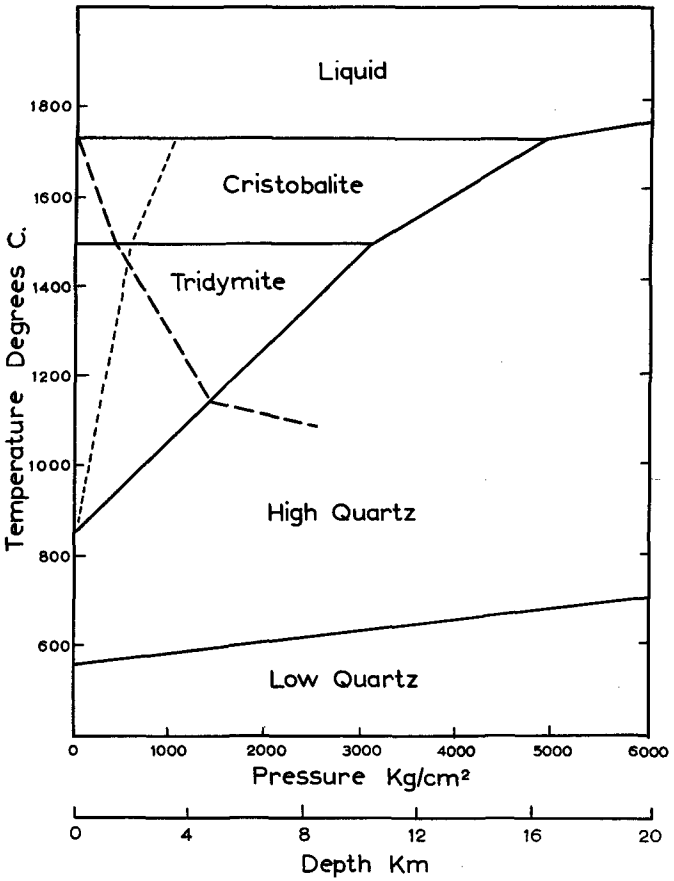

FIG. 3. Stability relationships of the various forms of SiO_2. ——— dry system; — — — liquidus in the system H_2O–SiO_2; - - - - - calculations of Mosesman and Pitzer.

vapour pressure and the relationships as calculated by Mosesman and Pitzer.

R. Roy *et al.* (1957) studied the high silica portions of the system SiO_2–$NaAlSiO_4$ from 500° to 1200° C and at pressures below 1000 atmospheres. The temperature of formation of tridymite decreases with the substitution of Na+Al until with about 10 mol. % $NaAlSiO_4$ it forms as low as 550° C. Thus, the use of tridymite as an indicator of a temperature above 870° C is not valid.

From the above work it appears that the only conclusion one can

arrive at from the presence of tridymite in a rock is that it crystallized under a low pressure. With regard to the Craignure composite intrusion, this can easily be deduced, for at the locality where it contains the tridymite pseudomorphs the level is the same as the base of the Mull lava pile where it rests on the Mesozoics. The figure of 6000 ft is quoted in the Mull Memoir as being the maximum thickness of the lava pile, but as Craignure lies towards the edge of this pile the thickness will probably be no more than 5000 ft. Using the figure of 5000 ft of basaltic lava (sp. gr. 2·9) at Craignure, we can deduce that the craignurite formed at a minimum load pressure of about 430 atmospheres.

References.

BAILEY (E. B.), and others, 1924. Tertiary and post-Tertiary Geology of Mull. Mem. Geol. Surv. Scotland.

BLACK (G. P.), 1954. Min. Mag., vol. 30, p. 518.

HAWKES (L.), 1916. Geol. Mag., dec. 6, vol. 3, p. 205.

MOREY (G.), 1953. Ann. Rept. Geophys. Lab., Yearbook 57, Carnegie Inst., p. 61.

MOSESMAN (M. A.) and PITZER (K. S.), 1941. Journ. Amer. Chem. Soc., vol. 63, p. 2348.

RAY (L. L.), 1947. Amer. Min., vol. 32, p. 646.

ROY (R.), ISAACS (T.), and SHAFER (E. C.), 1957. Bull. Geol. Soc. Amer., vol. 68, p. 1789.

TUTTLE (O. F.) and ENGLAND (J. L.), 1955. Bull. Geol. Soc. Amer., vol. 66, p. 149.

—— and BOWEN (N. L.), 1958. Mem. Geol. Soc. America, No. 74.

WAGER (L. R.), WEEDON (D. S.), and VINCENT (E. A.), 1953. Min. Mag., vol. 30, p. 263.

WALKER (G. P. L.), 1959. Quart. Journ. Geol. Soc. (for 1958), vol. 114, p. 367.