Epidiorite–limestone contact relations at Burawai, Hazara District, West Pakistan

With Plates VII and VIII

By B. C. M. Butler

Department of Geology and Mineralogy, Oxford

Summary. Special mineral assemblages in calcareous rocks 0–6 ft from the contact of an epidiorite sill are interpreted as the result of polymetamorphism–regional metamorphism superimposed on an earlier thermal metamorphism in which metasomatism, especially migration of potassium, was important.

Burawai (34° 56′ N, 73° 52′ E) is a hamlet in the Kaghan Valley in Hazara District of West Pakistan; it lies near the junction of the Kunhar River and the Jora Nala at a height of about 9600 ft above sea-level. The rocks of the area are schists and gneisses of the Salkhala Series (pre-Cambrian) into which have been intruded large bodies of biotite–granite gneiss, probably of Carboniferous age (Pascoe, 1950, p. 308) and a number of dolerite sills, probably of Upper Carboniferous and Permian age (Wadia, 1932, p. 223). The main orogeny of the Himalayas took place in the Tertiary and the final metamorphism of the Salkhala Series probably occurred at this time.

Wadia (1931, p. 200) records that 'the interaction of dolerite dykes with their limestone host, amounting to actual mutual absorption, has produced interesting rock-types, well exposed near Burawai'. During the summers of 1955 and 1956 the author visited the Burawai area, and the present descriptions are based on material collected on these visits. Though most of the work has been done on the sill on the north side of the Kunhar River half a mile north-east of Burawai, examination of other sills in the area showed that the contact phenomena are not restricted to one example, and that some of the other sills show even more complex contact relations than the sill now to be described.

Petrography

The sill is 70–100 ft thick and is conformable with the parallel banding of the adjacent limestones and calcareous schists, which have a gently undulating dip of 20–25° to the south-west. However, at a distance of about 20 ft from the contacts there is in effect a plane of structural discontinuity where the simple structure of the schists near the sill passes into complex isoclinal folding in the style typical of the rest of the area. All the schists adjacent to sills near Burawai show this feature, and it seems certain that the dolerite sills were more resistant to stress than the schists, deforming by block faulting rather than by folding, and buttressing the immediately adjacent schists so that these too show less intense deformation than the schists which are not supported by the sills.

Distinctive pale-coloured rocks are developed at the top and bottom contacts of the sill, which in the field show up in marked contrast to the dark grey schists and black epidiorite. The width of the zone in which special rock-types are produced is about 6 ft, though it may be less, and in some other sills is up to 10 ft in width. The rocks will be described in the form of a traverse across the upper contact, representing a synthesis of observations from a number of different localities in the 200 yards over which the contact is well exposed.

The normal regional schists just below the plane of discontinuity 20 ft above the sill show compositional banding on a half-inch scale and consist of calcite and a little dolomite, muscovite (γ 1·594–1·596) and phlogopitic biotite (γ 1·615–1·618). Garnet appears to be pseudomorphing original mica flakes in one slide (82307).[1] Minerals of the epidote group occur in three forms—(i) large fragmented porphyroblasts of α-zoisite enclosed by basic plagioclase (An_{85}–An_{92}) as though being replaced by the plagioclase (82326, plate VIII, fig. A), (ii) small anhedral grains of β-zoisite, and (iii) small elongate prisms of epidote. The occurrence of staurolite in pelitic schists near Burawai shows that the grade of metamorphism is probably the staurolite zone.

The rocks 6 ft above the contact are pale green, granular, impure, banded limestones. Twinned microcline is the major constituent, with calcite, epidote (β 1·722), oligoclase (An_{20}), pale green pyroxene (β 1·700), green actinolitic amphibole (β 1·674), and quartz present in varying amounts. Each of these minerals is found in contact with every other and the rocks appear to be in a state of stable mineralogical equilibrium. The rocks show slight preferred orientation of the amphibole prisms parallel with the banding.

Four feet above the contact the rocks are hard, massive, unfoliated,

[1] Five-figure numbers refer to specimens and slides in the Harker Collection in the Department of Mineralogy and Petrology, Cambridge.

pale green, impure, banded limestones. Calcite, microcline, Ca-rich garnet (n 1·760), α-zoisite, epidote, and pyroxene (β 1·701) are the chief components and are very variable in amount. The garnets sometimes form euhedral hollow crystals filled with quartz or calcite (plate VIII, fig. C). An interesting accessory mineral is vesuvianite, as prisms up to 1 mm in length, almost always radiating from a central grain of epidote.

The rocks 1–2 ft above the contact are massive, pale green, impure, banded limestones, often slightly pink in colour due to the presence of large amounts of Ca-rich garnet (n 1·740). Calcite, pyroxene (β 1·695), and epidote are the other main constituents; feldspars, both microcline and plagioclase, are notable for their absence.

The rocks 0–1 ft above the contact are massive, pale green, impure limestones, but as garnet is absent here they lack the pink shade of the overlying rocks. They consist of a granular aggregate of calcite, with rounded grains of epidote (β 1·716–1·721), pale green pyroxene (β 1·688), and rare prisms of blue-green amphibole (β 1·654–1·663); again, feldspars are absent. Each of the minerals is found in contact with every other, though the pyroxene and the amphibole tend to occur in separate bands.

The rocks of the contact zone show a well-developed compositional banding parallel with the contact. The banding is similar in scale to that of the regional schists and the rocks near the contact, and it is probable that it is related to the original banding of the rocks. This zone is of varying thickness up to 6 in., but locally almost absent; in a sill half a mile west of Burawai, however, the comparable zone is nearly 18 in. thick. The mineralogy is simple, though the proportions of the minerals vary widely. The major constituents are epidote (β 1·719–1·728) and blue-green amphibole (β 1·651–1·667, $\gamma \wedge c$ 15–20°, $2V_\gamma$ 98–102°); in some bands one or other of these two minerals make up nearly the whole of the rock and together they often form 90 % of the rock. The other minerals, usually accessory but sometimes becoming important constituents, are calcite, quartz, oligoclase, sphene, and Fe-rich garnet (n 1·788–1·790). A notable feature of these rocks is the occurrence of thin trains of small sphene crystals, which often form continuous septa separating bands of different mineralogical composition (plate VIII, fig. E).

The epidiorite at the contact is a fine-grained greenish-black rock with poorly-developed foliation, containing numerous white spots of oligoclase (An_{20}). Amphibole (β 1·658–1·667, $\gamma \wedge c$ 24–26°) is the main constituent and sphene is relatively abundant. The rock passes gradationally down into the normal epidiorite in which green amphibole (β 1·658–1·668, $\gamma \wedge c$ 15–16°, $2V_z$ 98–104°) sometimes shows well-developed lineation. Oligoclase (An_{17}) usually forms 20–25 % of the rock, but in one specimen (82309) its place is largely taken by epidote. Sphene is always present, and red-brown biotite and small amounts of garnet sometimes appear.

Three types of vein are found in the contact rocks—(i) calcite and pale green pyroxene with a little quartz and microcline, found only in the limestones 6 ft above the contact (82262); (ii) epidote with a little quartz, found in the rocks immediately above the contact and rarely in the marginal facies of the epidiorite (82278, 82280); (iii) a very complex and variable assemblage in which the main constituents are calcite, quartz, oligoclase, epidote, blue-green or dark brown-green amphibole, deep brown biotite, clusters of small pink garnets (which are often included in large plates of oligoclase and are usually perfectly euhedral, but sometimes hollow or atoll-like, with a rounded central core and a thin euhedral outer rim separated from each other by oligoclase in crystallographic continuity with that surrounding the garnets), and accessory sphene, apatite, and iron ore (82295–82298). This last type of vein is found at only one locality, where it can be traced for about 6 ft from just above the marginal epidiorite up into the contact rocks. None of these veins are found either in the central part of the epidiorite or in the normal unmodified regional schists above the sill.

Interpretation

It will be clear from the petrographic descriptions given above that distinctive parageneses are developed in the limestones at various heights above the upper contact of the Burawai sill. The complete mineral assemblages in the limestones and epidiorite are summarized in table I, and modal analyses of selected specimens are given in tables II–V. Approximate chemical compositions of some of the regional and contact limestones are given in table VI; these were determined from the modal compositions, making reasonable assumptions about the compositions of the component minerals as indicated by their optical properties. Despite the obvious uncertainties in this method of determining the compositions of the rocks, certain interesting facts emerge from a study of the analyses of the different rock-types.

It is clear that analyses of the limestones from 4 ft above the contact with the sill can be matched fairly closely with analyses of regional limestones of completely different mineral composition. 82263(i), containing

TABLE I. Mineral parageneses in rocks of the Burawai sill

	Regional limestones	Limestones 6 ft above sill	Limestones 4 ft above sill	Limestones 1–2 ft above sill	Limestones 0–1 ft above sill	Contact zone	Marginal epidiorite	Epidiorite
Calcite	A	X	A	A	A	X	x	x
Quartz	A	X	X	X	X	X		
Bytownite	A							
Muscovite	A							
Biotite	A	x		x		x	x	X
Microcline		A	A					
α-zoisite	x		A					
Grossular			A	A				
Pyroxene		A	A	A	A	x		
Epidote	x	A	A	A	A	A	x	x
Amphibole		X		x	x	A	A	A
Oligoclase		X	X		x	X	A	A
Sphene	x	x		x	x	X	X	X
Iron ore	x	x		x		x	x	x
Apatite						x	x	x
Almandine	x					x		x
Tourmaline	x					x		
Dolomite	x							
Vesuvianite			x					

A Mineral abundant and characteristic of assemblage.
X Mineral common or locally abundant.
x Mineral subordinate.

TABLE II. Modal analyses of regional limestones and calcareous schists

	82305(i)	82305(ii)	82306(i)	82306(ii)	82307(i)	82307(ii)	82307(iii)
Carbonate	82·7	42·1	59·8	55·5	7·4	39·5	65·6
Quartz	12·4	16·2	11·0	14·7	27·0	19·1	14·0
Plagioclase	1·7	15·3	13·6	10·8	26·8	17·2	6·4
Biotite	—	9·1	6·4	9·5	18·9	17·2	9·4
Muscovite	1·1	9·3	7·1	5·4	12·8	2·6	2·3
Epidote and zoisite	1·5	6·4	—	—	4·4	0·4	—
Garnet	—	—	—	—	0·2	—	—
Iron ore	0·3	0·6	—	2·3	2·3	3·6	2·3
Sphene	0·3	0·8	—	0·1	0·2	—	< 0·1
Tourmaline	—	< 0·1	0·6	0·1	< 0·1	0·4	—
Chlorite	—	0·2	1·5	1·6	—	—	—

Table III. Modal analyses of the limestones 4–6 ft from the contact with the epidiorite

	6 ft above the contact			4 ft above the contact		
	82262(i)	82262(ii)	82262(iii)	82263(i)	82263(ii)	82263(iii)
Calcite	13·2	2·4	11·0	63·0	27·8	0·8
Microcline	36·6	38·4	39·4	5·8	15·2	21·8
Quartz and plagioclase	14·4	15·0	15·4	2·8	7·6	10·9
Epidote and zoisite	24·1	16·4	13·7	4·7	15·0	54·1
Pyroxene	4·9	20·8	17·9	15·7	9·4	6·3
Amphibole	6·8	6·6	2·6	—	—	—
Garnet	—	—	—	7·1	25·0	6·1
Biotite	—	0·2	0·1	—	—	—
Sphene	—	0·2	0·1	—	—	—
Iron ore	—	—	0·1	—	—	—
Vesuvianite	—	—	—	0·9	< 0·1	< 0·1

Table IV. Modal analyses of the limestones 0–2 ft from the contact with the epidiorite

	1–2 ft above the contact				0–1 ft above the contact			
	82251	82264	82274	82293(i)	82258(i)	82265	82267	82277(i)
Calcite	17·3	28·0	19·1	42·1	45·0	53·8	20·0	49·1
Garnet	50·5	20·1	46·1	14·6	—	—	—	—
Pyroxene	24·0	21·8	13·2	14·4	8·7	11·5	17·9	9·0
Epidote	5·3	28·4	18·6	28·7	43·9	34·0	59·4	40·8
Quartz	2·9	1·7	3·0	0·2	1·3	0·7	—	0·5
Amphibole	—	—	—	—	0·9	—	2·7	0·6
Sphene	—	—	< 0·1	—	0·2	—	—	0·1
Plagioclase	—	—	—	—	—	—	—	< 0·1

Table V. Modal analyses of the contact rocks and epidiorite

	Contact facies of limestone				Marginal facies of epidiorite		Central part of epidiorite	
	82258 (ii)	82258 (iii)	82277 (ii)	82293 (ii)	82256	82294	82308	82309
Calcite	11·8	4·9	42·5	—	0·2	—	—	0·1
Amphibole	25·5	6·0	21·6	35·9	61·2	75·5	59·4	74·9
Epidote	60·9	66·7	35·1	25·1	—	—	—	12·0
Plagioclase	—	—	—	37·5	27·6	17·9	25·2	5·2
Quartz	1·5	17·5	0·6	—	—	—	—	—
Sphene	0·3	4·6	—	1·2	9·7	6·0	5·5	7·2
Iron ore	—	—	—	—	0·2	—	1·3	0·1
Biotite	< 0·1	0·3	—	0·1	1·1	0·6	7·7*	—
Pyroxene	—	—	0·2	—	—	—	—	—
Apatite	—	—	—	0·2	—	—	0·9	0·5

* Includes secondary chlorite after biotite.

TABLE VI. Calculated approximate chemical compositions of the regional and contact limestones

	Regional limestones				Contact limestones									
					6 ft above contact		4 ft above contact		1–2 ft above contact			0–1 ft above contact		
	82305 (ii)	82307 (i)	82307 (ii)	82307 (iii)	82262 (i)	82262 (ii)	82263 (i)	82263 (ii)	82251	82274	82293 (i)	82258 (i)	82265	82267
SiO_2	33·8	57·8	36·5	21·4	50·1	57·0	20·9	35·9	38·5	36·4	26·9	25·0	22·0	35·3
TiO_2	0·4	0·1	—	—	—	—	—	—	—	—	—	—	—	—
Al_2O_3	12·3	15·8	9·6	4·2	16·0	13·4	4·6	14·3	12·0	15·2	12·4	14·4	11·2	18·4
Fe_2O_3	0·9	0·7	0·5	3·0	1·2	2·8	0·6	1·8	2·8	3·2	2·1	2·1	1·6	2·7
FeO	1·2	2·2	1·8	2·2	2·7	2·8	2·2	1·2	2·8	1·6	1·9	1·2	1·5	2·9
MgO	2·2	5·3	4·4	2·3	1·2	3·2	2·1	1·2	2·7	1·5	1·8	1·1	1·5	2·4
CaO	27·8	9·4	25·9	36·9	16·4	12·9	42·4	31·2	35·0	34·9	38·1	37·1	39·8	29·5
Na_2O	0·2	0·3	0·2	0·1	0·6	0·7	0·1	—	—	—	—	—	—	—
K_2O	2·2	3·7	2·4	1·3	5·5	5·7	0·9	3·2	—	—	—	—	—	—
H_2O	1·0	1·5	1·0	0·5	0·7	0·5	0·1	0·3	0·1	0·3	0·6	0·9	0·7	1·2
CO_2	18·1	3·4	17·8	28·1	5·5	1·0	26·1	10·9	6·1	6·9	16·3	18·1	21·7	7·6

calcite and pyroxene, with microcline, garnet, and epidote is similar to 82307(iii), *containing calcite*, quartz, bytownite, and biotite, with a little muscovite and iron ore; 82263(ii), containing calcite, garnet, epidote, pyroxene, and microcline is comparable with 82305(ii) or 82307(ii), containing calcite, quartz, muscovite, biotite, and bytownite, with zoisite and iron ore. The essential differences are that the potassium, which in the regional limestones forms micas, in the contact limestones forms microcline, leaving the aluminium, iron, magnesium, and calcium of the micas and zoisite to form pyroxene, grossular and epidote in the contact limestones.

The limestones 4 ft above the top of the sill are the only ones that are strictly comparable chemically with the regional limestones. Potassium-bearing minerals are absent in the rocks closer to the sill, while the limestones 6 ft above the sill contain 35–40 % of microcline, equivalent to nearly 6 % of K_2O, which is more than enough to form micas with the calculated aluminium, iron, and magnesium contents of the regional limestones. Since potash feldspar is absent from the regional limestones it seems necessary to assume that the excess potassium was added to the rocks 6 ft above the sill, and that it was obtained by outward migration from the rocks closer to the contact, in which there is now a deficiency of potassium. The arrested 'front' of potassium metasomatism is represented in the rocks 6 ft above the contact, and the rocks 4 ft above the contact are those through which the front has moved, but which have now reverted to almost exactly their original potassium content.

The rocks of the contact zone, whose mineralogical composition is strikingly different from that of any of the limestones further away from the contact, must be interpreted as those in which the effects of metasomatism were much more extensive. The abundance of epidote, which in exceptional cases forms 90 % of the rock, and green amphibole suggest that aluminium and iron were the principal materials introduced; the precipitation of the various minerals was probably controlled by the compositional variation of the original rock, as is shown by the similarity in the scale of the banding in the regional and contact limestones and in the rocks of the contact zone.

The evidence of the geological structure indicates that the dolerite sills were sufficiently massive to resist much of the folding of the Salkhala Series during the regional metamorphism, and the buttressing effect of the sills appears to have protected the limestones from any severe folding up to a distance of about 20 ft from the contact.

However, the garnet–epidote–pyroxene–microcline assemblages of the contact rocks were not direct products of regional metamorphism under conditions in which the maximum possible shearing stress was not attained since the minerals of the typical regional calcareous mica-schists are developed in the same 'protected' zone further away from the sill, and, still more significant, the dolerite of the sill was converted into an epidiorite of apparently normal regional type in which preferred orientation of the amphibole crystals is sometimes well-developed. It must be assumed therefore that the special rock-types at the contact of the sill represent partly or wholly relict thermal assemblages which were not made over to the calcareous mica-schist type at the time of the regional metamorphism. (It is important to note that there is no textural or mineralogical evidence to suggest that the contact rocks are not in stable mineralogical equilibrium.) Two possible factors may have been responsible:

1. The preservation of relict thermal assemblages through the regional metamorphism may represent simply a failure to recrystallize, the locally diminished intensity of the regional deformation possibly being responsible.
2. The relatively anhydrous condition of the contact assemblages may have been preserved through failure of water to re-enter them during the regional metamorphism—the contact rocks in this case would not represent purely thermal assemblages but products of regional metamorphism under water-deficient conditions ('dipsenic metamorphism', Rosenqvist, 1952).

Neither of these explanations is entirely satisfactory, since (i) the development of preferred orientation in the epidiorite shows that at least some of the regional stress must have been transferred through the contact rocks, and (ii) the amphibolitization of the original dolerite during the regional metamorphism shows that water was readily available and presumably able to cross the contacts of the sill. It seems certain however that the appearance of the special mineral assemblages in the rocks close to the contact of the sill must be ascribed to one or other of these two causes.

Acknowledgements. The author is very grateful to Professor C. E. Tilley for his advice and encouragement during this work, which was carried out in the Department of Mineralogy and Petrology at Cambridge during the tenure of a D.S.I.R. Research Studentship.

References

PASCOE (E. H.), 1950. A manual of the geology of India and Burma, 3rd ed., vol. 1. Government of India Press, Calcutta.

ROSENQVIST (I. TH.), 1952. The metamorphic facies and the feldspar minerals. Universitet i Bergen Årbok, vol. 4, p. 1.

WADIA (D. N.), 1931. The syntaxis of the North-West Himalaya; its rocks, tectonics, and orogeny. Rec. Geol. Surv. India, vol. 65, p. 189.

—— 1932. Note on the geology of Nanga Parbat (Mt. Diamir), and adjoining portions of Chilas, Gilgit District, Kashmir. *Ibid.*, vol. 66, p. 212.

EXPLANATION OF PLATES

PLATE VII

Two specimens (82258–82259) forming a complete section through the upper contact of the Burawai sill. The upper half of the top specimen is the thermally metamorphosed limestone, and the lower half is the contact zone, in this case only 4 cm thick, composed mainly of epidote and amphibole in varying proportions. The lower specimen shows the spotted marginal facies of the epidiorite. The upper specimen shows on a small scale the block faulting which is the principal effect of deformation of the epidiorite and adjacent rocks of the Burawai sill. Actual size.

PLATE VIII

A. Normal regionally metamorphosed calcareous schist above the Burawai epidiorite sill (82326). Muscovite, pale brown biotite, quartz, and calcite with dusty iron ore and a little tourmaline occupy the top half of the photograph. In the lower right corner a shredded porphyroblast of α-zoisite is included in large plates of bytownite containing quartz inclusions, and similar zoisite and bytownite appear to the left of this. The black grains near the lower margin are deeply-coloured sphene.

B. Limestone 6 ft above the contact of the sill (82262). Euhedral prisms and a larger porphyroblastic crystal of amphibole, and small anhedral grains of epidote, pale green pyroxene (these two indistinguishable in the photograph), and calcite are set in a matrix of quartz and microcline.

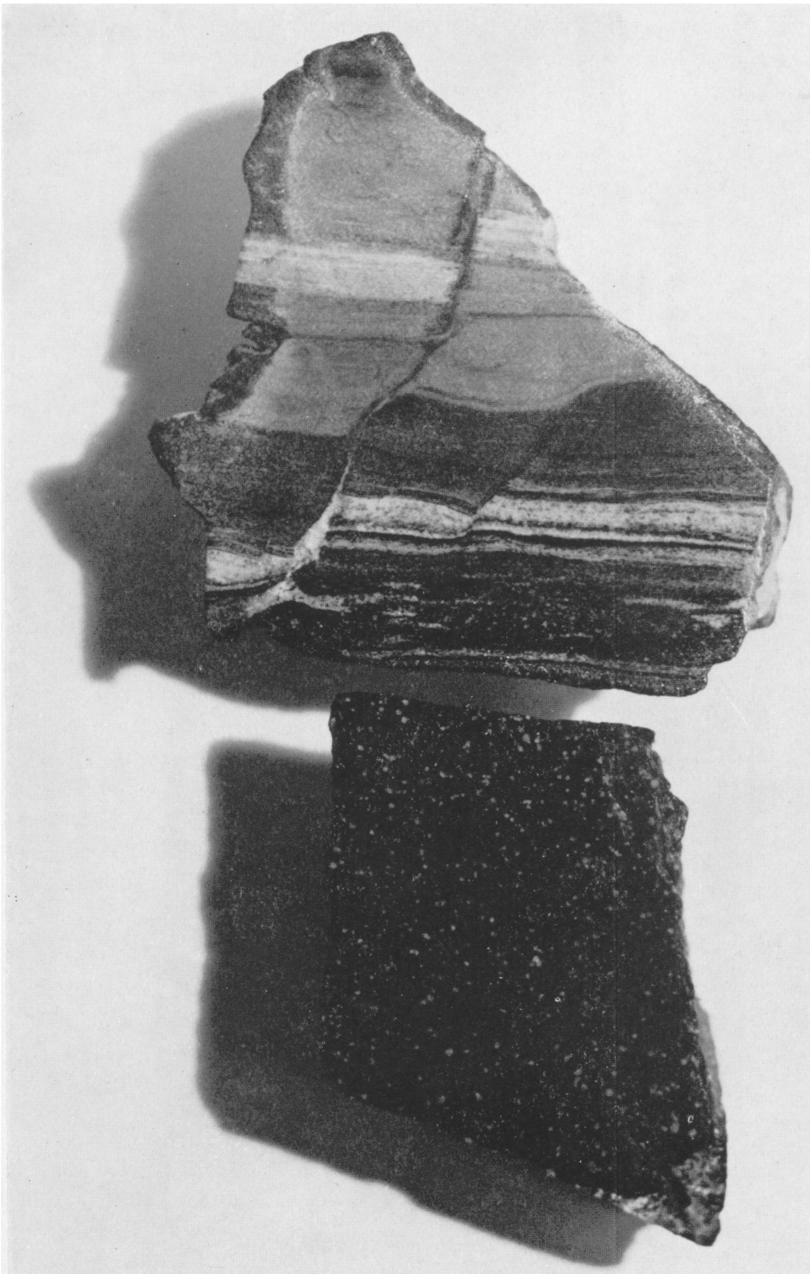
C. Limestone 4 ft above the contact of the sill (82263). Granular epidote, pyroxene, and calcite, with garnet (a hollow euhedral crystal appears near the middle of the left side) and large plates of α-zoisite (lower right corner) are set in a matrix of quartz and microcline. This rock is very similar in chemical composition to the schist illustrated in Fig. A.

D. Limestone 2 ft above the contact (82274). Large, often euhedral, garnets are surrounded by a granular aggregate of calcite, pyroxene, epidote, and quartz. There is no microcline or other potassium-bearing mineral in this rock.

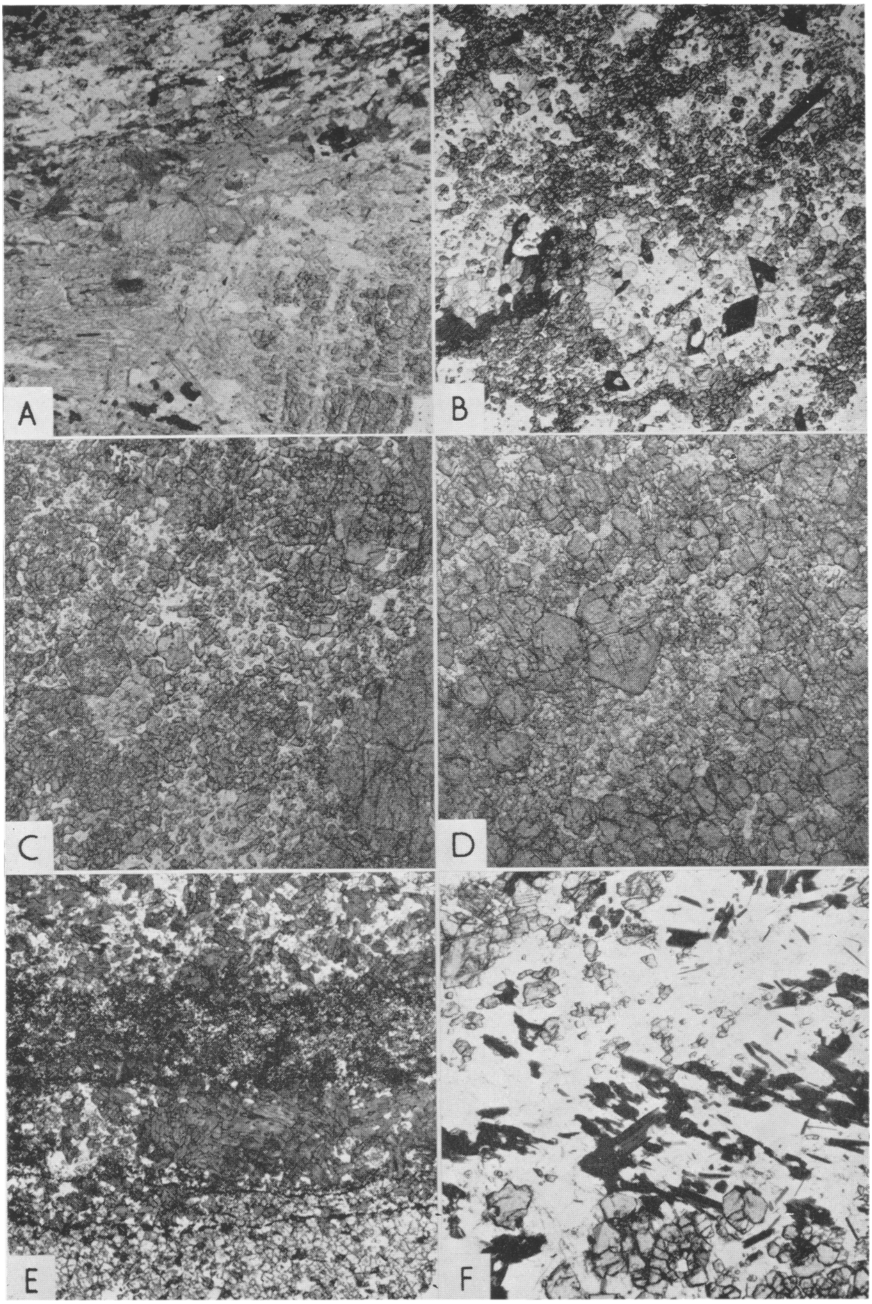
E. Part of the contact zone between the limestone and the epidiorite (82258). The minerals are amphibole (grey), epidote (moderate relief), calcite (interstitial in the upper one-third of the photograph), and plagioclase and quartz (interstitial in the rest of the photograph). Sphene (black) forms two thin parallel septa across the lower part of the photograph and two diffuse bands across the upper part.

F. Part of a complex vein in the contact zone (82296). The minerals illustrated are garnet (subhedral, at bottom of photograph, representing part of a cluster 1 cm in diameter), epidote (top half of photograph), and deeply-coloured amphibole and biotite (the latter distinguishable by the cleavages and straight-sided cross-sections of flakes), all set in large plates of oligoclase. The vein is extremely variable in composition—elsewhere in the section large crystals of epidote and calcite form most of the rock.

All photographs taken in ordinary light. Magnification × 15.



B. C. M. BUTLER: AN EPIDIORITE–LIMESTONE CONTACT



B. C. M. BUTLER: AN EPIDIORITE–LIMESTONE CONTACT