Metasomatism of cherts on the north-west margin of Dartmoor, Devonshire

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Summary. Contact metamorphic and metasomatic effects are described in the black radiolarian cherts of Lower Carboniferous age occurring at varying distances from the margin of the Dartmoor granite in the neighbourhood of Meldon, near Okehampton, Devon.

Development of biotite by contact metamorphism is over-printed by metasomatic conversion of chert to coarse-grained calc-silicate hornfels. Changes are localized and controlled by structural planes including faults and joints. Earliest effects are scapolitization giving black-and-white calc-flinta by local addition of calcium and subtraction of silicon. The same trend in transfer of elements is maintained in later phases: wollastonite–diopside reaction zones may enclose cores of black-and-white calc-flinta and are in turn replaced by wollastonite–grossular and grossular reaction zones marking the sites of main channels for migration of mineralizing fluids. Finally, veins with datolite–diopside, datolite–grossular–idocrase, and datolite–grossular–zeolite assemblages were formed in the altered cherts. Tin was available with aluminium and ferric iron during metasomatic changes in which garnet developed.

Some chemical transfer may be reciprocal changes with interbedded limestones, but appeal is made to external sources for the later metasomatizing agents.

IN 1895, Hinde and Fox described the occurrence in Devon and Cornwall of radiolarian cherts associated with a calcareous horizon in the Lower Culm Measures (Lower Carboniferous). They described outcrops of chert at the north-west margin of the Dartmoor granite that had been thermally metamorphosed and then changed to calc-flinta and calc-silicate hornfelses.

Calc-flinta was used by Barrow for very fine-grained metamorphic rocks of flinty aspect derived from calcareous mudstones. In the Devonian strata around the St. Austell granite in Cornwall, the altered rocks to which the name was first applied are calcareous siltstones of the Lower Devonian Meadfoot Group (Barrow and Thomas, 1908; Ussher, Barrow, and MacAlister, 1909). A similar lithology has been found in the Upper Devonian slates near the contact with the Bodmin Moor granite (Reid, Barrow, and Dewey, 1910) and also near the Dart-

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moor granite at Lydford, but the latter is different from the altered Lower Culm cherts cropping out nearby (Dearman and Butcher, 1959, plate 2). Cherts of the Dartmoor border are highest Viséan in age, forming part of the Calcareous Group (Dearman, 1959) about 250 ft thick at the junction of the Lower with the Upper Culm Measures. The rocks are folded and the cherts crop out more than once in an inlier at increasing distances from the granite contact (fig. 1); there are also

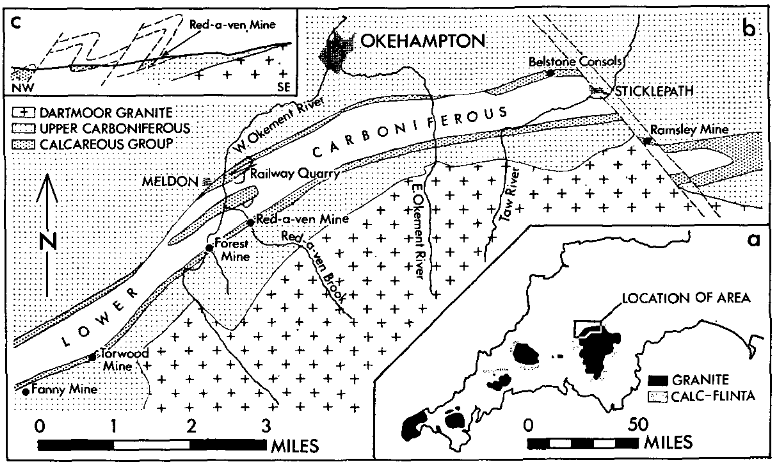

Fig. 1. Geology of the north-west border of Dartmoor. (*a*) Outline map of south-west England showing granite outcrops and areas of calc-flinta. (*b*) Map of calcareous horizons around Okehampton. (*c*) Cross-section illustrating structure at Meldon.

restricted outcrops north of the inlier. West of Bridestowe calc-flintas pass out into unaltered cherts.

The petrography of the calc-flintas is described in appropriate Survey memoirs (*op. cit., supra*). Phillips (1966) has reviewed present views on the effects of thermal metamorphism on calcareous sediments within the aureoles of the granites of Devon and Cornwall. It is the purpose of this paper to consider some quantitative aspects of the changes so obvious visually in the cherts of the Dartmoor aureole.

The cherts

The microscopical characters of the radiolarian cherts have been described by Hinde and Fox (1895, p. 632): 'The finely laminated character . . . is seen under the microscope to be due to regular lines of dark amorphous material and finely granular particles probably in part carbon and in part a compound of iron. . . . Thin sections of the comparatively soft shaly radiolarian beds are not materially different . . . from the hard cherty varieties.' These rocks are quartz aggregates, grain size approximately 0·05 mm, with finely divided chloritic material in the shaly parts.

An important feature of the cherts, particularly for assessing metasomatic gains and losses, is their gradational characteristics; chert may be expected to grade either into shale or through calcareous chert into siliceous limestone and then limestone. The latter sequence is a rhythmic sedimentary unit displayed repeatedly in exposures in the north bay of Meldon railway quarry where in 12 m of strata a typical thickness for each lithological type is about 4 cm. In chert quarries beyond the influence of granite, for example in the Barracadoes quarry near Launceston, 'The faces show banded chert with shaly partings, which are black below but become white and porous above' (Reid, Barrow, Sherlock, MacAlister, and Dewey, 1911, p. 32). Such porous layers are presumably the decalcified tops of composite chert beds similar to those from Meldon quarry.

Contact metamorphism of the cherts. Contact metamorphic changes cannot be detected in chert, but the influence of the shale fraction is apparent in the development of individual laminae and thin beds of flinty, dark brown, biotite hornfels. Spotted grey calcareous chert is present in beds up to 4 ft thick at the base of the Calcareous Group. In examples from the syncline in the north bay of Meldon railway quarry, dark grey spots, less than 1 mm across, are irregular porphyroblasts of diopside and wollastonite set in a lighter grey, very fine-grained matrix mainly of quartz with some scapolite. Original pigment is preserved in earlier spots that may be overprinted by continued development of wollastonite in irregular light-grey porphyroblasts up to 4 mm in size. A similar rock from Red-a-ven mine shows in hand specimen distinct 5 mm areas of pale green diopside. Siliceous limestones are white rather than grey, with more wollastonite than scapolite. Grain size increases with calcium content until the rock becomes a mass of interfering spherules of radiating wollastonite fibres with a little interstitial grossular and diopside.

Metasomatic changes in the cherts

In the Survey description of calc-flintas it is considered that the rocks were invaded by solutions resulting in the formation along bedding and joint planes of axinite veins containing some hedenbergite, garnet, epidote, and actinolite (Ussher *et al.*, 1909, p. 89). Little attention was paid to marginal effects along veins, except to remark that sometimes axinite and pyroxene could also be found in the body of the rock. There could be no doubt therefore that material had been introduced since similar rocks in areas without axinite veins do not contain these minerals.

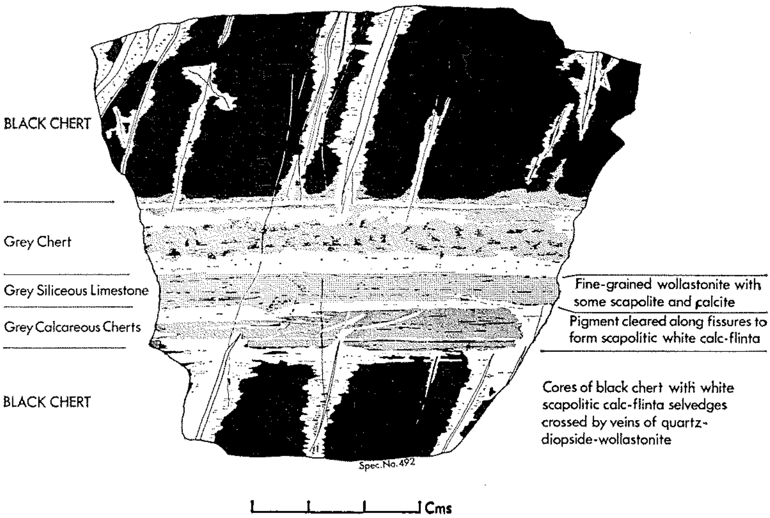

FIG. 2. Typical black-and-white calc-flinta. Specimen No. 492 from the normal limb of the anticline, north bay, Meldon railway quarry.

Formation of black-and-white calc-flinta. The obvious change in black chert is conversion to black-and-white calc-flinta. There are two distinct units in these rocks. Calcareous chert is cleared completely of pigment leaving laminated grey and white bands a few centimetres thick between thicker bands of black chert. The resultant black and white banding is broken into a rectilinear pattern of white bands by clearing of pigment from selvedges along joints crossing black chert at high angles to the bedding (figs. 2 and 3).

The original lamination of black chert is preserved in the white calc-flinta selvedge, the transition between the two types being marked by a narrow grey zone and small residual areas of grey within the white (fig. 3). The grey zones are quartz mosaics crowded with small fibrous crystals, which appear to be sodic scapolite by comparison with larger porphyroblasts in adjacent white zones. Thin veins in the white zones are infilled with quartz, diopside, and probably wollastonite, and veins of topaz cross all earlier veins and reaction zones.

Formation of grossular in calc-flinta. A further stage in the transformation of black chert is the development of grossular either in veins bordered by white calc-flinta selvedge or in much wider zones of garnet such as were formed at the faulted junction of calcareous rocks with

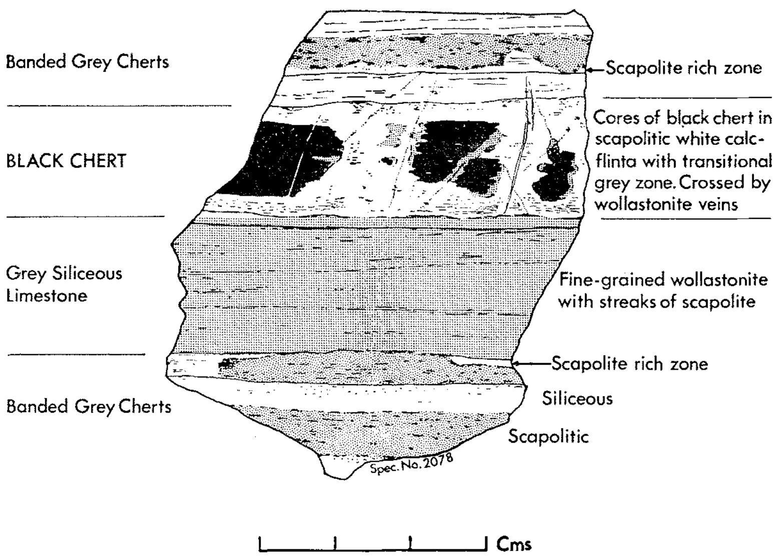

FIG. 3. Black-and-white calc-flinta with residual areas and intermediate selvedge of grey calc-flinta. Specimen No. 2078 from the normal limb of the anticline, north bay, Meldon railway quarry.

shales and tuffs in the north bay of Meldon railway quarry (Dearman, 1959, fig. 5*a*). In an example from the latter setting (fig. 4), remnants of black chert are surrounded by a broad white zone of scapolitic calc-flinta bordered in turn by massive light-brown grossular, which grades laterally into reddish-brown grossular. The inner limit of garnet cuts into the white calc-flinta halo towards the black chert core, suggesting superposition of a garnet selvedge on already formed black-and-white calc-flinta.

Another intermediate stage in the metasomatism of black chert is shown in two specimens from Red-a-ven mine. In the first (fig. 5), white calc-flinta is confined to thin reaction zones in a core of black chert that is enveloped by a pale green reaction zone of fine-grained

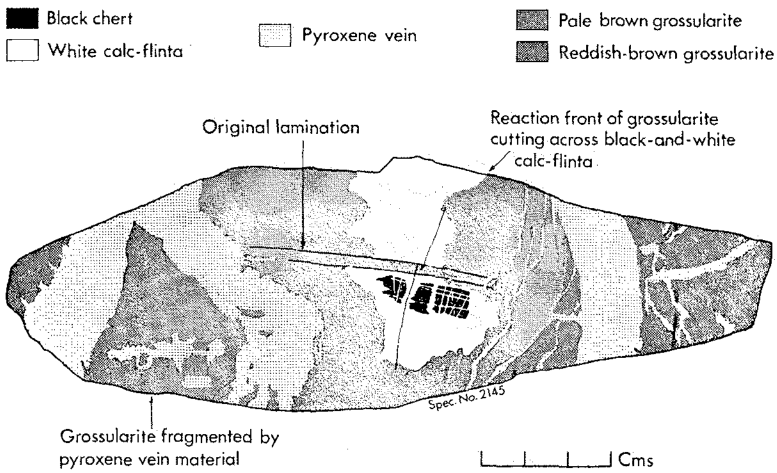

FIG. 4. Grossular reaction front in calc-flinta and later non-reactive pyroxene veins. Specimen No. 2145 from the normal limb of the anticline, north bay, Meldon railway quarry.

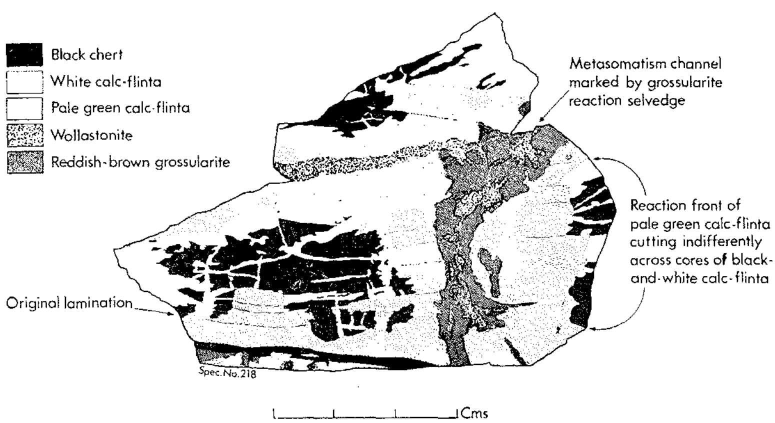

FIG. 5. Cores of black-and-white calc-flinta enveloped by pale green calc-flinta marginal to a grossular–wollastonite reaction zone. Specimen No. 218 from the dumps of Red-a-ven mine, Meldon.

wollastonite and veinlets of diopside. The green zone, apparently superimposed on an earlier reaction rim of scapolitic white calc-flinta, is in turn marginal to a coarse-grained irregular grossular–wollastonite vein. A 2 mm thick vein of wollastonite crossing the green calc-flinta is considered to be a precursor of the grossular–wollastonite vein, as textural relationships suggest that garnet has replaced wollastonite.

In the other example (fig. 6), a core of black chert with a narrow rim of white calc-flinta is surrounded by laminated green-and-grey calc-flinta. The latter is crossed by an irregular vein of reddish-brown grossular with a little wollastonite. Individual laminae in the green-

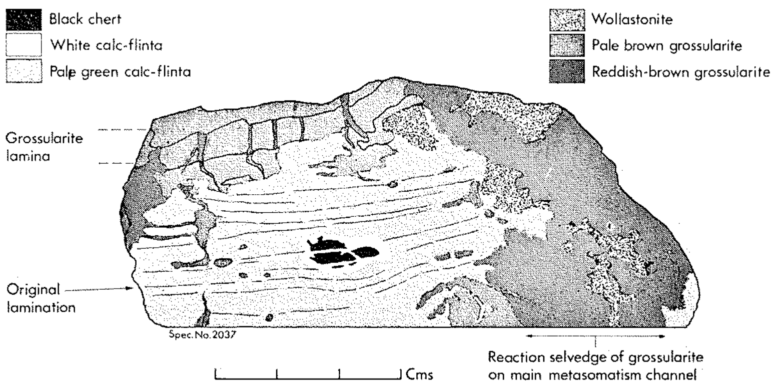

FIG. 6. Core of black-and-white calc-flinta enveloped by pale green calc-flinta, crossed by reddish-brown grossular and wollastonite reaction vein with marginal development of pale brown grossular. Specimen No. 2037 from the dumps of Red-a-ven mine, Meldon.

and-grey calc-flinta have been altered to pale-brown grossular for up to one centimetre inwards from the margin of the grossular–wollastonite vein. One 5 mm thick lamina, converted to pale-brown grossular, is crossed by thin reddish-brown grossular veins similar to the main vein; they extend for short distances into the green-and-grey calc-flinta to end in irregular areas of pale-brown grossular. Traces of the lamination of the original chert, appearing as parallel trails of minute dark inclusions and small irregular diopside grains, are retained in the pale-brown grossular. The vein grossular is shot through with needles of wollastonite, and stages can be traced of overprinting by garnet of acicular wollastonite standing normal to the vein walls. A later generation of coarser wollastonite fills interstices between garnets in the thick vein.

Veins in calc-flinta. Veins run indifferently across calc-flintas and calc-silicate hornfelses of different mineralogical compositions. They may be sharply defined dilatation veins apparently unreactive towards the enclosing rock, or else more diffuse and irregular. From the north bay of Meldon railway quarry dilatation veins 1 cm thick contain calcite–heulandite, with the latter as idiomorphic crystals, and calcite–quartz–actinolite. The Red-a-ven mine dumps have yielded thin grossular–datolite–zeolite veins of the same type. In an example from the railway quarry (fig. 4) three irregular veins of pale-green pyroxene with some datolite cross the grossular zone, in places giving a breccia of garnet in a matrix of vein material. Datolite–grossular–idocrase assemblages occur also in very irregular veins in the calc-flintas adjacent to the normal fault separating them from footwall tuffs.

Geochemistry of the changes

It is demonstrable that black chert has been converted through one or more intermediate stages to a grossularite, and the sequence varies with locality. In the railway quarry the sequence is from black chert through white calc-flinta to a grossularite; at the Red-a-ven mine an additional stage gives the sequence black chert, white calc-flinta, green-and-grey calc-flinta to grossularite. Because of the smallness of some of the reaction zones and unaltered chert remnants, it was not possible to analyse each group of reaction zones from one specimen. It is likely, in consequence, that the analyses conceal variations in the original chert, probably within the range of analyses 1 to 3 (table I), on which the metasomatism has been overprinted. The very low calcium content of black chert is notable, as is the progressive increase in calcium with diminution of silicon and aluminium.

To facilitate estimation of metasomatic gains and losses, the chemical analyses in table I have been recast into atomic proportions of cations in the 160 oxygen standard cell advocated by Barth (1952). It is considered that comparisons of metasomatic effects involving major changes in concentration of the abundant elements are likely to be correct in general trend; for the less abundant elements minor fluctuations may reflect initial compositional variations rather than actual metasomatic changes. The main metasomatic changes are summarized in table II.

Metasomatic gains and losses. Conversion of black chert to white calc-flinta, involving destruction of biotite and formation of scapolite, is directly correlatable with the addition of calcium and magnesium, loss of silicon and complete leaching of potassium (table II*a*). It would be reasonable to expect that diopside should result from the addition of magnesium, and it is probably present as minute highly refringent grains crowding the quartz mosaic of the groundmass.

The main trends thus established persist with the formation of a

TABLE I. Analyses of cherts and associated rocks from the Calcareous Group of the Lower Culm Measures, and some metasomatic derivatives

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	79·80	63·56	70·70	53·05	46·50	73·22	62·84	42·98	73·82	49·06	41·70	49·74	41·90	42·12
TiO_2	0·38	0·27	0·32	0·25	0·12	0·35	0·35	0·31	0·40	0·34	0·29	0·05	0·06	0·25
P_2O_5	0·07	0·01	0·21	0·09	0·06	0·19	0·01	0·01	0·04	tr.	0·01	tr.	0·14	tr.
Al_2O_3	8·38	5·63	8·80	3·82	1·54	7·37	9·31	11·02	7·74	6·66	11·01	nil.	13·78	5·58
Fe_2O_3	0·30	0·61	0·11	0·91	0·10	0·24	0·63	3·04	0·73	0·31	4·25	0·17	2·82	1·68
FeO	2·45	2·69	2·20	2·58	1·64	3·06	1·79	4·50	2·38	4·60	1·90	10·29	0·42	0·97
MgO	1·32	3·90	2·02	4·45	3·74	4·00	2·87	4·45	1·47	2·08	2·55	12·94	4·53	2·11
CaO	1·00	18·01	10·40	32·65	45·72	9·11	14·64	29·92	6·53	34·71	35·45	22·39	28·39	33·04
MnO	0·40	1·33	0·06	0·15	0·16	0·44	1·04	1·54	0·20	0·45	0·47	2·47	0·64	0·67
Na_2O	1·08	0·70	1·62	0·86	0·60	1·22	0·49	0·21	1·39	0·29	0·24	0·19	0·55	0·27
K_2O	3·99	2·81	2·10	0·58	tr.	tr.	4·78	0·04	4·95	0·05	0·08	0·05	2·24	tr.
H_2O^-	nil	nil	tr.	tr.	—	tr.	} 0·06	} 0·08	nil	nil	—	—	} 1·40	} 2·55
H_2O^+	—	—	—	—	—	—			—	—	0·02	0·31		
B_2O_3	—	—	—	—	—	—	—	—	—	—	n.d.	—	1·01	9·18
SnO_2	nil	nil	nil	—	—	nil	0·08	0·26	tr.	0·28	1·70	nil	n.d.*	nil
Total	99·17	99·52	98·54	99·39	100·18	99·20	98·89	98·36	99·65	98·83	99·67	98·60	97·88	98·42
D	2·64	2·76	2·64	2·90	2·98	2·70	2·99	3·74	2·86	3·10	3·25	—	—	—

Numbers of ions on the basis of 160 oxygen:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Si	69·26	60·10	63·98	53·14	48·68	64·94	59·40	44·62	66·21	50·37	43·41	51·46	41·42	39·86
Ti	0·26	0·23	0·22	0·18	0·06	0·21	0·23	0·25	0·27	0·25	0·25	—	—	0·23
P	—	—	0·11	0·12	—	0·10	—	—	—	—	—	—	0·12	—
Al	8·52	6·24	9·35	4·45	1·88	7·77	10·33	13·52	8·07	8·00	13·47	—	16·03	6·24
Fe^{3+}	0·21	0·45	0·11	0·72	0·13	0·10	0·45	2·38	0·43	0·25	3·37	0·13	2·25	1·25
Fe^{2+}	1·77	2·16	1·68	2·17	1·44	2·29	1·42	3·94	1·78	3·94	1·62	8·95	0·36	0·80
Mg	1·72	5·51	2·77	6·68	5·91	5·32	4·09	6·95	1·99	3·20	4·00	20·28	6·71	3·01
Ca	0·94	18·28	10·10	35·14	51·40	8·68	14·87	33·48	6·24	38·24	39·60	25·10	30·14	33·56
Mn	0·31	1·02	—	0·12	0·13	0·31	0·79	1·38	0·16	0·43	0·44	1·31	0·53	0·51
Na	1·77	1·25	2·82	1·69	1·26	2·02	0·91	0·37	2·48	0·62	0·50	0·38	1·07	0·45
K	4·48	3·41	2·44	0·72	—	—	5·79	—	5·71	—	0·13	—	2·73	—
H	—	—	—	—	—	—	—	0·50	—	—	0·13	2·13	9·26	16·01
B	—	—	—	—	—	—	—	—	—	—	—	—	1·78	14·99
Sn	—	—	—	—	—	—	0·03	0·11	—	0·12	0·69	—	—	—
Total	89·24	98·65	93·58	105·13	110·89	91·74	98·31	107·50	93·34	105·42	107·63	109·74	112·40	116·91

Key to Table I

1. Black radiolarian chert from black-and-white calc-flinta. Spec. No. 492; north bay of Meldon railway quarry, near Okehampton, Devon.
2. Spotted grey calcareous chert. Spec. No. 490; basal bed of Calcareous Group in the syncline in the north bay of Meldon railway quarry.
3. Grey calcareous chert. Spec. No. 2138A; north bay of Meldon railway quarry.
4. White siliceous limestone. Spec. No. 2138B; north bay of Meldon railway quarry.
5. Wollastonite hornfels with a little diopside and grossular. Spec. No. 2138C; north bay of Meldon railway quarry.
6. White calc-flinta selvedge to black chert, from black-and-white calc-flinta. Spec. No. 492; north bay of Meldon railway quarry.
7. White calc-flinta between black chert and grossularite selvedge. Spec. No. 2145; north bay of Meldon railway quarry.
8. Grossularite selvedge to white calc-flinta. Spec. No. 2145; north bay of Meldon railway quarry.
9. Black-and-white calc-flinta. Spec. No. 218; Red-a-ven mine, Meldon, near Okehampton, Devon.
10. Fine grained, pale green, diopside–wollastonite calc-flinta selvedge to core of black-and-white calc-flinta. Spec. No. 218; Red-a-ven mine, Meldon, near Okehampton, Devon.
11. Grossular–wollastonite vein crossing diopside–wollastonite green-and-grey laminated calc-flinta selvedge. Spec. No. 2037; Red-a-ven mine, Meldon, near Okehampton, Devon.
12. Green pyroxene vein in calc-flinta. Spec. No. 2145; north bay of Meldon railway quarry.
13. Grossular–datolite–zeolite vein in altered chert. Spec. No. 2151; Red-a-ven mine, Meldon, near Okehampton, Devon.
14. Datolite–grossular–idocrase vein cutting calc-flinta. Spec. No. 2144; north bay of Meldon railway quarry.

Analyst. M. A. El Sharkawi.

SnO_2 determined by X-ray fluorescence analysis; B_2O_3 determinations by W. A. Campbell.

Specimen numbers refer to the W.R.D. collection. The specimens have been presented to the museum of the Institute of Geological Sciences.

* The grossular contains 0·24 % SnO_2.

grossularite in white calc-flinta (table II *b* and *c*), but with some important differences. There is, for example, addition of aluminium and ferric iron to the grossularite; the grossular contains about 10 % of the andradite molecule. In contrast to the changes in black-and-white calc-flinta, potassium is retained in the white calc-flinta but is absent from the grossularite. Tin is not present in detectable amounts in either the black chert or the white reaction selvedge in black-and-white calc-flinta; tin is present, however, in the white calc-flinta selvedge to the grossularite. Such differences presumably indicate sequential changes in the composition of the metasomatizing fluids. Formation of the grossular vein was accompanied by continued development of a white calc-flinta selvedge, which retained potassium and became stanniferous.

Metasomatic changes in specimens from Red-a-ven mine (figs. 5 and 6; table II *d*, *e*, and *f*) again show overprinting on a core of black-and-white calc-flinta involving a reciprocal relationship between desilication and calcification. Tin, present in the core and surrounding zones, attains its highest concentration in the garnet reaction zone in which there

TABLE II. Metasomatic gains and losses. Concentrations of ions on the basis of 160 oxygen

	a	*b*	*c*	*d*	*e*	*f*
Si	−4·3	−9·9	−14·8	−7·1	−15·8	−7·0
Al	−0·7	+1·8	+3·2	−0·5	−0·1	+5·5
Fe^{3+}	−0·1	+0·2	+1·9	+0·2	−0·2	+3·1
Fe^{2+}	+0·5	−0·3	+2·5	0	+2·2	−2·3
Mg	+3·6	+2·4	+2·9	+0·3	+1·2	+0·8
Ca	+7·7	+13·9	+18·6	+5·3	+32·0	+1·4
Mn		+0·5	+0·6	−0·2	+0·3	0
Na	+0·2	−0·9	−0·6	+0·7	−1·9	−0·1
K	−4·5	+1·4	−5·8	+1·2	−5·7	+0·1
Sn		+0·03	+0·08		+0·12	+0·57
Total cations	+2·5	+9·1	+9·2	+4·1	+12·1	+2·2

(*a*) Black-and-white calc-flinta, Spec. No. 492, fig. 2, from Meldon railway quarry; changes in conversion of black chert (table I, 1) to white calc-flinta (table I, 6).
(*b*, *c*) Black-and-white calc-flinta with grossularite reaction zone, Spec. No. 2145, fig. 4, from Meldon railway quarry; changes (*b*) in conversion of black chert (table I, 1) to white calc-flinta (table I, 7) and (*c*) in conversion of white calc-flinta (table I, 7) to grossularite (table I, 8).
(*d*, *e*, *f*) Black-and-white calc-flinta overprinted by an inner zone of green calc-flinta and an outer grossular-wollastonite selvedge, Spec. No. 218, fig. 5, and Spec. No. 2037, fig. 6, from Red-a-ven mine; changes (*d*) in conversion of black chert (table I, 1) to black-and-white calc-flinta (table I, 9), (*e*) in conversion of black-and-white calc-flinta (table I, 9) to green calc-flinta (table I, 10), and (*f*) in conversion of green calc-flinta (table I, 10) to grossular–wollastonite zone (table I, 11).

has been addition of aluminium and oxidation of the ferrous iron content of the adjacent pale-green calc-flinta to the ferric state. The high concentration of both sodium and potassium in the black-and-white calc-flinta core relative to that of the original chert, and the very low concentrations in both outer reaction zones, suggest that the advancing diffusion front of the latter again inhibited in some way (cf. table II*b*) the outward diffusion of these elements.

The boron-bearing veins. Analyses of veins in calc-flintas, as distinct from reaction selvedges, are given in table I, 12, 13, and 14, and their compositions are in marked contrast to that of original chert. The composition reflects the mineralogy of the green pyroxene vein (table I, 12) in the grossularite of Specimen No. 2145 (fig. 4). Datolite-bearing veins are chemically similar to typical grossularite reaction selvedges, the main differences being in the boron and water contents of the veins. Tin is found in such veins from Red-a-ven mine, but not in those from the railway quarry.

The appearance of idocrase in grossular–datolite assemblages may be attributable to the presence of magmatically derived fluorine that also contributes to the formation of fluorite.

Distinction between sedimentary and metasomatic variation in cherts. The original variations in chemical composition of the chert to limestone rhythmic unit, as shown in table I, cannot be confused with the metasomatic changes in black chert. Metasomatism adds significantly to the aluminium and total iron content of chert as silicon content decreases and calcium increases; thus the calc-silicate end-product is chemically distinct from sedimentary variation in which aluminium decreases with the same changes.

Black cherts beyond the limit of contact metamorphism also show clearance of pigment along joint and bedding planes. This simulation of black-and-white calc-flinta involves simply removal of pigment; no mineralogical changes can be detected under the microscope, and X-ray fluorescence analysis reveals no chemical differences between the black and the white zones.

Discussion

There are difficulties, not easily resolved, in deciding the relative importance of contact metamorphic changes and subsequent metasomatic modifications in the rocks of the contact aureole. Considered in conjunction with the cordierite–anthophyllite-bearing altered keratophyric tuffs at Meldon, the assemblage diopside–grossular–wollastonite developed in calcareous sediments is characteristic of the hornblende-hornfels facies of contact metamorphism (Fyfe, Turner, and Verhoogen, 1958). But the same calc-silicate assemblage has arisen in response to fissure-controlled metasomatism of cherts originally highly siliceous and deficient in calcium carbonate. Chance preservation in individual chert beds of diffusion limits attained during metasomatism, as indicated by different lithologies separated by sharp boundaries, is the only trustworthy visual criterion of a metasomatic origin. Microscopic textural relationships, such as the preservation of original lamination in coarse-grained garnet, may serve to demonstrate that reaction has taken place in the solid, and so are equally applicable to both contact metamorphism and metasomatism. Clearance of such relict textures is a feature of the marginal zones of euhedral crystals in the hornfelses, as well as of the contents of reaction channels and veins in the calc-flintas.

The temperature reached within the Dartmoor aureole may have been significantly higher, at least locally, than that reached about the St. Austell granite. There, the calc-silicate hornfelses described by Flett (in Ussher *et al.*, 1909), in which epidote is an essential constituent with diopside, grossular, or actinolite, are characteristic of a relatively low metamorphic grade approximating to the albite–epidote facies of contact metamorphism (Phillips, 1966). The first metasomatic change in the cherts at Meldon is the development of a diopside–quartz–scapolite assemblage with scapolite taking the place of plagioclase. Later conversion to diopside–wollastonite and diopside–wollastonite–grossular assemblages may indicate conditions of temperature and pressure favourable for the development of the pyroxene-hornfels facies. It is of interest to note that along the north-west border of Dartmoor (fig. 1) epidote has been found at Forest mine in association with axinite, while at Belstone Consols mine the pale green amphibole associated with axinite is moulded on to well-formed crystals of andradite. Datolite and axinite are found with a little pale-green amphibole at the faulted junction of calc-flintas with tuffs in the north bay of Meldon railway quarry.

There has thus been, it seems, a reversion during boron metasomatism to the calc-silicate assemblage of the albite–epidote facies. At the Red-a-ven emanative centre, however, neither amphibole nor epidote has been found with calcium-boron minerals, although zeolites occur in non-reactive grossular–datolite veins, and conditions appropriate for the formation of at least the hornblende-hornfels facies persisted there longer than elsewhere.

The presence of tin in the calcareous rocks of the Meldon area has been described in more detail by Dearman and Sharkawi (1966). They have suggested, after geochemical prospecting in the soils of the area (*idem.*, 1965*a*), that a calcic-analogue of the usual type of cassiterite emanative centre occurs in the vicinity of Red-a-ven mine (*idem.*, 1965*b*). Tin metasomatism, moreover, is related to the second phase of alteration associated with grossular formation. In turn there are significant additions of iron and aluminium only during the same phase both at Red-a-ven mine and in Meldon railway quarry; but the geographical factor asserts itself since the garnet from the former locality has a higher concentration of the andradite molecule. The emanative centre on the Red-a-ven may be defined not only by a relative abundance of tin and iron, but also by a zonal arrangement of metamorphic facies around it.

In this paper attention has been directed to metasomatic replacements in cherts involving predominantly addition of calcium and removal of silicon. A later paper will deal with metasomatism of the interbedded limestones in which the relative roles of calcium and silicon are reversed. Local short-range metamorphic diffusion might have been responsible for the early formation of black-and-white calc-flinta from black chert, and determination of the behaviour of trace elements may lead to a solution of this problem. With the onset, however, of the next phase of metasomatism involving the formation of grossular reaction zones and subsequent boron hydrothermal activity, both with significant additions of tin, appeal must be made to a magmatic source for the active emanations.

Analytical methods. The rocks were analysed by the methods of Chalmers (1954), Riley (1958), and Riley and Williams (1959). Alumina in the presence of tin was determined by the method of Shapiro and Brannock (1962). Tin was determined gravimetrically and by X-ray fluorescence analysis using a Phillips model PW1540 X-ray spectrograph with chromium oxide as an internal standard.

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