PETROLOGICAL STUDIES IN THE ORDOVICIAN OF NEW SOUTH WALES. IV.*

THE NORTHERN EXTENSION OF THE NORTH-EAST VICTORIAN METAMORPHIC COMPLEX.

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(Plate xv; ten Text-figures.)

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Contents.

I. INTRODUCTION.

As implied by the title of this paper, the area under consideration is an extension of the great Victorian Metamorphic Complex, and although a good deal of petrographical work has been done on the Victorian rocks, it is not quite detailed enough to make possible the placing of the New South Wales types in the general metamorphic pattern; thus certain assumptions are made, which may prove incorrect when a more detailed study is made of the complex as a whole on the southern side of the Murray River.

Recently the writer (1944) published a brief account of the geology of the Albury district, and although subsequent more detailed work shows that slight modifications are necessary, the present paper is partly a petrological elaboration of that area together with a rather more generalized description of the country in the vicinity of Woomargama and Jingellic. The region examined has an area of approximately 800 square miles and represents work in varying degrees of detail (see Plate xv). It is hoped, however, that it gives a fairly reliable general picture of the metamorphism and of the various granite intrusions that have from time to time invaded this complicated area.

II. THE COUNTRY ROCKS.

1. NATURE OF THE ORIGINAL COUNTRY ROCKS.

(*a*). *Sedimentary Types.*

In the areas of less altered rocks about Jingellic, excellent sections of the sediments are exposed. Certain parts of the Holbrook Road, several miles east of Lankey's Creek Post Office, cut obliquely across the strike of a great series of comparatively

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narrow alternating beds of light grey, buff and black pelites and psammites. In places, the sandy type is the more prominent, in other parts, it is almost absent, and the beds, though still fairly narrow, and rarely exceeding 18″ in thickness, show alternations of black and grey pelite. Close examination shows that many of the pelites are somewhat sandy types and should be termed more correctly psammopelites.

In areas of greater metamorphism the same rock-types may be recognized among the high-grade schists, and chemical analyses show that the pelites are normal or aluminous pelites as defined by the present writer (1942). The siliceous pelites met with at Cooma (Joplin, 1942) and elsewhere in the Ordovician of New South Wales (Joplin, 1945) have not been observed in the Murray Valley; although a few rocks are more siliceous than the normal pelites, their high alumina content shows them to be variations of that group. Reference to Tables 1, 2 and 3 will show other variations from the normal as well. Thus a number of rocks (Table 2) contain lower magnesia

TABLE 1.

Normal Pelites.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.
SiO_2	55·49	56·52	56·33	59·42	51·33	54·18	58·87	56·40	54·63	56·05	59·05
Al_2O_3	24·45	23·13	22·94	21·44	25·69	25·48	21·23	23·20	25·35	24·91	22·95
Fe_2O_3	2·21	1·96	2·19	1·09	4·80	2·99	2·47	1·30	2·40	1·22	1·48
FeO	4·92	5·09	4·54	5·23	1·07	3·08	4·05	5·22	4·64	4·76	5·16
MgO	2·88	2·82	3·27	2·53	2·72	3·13	2·98	3·24	2·75	2·51	2·37
CaO	0·35	0·39	0·25	0·11	0·25	0·41	0·12	0·63	0·65	0·51	0·65
Na_2O	0·54	0·24	0·88	0·66	0·77	0·73	0·60	0·61	0·62	1·06	0·81
K_2O	5·21	6·14	6·10	6·14	6·13	5·70	5·73	5·65	6·28	6·12	5·85
H_2O+	2·09	2·27	3·07	1·82	5·20	2·88	2·59	2·77	1·25	1·23	1·17
H_2O-	0·07	0·20	0·80	0·19	1·53	0·48	0·22	0·30	0·26	0·22	0·18
TiO_2	0·78	1·17	—	0·96	0·49	0·73	0·84	0·57	0·86	0·86	0·68
P_2O_5	0·20	0·22	0·13	0·04	—	0·07	0·05	0·06	0·20	0·14	0·18
MnO	0·09	0·06	tr.	0·05	—	0·03	0·02	0·01	0·05	0·11	0·05
ZrO_2	n.d.	—	—	n.d.	—	n.d.	0·02	0·05	0·15	0·09	0·19
C	0·03	—	—	—	—	0·34	0·16	0·51	—	—	—
CO_2	0·30	—	—	abs.	—	abs.	abs.	abs.	abs.	abs.	abs.
BaO	—	0·11	—	—	—	—	—	—	—	—	—
	99·61	100·32	100·50	99·68	99·98	100·23	99·95	100·52	100·09	99·79	99·86

I. Knotted Schist. Just NW. of Hamilton Trigonometrical Station, Por. 275, Par. of Jindera, Albury. Anal. G. A. Joplin.
II. Andalusite Hornfels. Noorongong. Anal. C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929: 35.
III. Phyllite. Ensay Area. Anal. W. A. Howitt. *Proc. Roy. Soc. Vict.*, 22, 1886: 68.
IV. Permeation Gneiss. Eastern Hills, Pors. 107/74, Par. of Albury. Anal. G. A. Joplin.
V. Argillite. Waterford, Dargo Road and Mitchell River Crossing. Anal. A. W. Howitt. Ibid., 23, 1887: 130.
VI. Chlorite-sericite-schist. About half a mile east of McCarthy's Crossing, Por. 144, Par. of Coolrington. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 181.
VII. Plicated Mica-schist. Crossing of Slack's Creek and Dry Plain Road. Anal. G. A. Joplin. Ibid.
VIII. Knotted Andalusite-schist. Por. 137, Par. of Binjura. Anal. G. A. Joplin. Ibid.
IX. Spotted Granulite. Por. 212, Par. of Binjura. Anal. G. A. Joplin. Ibid.
X. Mottled Gneiss. Spring Creek. Por. 212, Par. of Binjura. Anal. G. A. Joplin. Ibid.
XI. Mottled Gneiss. Same locality as X. Anal. G. A. Joplin. Ibid.

than that characteristic of the normal types, and these, as well as the more normal and more siliceous pelites (Tables 1 and 3), show variations in soda and in total iron. Nevertheless, these discrepancies are not so great as to warrant the assumption that these sediments had a markedly different origin.

In Tables 1–3 analyses of the Albury–Jingellic pelites are grouped with rocks from various parts of the Victorian Complex, thus indicating that these types of sediment are widespread and form the dominant country-rock within the entire complex. Furthermore, with reference to the Victorian region, Howitt (1889) comments upon "the characteristic alternations of argillaceous and arenaceous beds"—a feature particularly noticeable in the Jingellic area, as mentioned above.

Although no graptolites have been found in the Albury–Jingellic area, the rocks have been traced into Upper Ordovician graptolite-bearing types by Howitt (1884) and by Tattam (1929), and in view of the close lithological and chemical similarities between these rocks and those of Cooma, they are regarded as Ordovician sediments, probably to be correlated with the Binjura Beds of the Cooma district.

TABLE 2.

Magnesia Content lower than that of the Normal Pelites.

	I.	II.	III.	IV.
SiO_2	53·88	57·74	59·43	52·91
Al_2O_3	27·95	23·06	23·37	24·49
Fe_2O_3	5·04	2·90	2·84	5·45
FeO	0·69	1·61	1·13	1·50
MgO	1·02	1·97	1·59	1·80
CaO	0·19	0·14	0·14	0·29
Na_2O	0·34	0·46	0·61	1·08
K_2O	5·64	5·38	5·09	6·60
H_2O+	3·44	3·76	2·48	3·81
H_2O-	0·72	1·03	0·61	0·61
TiO_2	1·12	0·92	0·98	0·83
P_2O_5	0·07	0·10	tr.	0·10
MnO	0·03	0·04	0·01	0·06
BaO	—	—	—	0·06
C	0·53	0·87	1·75	0·19
	100·66	99·98	100·03	99·78

I. Dark Grey Slate. Tumbarumba Road, 3 miles from Jingellic, Por. 12, Par. of Currajong. Anal. G. A. Joplin.
II. Spotted Black Slate. Near Abraham's Bosom, roadside cutting, Por. 23, Par. of Talmalmo. Anal. G. A. Joplin.
III. Dark Grey Slate. Holbrook Road, Por. 55, Par. of Currajong. Anal. G. A. Joplin.
IV. Slate. Eastern slopes of Mt. Wagra, near Tallangatta. Anal. C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929.

TABLE 3.

Silica Percentage higher than that of Normal Pelites, also Alkalis and Total Iron somewhat Irregular. Analysis I contains Lower Magnesia.

	I.	II.	III.	IV.	V.	VI.
SiO_2	65·73	64·00	62·28	62·30	61·92	61·13
Al_2O_3	21·04	19·82	20·16	19·22	20·74	23·43
Fe_2O_3 } FeO }	2·28	3·50	{ 0·53	1·80	2·28	0·09
			{ 3·84	4·01	3·90	4·84
MgO	0·75	2·14	2·54	2·95	2·19	1·99
CaO	0·14	0·32	0·82	0·44	0·42	0·63
Na_2O	0·27	1·10	1·29	2·07	3·51	1·08
K_2O	4·77	4·41	6·40	3·60	2·28	5·84
H_2O+	2·57	1·38	1·14	1·96	1·20	0·26
H_2O-	0·25	0·85	0·72	0·40	0·92	0·20
TiO_2	0·92	—	0·17	—	—	0·72
P_2O_5	0·08	0·10	0·15	0·23	0·16	0·24
MnO	—	—	—	—	0·17	0·09
C	1·59	3·32	—	—	—	—
ZrO_2	—	—	—	—	—	0·16
	100·39	100·94	100·04	98·98	99·69	100·70

I. Carbonaceous Sericite Schist, slightly hornfelsed. Por. 16, Par. of Burrumbuttock. Anal. G. A. Joplin.
II. Mica-schist. Wilson's Creek, Omeo Area. Anal. A. W. Howitt. *Trans. Roy. Soc. Vict.*, 24, 1887: 112.
III. Hornfels. Orr's Gully, Dargo Area. Anal. A. W. Howitt. Ibid., 23: 133.
IV. Slate. Junction Haunted Stream and Tambo River. Ibid., 20, 1884: 58.
V. Hornfels. Above Locality. Anal. A. W. Howitt. Ibid., 62.
VI. Mottled Gneiss. Mt. Gladstone, Cooma, Por. 145, Par. of Jillamatong. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942.

(*b*). *Rocks of Igneous Origin.*

Near Bethanga Bridge, just to the west of the Hume Weir Quarry, a mass of basic igneous rock occurs associated with the granite. The relation of the two rocks is rather obscure and it may represent a later intrusion into the granite or part of the country-rock occurring as a roof-pendant. In thin section the basic type shows a good deal of alteration, but does not appear to be in a high grade of metamorphism like the numerous pyroxene-granulite xenoliths found in the Bethanga gneiss within the quarry itself. Numerous blocks of quarried gneiss and granite contain this lower-grade type, however, and one of these was analysed and compared with an analysis of a granulite xenolith. It will be seen in Table 4 that the two rocks are comparable, though by no means identical, and the question of their relationship must be deferred until further field evidence becomes available. Reference to Table 4 shows also that these rocks appear to be of the same magma-type as certain hornblende and pyroxene granulites from Cooma, which, it was suggested (Joplin, 1942), represented basaltic flows or sills within the Binjura Beds.

TABLE 4.

	I.	II.	III.	IV.	V.
SiO_2	52·23	48·23	49·50	47·24	47·26
Al_2O_3	22·16	16·67	16·42	18·55	22·80
Fe_2O_3	0·72	2·66	0·72	6·02	2·21
FeO	8·50	6·09	9·10	4·06	5·41
MgO	4·75	7·65	7·47	5·24	7·76
CaO	7·29	9·22	14·79	11·72	10·93
Na_2O	0·43	1·67	0·47	2·42	1·72
K_2O	1·70	0·84	0·32	0·15	0·29
H_2O+	0·73	3·17	0·57	2·24	0·90
H_2O-	0·01	0·25	0·03	0·21	0·11
TiO_2	0·76	0·78	0·75	1·46	0·38
P_2O_5	0·46	0·26	0·05	0·26	0·06
MnO	0·11	0·15	0·16	0·31	0·31
CO_2	abs.	1·88	abs.	—	—
Etc.	—	—	—	0·24	0·10
	99·85	99·52	100·35	100·12	100·24
Sp. Gr.	2·83	2·81	—	—	—

I. Pyroxene-granulite. Large inclusion in Bethanga Gneiss. Weir Quarry, Por. 65, Par. of Thurgona. Anal. G. A. Joplin.

II. Altered Basic Rock. Road cutting between turn-off to Hume Weir and Bethanga Bridge. Pors. 66/67, Par. of Thurgona. Anal. G. A. Joplin.

III. Hornblende-granulite (with trace of pyroxene). Cooma Creek, near entrance to gorge, Por. 135, Par. of Cooma. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 172.

IV. Basalt (porphyritic central type) Tertiary lava. ½ mile SSW. of Derrynaculen, Mull. Anal. E. G. Radley. *Mem. Geol. Surv. Scot.*, 1924: 24.

V. Biotite-eucrite. Ring-dyke Centre 3, Ardnamurchan. Bank of stream 1 mile east 33 south of Achnaha. Anal. E. G. Radley. Ibid., 1930: 85.

The pyroxene granulites and certain related types, which are believed to represent admixtures of basic tuff and normal sediments, are described in detail in connection with the xenoliths in the cordierite-bearing gneiss (see p. 100).

2. THE METAMORPHIC ZONES.

In the Cooma district the metamorphic zones could be mapped fairly accurately, and it was shown that granitized areas, consisting of injection- and permeation-zones, surrounded the main mass of Ordovician gneiss. These were followed outwards by a zone of piezo-contact metamorphism, termed the andalusite-zone, and this again by biotite- and chlorite-zones. It was established that the granitized schists and andalusite-schists were formed directly as a result of the intrusion of the Ordovician gneiss, and although it was surmised that the biotite- and probably the chlorite-zones bore a causal relation, this point could not be verified owing to the paucity of outcrops.

In the Albury–Jingellic area the zones are not well defined and cannot be strictly correlated with those of Cooma since the Albury area represents only the northern periphery of the main complex of Victoria, and it is possible that this represents a different level of the intrusion from that of Cooma. Moreover, in the Murray Valley, the metamorphic pattern is obscured by intrusions of later granites, and many of these have superimposed hornfels-zones on the Ordovician schists.

The Albury district shows a conspicuous development of sills in the vicinity of the gneisses, and although these have been responsible for granitizing and sometimes felspathizing the schists, their margins are usually well defined and they do not give rise to injection-gneiss. Actually, a little very localized injection is to be seen within the zone of sills, as on the western shore of the Bowna Arm of the Hume Reservoir, and in several road sections within the town. At the northern end of Eastern Hills, a large sill has been responsible for the permeation of the surrounding schists, which compare with the permeation or mottled gneisses of Cooma.

Along the Howlong Road, between West Albury and Bungowannah, the schists are high-grade types, often sillimanite gneisses. These are within the zone of sills and pass rapidly into knotted schists which are also partly within the zone of sills. No attempt has been made to map the junction between the sillimanite-zone and the zone of knotted schists, but the line of demarcation between the zone of sills and the outer part of the knotted schist zone, though not sharply defined in the field, is shown as a rough sketch boundary on the map (Plate xv).

North of Albury the knotted schists pass into biotite schists, and again, the boundary shown on the map is only approximate, but it is fairly obvious that all three zones run approximately east and west and are possibly marginal to a gneissic body south of the Murray, the northern margin of which crops out west of the town on the banks of the river and on the lower southern flank of Monument Hill.

Other smaller masses of gneiss with their corresponding zones are to be found in the Parish of Bowna on the shores of the northern arm of the reservoir, at Woomargama, and about 10 miles from Jingellic on the Tumbarumba Road in the Parish of Coppabella. There is also good reason for believing that a mass of gneiss, subsequently engulfed by later granite, occurred a few miles south-east of Jingellic, since by analogy with other areas of gneiss, outcrops of knotted schist on Horse Creek and on the banks of the Murray suggest the former presence of gneiss.

Thus, though the metamorphic zones are not so easy to trace as at Cooma, they appear to exist or to have existed before being stamped out by later metamorphic changes.

In examining the metamorphic rocks in the Omeo district which is situated near the southern end of the complex, Howitt (1889) has traced the progressive regional metamorphism of what were then considered to be Silurian rocks into highly-crystalline schists and gneisses. He describes the unaltered rocks as a series of interbedded arenaceous and argillaceous rocks, and calls rocks showing an early stage of alteration "argillites" (see Table 1, Anal. V). He speaks of these low-grade rocks as containing members of the chlorite group and recognizes this change as "one of the earliest stages of metamorphism impressed upon them (the beds) during the folding of the strata". At the next stage, he observes phyllitic characters developed and mentions that these pass into mica-schists and ultimately into massive holocrystalline rocks with the characters of quartz-diorites. Although Howitt did not map these stages as, or call them, metamorphic zones, he tacitly recognized them as such. This is of very great interest, for it was not until 1893 that Barrow put forward his ideas concerning the Highland zones, and it was in 1925 that Tilley suggested the use of chlorite as an index of low-grade argillaceous rocks.

Tattam (1929), in describing the Victorian Complex as a whole, makes no attempt to trace metamorphic zones, largely on account of retrograde effects. Nevertheless he mentions the occurrence of chloritic slates and phyllites at Tawonga Gap and on the divide between Twist's and Commissioner's Creeks, near Yackandandah (pp. 12 and 18).

As already explained, the present writer is attempting to compare the Murray Valley rocks with those of Cooma where metamorphic zoning is fairly simple, but to do this satisfactorily the Victorian rocks must also be considered. Obviously zoning is possible in the areas where Howitt has worked, but it is a little difficult to correlate Tattam's phyllites, injection schists and schistose phyllite with the various zones. I have been greatly assisted in this correlation by the kindness of Mr. Baragwanath, who has lent me a large collection of microscope slides from this region, and, so far as I can ascertain, Tattam's phyllites cover all types from the lowest grade up to the zone of knotted schists. He speaks of the occurrence of chlorite and of biotite in these rocks and describes some types containing oval knots in a two-mica base. His injection schists appear to be comparable to some of my high-grade altered schists and gneisses which occur within the zone of sills, and so far as I am able to tell, his schistose hornfelses are the more psammatic types within this same zone.

In the Albury–Jingellic region, later granites have superimposed their contact effects, and Tattam has recognized similar phenomena on Indigo Creek in the contact of the Pilot Range granite and further south in the Tambo River area. These rocks Tattam (1929, p. 18) describes as hornfelses.

3. PETROGRAPHY OF THE ORDOVICIAN SCHISTS.

(*a*). *Schists of the Chlorite and Biotite Zones.*

Low-grade rocks belonging to the chlorite-zone are developed in the vicinity of Talmalmo and Jingellic, but many have suffered a superimposed contact metamorphism near the margins of the younger granite intrusions (see p. 122).

In both these areas the pelitic type of sediment is more common than the psammatic, though the microscope reveals minute sandy bands in most of the pelitic rocks.

In handspecimen the rocks are grey or black slates with a fairly well-developed cleavage. Occasionally they are slightly phyllitic.

Under the microscope they are found to be slightly banded, and minute cross-cutting veins of quartz or of iron ore are not infrequent.

Chlorite, sericite and a little quartz are the main constituents, the latter being more abundant in the psammatic bands. In the darker rocks carbonaceous material is prominent. Accessory minerals are zircons and iron ore. Chlorite usually occurs in minute flakes in parallel orientation, but in some types larger flakes or plates, clouded with carbonaceous material, occur. The chlorite is optically negative and colourless to very pale green. The double refraction varies from nothing to 0·005. In the vicinity of the cross-cutting veins containing haematite, a little biotite or green mica may be developed, and in some slates darker micas are developed near haematite streaks which are parallel to the schistosity. Sericite occurs in flakes parallel to the schistosity or as minute blades piercing chlorite plates.

Biotite-schists occur north-west of Albury near Burrumbuttock, to the north-east near Woomargama and up the river near Jingellic. In many cases they have suffered a subsequent contact metamorphism.

The biotite-schists vary a good deal in handspecimen, some of the Jingellic types looking not unlike phyllitic slates and being indistinguishable from the slates of the chlorite-zone. North and north-west of Albury, however, they are usually coarser grained, and often mica may be distinguished in handspecimen. In this area, and also in the area about Woomargama, psammatic types are prominent, and these form typical quartz-mica-schists.

Under the microscope the pelites of the biotite-zone vary a good deal in texture and grain-size. Near Jingellic a fine-grained biotite-schist shows a slight development of false cleavage. There is a great development of minute flakes of greenish-brown mica parallel to the schistosity and small porphyroblasts of biotite are developed across it. Harker (1932, p. 215) considers this to be an early stage in the biotite-zone. The development of biotite in the vicinity of haematite is mentioned above in connection with the chlorite-zone and a specimen from Burrumbuttock, within the biotite-zone, shows a related feature. In this case an aureole of chlorite-sericite-schist surrounds haematitized pyrites crystals in a rock which normally contains a good deal of greenish-brown mica.

At Burrumbuttock carbonaceous quartz-sericite-schists are fairly common, and though they contain no biotite, their well-marked plication and schistosity indicate that they probably belong to the biotite-zone, their initial composition inhibiting the production of the index mineral.

The biotite-schists are often finely banded with minute (0·5 mm.–3 mm.) seams of psammite alternating with pelite.

Lenses of biotite, or small porphyroblasts orientated with their basal cleavage at an angle of about 30° to the schistosity, may be developed in a fine lepidoblastic aggregate of biotite, sericite and quartz. The amount of biotite is variable and white mica may be poorly developed in some types.

Tourmalinitized biotite-schists have been collected from Por. 317, Parish of Moorwatha, and Por. 131, Parish of Mungabarina.

Psammopelites are fairly common in the areas where the biotite-zone is developed. These contain a greater proportion of quartz than the pelites, but the mineral constituents and structures are similar. The quartz usually occurs in small elliptical grains with their longer axes parallel to the schistosity.

About Burrumbuttock the most prominent rock-type is a fine-grained buff-coloured slate, which, on microscopic examination, proves to be an extremely fine-grained psammopelite containing quartz, greenish mica, biotite, some muscovite, iron ore and tourmaline. In some types small porphyroblasts of chlorite lie athwart the schistosity.

Unlike the psammites in the biotite-zone of Cooma, those of the Burrumbuttock and Woomargama districts show a well-preserved clastic structure. The clastic grains are usually quartz of varying size (1·0 mm.–0·1 mm.). These are somewhat lenticular and often granulated, but not infrequently occur in irregular grains across the schistosity. Undulose extinction is common, and cross-cracking and lines of minute inclusions at right angles to the incipient schistosity of the rock are often developed. The matrix consists of biotite, green mica, muscovite and quartz, whilst tourmaline and iron ores are often accessory. Detrital grains of sphene and of apatite occur. The former are sometimes recrystallized.

A rock east of Moorwatha Trig. shows clastic quartz grains with undulose extinction and a marginal development of secondary quartz. There is little evidence of regional metamorphism, and the rock appears to have been slightly hornfelsed, although no granite mass has been observed in the vicinity.

A rock from the roadside opposite the T.S.R., south of Woomargama, contains a small quantity of clastic plagioclase showing a clouding of minute black grains (Macgregor, 1931). The rock may represent an arkose or may contain a little original tuffaceous material. In the field it appears as a greenish-grey psammite.

(*b*). *Zone of Knotted Schists.*

The inner part of the zone of knotted schists lies within the zone of sills. All of the pelites and most of the psammopelites and psammites within this zone show a development of dark spots, which stand out as knots on weathered surfaces. The knots vary considerably in size from a few millimetres up to an inch (Fig. 1). The schists are distinctly micaceous and within the zone of sills mica is developed in very large flakes and the rock appears coarser than usual.

In thin section the spots may show a distinct zoning, which when examined more closely under the microscope is not so apparent. Sometimes the zoning is due to a difference in texture, sometimes to a concentration of carbonaceous material or to the development of biotite in the centre of the spot. Most of these areas are circular or elliptical in section and consist largely of green micaceous material exactly similar to the altered cordierite of the cordierite-bearing gneiss (see p. 107). Often the green mica shows a well-developed sieve structure. Chlorite, red-brown biotite and quartz are usually present as well, and sometimes white mica or a large quantity of carbonaceous material—probably finely-divided graphite. A rock from the track just west of Bungamba Trig. shows a zoned spot consisting of an inner core of bright orange, isotropic pinite and an outer rim of green micaceous material. Both show well-developed sieve-structure. The presence of pinite suggests strongly that the original spot consisted of cordierite. Another rock from the Gap Road north of Hamilton Trig. contains large plates of green mica threaded with parallel bands of haematite around which wisps of biotite have developed. These seem to mark an original cleavage and suggest that the knot was originally andalusite. In the twenty-six microslides examined from this zone, no fresh cordierite or andalusite has been detected, but in slides kindly lent by Mr. W. Baragwanath from the head of Forest Creek, Talgarno, Victoria, both these minerals have been observed. These highly-plicated carbonaceous rocks from Victoria would appear to lie within the zone of knotted schists and outside the zone of sills. It is of interest to note that the analysis of a knotted schist from the Albury district compares closely with a knotted andalusite-schist, containing some cordierite, from Cooma, and with an andalusite hornfels described by Tattam (1929) from the Mitta Mitta Valley (Table 1). Furthermore, in a higher grade of metamorphism, andalusite and/or sillimanite and occasionally cordierite are developed in the Albury area.

Although no direct comparison can be made, it is of interest to examine three analyses carried out by Tattam. The first is a "chloritic" nodule from a knotted phyllite which would appear to correspond to the spots of the Albury knotted schists, and the others are analyses of pinitized cordierite.

TABLE 5.

	I.	II.	III.
SiO_2	50·01	45·73	44·92
Al_2O_3	23·15	27·83	27·30
Fe_2O_3	4·07	1·05	2·84
FeO	4·71	6·80	7·60
MgO	4·35	4·95	3·05
CaO	0·20	0·20	0·40
Na_2O	0·50	0·27	1·21
K_2O	5·81	8·17	7·46
H_2O+	5·56	4·00	4·53
H_2O-	1·37	0·40	0·43
TiO_2	0·70	0·13	abs.
P_2O_5	—	—	—
MnO	0·07	0·06	0·10
F_2	—	0·06	0·39
Less $O=F_2$	—	0·03	0·16
	100·50	99·62	100·07

The high potash of these analyses suggests the presence of mica which has been noted in the pinite or chloritic material of the spots in the Albury schists.

Both the New South Wales and Victorian rocks show a fine banding and a well-marked plication or false-cleavage. The pelitic layers usually contain an abundance of knots in a base consisting of elongated flakes of brown, green and white mica—no doubt the two-mica base described and analysed by Tattam (1929). The structure of this base is lepidoblastic. The intermediate sandy bands contain an abundance of quartz and show a tendency towards a granoblastic structure, although a parallelism of the mica flakes is apparent. Small elongated grains of quartz are also present in the pelitic layers and they sometimes become larger in the vicinity of the knots, where the texture of the pelite often becomes coarser. Iron ore and sphene are accessory, tourmaline is well developed in certain localities, and graphite is very abundant in some types.

Psammopelites and psammites show similar features. The schistosity is less well marked and there is a greater development of the granoblastic structure. The knots, so characteristic of the pelites, are not always developed in the interbedded psammite, but when present they consist almost exclusively of the green micaceous material and occur as large poikloblastic porphyroblasts whose margins are interlocked with the xenoblastic quartz and micas surrounding them (Fig. 1, A and C).

These rocks appear to have suffered a fairly high-grade metamorphism which seems comparable in degree with the schists of the andalusite-zone at Cooma. In view of their advanced recrystallization, it seems probable that the micaceous and chloritic material

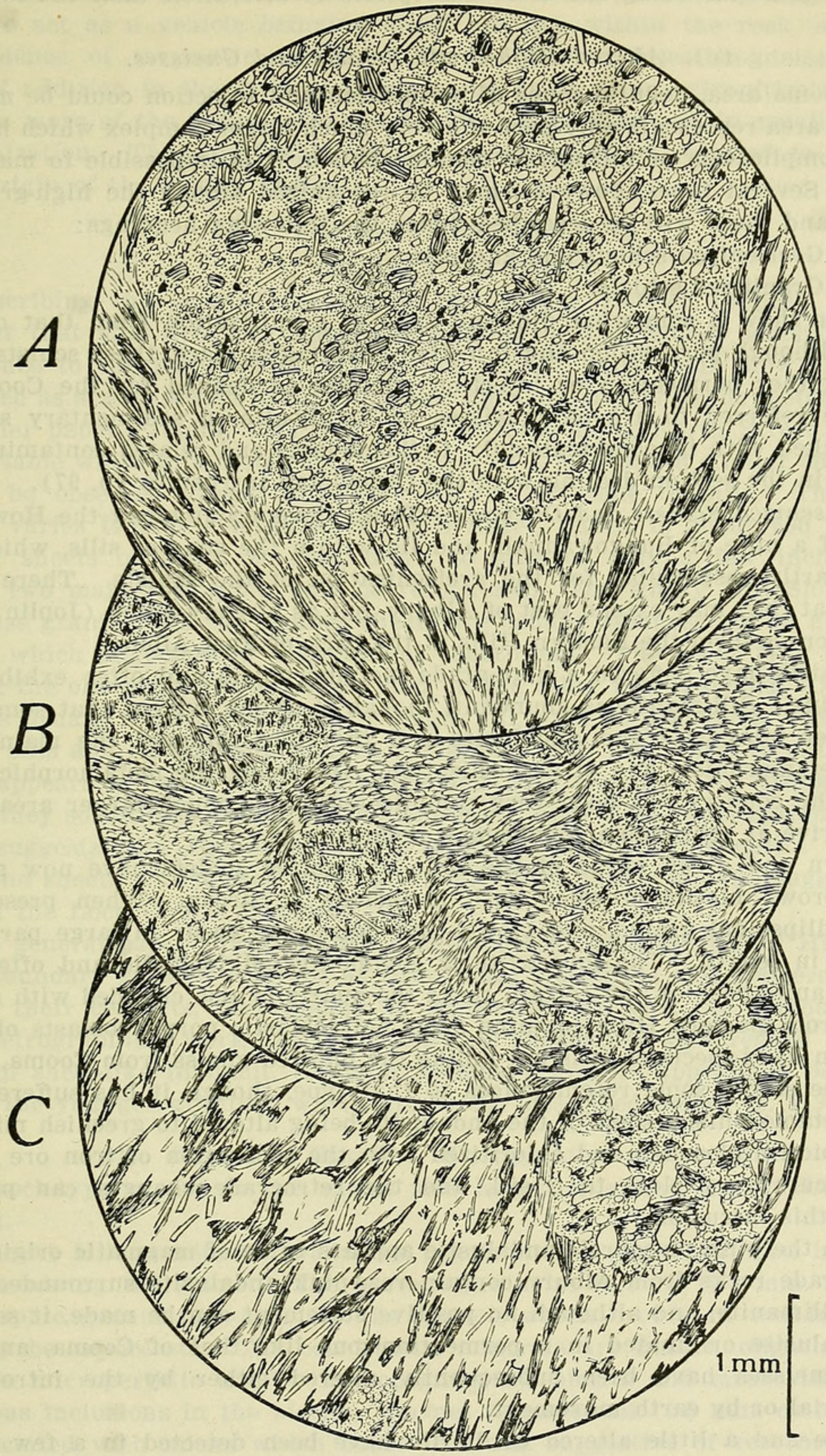

Fig. 1.—Knotted schists.

A. Psammopelite showing portion of a large knot. This consists of a mass of chlorite and sericite and contains numerous inclusions of biotite, muscovite and quartz. The base consists of elongated grains of quartz, biotite and muscovite which are bent around the knot. × 16.

B. Pelite showing numerous small knots, much altered and with a sieve-structure. The base has a marked schistosity with bending around the knots and consists of small elliptical grains of quartz and flakes of micas. × 16.

C. Psammite showing large altered knots with sieve-structure in a coarse base of quartz and mica having a marked schistosity. × 16.

of the knots represents a retrograde rather than an incipient change, in spite of the fact that the main body of the rock shows no sign of retrogressive metamorphism. There is little doubt, however, that the spots were originally cordierite and/or andalusite crystals, both minerals being far more susceptible to alteration than the micas of the base.

(c). Altered High-Grade Schists and Gneisses.

In the Cooma area, definite zones of permeation and injection could be mapped, but as the Albury area represents only part of a very much larger complex which has suffered the further complication of retrograde metamorphism, it is impossible to map either of these zones. Several types, however, may be recognized among the high-grade schists and gneisses and these will be described under the following headings:

(i). Greisenized schists and gneisses.

(ii). Granitized schists.

The latter show a somewhat different type of granitization from that observed at Cooma, and although permeation and injection have taken place, these schists cannot be classified as either permeation or injection gneisses as defined for the Cooma region. Gneisses here referred to are paragneisses or highly-altered sedimentary schists that have been soaked with igneous material. Orthogneisses and related contaminated types are described in the section dealing with the Ordovician intrusives (p. 97).

(i). *Greisenized Schists and Gneisses.*—These types occur along the Howlong Road to within half a mile of Bungowannah, and lie within the zone of sills, which have no doubt been partly responsible for the greisenization of the schists. There are slight indications that they may extend east of Albury, but as already noted (Joplin, 1944), the only good outcrops form the Eastern Hills at the back of East Albury.

These schists have suffered a high-grade metamorphism and often exhibit a coarse gneissic banding. Sillimanite is abundant, though it seems evident that some of it has developed after muscovite and andalusite and therefore followed the main period of high-grade metamorphism and of greisenization. Obviously the metamorphic history of this part of the country has been very complicated and a much larger area should be studied to arrive at reasonable conclusions regarding it.

The brown and green micas of the zone of knotted schists have now given place to deep red-brown biotite crowded with inclusions of zircon. When present, quartz forms large ellipsoidal grains, and biotite and muscovite occur in large parallel flakes up to 2 mm. in length. The muscovite is commonly poikloblastic and often contains mats of sillimanite needles. In certain rocks the quartz is also crowded with sillimanite. A specimen from Eastern Hills contains large poikloblastic porphyroblasts of pale pink andalusite. In hand-specimen it is not unlike the mottled gneiss from Cooma, and under the microscope shows some resemblances to that type, though it has suffered a severe retrograde metamorphism, some of the andalusite being altered to greenish mica and the original red biotite bleached and chloritized with the separation of iron ore and rutile. This rock occurs very close to a sill, and the retrograde changes can probably be attributed to this intrusion.

At Cooma the pink pleochroic andalusite appears to be of magmatic origin. Several of the high-grade rocks from Albury contain rose-pink andalusite surrounded either by mica or by sillimanite, and although no positive statement can be made, it seems likely that the andalusite originated in a permeation-zone like that of Cooma, and that the permeation gneisses have been subsequently altered either by the introduction of igneous material or by earth movement.

Orthoclase and a little altered cordierite have been detected in a few rocks that have not been completely greisenized just as in the permeation types of Cooma.

(ii.). *Granitized Schists.*—These rocks occur near Woomargama, on the steep hill on the Tumbarumba Road, 10 miles from Jingellic, near the Orphanage at Albury, and among the xenoliths in the two-mica gneiss at Albury. They appear to represent the soaking of high-grade psammites or psammopelites with magmatic material, and seem to correspond to Tattam's schistose hornfelses (Tattam, 1929, p. 17). In some cases large grains of orthoclase have developed in the schists and have either enveloped or pushed aside the original minerals of the rock. Subidioblasts of plagioclase, however, occur more often as the indicator of this granitization process, which is comparable to the acidification processes observed in xenoliths (Nockolds, 1932). Quartz and muscovite also show evidence of having been derived from the igneous mass.

In the case of the permeation-gneisses of Cooma, the permeating magmatic material appeared to act as a vehicle bringing about changes within the rock, and there was rarely evidence of magmatic addition. In the Cooma injection-gneisses there was evidence of addition in the form of discrete *lits* or of veins. Granitization at Albury, however, is more of the nature of a mechanical permeation and is usually in the form of felspathization. The significance of this process will be referred to in connection with the origin of the Albury gneiss.

III. The Ordovician Intrusives.

1. The Sills and Sheets.

In describing the general geology of the Albury district (Joplin, 1944), it was pointed out that sills are very numerous among the Ordovician schists near Albury, and reference to the map (Plate xv) in the present paper will show that they have been mapped as a zone which is superimposed upon the higher grade metamorphic zones. In an earlier paper (Joplin, 1944, Fig. 1) a traverse along North Street shows sixteen sills of variable width in a distance of a quarter of a mile and a similar concentration of sills may be observed almost anywhere within the zone of sills. The size of the intrusions varies from the large Rocky Hill Sheet, which is about 600 feet in width, to smaller sheets of about 60 feet, down to sills of only a few inches. In these intrusions two main rock-types may be recognized. The Rocky Hill Sheet consists of an oligoclase granite, and the smaller sheets are usually composed of an aplite or microgranite in which oligoclase is a prominent constituent. The other type is a pegmatite grading on the one hand into a greisen and on the other into a schorl. One or other of these types usually constitutes a small single sill, and, as previously indicated (1944), the larger sills and sheets show sudden variations from fine aplite to coarse pegmatite, but there appears to be no regular arrangement with regard to the disposition of these types and they sometimes grade into one another. Very close examination of the sheets, however, suggests that the pegmatite is slightly later, the pegmatite veins possibly invading the sheets whilst they were still hot. Read (1931, p. 145) suggests a similar relation in the Loch Choire Complex.

In the general paper (1944) it was suggested that both the Rocky Hill granite and the Run Boundary granite occurred as Ordovician phacoliths since, where it is possible to discern their contacts, they appear to be concordant with the surrounding schists. Detailed petrographical work has confirmed this suggestion with regard to Rocky Hill, but, though sheet-like in habit, the Run Boundary granite appears to be more closely related to the younger granites, which are briefly described below (p. 119).

(*a*). *Oligoclase Granites, Microgranites and Aplites.*

This rock-type occurs in the sheets and larger sills, the Rocky Hill Sheet being the largest.

The Rocky Hill granite is invaded by pegmatite but the main mass is an oligoclase granite containing red garnet. The average grainsize is from 2–3 mm. and the fabric allotriomorphic granular, except for the garnet, which occurs in well-formed crystals which may be xenoblasts. The constituent minerals are quartz, oligoclase, orthoclase (sometimes microperthite and/or micropegmatite), biotite and muscovite with zircons as numerous inclusions in the biotite. Garnet forms small (0·5 mm. or less) idioblasts often associated with micas which occur in trails suggestive of resorbed sedimentary fragments, and partly sericitized grains of andalusite sometimes occur. Associated small areas of fine granular quartz also suggest a xenolithic origin for these minerals, although the occasional bending of micas and undulose extinction in quartz suggests that the fine patches may be due to granulation. The Rocky Hill granite shows variations from place to place and sometimes biotite is absent and the rock appears to grade into a pegmatite.

A sheet occurring on the track between Jindera Gap and Hamilton Trig. also contains red garnet, but in this case it occurs in large (2 mm.) irregular grains.

The sheet at the northern end of Eastern Hills is made up largely of oligoclase microgranite or aplite, but pegmatite-injection appears to have followed closely. This has a grainsize of about 0·75 mm. and is hypidiomorphic granular. It contains quartz and small grains of microcline and the oligoclase is idiomorphic against these. Sericitized grains of andalusite associated with trails of muscovite suggest sedimentary rafts. A somewhat similar type occurs in the large sill which has been quarried at the western end of North Street, but here the pegmatitic phase is more prominent. Obviously, these rocks are slightly contaminated, though far less so than the gneisses described below, and it is likely that the original magma contained only the ingredients of quartz, oligoclase and potash felspar.

These rocks compare in composition with the quartz-felspar injection type described and analysed by Tattam (1929, pp. 25 and 38), who refers to the occurrence of garnets in an acid leucocratic type at Kergunyah Gap (p. 24), Tawonga (p. 25), and in the Mitta Mitta Region (p. 27). A muscovite granite from Omeo is evidently of the same magma-type and is compared in Table 6. Furthermore, these rocks bear a close chemical resemblance to the albite-muscovite gneiss at Cooma (Joplin, 1942, p. 189), which was believed to represent an altered phase of the Cooma gneiss, but in view of the composition of the Albury sheets, is now considered to be a separate marginal injection of this magma-type. Reference to Table 6 will show that alumina is a little high for rocks of this silica percentage. Furthermore, alkalies are high, and although potash is

TABLE 6.

	I.	II.	III.	IV.	V.
SiO_2	72·71	73·99	72·85	76·10	73·66
Al_2O_3	17·07	16·08	15·83	15·95	17·89
Fe_2O_3	0·05	0·65	0·25	tr.	tr.
FeO	0·90		0·14		
MgO	0·29	0·31	0·17	0·11	0·09
CaO	0·14	0·09	0·51	0·23	0·27
Na_2O	3·09	3·67	3·31	2·90	2·36
K_2O	4·34	4·04	5·68	3·27	5·12
H_2O+	0·43	0·45	0·76	0·98	0·58
H_2O-	0·08	0·06	0·23	0·18	0·07
TiO_2	abs.	abs.	tr.	—	n.d.
P_2O_5	0·41	0·43	0·21	—	0·02
MnO	0·35	tr.	tr.	—	tr.
BaO	—	—	0·06	—	—
	99·86	99·77	100·00	99·72	100·06
Sp. Gr.	2·66	2·66	—	2·673	2·67

I. Garnet-bearing Oligoclase Granite. Rocky Hill, Por. 126, Par. of Mungabarina. Anal. G. A. Joplin.
II. Oligoclase-microcline Granite. Quarry near Saleyards, Eastern Hills, Por. 107, Par. of Albury. Anal. G. A. Joplin.
III. Quartz-felspar Injection Type. Tawonga. Anal. C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929: 38.
IV. Muscovite Granite. Near Hinnomunjie Morass, Omeo. Anal. A. W. Howitt. *Trans. and Proc. Roy. Soc. Vict.*, 24, 1887.
V. Albite-muscovite Gneiss. Dry Plain Road, Por. 161, Par. of Binjura. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 188.

always a little in excess of soda, they are not strikingly different, as is the case in the pegmatites (Table 7). Comparison of these two tables will show that although the silica percentage is approximately similar in both rock-types they differ with regard to alumina, magnesia and alkalies, especially with respect to potash and soda. Although closely associated in the sills and sheets the oligoclase granites, therefore, appear to represent a distinctly different magma from that which gave rise to the pegmatites, although they may be related by differentiation.

The chemical uniformity of the oligoclase granites almost precludes the possibility of much contamination, and the analyses in Table 6 probably represent a true magma-type, although it is shown below (Table 12) that with extensive contamination a certain degree of stability may be reached and a fairly uniform rock-type formed.

(*b*). *Pegmatites, Greisens and Schorls.*

The field relation of the pegmatites and oligoclase granites and aplites has already been discussed. In hand-specimen the former are either coarse and massive or may show a graphic structure which may be very coarse or extremely fine. In the coarse graphic types grains of microcline may measure over 2 inches, but in the more common finely graphic types they average about 2 mm. with the intergrown quartz units measuring about 0·5 mm. or less. Sometimes the quartz shows slight granulation or undulose extinction indicating some post-consolidation movement, but this is not a notable feature as is the case in the Cooma pegmatites. Sometimes tourmaline forms a fine graphic intergrowth with the quartz units, which are themselves intergrown with the microcline. In some rocks the microcline is partly albitized and is thus a microcline-microperthite. Reference to Table 7, Anal. IV, will show that the soda is a good deal higher and the potash correspondingly lower in the albitized type. Oligoclase and muscovite are usually present in varying amount and biotite is occasionally present.

TABLE 7.

	I.	II.	III.	IV.
SiO_2	74·26	74·71	70·91	71·94
Al_2O_3	14·87	15·51	15·32	15·71
Fe_2O_3, FeO	0·20	tr.	tr.	0·35
MgO	0·03	abs.	0·07	tr.
CaO	0·25	0·34	0·58	0·34
Na_2O	1·81	1·59	2·31	4·41
K_2O	8·39	8·11	10·07	7·58
H_2O+	0·37	0·10	0·36	0·20
H_2O-	0·07	0·03	0·15	0·01
TiO_2	abs.	n.d.	—	abs.
P_2O_5	abs.	0·10	—	0·06
MnO	abs.	abs.	—	tr.
	100·25	100·49	99·77	100·60

I. Graphic Pegmatite. Albury Common, Black Springs Creek, Pors. 43/45, Par. of Albury. Anal. G. A. Joplin.
II. Graphic Pegmatite. Soho Street, Cooma. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 188.
III. Graphic Granite. Wilson's Creek, Omeo. Anal. A. W. Howitt. *Trans. and Proc. Roy. Soc. Vict.*, 24, 1887.
IV. Albitized Graphic Pegmatite. Quarry near Saleyards. Por. 107, Par. of Albury. Anal. G. A. Joplin.

With increase in muscovite and an accompanying decrease in felspar the rocks grade into greisens—books of white mica often measuring an inch or more across. In some types the muscovite is plumose in its development and radiating masses may measure up to 3 inches. With increase in tourmaline the pegmatites grade through tourmaline pegmatites into schorls. In thin section the tourmaline is blue or brown and often zoned. In the coarser types of schorl or pegmatite the tourmaline crystals measure over 2 inches in length. Small veins of almost pure tourmaline frequently cut the two-mica gneiss and these may be seen very well on the Howlong Road between the west end of Smollett Street and the West Albury Post Office.

2. THE CONTAMINATED GNEISSES.

Reference to the map (Plate xv) will show that gneisses occur within the town of Albury beneath Monument Hill, on the shore of the northern arm of the Hume Reservoir, near Woomargama, and north of Jingellic about 10 miles along the Tumbarumba Road.

All these gneisses are contaminated with sedimentary material and among them two types are recognized—one characteristically containing cordierite, the other a more acid type particularly rich in mica. The latter bears a close resemblance to the Cooma gneiss.

(*a*). *Cordierite-bearing Gneisses.*

This type is developed along the northern and western shore of the Bowna Arm of the Hume Reservoir and large remnants of it occur in a younger granite which has been quarried for the construction of the dam wall. Fresh material from this quarry has been briefly described in an earlier paper (Joplin, 1944), where it was pointed out that it bore such a close resemblance to the Bethanga gneiss of Victoria, described by Tattam, that it seemed desirable to use the same name.

Further, in this earlier paper it was suggested that the gneiss developed on the western shore of the reservoir north of the quarry was possibly another type. Though deeply weathered, it appeared to be non-porphyritic, to contain no garnets and often to show *lit-par-lit* injection. In view of this uncertainty it was tentatively named the Bowna gneiss. Since examining a still more northerly mass, however, it seems fairly evident that it is a local phase of the cordierite-bearing gneiss, though the weathering prevents the recognition of some of the characteristic minerals.

Both field and microscopic studies point to the contamination of the cordierite-bearing gneiss, and before proceeding to a description of the gneiss, it is desirable first to examine the xenoliths which are very numerous and are no doubt responsible for the contamination.

i. *The Xenoliths.*

Xenoliths of all sizes and degrees of resorption occur within the cordierite-bearing gneiss. They are best studied in the quarry, Por. 65, Parish of Thurgona, where two main types may be recognized—a basic granulite and an aluminous pelite. The former usually forms the larger inclusions and may measure up to 2 feet across. The smaller pelitic xenoliths are by far the most numerous and the most modified. They show considerable resorption and variation in size and are often represented only by tiny wisps, a single microsection often containing several in different stages of resorption. The pelites also show differences of composition, there being present silica-rich and silica-poor types.

(*a*). *Granulites.*—The granulites present evidence of strong thermal metamorphism, but there is little evidence of assimilation—a fact noted with regard to the basic granulites at Cooma (Joplin, 1942), where reference was made to similar observations by Read (1927). Three types of granulite have been recognized and these are frequently interbedded. A pyroxene-bearing type possibly represents a basic igneous rock—a basalt or dolerite (see Table 4, Anal. I); a garnet-bearing type may represent an admixture of sedimentary and basic igneous material and is possibly tuffaceous; and a plagioclase-biotite assemblage appears to be a related type still richer in the sedimentary material (see Fig. 2).

The pyroxene granulites are dense, granular rocks varying from dark purplish-grey to a greenish colour according to the presence or absence of biotite. Under the microscope these rocks are often seen to be blastoporphyritic in plagioclase, large (3 mm.), recrystallized grains of labradorite ($Ab_{35}An_{65}$) occurring in a granoblastic groundmass of labradorite, diopside, biotite, magnetite, apatite and quartz (Fig. 2, A). The original felspar phenocrysts show nibbled margins, complicated interpenetration twinning and irregular inclusions of quartz. Sometimes the felspar shows alteration to white mica. Reference to Table 4 will show that this rock compares with rocks of the Porphyritic Central Magma Type (Bailey and Thomas, 1924) which is characterized by the development of plagioclase phenocrysts.

The plagioclase of the groundmass is not well twinned and often occurs in irregular grains (0·15–0·6 mm.) intergrown with diopside, biotite and quartz. Quartz grains are sporadic in their distribution and those occurring as inclusions in the larger felspars are comparable in size with those of the groundmass.

A type without biotite is much richer in quartz, suggesting an admixture of psammitic material. Diopside is usually fresh, but in certain banded types, alteration to an amphibole occurs and seems to mark the first stage in the disintegration of the xenolith. In certain types the quartz and felspar show slight elongation and the schistosity is further emphasized by the amphibolization of the pyroxene, some of which may have developed prior to assimilation. In some types sphene is abundant, especially in the case of biotite-poor varieties, thus suggesting the entrance of titania into the biotite-molecule.

The most common type of granulite is a garnet-plagioclase-biotite-quartz assemblage (Fig. 2, B), but a good deal of variation is shown in the relative abundance of these four

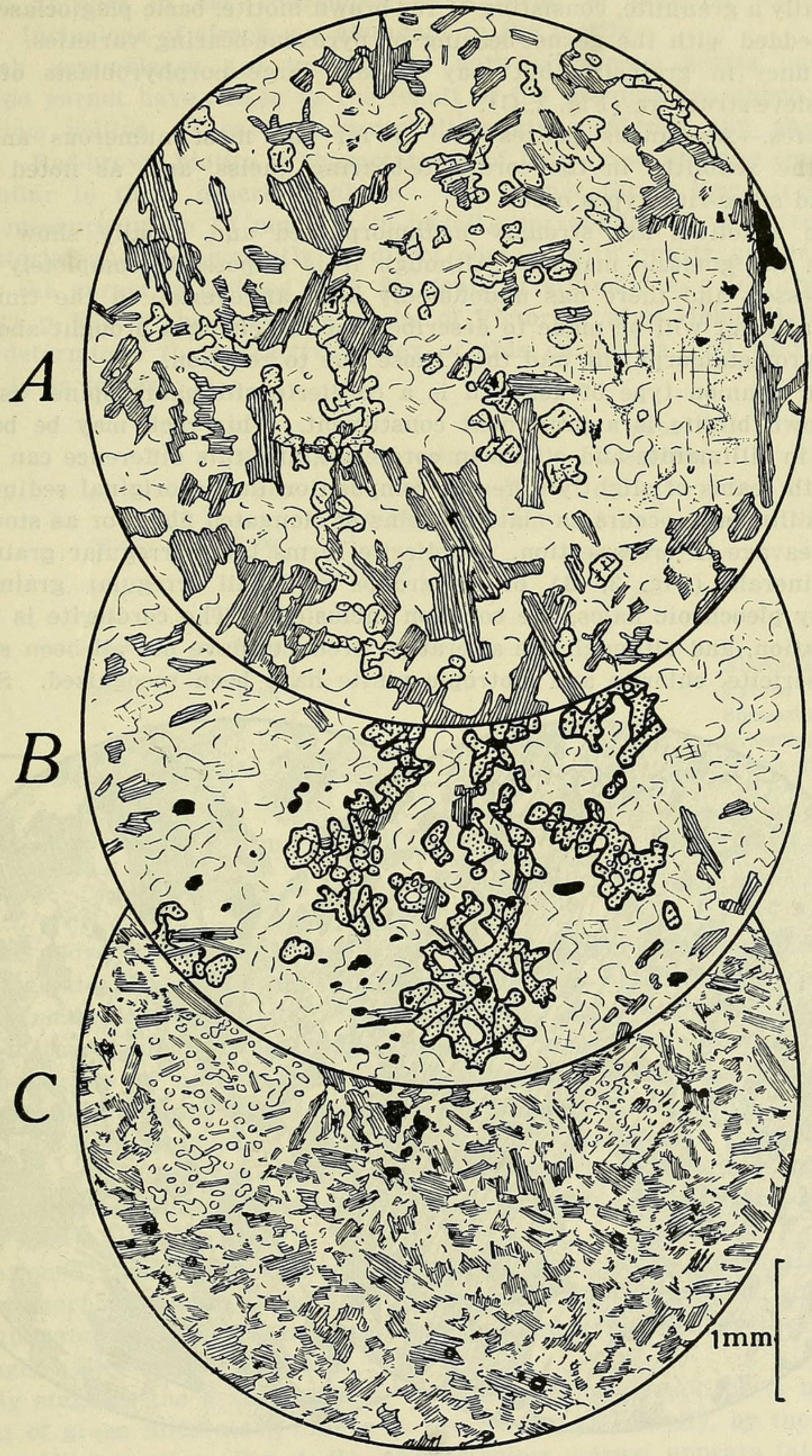

Fig. 2.—Granulite xenoliths.

A. Granulite showing blastoporphyritic structure; a large crystal of labradorite, on the right, is surrounded by a granoblastic groundmass of diopside, biotite, plagioclase and quartz. × 16.

B. Granulite consisting of a granoblastic mass of garnet, plagioclase, biotite, quartz and magnetite. × 16.

C. Granulite showing large porphyroblasts of plagioclase with a sieve-structure in a granoblastic mass of biotite, plagioclase and quartz. × 16.

constituents. Magnetite is usually a minor accessory, but may be fairly abundant in some types. Red garnet forms irregular poikiloblasts and sometimes shows alteration into chlorite. This alteration is particularly common in banded types that also show alteration of pyroxene to amphibole and may thus evidence either dynamic metamorphism or reaction.

Occasionally a granulite, consisting of red-brown biotite, basic plagioclase and quartz, occurs interbedded with the garnet-bearing or pyroxene-bearing varieties. These rocks are usually finer in grainsize, but may contain large porphyroblasts of plagioclase exhibiting a sieve-structure (Fig. 2, C).

(*b*). *Pelites*.—Aluminous pelites are by far the most numerous and the most modified of the xenoliths in the cordierite-bearing gneiss, and, as noted above, both silica-poor and silica-rich types occur.

All these xenoliths are strongly metamorphosed and usually show evidence of reaction with the gneissic magma. Although it is impossible completely to separate the two processes, and there has undoubtedly been an overlap in the time that each occurred, an attempt will be made to describe first the changes brought about solely by thermal or pyrometamorphism, and then those due to reaction.

The most common type of xenolith is a cordierite-sillimanite-spinel assemblage in which red-brown biotite is a prominent constituent. This rock may be banded, some seams richer in sillimanite and others in cordierite, and this difference can no doubt be correlated with seams of slightly different composition in the original sediment (Fig. 3, A, B). The sillimanite occurs as matted skeins of elongated fibres or as stout rods with a diagonal cleavage in cross-section. Cordierite forms large irregular grains enclosing the other minerals (Fig. 3, B) or as groups of small irregular grains. Zircons, surrounded by pleochroic halos, are common inclusions. The cordierite is very susceptible to alteration, and although the alteration products have not all been satisfactorily determined, sericite, chlorite and isotropic pinite have been recognized. Spinel forms

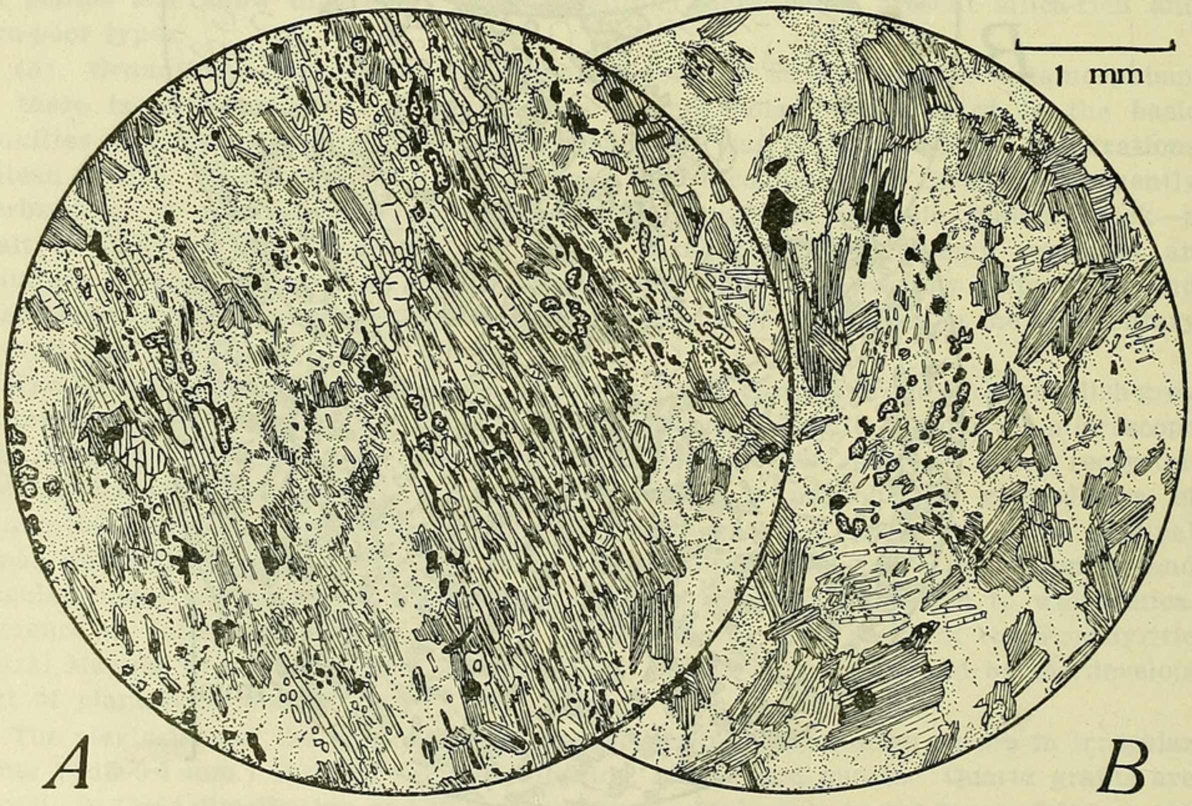

Fig. 3.

A. Banded hornfels xenolith showing seams of sillimanite-spinel-biotite-magnetite and cordierite-sillimanite-spinel-biotite-magnetite assemblages. Note partial alteration of cordierite. × 16.

B. Xenolith showing large crystals of cordierite enclosing spinel, sillimanite, biotite and magnetite. Smaller grains of cordierite, partly altered, also occur. At the top of the figure the contaminated gneiss consisting of quartz, biotite and altered cordierite, is adjacent to the xenolith which is fringed by larger flakes of biotite. × 16.

clusters of small octahedral crystals or minute irregular grains which vary in colour from light to dark green or to purplish-brown. They are usually associated with aggregates of magnetite granules and sometimes mantle the iron ore. Biotite, evidently rich in the haughtonite-molecule, occurs in small irregular flakes within the cordierite or is intergrown with the sillimanite. Sometimes it forms large flakes surrounding the xenolith and appears to have developed as a result of reaction with the magma (Fig. 3, B). Inclusions of zircon are abundant in the biotite.

Silica-rich assemblages are interbedded with silica-poor seams and two types containing red garnet have arisen as the result of the pyrometamorphism of the silica-rich aluminous pelites. These are garnet-sillimanite-cordierite and garnet-cordierite assemblages. Red-brown biotite is characteristic of both types and the cordierite shows features similar to those described above. The garnet forms large irregular grains which may measure up to 10 mm. It is usually surrounded by a narrow margin of chloritic material and is frequently in direct contact with quartz grains (Fig. 4, A). Occasionally the garnet is clouded with filaments of sillimanite, a feature observed by Tattam (1929, p. 28) in the Bethanga gneiss of Victoria. Miss Helen McRoberts, B.Sc., has kindly determined the refractive index of this garnet as 1·80, and the chemical composition is as follows:

		Metal Atoms on basis of 12 O.			Ideal Composition.
SiO_2	37·30	2·94		3·00	3
Al_2O_3	22·55	2·09	0·06 / 2·03	2·03	2
TiO_2	tr.	—			
Fe_2O_3	3·07	0·18			
FeO	27·78	1·83			
MgO	4·91	0·58		2·87	3
MnO	2·79	0·18			
CaO	1·15	0·10			
	99·55				

Sp. Gr. = 4·085
n. = 1·80

Almandine	67·73
Pyrope	16·48
Spessartine	6·41
Grossular	3·15
Sillimanite	5·75
	99·52

From the above calculation it would seem that the whole of the ferric iron enters the group of divalent elements, and Alderman (1935) has noted that this substitution is common in almandine-rich garnets. The calculation further shows that the analysis is a little low in the divalent elements, and this would in part account for the presence of the large proportion of normative sillimanite, though it was noted that this mineral was often present as minute inclusions in the garnet, and it is possible that the analysed sample had not been completely freed from them. Reference to Alderman's diagram (1936, Fig. 3) will show that this garnet, rich in the almandine and spessartine molecules, falls within the composition field of the garnets characteristic of sedimentary schists.

As mentioned above, it is difficult to dissociate completely the effects produced by thermal metamorphism from those due to reaction with the magma, and matters are further complicated by changes that may have been superimposed by the later invasion of the younger (Hawkesview) granite.

An early stage in the assimilation of the garnetiferous xenoliths is marked by the development of green mica along cracks in the garnet, and finally, by the separation of minute magnetite granules (Fig. 4, B). Nevertheless, garnet appears fairly stable and other minerals associated with it in the hornfels-stage disappear first, isolating the large irregular garnets which thus appear to be the products of crystallization from a contaminated magma. In handspecimen the cordierite-bearing gneiss exhibits patches of red garnet up to half an inch in diameter, and their origin is attributed to this cause. The red-brown biotite of the original hornfels becomes bleached or chloritized during assimilation and there is a concomitant separation of rutile needles in the form of a sagenite-web. The cordierite is completely broken down into chlorite, sericite and pinite (Fig. 4, B).

The silica-poor xenoliths show a more marked reaction with the magma. Again, the cordierite becomes changed into chlorite, sericite and pinite, and this change appears to have taken place long before the sericitization of the sillimanite, unaltered sillimanite

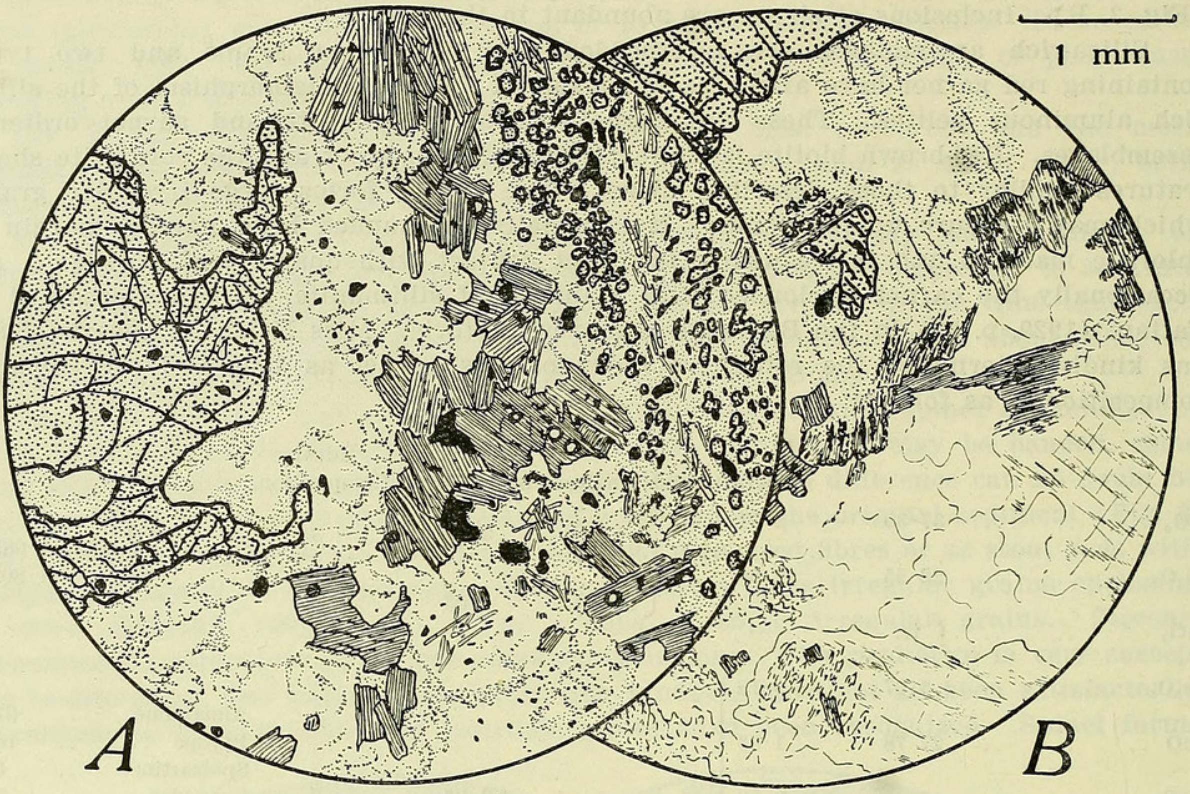

Fig. 4.

A. Banded xenolith showing seams of silica-poor and silica-free hornfels. A large irregular grain of garnet, bordered by chlorite and intimately associated with quartz, occurs in a cordierite-biotite assemblage and this adjoins a type consisting of spinel, sillimanite and altered cordierite. × 16.

B. Xenolith of garnet-cordierite-biotite hornfels showing reaction with enclosing magma. The small mass of garnet, just above the centre of the figure, shows alteration into chlorite and magnetite granules, cordierite is sericitized and chloritized and biotite is chloritized and bleached. In the lower part of the figure the gneiss, consisting of orthoclase and quartz, shows chloritization and sericitization of the felspar. × 16.

occurring with spinel, biotite and magnetite in a base of sericite and chlorite (Fig. 5, B). Large flakes of muscovite may develop within the xenolith and these seem to be a product of interaction between xenolith and magma rather than one of magmatic crystallization (Fig. 5, A). Schistosity and plications are often preserved within the xenolith even after much reaction has taken place. Spinel is very stable and often occurs as small granules in wisps of chlorite and sericite that mark the position of an almost completely resorbed fragment. The final product of reaction is a criss-cross mass of mica in which muscovite is the most important constituent.

Spinel-bearing xenoliths are not uncommon in basic igneous rocks (Read, 1932), but it is very unusual for them to occur in a rock so acid as the cordierite-bearing gneiss (Table 8, Anal. I). Moreover, their development is even more puzzling in that there is no evidence of silica-poor types among the original sediments, unless such occur as restricted bands among the normal pelites. Tattam (1929) refers to the occurrence of spinel in the "clots" of the Bethanga gneiss of Victoria, but makes no attempt to explain the anomaly. This matter is discussed further, below, where some attempt is made to account for the genesis of this assemblage.

ii. *The Gneisses.*

In handspecimen the cordierite-bearing gneiss is a porphyritic rock with the phenocrysts varying both in size and concentration. Large clusters of red garnet up

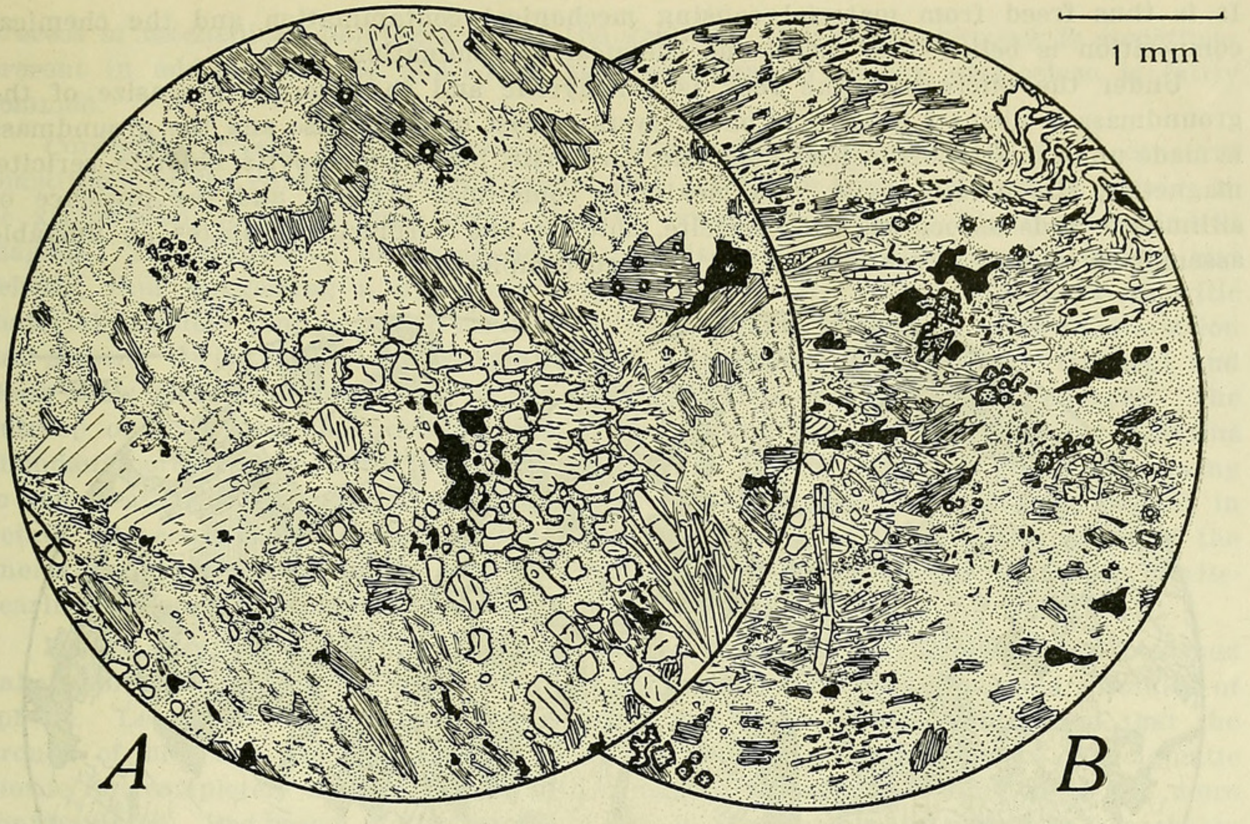

Fig. 5.

A. Cordierite-sillimanite-biotite-spinal xenolith showing alteration of cordierite and development of large flakes of muscovite. Spinel is not well represented in this field, but is more abundant elsewhere in the slide. × 16.

B. Later stage in the resorption of the same xenolith. Plication of original schist is visible in NE. quadrant where sillimanite occurs in the fold axes. Sillimanite, spinel, magnetite and biotite occur in a mass of chlorite and sericite which represents altered cordierite. The remains of a little fresh cordierite are seen near the top of the figure and pleochroic halos about zircon inclusions are visible. × 16.

to half an inch across are common and the rock is crowded with xenoliths of all sizes and in all stages of disintegration. The lighter part of the gneiss has a slightly greasy greenish appearance which is no doubt due to the presence of cordierite. This mineral may be in part xenocrystal, but the greater part of it appears to be pyrogenic and to have crystallized from the contaminated magma. Although the gneiss has a fairly uniform mineral constitution, it shows a great deal of variation both in grainsize and in the relative proportions of the minerals present. This is to be expected in a highly-contaminated rock in which xenoliths of different composition are present in various stages of assimilation. Nevertheless, a type showing some degree of uniformity is regarded as a close approach to the end-product of assimilation, and this type may be called a cordierite-bearing gneiss.

In the immediate vicinity of the pelitic xenoliths heavy chloritization and greisenization of the orthoclase, and sometimes of the less abundant plagioclase, is apparent. The biotite is chloritized and bleached with separation of rutile in the form of a sagenite-web (Fig. 6, A). The altered cordierite associated with this contaminated phase is probably xenocrystal and represents fragments wedged off from the xenolith.

Another highly-contaminated type, usually in juxtaposition to a xenolith of aluminous pelite, consists largely of fairly fresh cordierite, large flakes of red-brown biotite, red garnet (sometimes containing mats of sillimanite needles) quartz, usually orthoclase and a certain amount of chlorite.

The two types referred to above are obviously highly contaminated and bear no resemblance to an igneous rock, but the cordierite-bearing gneiss described below is essentially igneous, and although not a true representative of the original magma, it is the closest approximation that could be obtained, and the analysis given in Table 8 represents a rock from which all macroscopic xenoliths and garnets have been removed.

It is thus freed from material causing mechanical contamination and the chemical composition is believed to reflect the chemical contamination.

Under the microscope the rock is porphyritic and the average grainsize of the groundmass is about 2 mm. The phenocrysts consist of orthoclase and the groundmass is made up of quartz, orthoclase, andesine, cordierite, biotite, muscovite, chlorite, sericite, magnetite, zircon and rutile. Myrmekite is sometimes present, and the presence of sillimanite rods associated with sericite, chlorite and cordierite indicates an unstable assemblage in which reaction has not reached completion.

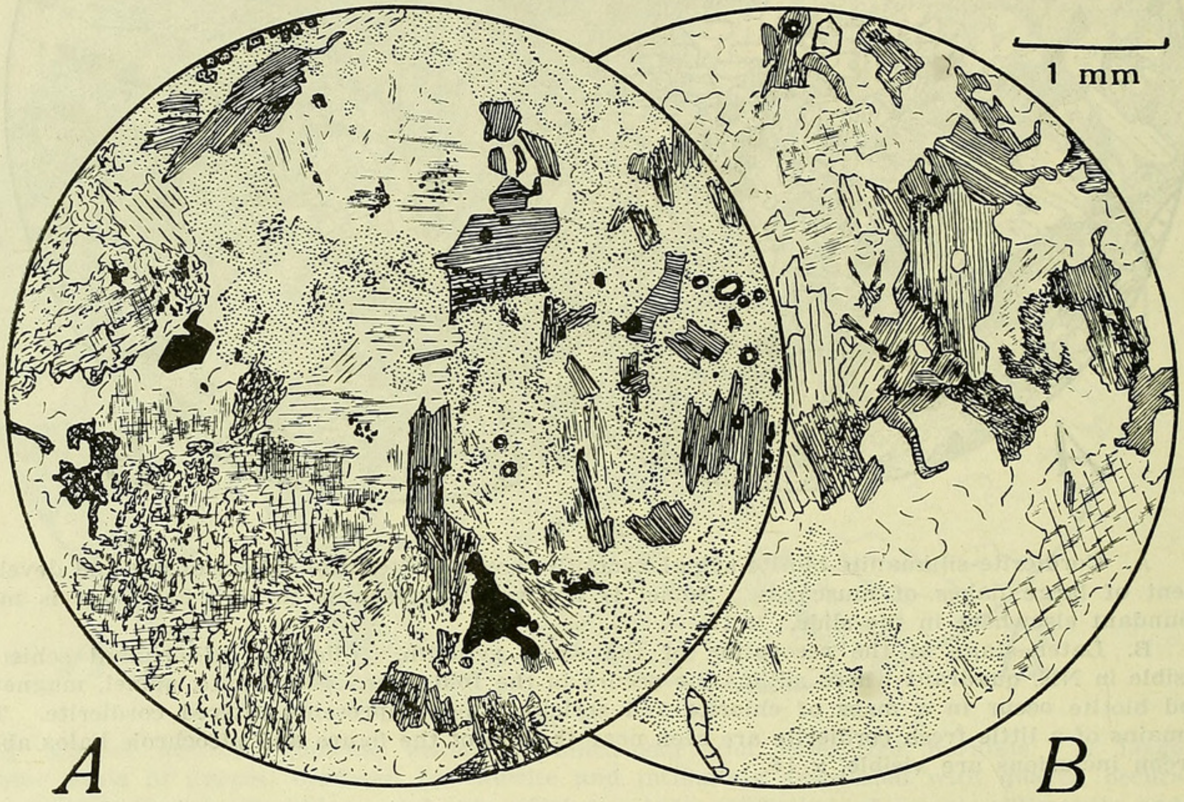

Fig. 6.

A. A highly-contaminated gneiss at margin of xenolith. A small cluster of spinel granules, near the top of the figure, is embedded in altered cordierite, marking the remains of a xenolith which extends down the right side of the figure. It consists mainly of altered cordierite, with pleochroic halos, and biotite. A little fresh cordierite is present in the NE. quadrant. At the margin of the xenolith, orthoclase is both chloritized and sericitized, plagioclase is unaffected and biotite is bleached with a separation of rutile needles. × 16.

B. Contaminated gneiss consisting of quartz, plagioclase, orthoclase, muscovite, biotite (partly altered), subidiomorphic pyrogenic cordierite (completely altered), apatite and zircon. × 16.

Part of the crystallization of the orthoclase phenocrysts appears to have been contemporaneous with that of the groundmass minerals, for there is an interlocking of the mineral grains about the margins of the phenocrysts. Some phenocrysts, containing numerous rounded grains of quartz and small flakes of red-brown biotite, suggest that the felspar has wedged apart and enveloped a granulite xenolith. Sometimes a fan-shaped mass (3 mm. in length) of sillimanite represents the envelopment of an aluminous pelite xenolith. Orthoclase also occurs as irregular grains in the groundmass where it is usually interlocked with quartz, andesine and cordierite. Marginal incursions of myrmekite are common and very small areas of graphically intergrown quartz sometimes occur. The orthoclase often shows alteration into sericite and kaolin and is occasionally almost completely pseudomorphed by these minerals.

Quartz is abundant and forms large irregular grains often acting as wedges in the mechanical disintegration of the xenoliths (Nockolds, 1933). Small quartz grains occurring as inclusions suggest a sedimentary origin.

Andesine ($Ab_{62}An_{38}$) usually forms irregular grains intergrown with the other minerals of the groundmass, but may form large grains which help further in the process of mechanical disintegration of the xenolith. Periclase twinning is sometimes present in addition to the albite-type and sericitization of the plagioclase is fairly common.

Cordierite, fresh, partly altered, or completely pseudomorphed, is a constant constituent of the cordierite-bearing gneiss, and though in some instances it appears to be xenocrystal, it seems more often to have crystallized from a highly-contaminated magma. The cordierite, or its pseudomorphs, is subidiomorphic against quartz and felspar, thus suggesting a pyrogenic origin (Fig. 6, B). Alteration to a chloritic material, possibly pinite, and to sericite is common, and when both types of alteration are present, sericitization follows pinitization. Inclusions of zircon are frequent and these show pleochroic halos both in the fresh cordierite and in its pseudomorphs. The outcrop of gneiss on the northern end of the Bowna Arm of the reservoir contains abundant cordierite showing alteration into bright orange, isotropic pinite, but owing to the weathering of most of these rocks, their petrography has not been studied in detail. It seems certain, however, that they represent a northern continuation of the gneiss examined at the quarry and they can certainly be grouped with the cordierite-bearing gneisses, though their cordierite is usually xenocrystal.

Biotite occurs in red-brown flakes as well as in masses of chloritized and bleached flakes containing a sagenite-web of rutile needles and sometimes elongated granules of sphene. Lenses of chlorite are very common and there is some suggestion that the groups of bleached flakes represent an earlier unstable crystallization of magmatic biotite not completely in equilibrium with a magma which is becoming more and more contaminated. Red-brown biotite, probably rich in the haughtonite-molecule, is probably a stable crystallization from the contaminated magma. This point, however, is still open to doubt as the red biotite occasionally appears to be breaking down in the same way. Nevertheless, this alteration may belong to a much later period when the cordierite-bearing gneiss was engulfed by the Hawksview granite. Zircon inclusions with their characteristic pleochroic halos are always present.

Muscovite occurs as independent flakes up to about 1·5 mm., and is sometimes in parallel intergrowth with biotite. It also occurs in radiating tufts in masses of sericite which is the alteration product of felspar and cordierite.

Apatite is sporadic in its occurrence and may be quite abundant, forming crystals up to 0·5 mm. across.

TABLE 8.

	I.	II.	III.	IV.
SiO_2	66·94	66·68	67·41	66·80
Al_2O_3	16·65	16·50	15·76	15·80
Fe_2O_3	0·40	2·41	1·93	1·62
FeO	4·77	1·93	1·96	3·63
MgO	2·19	1·44	1·43	2·25
CaO	0·94	3·51	3·54	0·47
Na_2O	2·11	4·03	3·45	1·00
K_2O	3·56	2·71	3·76	5·02
H_2O+	2·13	—	—	2·10
H_2O-	0·12	—	—	0·34
TiO_2	0·60	0·58	0·51	0·69
P_2O_5	0·01	0·15	0·19	0·66
MnO	0·06	0·06	0·06	0·08
Etc.	—	—	—	0·14
	100·48	100·00	100·00	100·60

I. Cordierite-bearing Gneiss. Weir Quarry, Por. 65, Par. of Thurgona. Anal. G. A. Joplin.
II. Average Dacite (90 analyses). R. A. Daly, Igneous Rocks and the Depths of the Earth, p. 457.
III. Average Quartz Monzonite (20 analyses). Ibid.
IV. Felspathic Pinite-gneiss (contaminated Granitic Gneiss). Ensay. Anal. C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929: 38.

The analysis of the cordierite-bearing gneiss shows it to be an intermediate rock, but the excess of magnesia over lime and of potash over soda indicates that it is not a normal type and has arisen as the result of magmatic contamination, magnesia and potash having been derived from the xenolithic material.

In Table 8 the analysis of the cordierite-bearing gneiss is compared with the average analyses of two common normal igneous rocks, both members of the grano-diorite clan, and having a silica percentage similar to that of the gneiss. In Table 9 the norms of these three analyses are compared, and the greater amount of corundum and of hypersthene in the gneiss bears striking testimony to the fact that cordierite is present in the mode. In the normal, uncontaminated rocks the higher lime and soda are further responsible for the lower corundum as these combine with the alumina to give the greater amounts of anorthite and albite, respectively.

TABLE 9.

	I.	II.	III.
Quartz	32·22	23·22	23·22
Orthoclase	21·13	16·12	22·24
Albite	17·82	34·06	28·82
Anorthite	4·73	16·68	16·68
Corundum	7·65	0·82	—
Hypersthene	12·89	5·81	4·95
Magnetite	0·70	3·48	2·78
Ilmenite	1·22	1·22	0·91
Apatite	—	0·34	0·34

iii. *The Contamination Process.*

Obviously the magma has been contaminated by the addition of magnesia, alumina and potash. The addition of magnesia finds mineralogical expression in the chloritization of felspars and of biotite and in the development of pyrogenic cordierite. According to Tilley (1940), the idiomorphic outline of the cordierite in the pegmatites from the moraines of Cape Denison, Antarctica, indicates that it has crystallized from a contaminated magma, and is not xenocrystal material; and a similar origin is suggested by the subidiomorphic development of the cordierite in the cordierite-bearing gneiss. The cordierite of the cordierite-aplite and pegmatite of Broken Hill (Browne, 1922) is also believed to be pyrogenic. The altered cordierite in the gneiss on the northern shore of the reservoir in the Parish of Bowna is, however, probably xenocrystal and the contamination process purely a mechanical one.

In the cordierite-bearing gneiss of the quarry the orthoclase forms phenocrysts and these often show chloritization as a result of reaction with the xenoliths, so it seems likely that this felspar had started to crystallize before the liquid fraction had been much affected by contamination.

It is reasonable to assume that both granulite and pelite xenoliths have played their part in the contamination process. Although the latter xenoliths are smaller and appear to be more numerous, this might be explained by the fact that the granulites were more readily assimilated and the larger, comparatively unaltered masses now present are those that were caught up by the magma during the late stages of its crystallization after reaction had ceased. The pelites on the other hand represent the small fragments that the magma was unable to digest after a good deal of reaction and mechanical disintegration had taken place.

Bowen (1922) and Nockolds (1933) have shown that if a xenolith contains minerals that represent phases lower in the reaction series than those with which the magma is in equilibrium, then they tend to become part of the magma by precipitating phases with which it is saturated. This process also assists in the mechanical disintegration of the xenolith.

It has been shown that the granulites consist usually of labradorite, diopside, biotite, quartz, magnetite and apatite. Biotite and quartz would probably be lower in the reaction series than the minerals being precipitated by the magma, whilst the plagioclase and diopside would readily react with it to give a more acid plagioclase and a greater quantity of biotite, thus enriching the magma in lime and magnesia. These reaction processes would have been accelerated by the disintegration of the xenolith owing to the melting out of the low-phase constituents, quartz and biotite; the effect is thus twofold.

In the case of the pelitic xenoliths, the process would have been again both mechanical and chemical, but as the composition of these rocks is so much further removed from that of an igneous magma, it is not surprising to find them a little less digestible. Thus the magma was not always able to deal with the large quantities of alumina introduced, and though much sericitization of sillimanite has taken place, some still remains unaltered in the incompletely resorbed xenoliths.

Table 10 shows the analysis of a spinel-bearing xenolith where it is compared with xenoliths and contact rocks from other parts of the Victorian Complex and with the average analysis of eleven normal pelites—the sedimentary type from which it was

TABLE 10.

	I.	II.	III.	IV.	V.
SiO_2	52·36	54·22	55·94	58·87	56·07
Al_2O_3	25·81	21·01	23·39	16·95	23·65
Fe_2O_3	1·78	1·79	0·45	8·62 }	6·79
FeO	7·03	5·61	4·69	3·93 }	
MgO	3·41	2·43	3·58	2·32	2·83
CaO	1·49	0·49	0·81	0·97	0·39
Na_2O	1·15	1·75	1·45	1·48	0·68
K_2O	4·11	7·41	6·98	5·98	5·90
H_2O+	0·99	2·46	3·17	— }	2·79
H_2O-	0·39	0·36	0·43	— }	
TiO_2	1·38	1·78	—	—	0·72
P_2O_5	tr.	0·31	0·10	—	0·13
MnO	n.d.	0·14	—	—	0·05
	99·90	99·76	100·99	99·12	100·00

I. Sillimanite-cordierite-spinel Xenolith in Bethanga Gneiss. Hume Reservoir Quarry, Por. 65, Par. of Thurgona. Anal. G. A. Joplin.
II. Micaceous Xenolith in Granite. Mt. Wagra. Anal. C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929 : 35.
III. Metamorphic Gneiss. Little River, Ensay. Anal. A. W. Howitt. *Proc. Roy. Soc. Vict.*, 22, 1886 : 75.
IV. Mica-schist. Hinnunjii Morass, Omeo. Ibid., 24 : 107. Anal. A. W. Howitt.
V. Average Normal Pelite (11 analyses). See Table 1. As the ratio of FeO/Fe_2O_3 varies with the degree of metamorphism, total ferric oxide is given in the average.

possibly derived. The xenolith has undoubtedly been influenced by reaction with the magma and is not solely the product of pyrometamorphism. As iron oxides, alumina and magnesia are higher in the xenolith than in the average pelite, there appears to have been some selective reaction and a storing up of these constituents within the xenolith. This may be accounted for by assuming that certain minerals lower in the reaction series than those being precipitated by the magma were dissolved out, thereby enriching the xenolith in phases higher in the reaction series and not so readily assimilated by the magma.

The knotted schists of the andalusite-zone at Cooma (Joplin, 1942) were believed to have formed as a contact-zone about the Cooma gneiss, and the knotted schists of the Albury region probably bear a similar relation to the igneous material. Thus it cannot be assumed that the knotted schists were already formed and completely stable at the time of their immersion by the magma, but it is not unreasonable to assume that some segregation of chlorite and of iron ores had already taken place as the magma worked its way up beneath the sediments and subjected them to a gradually increasing temperature. Such an early spotting is a common feature of normal contact-zones and may take place well outside the hornfels zone at some distance from the igneous body. Such clots of chlorite (probably with some sericite) were undoubtedly surrounded by a base very similar in composition to the aggregate surrounding the "knots" of the more highly-developed knotted schists and referred to by Tattam (1929) as a two-mica base. It has already been stated that the psammopelite is the most common type of sediment in this district, and these rocks contain varying amounts of quartz associated with the micas of the base. Thus the base of these rocks, at the time of the invasion of the granite, probably consisted of quartz, sericite and a little chlorite. These minerals being low in the reaction-series would dissolve in the magma (Type I, Nockolds, 1933), leaving the incipient knots or any chlorite-rich bands that might have been present in the psammopelite. Subsequently these solid bodies, rich in alumina, magnesia and iron oxides, were altered by pyrometamorphism to give cordierite-spinel-sillimanite assemblages (see Equations, p. 112).

Reference to Table 10 suggests that the xenolith has gained soda and lime from the magma and has probably contributed potash. Although the analysis of the xenolith shows high alumina and magnesia there is little doubt that small quantities of both have been added to the magma, this being masked by the storing up of these constituents within the xenolith. Most of the magnesia and alumina added to the magma, however, would have been derived from the lower phase minerals of the base.

The more siliceous types of psammopelite suffered a similar disintegration by the solution of the low-grade minerals, but in this case there was sufficient silica present in the incipient spots to give rise to garnet under the appropriate conditions of pyrometamorphism.

Thus both granulites and pelites have contributed towards the contamination of the magma. This has been brought about first by a solution of the lower phase minerals and an accompanying mechanical disintegration and segregation of the constituents of higher melting-point and later by reciprocal reaction between the magma and undissolved xenoliths, the latter in the meantime having been subjected to pyrometamorphism.

The chemical effects of the contamination process may be represented diagrammatically thus:

$$\text{Granulite} \begin{array}{c} \nearrow CaO + Al_2O_3 + MgO \searrow \\ \nwarrow K_2O + Na_2O + SiO_2 \swarrow \end{array} \text{Magma} \qquad \text{Pelite} \begin{array}{c} \nearrow K_2O + Al_2O_3 + MgO \searrow \\ \nwarrow Na_2O + CaO \swarrow \end{array} \text{Magma}$$

iv. *Chemical Discussion.*

Apart from the two contaminated gneisses at present under discussion the only other Ordovician igneous rocks of this area are the oligoclase granites and the pegmatites described above. Of these the first are the more abundant, and form the larger sills, so it is not unreasonable to assume that it was a magma of this type which became contaminated to form the cordierite-bearing gneiss.

Although the calculation of a theoretical analysis is highly speculative, there is good evidence to show that contamination has taken place and that both basic granulites and pelites have played their part in bringing it about. Reference to Table 6 will show that the oligoclase granites, which possibly represent the parent magma, contain much less lime than the cordierite-bearing gneiss (Table 8), and to calculate a theoretical rock of this composition, it is necessary to add both granulite and pelite as presupposed in the above discussion and supported by the petrographical evidence. This could have been done in a single step, as was probably the case in nature, but to facilitate calculation and to explain each step of the process, two parts of oligoclase granite are first mixed with one part of the granulite and then two parts of this mixture are added to one part of the base of the pelite. This means that four parts of magma react with three parts of country-rock, and it is thus necessary to postulate a large underlying magma chamber, the present surface exposures representing only the roof. Unfortunately the writer has not analysed the mica-quartz base of the psammopelites which are so common in the Albury district; and the calculation has therefore been made on Tattam's analysis of a two-mica base, a type evidently free from quartz, and this has been re-calculated after adding sufficient silica to make it comparable with that of the cordierite-bearing gneiss (Table 11). Thus the actual amount of silica has been assumed, but the resultant analysis (VI) when compared with the actual analysis of the gneiss (VII) shows a fairly close parallelism, and though oxides are not identical in the two analyses, they are of the right order, and better results might easily have been obtained from other analyses of the same rock-types as these show small variations among themselves as the tables throughout this communication tend to show.

TABLE 11.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2 ..	73·99	52·23	67·09	48·80	57·94	66·94	66·94
Al_2O_3	16·08	22·16	18·20	25·20	21·70	18·06	16·65
Fe_2O_3	0·65	0·72	3·84	4·00	6·25	5·20	0·40
FeO ..	—	8·50	—	4·20	—	—	4·77
MgO	0·31	4·75	1·80	3·82	2·80	2·32	2·19
CaO ..	0·09	7·29	2·50	0·45	1·32	1·09	0·94
Na_2O	3·67	0·43	2·60	0·96	1·78	1·48	2·11
K_2O ..	4·04	1·70	3·28	6·75	5·01	4·17	3·56
H_2O ..	0·51	0·74	—	4·78	—	—	2·25
TiO_2	abs.	0·76	0·25	1·16	0·72	0·59	0·60
P_2O_5 ..	0·43	0·46	0·44	—	0·15	0·12	0·01
MnO ..	tr.	0·11	—	0·09	0·03	0·03	0·06
	99·77	99·85	100·00	100·21	97·70	100·00	100·48

I. Oligoclase-microcline Granite. See Table 6.
II. Pyroxene-granulite. See Table 4.
III. Calculated analysis consisting of two parts of I and one part of II.
IV. Two-mica base, Knotted Schist. Anal. C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929 : 35.
V. Calculated analysis consisting of two parts of III and one part of IV.
VI. Analysis V re-calculated as explained in text.
VII. The Cordierite-bearing Gneiss. See Table 8.

v. *Mineral Transformations.*

In the above discussion on the contamination of the gneiss, it was suggested that the silica-poor assemblages arose either from spots representing the incipient knots of the knotted schists or from very restricted chlorite-rich bands in the psammopelites.

Before pyrometamorphism occurred, therefore, it must be assumed that such spots or seams have been isolated from their more siliceous lower melting-point base by solution in the magma. The solid, insoluble material has been strewn about in the magma, therefore, to form the minute silica-poor xenoliths which are not very apparent in handspecimen but which appear so numerous under the microscope.

Mineral transformations due to pyrometamorphism, or very high-grade thermal metamorphism due to immersion, will first be considered with regard to the pelitic xenoliths and then reaction changes will be dealt with. As no very noteworthy changes take place during the pyrometamorphism and subsequent assimilation of the basic granulites, these will not be considered.

(*a*). *Pyrometamorphism.*—At the time of immersion, the incipient spots in the schists probably consisted mainly of chlorite, iron ores and sericite, and the commonest high-grade assemblage consists of cordierite, sillimanite, iron-rich biotite and spinel.

It is probable that a very small quantity of quartz remained in the "knot" after its immersion and this would have been used in converting chlorite and sericite into cordierite, sillimanite and biotite. Unfortunately the chemical composition of this chlorite is unknown, but as the analyses of a number of pelites are available, it is assumed that it contained both magnesia and alumina, probably with a greater preponderance of alumina, so amesite is considered to be a likely composition and is used in the following equations:

$$2\{4(Mg.Fe)O.2Al_2O_3.2SiO_2.4H_2O\} + 2\{K_2O.3Al_2O_3.6SiO_2.2H_2O\} + 11SiO_2 =$$

Chlorite (Amesite) Sericite Quartz

$$2\{K_2O.3(Mg.Fe)O.Al_2O_3.8SiO_2.2H_2O\} + 2(Mg.Fe)O.2Al_2O_3.5SiO_2 +$$

Biotite Cordierite

$$6\{Al_2O_3.SiO\} + 8H_2O.$$

Sillimanite Water

When no further silica was available the remaining chlorite and sericite would react with magnetite to form an iron-rich spinel. It was noted in the petrography that spinel often formed rims around the granules of magnetite. Ferric oxide probably passed out to the magma, this oxide being very mobile as the formation of skarns has shown. Biotite again arises as a result of this reaction, and though not shown in the equation, it might have become enriched in ferric iron.

$$4(Mg.Fe)O.2Al_2O_3.2SiO_2.4H_2O + K_2O.3Al_2O_3.6SiO_2 2H_2O + 3\{FeO.Fe_2O_3\} =$$

Chlorite (Amesite) Sericite Magnetite

$$4\{(Mg.Fe)OAl_2O_3\} + K_2O.3(Mg.Fe)O.Al_2O_3.8SiO_2.2H_2O + 3Fe_2O_3 + 4H_2O$$

Spinel Biotite Ferric Oxide Water

In the spinel the ratio Mg/Fe is 1/7, and it has been taken as 1/1 in the other minerals.

Among the silica-rich pelite xenoliths the most common type is the garnet-cordierite-sillimanite-biotite assemblage, sillimanite usually clouding the garnet even when it is not present as a normal constituent in the body of the rock. In these rocks the quartz has been more abundant in the knots and seams and has either been "armoured" by the other minerals, and therefore incapable of being removed by solution, or the schists have been immersed in the magma at a time when quartz was already in phasal equilibrium with it.

$$2\{4(Mg.Fe)O.2Al_2O_3.2SiO_2.4H_2O\} + K_2O.3Al_2O_3.6SiO_2.2H_2O + 9SiO_2 =$$

Chlorite (Amesite) Sericite Quartz

$$3(Mg.Fe)O.Al_2O_3.3SiO_2 + 2(Mg.Fe)O.2Al_2O_3.5SiO_2 + 3\{Al_2O_3.SiO_2\}$$

Garnet Cordierite Sillimanite

$$K_2O.3(MgFe)OAl_2O_3 8SiO_2.2H_2O + 8H_2O$$

Biotite Water

(*b*). *Reaction.*—As quartz, sericite and a little chlorite actually dissolve in the magma at an early stage in the assimilation process, their constituent elements become available for the formation of other minerals, so it is not necessary to use the formulae of any of these minerals on the magmatic side of the following equations.

It was noted above that orthoclase was being precipitated when the magma was contaminated and that it was subsequently altered to chlorite and sericite as a result of the contamination thus:

$$K_2O.Al_2O_3.6SiO_2 + 4(Mg.Fe)O + 4Al_2O_3 + 2SiO_2 + 6H_2O =$$

Orthoclase Oxides in contaminated Magma

$$K_2O.3Al_2O_3 6SiO_2.2H_2O + 4(Mg.Fe)O.2Al_2O_3.2SiO_2.4H_2O$$

Sericite Chlorite

After the high-grade metamorphism of the pelites these too suffer reaction, sillimanite being converted into sericite, and cordierite to a mixture of chlorite and sericite. For these changes to have been brought about, potash must have been added by the magma, though it was shown above that potash was originally derived from the schist in the form of sericite. At this late stage, however, the magma has begun to precipitate pyrogenic cordierite, thus binding part of the alumina of the original sericite with magnesia and setting free its potash. Obviously a quantity of both magnesia and alumina would have been made available earlier by the solution of, and reaction with, the pyroxene-granulite:

$$4(Mg.Fe)O.2Al_2O_3.2SiO_2.4H_2O + K_2O.3Al_2O_3.6SiO_2.2H_2O + 2SiO_2 =$$

Chlorite Sericite

$$2\{2(Mg.Fe)O.2Al_2O_3.5SiO_2\} + K_2O + Al_2O_3 + 6H_2O$$

Pyrogenic Cordierite Released Oxides

The available alumina is used for the conversion of biotite into chlorite:

$$4\{K_2O.3(Mg.Fe)O.Al_2O_3.8SiO_2.2H_2O\} + 2Al_2O_3 + 4H_2O =$$

Biotite

$$3\{4(Mg.Fe)O.2Al_2O_3.2SiO_2.4H_2O\} + 4K_2O + 26SiO_2$$

Chlorite

Thereby a further quantity of potash is released for the sericitization of sillimanite:

$$3\{Al_2O_3.SiO_2\} + 3SiO_2 + K_2O + 2H_2O = K_2O.3Al_2O_3.6SiO_2.2H_2O$$

Sillimanite Sericite

Cordierite, in both xenolith and contaminated igneous rock, is made over into a mixture of chlorite and sericite which is a reversal of the equation showing the genesis of pyrogenic cordierite:

$$2\left\{ \underset{\text{Cordierite}}{2(Mg.Fe)O.2Al_2O_3.5SiO_2} \right\} + K_2O + Al_2O_3 + 6H_2O =$$

$$\underset{\text{Chlorite}}{4(Mg.Fe)O.2Al_2O_3.2SiO_2.4H_2O} + \underset{\text{Sericite}}{K_2O.3Al_2O_3.6SiO_2 2H_2O} + 2SiO_2$$

These reactions continue until equilibrium is set up and the pelitic xenolith consists entirely of a mass of chlorite and sericite, or until the magma has cooled to such an extent that further reaction is impossible. Thus all stages in the reaction process are to be found among the numerous, minute pelitic xenoliths.

(*b*). *Two-Mica Gneisses.*

The Albury or two-mica gneiss crops out on the Howlong Road, on the northern bank of the Murray River, just below Monument Hill, the main outcrop probably being in Victoria. Good exposures of the gneiss may be seen in the Municipal Quarry and in the road cuttings between the western end of Smollett Street and West Albury Post Office.

A rather similar type of gneiss occurs about 10 miles from Jingellic on the Tumbarumba Road, and a slightly different, though closely related type, occurs just north of Womargama on the Holbrook Road.

At the intersection of the roads, Pors. 107/112, Parish of Albury, just south of the Roman Catholic Orphanage, several tors and a weathered exposure in the road cutting suggest the presence of an igneous rock. Large pink felspars, often up to an inch across, are common and the weathered mass is threaded with veins of pegmatite. This occurrence suggests the Albury gneiss, but closer examination discloses the fact that it is a highly-granitized schist, and its relation to the Albury gneiss is discussed below.

i. *Xenoliths and Granitized Schists.*

An examination of the altered sediments on Monument Hill, in the immediate vicinity of the Albury gneiss, indicates that they are mainly psammites and psammopelites. Very good exposures of these may be seen in a quarry on the western side of the hill overlooking West Albury. At this locality the sediments are unaffected by granitization and the pelitic sediments occur only as very narrow bands in a great thickness of psammite and banded psammopelite not unlike the corduroy granulite of Cooma.

In the Municipal Quarry on the Howlong Road the gneiss is seen to be crowded with xenoliths in all stages of disintegration. Pelites are mainly represented by highly-micaceous patches and the less pelitic types by granulites and banded granulites. The latter usually form the larger inclusions which show little evidence of assimilation. Small xenoliths of granulite are not so evident as small fragments of pelite and were apparently more digestible just as the basic granulite was more digestible in the cordierite-bearing gneiss. The large unassimilated masses of granulite were probably caught up at a late stage in the cooling history, but even at this stage the more schistose pelite was capable of being split up by mechanical disintegration and was no doubt already a mica-schist. Furthermore, the pelites occurred only as fairly narrow seams in the granulites, so at an earlier stage, when the granulite was capable of being assimilated, the thin rafts of micaceous schist were probably in equilibrium with the magma and remained as mica clots.

In describing the granitized schists it has been pointed out (p. 96) that the psammites and more psammitic psammopelites are usually affected by felspathization, and this process is significant in considering the origin of the two-mica gneiss.

(*a*). *Psammites and Psammopelites.*—In handspecimen these do not appear to have suffered an advanced stage of alteration, although some types do show obvious felspathization.

Under the microscope all stages between the slightly granitized psammite and the completely soaked and resorbed fragment can be discerned. The least altered types consist of a granoblastic aggregate of quartz, muscovite and red-brown mica and the grainsize varies from 1–2 mm. The more pelitic varieties contain aggregates of the two micas which form wisps or wide swirls and sinuous streaks through the rock, indicating an earlier plication. Quartz and muscovite often contain needles of sillimanite. Zircons

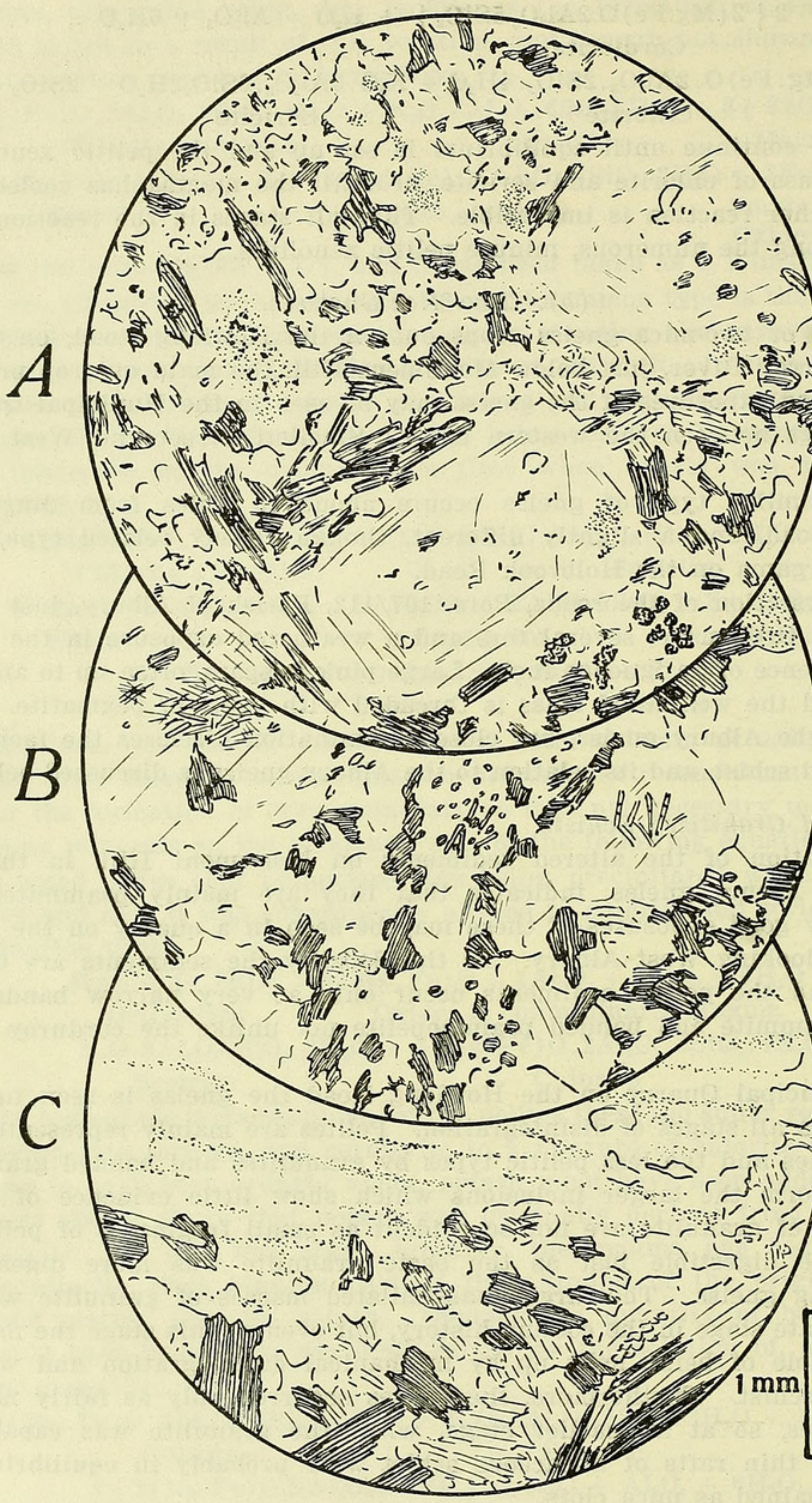

Fig. 7.

A. Granitized schist showing large "phenocrysts" of oligoclase in psammite consisting of a granoblastic aggregate of quartz, biotite, muscovite and altered orthoclase. A little tourmaline is present in the NE. quadrant.

Ten miles north of Jingellic on the Tumbarumba Road. × 16.

B. Large quartz, plagioclase and orthoclase grains wedged into schist consisting of biotite, cordierite, quartz, orthoclase and sillimanite. The plagioclase at the left of the figure and the quartz at the right have enveloped masses of sillimanite.

Near the Orphanage, Albury. × 16.

C. Two-mica gneiss showing portion of large grain of microcline and long blade-like crystals of biotite and muscovite developing in a fine granoblastic mass of quartz and greisenized felspar.

Municipal Quarry, Albury. × 16.

are commonly present in the biotite. Felspathization is usually marked by the development of large plagioclase felspars which are wedged in among the original minerals of the psammite (Fig. 7, A).

(*b*). *Pelites.*—These are much altered, and although andalusite, cordierite and sillimanite sometimes occur, they are more often completely altered into an aggregate of micas—mainly muscovite and green mica crammed with rutile needles. The latter possibly represents the breakdown of an earlier red biotite which had now reached a state of equilibrium with, but has not been completely resorbed by, the magma.

ii. *The Gneiss.*

As exposed in the Municipal Quarry, the Albury gneiss is a light grey rock containing much mica and rounded masses of quartz and pink phenocrysts of felspar up to about 1½ inches across. In handspecimen it is extremely like the Cooma gneiss. The mass is cut by many dykes and veins of pegmatite and schorl, and sometimes by veins of pure tourmaline. As stated above, xenoliths are numerous.

The two-mica gneisses near Woomargama and on the Tumbarumba Road are very similar.

The granitized schist near the Orphanage is an excellent example of an intermediate step between granitized schist and gneiss. In the field it appears to be an outcrop of an igneous rock, but under the microscope it is revealed as a granitized schist consisting of andalusite, sillimanite, cordierite, muscovite, red-brown biotite and striated orthoclase. The orthoclase may form bands indicating a gneissic structure and the rock is rather suggestive of the coarser types of mottled gneiss from the permeation-zone of Cooma. This rock has obviously been soaked by "granitic fluid" and large units of orthoclase, oligoclase ($Ab_{72}An_{28}$) and quartz have wedged apart the schist and enveloped some of its minerals. Needles of sillimanite are commonly present in the newly formed plagioclase (Fig. 7, B).

Specimens from the Municipal Quarry showing no obvious xenoliths in handspecimen mark a further stage in the resorption and granitization of the psammopelitic material, but no specimen has been examined in which original sedimentary quartz, orthoclase and micas have not been identified among the later developed larger grains of oligoclase, microcline, quartz and micas of igneous origin. The original biotite is often chloritized or bleached and the felspar completely replaced by muscovite, and it is sometimes difficult to identify these in between the larger blades of magmatic muscovite and chocolate-brown biotite (Fig. 7, C). That part of the muscovite that has an igneous origin is not infrequently plumose in its development. This type is very similar to the muscovite-rich phase of the Cooma gneiss (Joplin, 1942, p. 187) which was noted as occurring in isolated outcrops among the granitized schists. It is now considered that the Cooma rock developed in the same way as that suggested for the Albury gneiss. In the normal phases of the Cooma gneiss, however, pink pleochroic andalusite is a typical constituent and this is fairly rare in the Albury gneiss which compares more closely to the muscovite-rich phase at Cooma. The difference is probably a matter of volatiles, particularly of water content in the invaded rocks and in the intrusive magma.

A microscopic study of the Albury gneiss reveals a definite tendency towards mantling, and it is of interest to note that most of the large "phenocrysts" are composite bodies. They consist either of microcline, often albitized, or of oligoclase, and these enclose partly resorbed grains of orthoclase, sometimes mantled by a more basic plagioclase, as well as independent crystals of the more basic plagioclase. The development of oligoclase about orthoclase recalls some of the features of the Finnish rapikivi granites (Wahl, 1925; Sederholm, 1928), for though not a true rapikivi texture it is closely allied to it. In the rapikivi granites the orthoclase grains are usually rounded and the mantling plagioclase is in parallel intergrowth with them. In the Albury rocks, however, the orthoclase shows a more irregular resorption, and though these incompletely resorbed fragments may be in optical continuity with one another, they are not necessarily in parallel intergrowth with the mantling oligoclase (Fig. 8). Furthermore, the partly resorbed orthoclase may be mantled with microcline, or by a more basic plagioclase before being included in either microcline or oligoclase. When the basic plagioclase forms independent crystals the mantling oligoclase is often in parallel intergrowth with them and this gives the oligoclase a peculiar checked appearance. Orthoclase often shows marginal alteration to myrmekite.

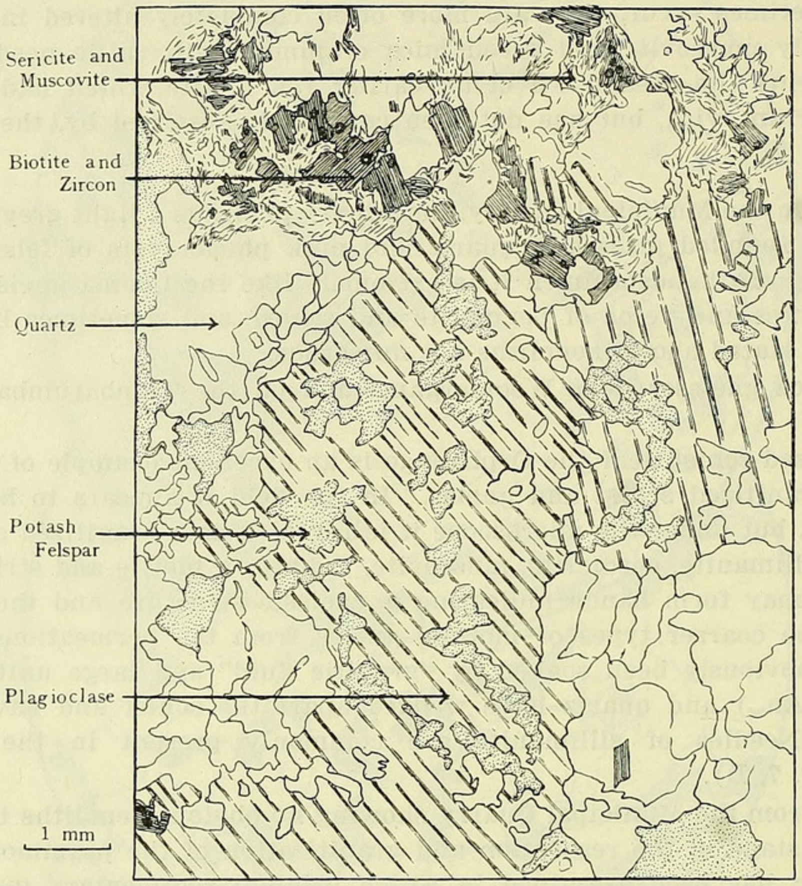

Fig. 8.—Composite unit occurring as a "phenocryst" in the two-mica gneiss.

iii. *The Contamination Process.*

In discussing the rocks of the permeation—or sillimanite—zone at Cooma (Joplin, 1942), it was shown that orthoclase developed as the result of high-grade metamorphism; and although this zone cannot be traced at Albury, there is some evidence of its existence prior to the heavy greisenization caused by the numerous sills which invaded this zone. Thus it can be assumed that the high-grade rocks, before they were granitized, contained varying amounts of orthoclase felspar. The granitized schist near the Orphanage gives further corroboration of this.

The largest sills of the district consist of oligoclass-granite and, as in the case of the cordierite-bearing gneiss, it is assumed that this magma type was responsible for the granitization. The schists were actually soaked in the quartz-felspar magma, and since the psammites and psammopelites consisted largely of quartz, it would probably represent a phase lower in the reaction series than those being precipitated by the magma. The orthoclase of the schists tended to be resorbed, but before this process was complete, magmatic material was deposited in the interstices of the partly disintegrated xenolith. Thus plagioclase of a slightly basic type was first deposited by the magma either enveloping the partly resorbed orthoclase or as independent small crystals. As the crystallization of the magma continued, a more acid plagioclase mantled these as well as an occasional grain of original quartz which had failed to go into solution. Microcline and quartz were also deposited from the magma at about this time and thus early magmatic minerals and partly resorbed sedimentary ones are characterized by mantling.

Thus there are all stages between the partly granitized or felspathized psammopelite and the most completely stabilized type, which in handspecimen closely resembles a true porphyritic igneous rock. As the psammopelites are not so far removed in mineral composition from the granites themselves, there is no very marked evidence of reciprocal reaction, and the contamination process has been due partly to a solution of the constituents low in the reaction series, and partly to mechanical disintegration of the xenolith brought about by both dissolution and by the wedging in of large grains of quartz and felspar.

iv. *Chemical Discussion.*

Again, any attempt to calculate a theoretical analysis must be highly speculative and must presuppose a large underlying magma chamber of oligoclase granite, but it has been shown in the petrography that it is possible to trace almost every step in the granitization of the psammopelite through to the formation of the contaminated gneiss and the writer is emboldened to attempt such calculations. Unfortunately no analyses have been made of the psammopelites of the Albury district, but there are available types, which are believed to be similar, from the Victorian part of the complex and from Cooma. Table 12 shows analyses of both actual and theoretical gneiss, and it can be seen that by mixing various quantities of psammopelite and oligoclase granite from these areas it is possible to calculate the analyses of rocks whose compositions closely resemble the two-mica gneiss type. In doing this, care was taken to choose pairs of analyses from the same locality in each case, and thus there is no theoretical gneiss for the Albury district itself.

TABLE 12.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	70·44	71·93	69·79	70·65	72·44	69·14	69·79
Al_2O_3	15·84	14·62	16·47	15·25	14·72	18·04	16·81
Fe_2O_3	0·53	0·83	0·53	0·83	2·41	2·40	3·65
FeO	3·35	2·25	2·97	3·45			
MgO	1·24	1·18	1·95	1·63	1·21	1·32	1·50
CaO	0·73	0·91	0·73	0·94	0·57	0·52	0·73
Na_2O	1·70	1·98	1·68	1·77	2·14	2·09	1·65
K_2O	4·09	5·03	3·44	4·63	4·56	4·83	4·09
H_2O+	0·62	0·75	0·99	0·60	1·22	1·15	0·91
H_2O-	0·09	0·34	0·49	0·09			
TiO_2	0·66	0·33	—	0·65	0·59	0·44	0·63
P_2O_5	0·22	0·22	0·06	0·12	0·14	0·07	0·20
MnO	tr.	0·03	—	0·05	—	—	0·04
BaO	—	0·02	—	—	—	—	—
	99·51	100·42	99·10	100·66	100·00	100·00	100·00
Sp. Gr.	2·74	—	2·72	2·79	—	—	2·70

I. Albury Gneiss. Municipal Quarry, Howlong Road, base of Monument Hill. Anal. G. A. Joplin.
II. Granite. Mt. Wagra, North-eastern Victoria. Anal. C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929: 38.
III. Slightly foliated Granite. Wilson's Creek, Omeo. Anal. A. W. Howitt. *Trans. Roy. Soc. Vict.*, 24, 1887.
IV. Cooma Gneiss. Massie Street, Cooma. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 188.
V. Equal parts of Cordierite Hornfels (Anal. 8) and Quartz-felspar injection type (Anal. 24). Both analyses from C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929: 36 and 38.
VI. Equal parts of Hornfels (Orr's Gully, A. W. Howitt, see Table 3) and Muscovite-granite (Omeo, A. W. Howitt, see Table 6, this communication).
VII. Two parts of Corduroy Granulite (Anal. III. PROC. LINN. SOC. N.S.W., 67, 1942: 168) and one part of Albite-muscovite Gneiss (Cooma, see Table 6, this communication).

The Woomargama gneiss is on the northern edge of the area mapped and has not been examined very carefully, but in handspecimen it is identical with the Albury gneiss, and on approaching it from the west, a zone of biotite schists, a zone of knotted schists and a zone of granitized schists were traversed, as in the case of the Ordovician two-mica gneisses elsewhere. It is assumed that it has a somewhat similar origin, though the chemical composition suggests that the assimilated material may have been more basic. Low-grade psammopelites with a tuffaceous matrix have been noted on the road opposite the T.S.R., just south of Woomargama, and the fact that this rock is comparable to the theoretical type calculated by mixing oligoclase-microcline granite and pyroxene-granulite may have some significance.

TABLE 13.

	I.	II.
SiO_2	66·43	67·09
Al_2O_3	17·53	18·20
Fe_2O_3	0·15 }	3·84
FeO	3·76 }	
MgO	1·91	1·80
CaO	2·55	2·50
Na_2O	2·37	2·60
K_2O	3·22	3·28
H_2O+	0·61	—
H_2O-	0·21	—
TiO_2	1·10	0·25
P_2O_5	0·07	0·44
MnO	—	—
	99·91	100·00

I. Two-mica Gneiss. Por. 204, Par. of Woomargama. Anal. G. A. Joplin.
II. Theoretical Gneiss. See Table 11, Anal. III.

3. THE LEVEL OF THE INTRUSIONS.

It is obvious from the foregoing discussion that the type of metamorphism and the nature of the rocks involved in it are closely comparable in the Albury and Cooma districts; but, as indicated in the section of this paper dealing with the metamorphic zones (p. 90), the zones at Cooma are more sharply defined and there is no zone of sills to complicate the higher grade zones as in the Albury region. Furthermore, although a later granite occurs at Cooma, it is well away from the main centre of Ordovician metamorphism, and did not interfere with it, whilst between Albury and Jingellic the contact-zones of the later granite often obscure the high-grade zones of Ordovician metamorphism. Nevertheless, these high-grade zones do not appear to have been so well developed in the Albury area. Again, the Cooma Complex could be distinguished as a complete unit in itself, whilst the area examined on the northern bank of the Murray represents only the northern fringe of the great complex of North-eastern Victoria.

Nevertheless, the apparently more restricted development of the high-grade zones, together with the great development of sills at Albury, suggests that this area represents a higher level in the complex as compared to that of Cooma. The fact that it was possible to trace the various stages in the development of the gneiss by the granitization and assimilation of the sediments also points to the magma's having cooled at a higher level where chemical and mineralogical changes had not had time to become completely stabilized.

It is likely, however, that several levels are represented within the Victorian Complex and studies further south may reveal that the main mass was more deep-seated and that the Albury area represents only the uppermost margin of the Ordovician intrusions.

IV. THE POST-ORDOVICIAN INTRUSIVES.

In the present paper these rocks are not studied in detail, but reference must be made to them as they have engulfed great areas of the Ordovician schists and have superimposed their contact effects upon them.

1. THE INTRUSIVE ROCKS.

At Mullanjandra, a mass of sheared gneiss or porphyry strikes about N. 50° W. across the main road, where it is covered by the alluvium of Mullanjandra Creek, but elsewhere forms a ridge of prominent hills. The full extent of the outcrop has not been mapped, but it is at least 6 miles in length and up to 1½ miles in width. A little faulting has possibly occurred in the region of Mullanjandra Creek (see Plate xv).

In handspecimen this rock bears a striking resemblance to the white gneiss of Cooma (Browne, 1914, 1943; Joplin, 1943) to which Browne has assigned a Silurian age.

Nowhere have very satisfactory contacts been observed but it appears to invade the Ordovician schists and the porphyries which are unconformable with them. Slates interbedded with the porphyries appear to be silicified along the creek in Por. 158, Par. of Mullanjandra, and as this is only a short distance from the gneiss, it is likely that it is responsible for the silicification. It has been suggested that the porphyries are of Lower Devonian age, but this must still remain an open question, for even though they may be silicified by the gneiss, it has been assigned a Silurian age only upon a lithological resemblance.

Even-grained and porphyritic granites, associated with large masses of granite-porphyry, are very numerous along the northern bank of the Murray at intervals between Wymah and Jingellic and probably occur in much of the mountainous country to the north. To the north of Albury there is a large area of granite, partly covered by soil and alluvium near Jindera, and this extends east to Table Top (Plate xv).

It is likely that granites of several ages are represented among these outcrops.

A porphyritic granite showing a marked parallelism of the phenocrysts occurs just east of Jingellic on the Tooma Road and the same type crops out on the Tumbarumba Road about 10 miles from Jingellic, and about 9 miles north of the outcrop on the Tooma Road. The relation between these two outcrops has not been studied but it is likely that they are continuous and boulders in the eastern tributaries of Horse Creek suggest that the hills to the east are composed of this rock-type. This rock may possibly be of Silurian age.

The Jindera granite, briefly described in an earlier communication (Joplin, 1944), is also porphyritic, but shows no directional structures and is very similar to types occurring near Dora Dora and Talmalmo, where large masses of granite-porphyry also occur.

The Hawksview granite, also previously described, is a massive two-mica granite with a very occasional phenocryst of orthoclase, and is particularly rich in white mica. It shows very sharp contacts against the cordierite-bearing gneiss and is obviously of much later origin.

Howitt (1887) has described a porphyritic granite from Omeo, which, except for its higher MgO, is rather similar to the Hawksview granite in chemical composition. Howitt has stated that in the field the porphyritic granite is closely related to a foliated type, and quotes analyses of both. The foliated type is obviously related to the two-mica gneisses with which it is compared in Table 12. Concerning the relation of the porphyritic and foliated granites at Omeo, Howitt concludes: "for the present I must leave this in a state of doubt". The present writer's experience on the Upper Murray, however, leads her to the conclusion that the porphyritic granite of Omeo is probably much later and has invaded the earlier two-mica gneiss which is intimately related to the Ordovician schists.

In the earlier paper (Joplin, 1944), it was suggested that the two-mica granite at Run Boundary occurred as an Ordovician sill, but a more detailed petrological and chemical examination has shown that it bears no relation to the other sills of the area, and, though apparently a concordant intrusion, is possibly of later origin. In Table 14 the analysis of this rock is compared with the Corryong granite and it is interesting to note that Edwards (1937) has said: "outcrops of the granite salients are more or less linear and parallel to the strike of the invaded Ordovician".

As these granites have not been studied in detail, it is not fitting to discuss their relative ages, but there certainly seems to be several periods of igneous intrusion represented, possibly Silurian, Middle Devonian and Kanimbla, and the problem would well repay a more detailed study. Edwards has made a detailed study of the Corryong and Pine Hill granites and considers that they are of two ages—both post-Ordovician. In discussing this he says: "If the orogony can be regarded as Lower Devonian in age, then the Corryong granite may be post-Lower Devonian, whilst the Red granite series may coincide with a Middle or Upper Devonian minor orogony. If the Corryong granite, on the other hand, is post-Middle Devonian, the Red granite series cannot be older than Lower Carboniferous and may be much younger."

Although MgO is higher in the Corryong granite, it bears some chemical relation to the Run Boundary and Koetong granites with which it is compared in Table 14, whilst the Hawkesview granite, with its lower CaO and Na_2O and higher K_2O, seems to be more closely related to the porphyritic granite of Omeo, though here again there is a discrepancy in the MgO content. Edwards (1937) has shown that the later types, of which the Pine Mt. granite is a representative, also contain high K_2O, but as these have a very much higher silica content, they cannot readily be compared with the two analyses in Table 15.

It is possible that detailed chemical work might show that these various granites fall into groups, and this may be a means of distinguishing their relative ages.

TABLE 14.

	I.	II.	III.	IV.	V.	VI.
SiO_2	70·73	68·92	67·25	70·78	71·50	67·67
Al_2O_3	15·38	16·21	16·46	15·77	14·13	14·50
Fe_2O_3	0·50	0·57	0·42	0·69	0·60	0·87
FeO	2·31	2·42	1·99	2·44	3·23	3·78
MgO	0·79	1·04	1·00	0·72	1·17	2·21
CaO	2·54	2·31	2·74	2·53	2·70	2·18
Na_2O	3·78	2·43	2·91	2·88	2·97	2·38
K_2O	3·29	4·36	5·64	2·44	2·86	3·42
H_2O+	0·29	0·93	0·48	0·50	0·32	1·81
H_2O-	0·10	0·08	0·20	0·06	0·10	0·11
TiO_2	0·34	0·52	0·40	0·45	0·41	0·61
P_2O_5	0·42	0·30	0·19	0·25	0·35	tr.
MnO	0·04	0·03	0·02	0·08	tr.	—
Etc.	—	0·04	0·08	—	—	—
	100·51	100·16	99·78	99·59	100·34	99·54
Sp. Gr.	2·69	—	—	2·68	2·59	—

I. Two-mica Granite. Run Boundary Trigonometrical Station, Por. 244, Par. of Mungabarina, Albury district. Anal. G. A. Joplin.
II. Granite. Koetong Mass, Tallangatta-Granya Road. Anal. C. M. Tattam. *Geol. Surv. Vict.*, Bull. 52, 1929 : 38.
III. Granite. Osborne's Flat, Yackandandah Creek Basin. Anal. C. M. Tattam. Ibid.
IV. Biotite-granite. Moruya district. Anal. I. A. Brown. PROC. LINN. SOC. N.S.W., 53, 1928 : 160.
V. Granite. Enoggera, Queensland.
VI. Grey Biotite Granite. East of Lot 8, Section VII, near Contact. Par. of Cudgewa. Anal. F. F. Field. A. B. Edwards and J. G. Easton. *Proc. Roy. Soc. Vict.*, 50, 1937 : 82.

TABLE 15.

	I.	II.
SiO_2	69·71	68·87
Al_2O_3	17·90	16·62
Fe_2O_3	1·16	0·43
FeO	0·88	2·72
MgO	0·16	1·60
CaO	1·22	0·71
Na_2O	1·76	1·80
K_2O	6·14	6·48
H_2O+	0·73	0·74
H_2O-	0·04	0·21
TiO_2	0·34	—
P_2O_5	0·42	0·05
MnO	—	—
	100·46	100·23
Sp. Gr.	—	2·762

I. Two-mica Granite (Hawksview Granite). Hume Weir Quarry, Por. 65, Par. of Thurgona. Anal. G. A. Joplin.
II. Porphyritic Granite. Wilson's Creek, Omeo. Anal. A. W. Howitt. *Trans. Roy. Soc. Vict.*, 24, 1887.

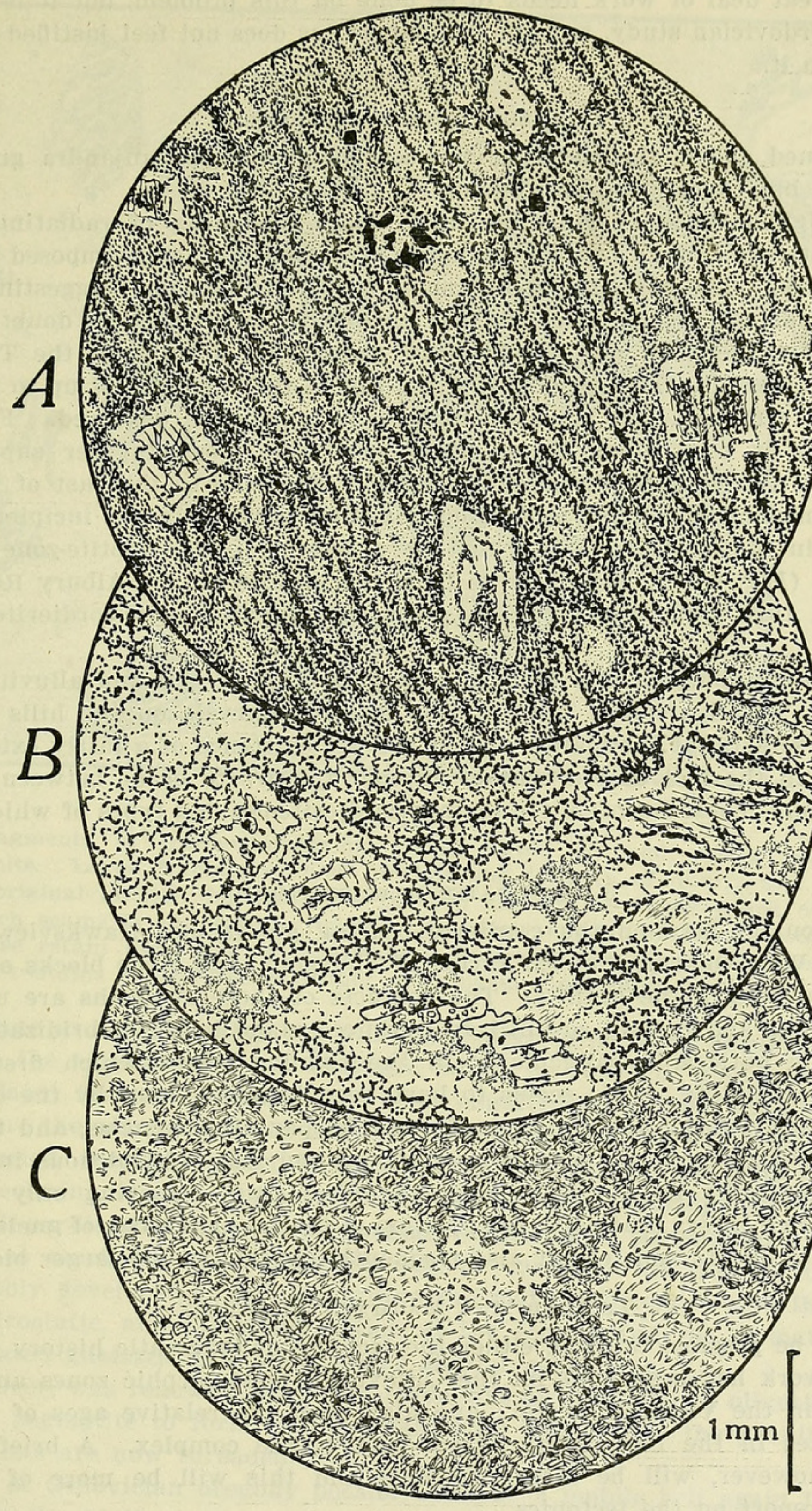

Fig. 9.—Hornfels in the aureoles of the younger granites.

A. Chiastolite-cordierite hornfels, about 1½ miles north of Jingellic, on the Tumbarumba Road. Small porphyroblasts of idioblastic chiastolite show a marginal alteration into sericite. Small porphyroblasts of cordierite are xenoblastic and completely altered. The base shows a marked schistosity and consists almost entirely of quartz and graphite. × 16.

B. A more advanced thermal alteration of the same rock-type from the roadside, 5 miles west of Jingellic, on the Albury Road. Porphyroblasts of andalusite (some chiastolite) and cordierite are much larger, and the base consists of a granoblastic mass of quartz and graphite, all traces of schistosity having been lost. × 16.

C. Cordierite hornfels from Burrumbuttock. Large irregular porphyroblasts of cordierite show sieve-structure. These occur in a fine base of biotite, muscovite, quartz and magnetite. × 16.

Obviously a great deal of work needs to be done on this problem, but it is outside the scope of this Ordovician study, and the present writer does not feel justified in spending further time on it.

2. Their contact aureoles.

As mentioned above, the slates at the contact of the Mullanjandra gneiss appear to be silicified, but there is no hornfelsing.

In the neighbourhood of Jingellic, large spots consisting of radiating masses of chlorite suggest that a weak contact metamorphism has been superimposed on the zone of spotted schists. The chlorite "spots" show crystal boundaries suggesting that they are pseudomorphs after cordierite, and the change to chlorite is no doubt due to the low-grade contact effects of the (?) Silurian porphyritic granite on the Tooma Road, 3 miles east of Jingellic. This type of spotting can be followed almost up to the junction of the granite although the actual boundary is somewhat obscured. Furthermore, similar spotting is seen along Horse Creek, and this lends further support to the assumption that the porphyritic granite occurs in the hills to the east of this stream.

On the Tumbarumba Road, 2 miles from Jingellic, chiastolite and incipient cordierite are developed in the pelitic schists which were possibly in the biotite-zone of regional metamorphism (Fig. 9, A). At 10 yards from the granite on the Albury Road, 5 miles from Jingellic, this same rock-type has given rise to andalusite-cordierite hornfelses (Fig. 9, B).

Between Burrumbuttock and Jindera a large stretch of soil and alluvium probably covers granite. Small areas of granite crop out at intervals on the hills adjacent to the Ordovician schist, but the main evidence for the existence of a fairly extensive mass of granite lies in the fact that a contact aureole appears to occur between the schists and the alluvium. These hornfels are mainly cordierite-bearing types of which Fig. 9, C, is an example.

3. Associated hybridization.

A sharp contact between the cordierite-bearing gneiss and Hawksview granite is exposed in the Weir Quarry, Por. 65, Parish of Thurgona, and large blocks of the gneiss frequently occur within the granite. The contacts of these xenoliths are usually very sharp and angular and remain so until an advanced stage in the hybridization process. Hybridization is noticeable particularly in the smaller blocks which first develop a marked gneissic banding. This seems to have been brought about by the development of new quartz and felspar about the quartz and felspar of the gneiss, and thus a faint original gneissic structure has become accentuated and more conspicuous in the hybrid types, which gradually merge into the surrounding granite leaving only a series of parallel biotite-rich layers that mark the position of the original block of gneiss (Fig. 10). Large tongues of quartz and felspar also frequently develop in the larger blocks.

V. Tectonic and Magmatic Histories.

It will not be possible to write either the tectonic or magmatic history of this area until further work has been done on the Ordovician metamorphic zones and upon the later granites in the Victorian sector; and also upon the relative ages of the various younger granites in the New South Wales part of the complex. A brief outline or introduction, however, will be attempted here and this will be more of the nature of a progress report on the tectonics.

At Cooma (Joplin, 1942, p. 194) petrological evidence suggested that compressional forces had been active before the injection of the magma, and that the schists had possibly been raised to the biotite-zone of regional metamorphism by such shearing stresses. As andalusite and cordierite are usually regarded as anti-stress minerals, it was suggested that stress declined at Cooma immediately after the injection of the magma and that the andalusite-zone was of the nature of a contact aureole. This explanation of the zoning seems to apply to the Albury–Jingellic region, and isoclinal folding and plicated structures suggest a strong compression. The lower grade rocks of the chlorite-zone, so well exposed north of Jingellic, do not usually show these structures and thus the metamorphic grade seems to be related to the degree of compression.

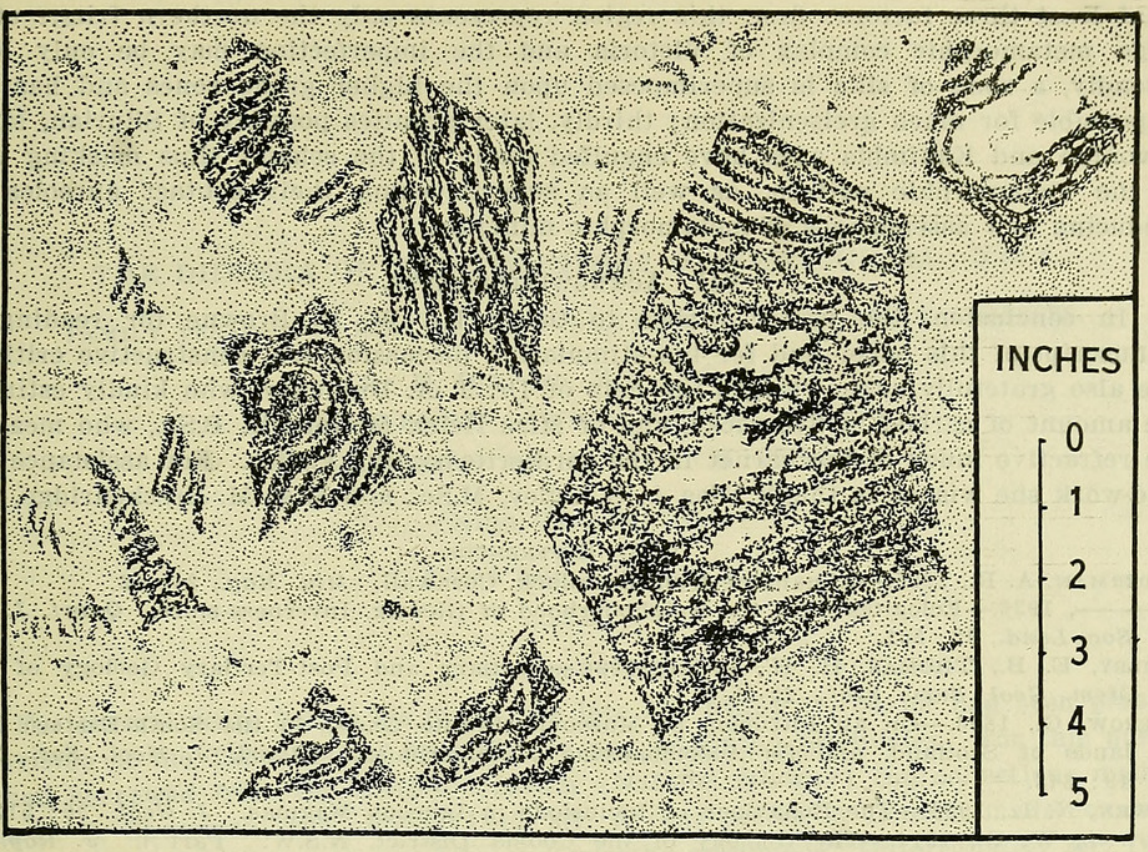

Fig. 10.

Angular fragments of cordierite-bearing gneiss rifted off and partly assimilated by Hawksview granite. Large fragments show patches and tongues of quartz and felspar that accentuate the original gneissic banding. At the top and at the extreme left of the figure, minute biotite-rich seams in the granite represent the last remains of almost totally resorbed fragments. These retain their original shape until complete resorption has taken place and the granite only contains a few clots of rather more basic composition.

Reference to Plate xv suggests that the knotted schists form zones about the two-mica gneisses, and in the neighbourhood of Jingellic, where no two-mica gneiss is exposed, it has been postulated that such a mass has been engulfed by a later granite, since by analogy elsewhere the arrangement of the knotted schists indicates its former presence.

It is suggested that the main injection of oligoclase-granite took place under conditions of declining stress; thus there was not so much development of injection-gneisses or of *lit-par-lit* structures as at Cooma; furthermore, permeation by magmatic fluids was not so marked. The andalusite and/or cordierite of the knotted schists, therefore, probably developed under high-grade thermal conditions where the pressure was mainly hydrostatic, and the granitization of the schists and the formation of the highly-contaminated gneisses took place under similar conditions.

Stress, however, was renewed later, and there was an injection of oligoclase-granite accompanied by pegmatite to form the abundant sills with which the granitized rocks and knotted schists are now threaded.

This region of Ordovician orogony possibly became a mobile belt again in Silurian time, when both the Mullanjandra gneiss and the porphyritic granite were injected. Finally, the same tract was probably the centre of orogony during Middle Devonian time and during the Kanimbla Epoch. As indicated by the work of Edwards and Easton, the same tectonic history applies in Victoria, thus suggesting the permanence of the mobile belts over several geological periods, and the successive injection of magmas into previously consolidated rocks of magmatic derivation.

VI. Summary.

It has been shown that, as in the Cooma district, the Albury–Jingellic region consists largely of Ordovician schists in varying grades of metamorphism. A chlorite- and biotite-zone, a zone of knotted schists and a zone of granitized schists have been recognized, although zoning is not so perfect as at Cooma. This imperfection is due to at least three factors: first, this region represents only the northern fringe of the large metamorphic complex of Victoria and the imperfection may be only local; secondly, a zone of sills is superimposed upon the higher grade zones and has been responsible for much greisenization; thirdly, later granites possibly of Silurian, Middle Devonian and Kanimbla ages have engulfed many of the schists, thus masking much of the metamorphic pattern, as well as superimposing their contact aureoles and producing new assemblages of metamorphic minerals.

VII. Acknowledgements.

In conclusion, the writer wishes to thank Dr. W. R. Browne for reading the manuscript of this paper and for his stimulating discussion and constructive criticism. She also gratefully acknowledges the help of Dr. J. A. Dulhunty, who kindly estimated the amount of carbon in five rocks, and of Miss Helen McRoberts, B.Sc., who measured the refractive index of the garnet in the cordierite-bearing gneiss. For assistance with field-work she wishes to thank Miss A. G. Culey, M.Sc., and Miss M. Breckenridge, B.Sc.

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