Earlier stages in the metamorphism of siliceous dolomites.

(With Plates XVII and XVIII.)

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In the progressive thermal metamorphism of siliceous dolomites, tremolite and calcite are usually considered the earliest of the new mineral phases formed by reaction of the primary materials, dolomite and quartz. An early formation of forsterite has also been recorded, as, for example, in the dolomitic zones of the Durness limestone surrounding the Tertiary Beinn an Dubhaich granite of Skye. In this aureole, however, the relation of forsterite to tremolite has hitherto not been closely investigated. As Bowen[1] has pointed out in his systematic study of the progressive metamorphism of siliceous limestones and dolomites, a first formation of forsterite from dolomite and quartz could not rank as an equilibrium reaction since forsterite and quartz can have no stable coexistence. Tremolite has accordingly been regarded as the first metamorphic product in an equilibrium series of reactions of increasing decarbonation affecting siliceous dolomites in an advancing higher temperature environment at any given pressure. In the Broadford–Kilchrist area of Skye, the Cambrian dolomites belong particularly to horizons known locally as the Beinn an Dubhaich and Strath Suardal zones. Those in the inner aureole of the granite provide spectacular examples of high-grade metamorphism which has been detailed by Harker[2] in the Skye memoir. Outcrops of dolomite in the outer aureole of this intrusion providing data on earlier stages of alteration occur in the area east of Ben Suardal where bands of the Strath Suardal zone are brought up by folding and thrusting and are enveloped by the Ben Suardal limestone zone (a^{v1}) of the Durness group. This zone of dolomite forms a band running NNE. from $\frac{1}{2}$ mile NE. of the summit of Ben Suardal to a point nearly $\frac{1}{2}$ mile south of the same position. At the north end of the outcrop the dolomite is approximately one mile from

[1] N. L. Bowen, Journ. Geol. Chicago, 1940, vol. 48, pp. 225–274. [M.A. 8–243.]

[2] A. Harker, The Tertiary igneous rocks of Skye. Mem. Geol. Surv. Scotland, 1904, pp. 144–151.

the nearest exposed granite and the south end approaches to a distance less than $\frac{3}{4}$ mile from the granite.

The Strath Suardal zone is characterized by chert nodules and lumps an inch or two across which resemble sponge forms but show no clear organic structure, and it is at the contact of the dolomite with these chert nodules that the first signs of metamorphism involving the production of new minerals are found. Examination of numerous specimens from this band of the Strath Suardal dolomite makes clear that *talc* is the first new-formed phase to be recognized and its formation is therefore to be ascribed to reaction between dolomite and quartz.[1] The chert forms become invested with a thin dense white unctuous skin which microscopic examination reveals as talc (pl. XVII, figs. 1 and 2).

At the north end of the outcrop a few examples were studied in which there were no signs of reaction between the carbonate and chert, but the great majority show the production of one or more new mineral phases.

In the earliest stage talc then appears immediately adjacent to chert as fine flakes together with calcite forming the skin referred to above. In a more advanced stage of talc development the talc zone can be divided into two or more sub-zones: (1) an inner zone against the chert built up of relatively coarse-grained talc, quartz, and calcite, the grain size of the quartz being often notably coarser than that in the interior of the nodule; (2) a fine-grained zone, rich in talc but associated with fine granular calcite which gives turbidity to this zone; (3) an outer coarse zone with subordinate talc associated with calcite and dolomite. In the dolomite ground which invests these zones sparse flakes of talc can be recognized adjacent to the contact. Their presence is readily made out if a thin section of the rock is treated with acid to remove the dominant carbonate. Talc also occurs in the body of the chert either in irregular areas or forming with calcite pseudomorphs after former idioblastic rhombohedra of dolomite.

The distribution of the three zones just described is depicted in pl. XVIII, figs. 1 and 2.

In still more advanced stages tremolite appears as a new phase. Its incoming is associated with the inner zone where quartz, calcite, and talc are intimately associated. The tremolite appears as diversely arranged prisms—sometimes more regularly set at right angles to the surface of the chert form, and they spring into the fine turbid zone of

[1] The associated Ben Suardal limestone containing black cherts (quartz-calcite association), unless partially dolomitized, shows no new mineral phase development at the stages here considered.

talc (zone 2) which follows. The distribution is seen in the photomicrograph 3 of pl. XVIII. Numerous examples of chert surrounded by a tremolite zone fringed towards the dolomite groundmass by a talc zone in which incipient tremolite spears are developing are to be found in these dolomite outcrops. Ultimately the talc zone itself disappears and is replaced by a tremolite zone. In the inner zones of the aureole talc is found only as a retrograde mineral and is then readily recognized in the form of pseudomorphs after tremolite and also olivine. Retrograde talc is also found though sparingly in the tremolite-bearing zones of the outer aureole.

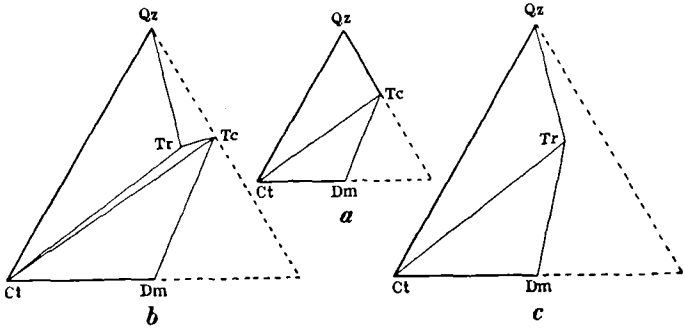


FIG. 1. Projection of the CaO–MgO–SiO_2–CO_2 tetrahedron to show earlier stages of metamorphism.

Ct calcite, Dm dolomite, Qz quartz, Tc talc, Tr tremolite.

In the outer band of dolomite now described, talc and tremolite are the dominant new mineral phases, and their mutual relations make clear that talc is the initial product in the metamorphism.

Of about 50 specimens showing chert nodules collected from this band of the outer aureole only two were found to contain no new mineral phase at the contact of dolomite and chert. Talc is a constituent of the great majority, about 50 % showing talc alone. Of the rest the major number show both talc and tremolite. Only two specimens showed the presence of diopside (associated with tremolite) and one of these exhibited sparse forsterite with tremolite in the dolomite groundmass.

Forsterite and diopside are to be recognized as products of higher grades, but the onset of reactions producing them here is doubtless to be ascribed to conditions permitting reduction in the pressure of CO_2, perhaps through circulating solutions. The rare development of these two phases shows that this condition was only locally reached. The production of talc and tremolite, the predominant new mineral phases

of the outer aureole, can be ascribed to a series of reactions of increasing decarbonation. They are as follows:

(*a*) 3 Dolomite + 4 Quartz + $H_2O \rightleftharpoons$ 1 Talc + 3 Calcite + $3CO_2$. Many of the rocks belong to this stage of metamorphism (assemblages talc-calcite-quartz, talc-calcite-dolomite).

This reaction involving water, one of five components, has the attributes of a univariant equilibrium, as Bowen has shown in his discussion of a *first* formation of tremolite, if a liquid solution is postulated as present (6 phases). The simplified treatment using the 'dry' formula for talc (and diagrammatically portrayed) implies the absence of a participating liquid phase, and the condition of univariancy may be considered unchanged.

(*b*) 5 Talc + 6 Calcite + 4 Quartz $\rightleftharpoons$ 3 Tremolite + $6CO_2$ + $2H_2O$, leading to the initial formation of tremolite with associations tremolite-talc-calcite; tremolite-calcite-quartz of the inner zone depicted in pl. XVIII, fig. 3.

(*c*) 2 Talc + 3 Calcite $\rightleftharpoons$ 1 Tremolite + 1 Dolomite + CO_2 + H_2O.

These three stages are graphically depicted in text-fig. 1 (*a*, *b*, *c*) which presents a projection of the quaternary system CaO–MgO–SiO_2–CO_2, with the phases talc and tremolite represented by their anhydrous formulae ($3MgO.4SiO_2$ and $2CaO.5MgO.8SiO_2$ respectively). The successive assemblages formed in the three stages correspond to the succession of overlapping planes in the tetrahedral figure met by lines proceeding from the CO_2 apex. It is of interest to note that the production of tremolite in reaction (*c*) leads to the reformation of dolomite.

Neither enstatite nor anthophyllite appear to be formed during the metamorphism of siliceous dolomite though they are possible members of assemblages in a successive decarbonation series. Unlike talc, however, they appear to be unstable in the presence of calcite. Both these phases might be expected to develop from carbonate assemblages of more highly magnesian character than quartz-dolomite associations, e.g. those bearing magnesite.

Explanation of Plates XVII and XVIII.

Plate XVII. Talc surrounding chert in dolomite from Skye.

Fig. 1. Talc envelopes to chert nodules on weathered surface of dolomite: centres of nodules contain calcite and quartz, ½ mile NE. of summit of Ben Suardal. Natural size.

Fig. 2. Talc envelopes to chert nodules in dolomite. A polished slab of the dolomite has been etched and stained (ferrous ferricyanide). Cores of chert (clear) with zone of talc and calcite (stained), fine talc zone (clear),

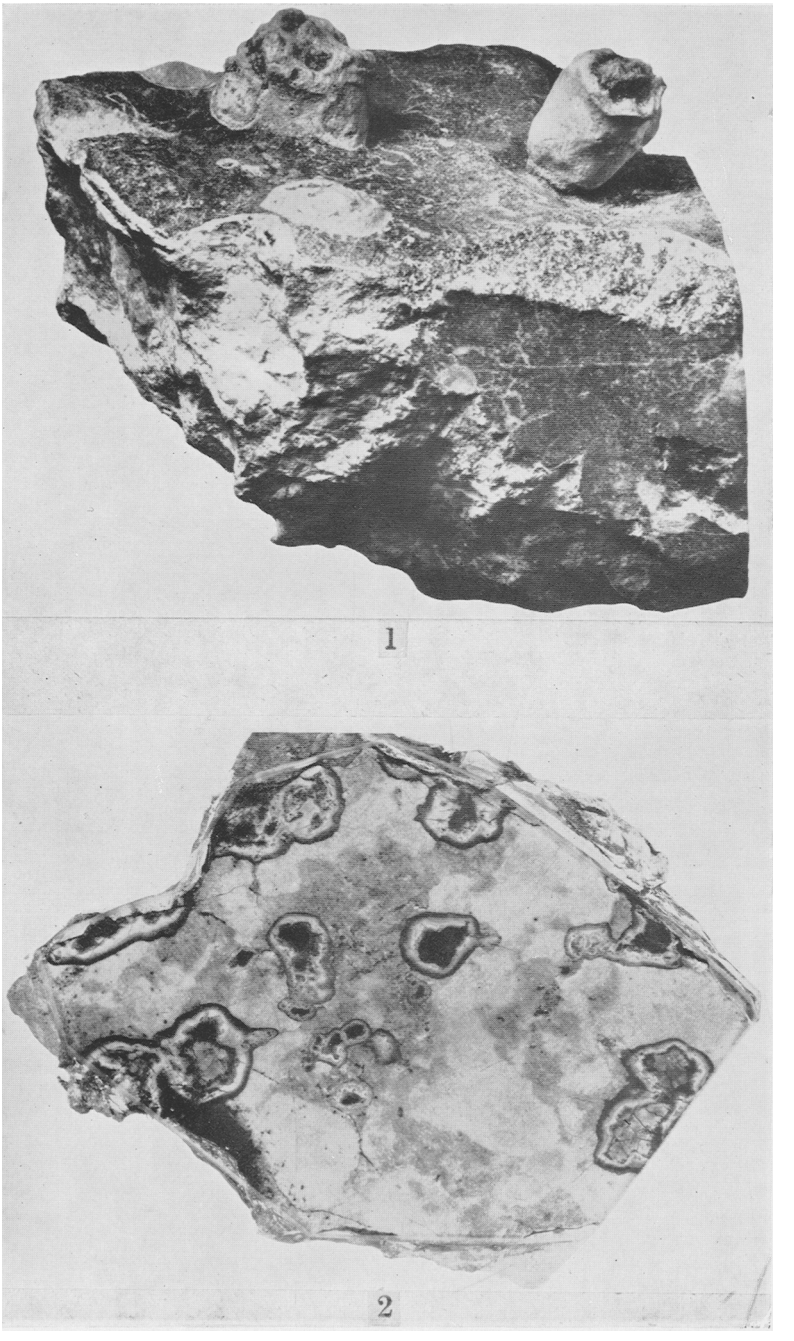
calcite-talc-dolomite zone at edge (calcite stained). The exposed centres of some nodules are filled with calcite (stained). The mottled dolomite of the groundmass is unstained, ½ mile NE. of summit of Ben Suardal. ¾ natural size.

PLATE XVIII. Photomicrographs of talc and tremolite zones around chert in dolomite from Skye.

Fig. 1. Zones around chert nodules in dolomite, nearly ½ mile SE. of summit of Ben Suardal. ×25 diameters.
(1) Chert below,
(2) zone of clear coarse-grained talc with some calcite,
(3) turbid zone of fine talc with some granular calcite passing into coarser zone rich in calcite, dolomite, and subordinate talc,
(4) above, normal dolomite.

Fig. 2. Dolomite with talc zones, ½ mile NE. of summit of Ben Suardal. ×20 diameters.
(1) Below, zone of chert with some talc and calcite replacing it,
(2) narrow fine clear talc zone,
(3) turbid talc zone, fine with some granular calcite,
(4) coarser zone rich in carbonate (calcite and dolomite) with subordinate talc,
(5) normal dolomite.
In the chert zone, original dolomite rhombohedra are seen replaced by talc.

Fig. 3. Dolomite with talc and tremolite zones, ½ mile E. of summit of Ben Suardal. ×25 diameters.
(1) Below, chert, some calcite,
(2) tremolite zone with calcite, some talc or quartz,
(3) above, talc zone with spears of tremolite springing into it from tremolite zone. The talc zone is followed by
(4) normal dolomite not shown in the photomicrograph.



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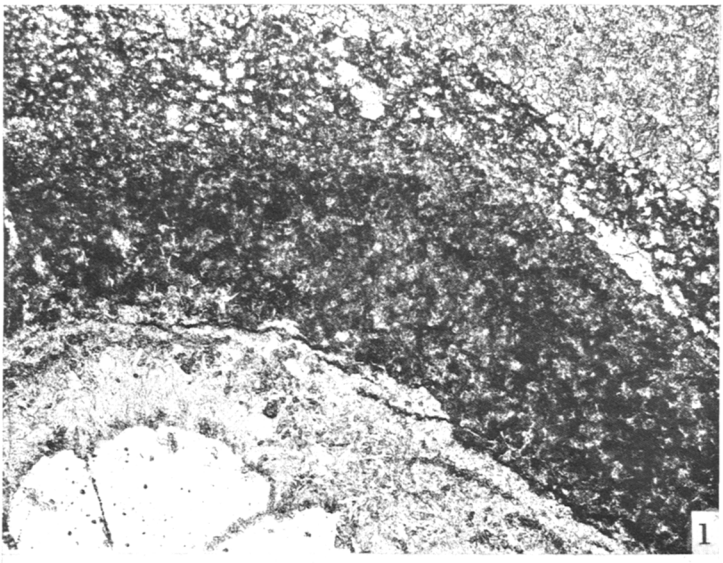

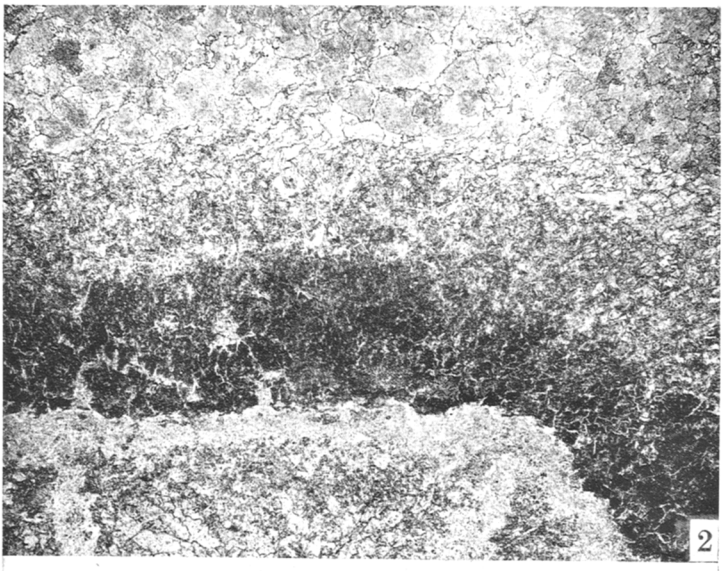

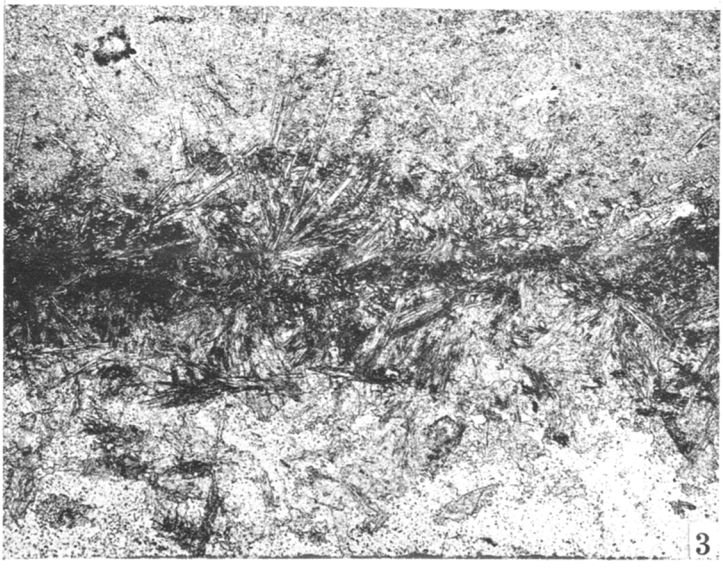

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