Although plagioclase of such a composition would crystallize from the granodiorite (as a result of the Reaction Principle), it seems likely that some plagioclase was an original constituent of the xenoliths.

Clinozoisite is present in the calcareous pelites, and occurs in subidioblastic crystals associated with quartz and plagioclase. This association rapidly grades into one in which hypersthene takes the place of clinozoisite. Clinozoisite or epidote, in strings of granules, occurs in some of the silica-poor pelites. Its occurrence here is rather unexpected, and its presence may be due to extremely thin calcareous bands in the original sediment (cf. Tilley, 1924, p. 40). Sediments exhibiting such a degree of metamorphism could well be expected to have all the clinozoisite converted to calcic plagioclase (Harker, 1932).

Other minerals in the pelitic xenoliths which make an occasional appearance are sphene and blue-grey tourmaline. The latter may be derived from recrystallization of tourmaline in the original sediment, as no tourmaline has been found elsewhere in the Cowra Intrusion.

(2) Psammites and Psammopelites.

Psammitic xenoliths are of much rarer occurrence than pelitic. They are fine to medium-grained banded granulites with quartz, felspar and biotite. Some hypersthene-bearing types are found, and these grade into the quartz-felspar-hypersthene assemblages of the pelitic xenoliths, marking the gradation in the original sediment from pelite through psammopelite to psammite.

Diopside has been detected in one of these xenoliths, showing alteration to a fibrous green amphibole. Epidote, muscovite, apatite and zircon may also be present. Plagioclase shows more variation in composition than in the pelites, ranging from albite-oligoclase to andesine.

(3) Calcareous Xenoliths.

These are characterized by the minerals clinozoisite and epidote, and they are accordingly yellowish-green in hand specimen. The grainsize is fine and most of the minerals are xenoblastic. Some xenoliths are made up mostly of quartz and clinozoisite, with accessory tremolite, and others (richer in iron) consist of quartz and yellow-green epidote, with a little actinolite. Reaction-zones of such xenoliths consist of biotite, quartz, plagioclase and hypersthene. It is possible that some of the quartz-felspar-hypersthene assemblages previously noted may have been calcareous types which have suffered much reaction with the magma.

(4) Xenoliths of Igneous Origin.

Very few of the xenoliths are of definite igneous origin. A former basalt or dolerite is represented by a hypersthene-plagioclase-magnetite rock with blastophitic fabric. A reaction-rim, one-fifth of the diameter of the xenolith, consists of biotite, quartz and plagioclase.

A plagioclase-hypersthene-quartz-biotite xenolith, similar in mineralogical composition to some derived from pelites, differs from them in its texture and complete lack of evidence of former bedding. Occasional large plagioclases are intergrown with quartz, and the hypersthene in these xenoliths is notable for its strong pleochroism. The chemical analysis (Table 3) corresponds to that of an igneous rock, e.g., an andesite.

(5) Granitized Xenoliths (quartz-felspar-biotite assemblages).

There are numerous xenoliths containing the same minerals as the granodiorite, but showing no signs of bedding. They are of slightly finer grainsize than the granodiorite and more melanocratic. At Cowra, a few transition types between sedimentary xenoliths and "igneous-looking" xenoliths have been found.

Origin of the Xenoliths.

(*a*) Sedimentary Xenoliths other than those of the Silica-Poor Group (1*a*, 2 and 3 above).

As the Silurian wall-rocks are not greatly affected by the intrusion, and all xenoliths (even near the margin of the intrusion) have suffered fairly high-grade metamorphism, it is likely that the sedimentary ones have been derived from Ordovician or older sediments occurring at depth, and have been carried upward by the magma, i.e., they are hypoxenoliths (Goodspeed, 1948).

The mineral assemblages of the pelitic xenoliths indicate an abundance of iron oxides, magnesia and alumina. It is not certain, however, that the original sediment was abnormally high in these oxides, for we do not know to what extent chemical change has affected the composition. Garnet in the pelitic xenoliths probably occurred in the country rock before it was enclosed in the magma, and may have been a constituent of pre-existing regionally metamorphosed schists. When isolated from the xenoliths by mechanical disintegration, it is found in the granodiorite encased in a reaction rim of biotite and, less commonly, hypersthene and magnetite (Plate vii, fig. 4). The pelitic xenoliths of Cowra differ from those of Albury mainly in the amount of plagioclase in the former, indicating that the original pelites at Cowra were richer in soda and lime.

Table 3.

	1	2
SiO_2 ..	59·44	59·20
Al_2O_3 ..	14·27	15·98
Fe_2O_3 ..	0·45	3·30
FeO ..	8·48	3·69
MgO ..	4·84	3·10
CaO ..	5·61	7·02
Na_2O ..	3·47	3·31
K_2O ..	0·95	1·26
TiO_2 ..	1·35	0·55
P_2O_5 ..	pnd.	0·17
MnO ..	0·10	0·30
H_2O+ ..	0·75	1·13
H_2O- ..	0·22	0·73
Etc. ..	—	0·48
	99·93	100·22
S.G. ..	2·86	2·74

1. Hypersthene - plagioclase - biotite - quartz xenolith. The Beacon, Cowra. Anal. N. C. Stevens.
2. Hypersthene andesite. Blair Duguid, N.S.W. Anal. H. P. White. W. R. Browne and H. P. White, *J. Proc. Roy. Soc. N.S.W.*, 60 (1926): 372.

The psammites and psammopelites also show the same tendency, as shown by the presence of intermediate plagioclase and occasional diopside, epidote and clinozoisite. The calcareous xenoliths, with their high proportion of quartz, appear to have been calcareous sandstones or tuffs.

(*b*) Igneous Xenoliths.

The few igneous xenoliths that have been found seem to have been derived from basalts and andesites (Table 3), probably of Ordovician age, similar to types outcropping a few miles north-east of Cowra.

(*c*) Granitized Xenoliths (5, above).

It is considered from the general features of texture and constitution that these types could be either (*a*) cognate xenoliths or (*b*) sedimentary xenoliths showing a high degree of reaction with the magma, i.e., granitization. Grout (1937) cites much evidence to show that sedimentary xenoliths can be converted to "igneous-looking" rocks having the same minerals as the enclosing rock and thus being in complete equilibrium with the surrounding magma. The texture may be finer-grained, with the occurrence of "phenocrysts". In view of the transition between sedimentary and igneous-looking xenoliths (mentioned above) it is possible that the more siliceous pelites gave rise to the quartz-felspar-biotite assemblage (after granitizing reaction), while the pelites with 50%-60% silica were the source of the silica-poor xenoliths (see next paragraph).

(*d*) Silica-poor Xenoliths (1*a*).

The silica-poor xenoliths, represented by those containing spinel in association with cordierite or sillimanite or both, are very similar to those described by Joplin (1947) from gneiss contaminated by Ordovician sediments at Albury, N.S.W. The occurrence of spinel-bearing xenoliths in a rock with nearly 67% SiO_2 is unusual, especially when

TABLE 4.

	1	2	3	4	5	6	7	8
SiO_2	43·11	44·52	45·30	42·08	40·16	62·23	70·17	69·98
Al_2O_3	32·61	28·63	30·51	32·40	29·50	12·20	13·00	12·74
Fe_2O_3	0·68	1·78	0·24 }	13·44	19·66	6·49	5·22 }	6·25
FeO	7·51	10·75	8·80 }		5·80	0·84	1·26 }	
MgO	3·93	4·14	3·11	3·30	tr.	3·07	1·83	4·19
CaO	2·90	1·25	0·90	1·42	0·85	3·23	0·32	0·76
Na_2O	0·77	3·21	1·65	1·60	1·46	3·21	1·15	pnd.
K_2O	6·01	2·69	4·84	2·20	1·36	2·48	3·17	pnd.
TiO_2	2·06	2·05	1·48	2·16	—	1·30	0·97	0·82
P_2O_5	pnd.	0·03	0·12	—	—	pnd.	0·14	pnd.
MnO	0·10	tr.	0·20	—	—	0·14	0·06	0·23
H_2O+	0·62	0·45	1·05 }	1·60	—	3·34	2·47	—
H_2O-	0·25	0·20	0·26 }		—	2·07	0·96	—
S	—	0·27	1·32*	—	0·82	—	—	—
SO_3	—	tr.	0·04	—	—	—	—	—
Etc.	—	—	0·30	—	—	—	—	—
	100·55	99·97	100·12	100·20	99·61	100·60	100·72	—
S.G.	2·89	—	2·835	—	—	2·54	2·62	2·69

* 0·36% FeS_2 and 0·96% Fe_7S_8.

1. Cordierite-sillimanite-spinel xenolith. ½ mile N. of Cowra Post Office. Anal. N. C. Stevens.
2. Cordierite-spinel hornfels, at contact with diorite. Craig More, Comrie, Scotland. Anal. C. E. Tilley. *Quart. J. Geol. Soc. Lond.*, 80, 1924 : 22.
3. Corundum-cordierite-spinel hornfels. Ascutney Mtn., Vermont. Anal. W. F. Hillebrand. R. A. Daly, *U.S. Geol. Surv. Bull.*, 209, 1903 : 29.
4. Cordierite-hornfels. N. end of Black Hill, Aberdeenshire. Anal. J. J. H. Teall, *Geol. Surv. Gr. Brit.* (Braemar), 1912 : 16.
5. Manhattan Schist, on contact of Cortlandt Series. Anal. F. L. Nason. G. H. Williams, *Amer. J. Sci.*, 36, 1888 : 259.
6. Slate (buff-coloured, somewhat weathered). Cowra Brickworks Quarry.
7. Slate (buff-coloured). Mining Reserve, Burdett; N.N.W. of Canowindra.
8. Phyllitic slate (greenish-coloured). Cowra Brickworks Quarry.

Analyses 6, 7 and 8 by N. C. Stevens.

there is an apparent lack of silica-poor sediments among the country rocks. The acidity of the Cowra Granodiorite is comparable with that of the Albury Gneiss, and it is to be noted that no silica-poor sediments have been found near Cowra. Analyses of slates from the Cowra district (Table 4) show that they are even more siliceous than the normal pelites at Albury.

Dr. Joplin suggests that the silica-poor xenoliths were derived from chlorite-rich bands or knots, the latter being formed by segregation during contact metamorphism. Xenoliths derived from these knots would be limited in size, and would not show bedding. At Albury, iron oxides, alumina and magnesia are higher in an analysed silica-poor xenolith than in the average normal pelite (and silica is lower). According to Dr. Joplin, "storing up of these constituents within the xenolith . . . 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".

These ideas are similar to those expressed by Tattam (1925), when dealing with silica-poor xenoliths in the granodiorite of Bulla, Victoria. Quártz is melted out of quartz-chlorite-sericite xenoliths and plagioclase crystallizes within them, so that they are desilicated, with the formation of sillimanite and spinel.

It is difficult to imagine these processes taking place without complete disintegration of the xenolith, and if such a disruption did not occur, why should the quartz have shown such a marked tendency to leave the xenolith and enter the magma?

An analysis of a typical silica-poor xenolith from Cowra is compared in Table 4 with rocks of similar composition and with some Silurian slates.

Such changes have been illustrated by Daly (1903), who described a progression in contact metamorphism in the same lithologic unit at Ascutney Mtn., Vermont. Variation from phyllite to corundum-cordierite-spinel hornfelses occurred as the contact with an intermediate plutonic rock was approached.

Reynolds (1946) has shown that pelitic rocks undergo changes in two stages, first desilication then granitization; also that during desilication there is commonly an introduction of Fe, Mg, Ca and one or more of TiO_2, P_2O_5 and MnO. Iron and magnesia are regarded as constituents driven from country rocks which have been granitized; however, the abnormal alumina percentages noted above remain unexplained. Read (1951) gets closer to this problem by suggesting that in certain cases "NaSi has been extracted with consequent piling up of AlFeMg" and that some occurrences of highly aluminous rock might be due to subtractions connected with metamorphic differentiation.

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EXPLANATION OF PLATE VII.

1. Cowra Granodiorite (× 30).
2. Granodiorite porphyry (crossed nicols, × 30).
3. Cordierite-sillimanite-spinel xenolith (× 50).
4. Magnetite and hypersthene at the margin of a garnet xenocryst in the granodiorite (× 60).
5. Clinozoisite-quartz xenolith (× 50).
6. Sillimanite-spinel xenolith (× 50).
7. Spinel bordering sillimanite in a xenolith (× 60).
8. Intergrowth of biotite and cordierite in a mottled pelitic xenolith (× 30).

Photomicrographs by G. E. McInnes and N. C. Stevens.

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