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VEIN MINERALS FROM THE TAMWORTH AND PARRY GROUPS (DEVONIAN AND LOWER CARBONIFEROUS), N.S.W.

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ABSTRACT

Veins in the Tamworth and Parry Groups bear the following minerals: calcite, laumontite, stilbite, heulandite, prehnite, pumpellyite, epidote, axinite, chlorite, muscovite, quartz, albite, bytownite, and amphibole. The stratigraphic distribution of each species is different. Mineral assemblages are characteristic of the albite-epidote mineral facies, the prehnite-pumpellyite facies, and the laumontite subfacies and heulandite-analcite subfacies of the zeolite facies. Those characteristic of the first two facies occur in irregular veins, those of the heulandite-analcite subfacies in joints, and those of the laumontite subfacies in bedding veins, faults and shear zones.

Comparison with the stratigraphic distribution of diagenetic minerals indicates the irregular veins are diagenetic. Later the zeolite facies veins formed under lower P-T conditions, those in the joints being earliest and characteristic of the lowest P-T conditions.

A quartz-bytownite-amphibole vein in a hornfels, thought to be a metamorphosed laumontite-chlorite vein, is described.

INTRODUCTION

The Tamworth and Parry Groups, which are the lowest units in the Tamworth Trough sequence of western New England, New South Wales (Fig. 1) have been described stratigraphically and petrographically by the author (Crook, 1961 *a*, *b*, *c*). An outline of their stratigraphic subdivision is presented in Table 1.

In the Tamworth-Nundle district, and westwards the two groups exhibit a depth sequence of diagenetic minerals (Crook, 1961*c*), in which three diagenetic facies are represented—the laumontite, the prehnite-pumpellyite, and the albite-epidote. In addition, veins bearing calcium-aluminium silicates are common in the sequence, seventy-odd having been examined. These are described herein.

Optical data, incorporated in Table 2, have been obtained from mineral fragments in most cases, although thin sections were utilized for quartz-rich veins (R964–R970). Refractive indices were measured by the immersion method, using Cargille oils checked on an Abbe refractometer. Accuracy is ±0.002 for values below 1.600 and generally somewhat poorer for values above this. Specimen numbers of the W-series are the author's field numbers (series KCW . . . . /56, 57 or 58). Those of the R-series are University of New England collection numbers (old series). All material is housed in the University of New England.

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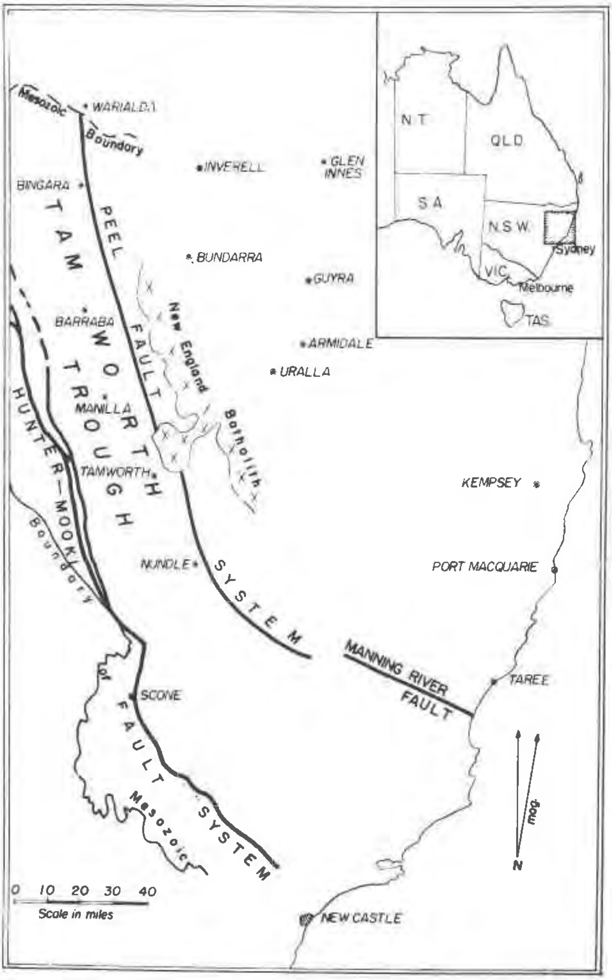

FIG. 1. Locality map (geological data from Voisey, 1959).

The veins occur in several different ways:

(*a*) straight or irregular macroscopic or microscopic veins apparently unrelated to any structural features of the rock.

(*b*) joint fillings

(*c*) bedding veins

(*d*) in fault planes, along the margins of dykes which occupy faults, or in shear zones in dykes.

Those of type (*a*) are the earliest, being cut by joints. As will be shown elsewhere, jointing was the earliest structure formed during deformation

TABLE 1. STRATIGRAPHIC SUBDIVISIONS OF THE TAMWORTH AND PARRY GROUPS

			Eastern and Southern Regions			Western and Northern Regions
Lower Carboniferous	Visean		(not preserved)			"Lower Kuttung Group" (CK)
	Tournaisian	PARRY GROUP	Pyramid Hill Arenite Members (Clp) -1 -2 -3 -4 -4a -5 -6 -7 P- Q- R- S- T- U- V- Va- W- -8 X- -9 Y- -10 Z- -Benama Graywacke Member (Clbg) -Wombramurra Formation (Clw) -Scrub Mountain Conglomerate Member (Cls) -Hyde Graywacke Member (Clh)	Goonoo Goonoo Mudstone (Clg)	Goonoo Goonoo Mudstone (Clg)	-Boiling Down Sandstone Member (Clbs) -Gowrie Sandstone Member (Clgs) -Turi Graywacke Member (Clt) -Garoo Conglomerate Member (Clgc) -Scrub Mountain Conglomerate Member (Cls) -Kiah Limestone Member (Duk)
Upper Devonian			Baldwin Formation (Dub)			Baldwin Formation (Dub)
Middle Devonian		TAMWORTH GROUP (DT)	Yarrimie Formation (Dmy) Silver Gully Formation (Dms)			Yarrimie Formation including Levy Graywacke Member (Dmlg) Silver Gully Formation (Dms)
Lower Devonian			Wogarda Argillite (Dlw) Drik-Drik Formation (Dld) Cope's Creek Keratophyre (Dlc) Pipeclay Creek Formation (Dlp) - - - - - - - - - - - - Hawk's Nest Beds (Dh) Stratigraphic position unknown)			Seven Mile Formation (Dls)

of the area, pre-dating the folding. Thus the joint fillings (*b*) post-date type (*a*). The bedding veins (*c*), which are clearly later than the joint fillings, where intersections occur, are probably related to the folding, as relief of load pressure would be necessary for material to be deposited along bedding planes.

The veins of type (*d*) are probably also related to the folding. In another place the faults and shears in which they occur will be shown to be related to the folding or to be later than it. Veins of type (*d*) may therefore be considered as roughly contemporaneous with those of type (*c*).

TABLE 2. PROPERTIES OF VEIN MINERALS

No.	Formation and Position	Vein Type	CO$_3$	Laumontite		Stilbite		Epidote	Prehnite	Quartz p (present) m (minor)
			ω	β	Z∧c	α	γ	β	β	
W5	Clg below Clp$_8$	d	1.658	1.516	13°					
W106	Clg above Clp$_4$	c		1.520	10°					
W111	Clg above Clp$_4$	b^3								
W112	Clg above Clp$_4$	c	1.658	1.520	—					
W125	Clg below Clp$_8$	b				1.494	1.503			
W145	Clg below Clp$_7$	b				1.494	1.505			
W146	Clg below Clp$_7$	–^{1}	1.658	1.515	36°					
W152	Clg below Clp$_8$	–	1.658							
W153	Clg below Clp$_5$	–	1.658			1.492	1.505			
W154	Clg below Clp$_8$	–	1.658							
W160a	Clg above Clp$_8$	d	1.658 and also anom. biaxial $\beta=1.632$; $\gamma=1.640$ (strained)							
W160b	Clg above Clp$_8$	d	1.658	1.517	50°					
W174	Clg above Clp$_4$	d	1.658			1.489	1.503			m
W177	Clg above Clp$_{5a}$	–		1.517	36°					
W180	Clg above Clp$_8$	b				1.489	1.505			
W183	Clg bet. CK & Clp$_4$	b				1.489	1.503			
R964	Dmy	a						1.764		p
W282a	Clg below Clp$_5$	d		1.517	46°					
R965	Clp$_9$?	–^{3}	pres.						1.620	p
W331	Clg above Clbg	d	1.658							
W340b	Clbg	–	1.658					1.764		p
W353a	Clbg	–							1.620	p
W369	Clg (low)	–						v. minor		p
W402	Dmy	–	1.682							p
W487	Clw	a	1.658						1.621	p
W489	Clw	a						1.748		p
W498	Clw	a						1.753		p
W583	Dmy	a								p
W608	Clg below Clp$_8$	b		1.514	41°	1.489	1.505			
W615	Clg above Clp$_8$	c		1.517	41°					
W623	Clg above Clp$_{5a}$	b				1.489	1.504			
W626	Clg below Clgc	–		1.517	41°					
W630	Clg below Clgc	c	1.658	1.517	16°; 43°					
W658	Clg below Clp$_x$	–	1.658							
W661	Clg below Clp$_x$	a	1.658							p
W673	Clg below Clp$_9$	–	1.658	1.517	36°					
W682	Clp$_7$	d							1.621	p
W691	Clg below Clp$_8$	c		1.517	16°; 36°					
W700	Clg below Clp$_8$	b^3								
W701	Clg below Clp$_8$	c	1.658	1.517	26°; 53°					p
W705	Clg below Clp$_8$	b	1.658	1.517	16°	1.490	1.505			
W706	Clg above Clp$_8$	d	1.658							
W707	Clg below Clp$_8$	d		1.517	49°					
W726	Clg above Clgs	–	1.658						1.621	
W730	Clg above Clgs	d^3	1.658	1.517	16°; 42°	1.489	1.504			
R966	Clg above Clgs	d	1.658	1.517	45°				1.634	p
W879	Clp$_x$	c								p
W876	Clp$_9$	d	1.658 1.704							
W898	Cls	–							1.621	p
W909	Clg below Cls	b	1.658							
W917	Dms	a	1.658							
W932	Dmy	–		1.517	40°					
W941	Dlw	a						1.750		
W949	Clg below Clp$_R$	d	1.658	1.517	45°					
R967	DT (?Dms)	a^3	1.658					1.750		
W956	DT (?Dms)	a^3								
R968	DT (?Dms)	a	1.658^2					present	present	p
W1051	Dub	–	1.658	1.517	43°					
W1098	Dmy	–	1.658							p
R970	Dub	a	1.658	minor				present		p
W1106	Dub	b				1.489	1.506			
W1114	Clg above Duk	–^{3}								p
W1116	Clg sl. above Duk	–							1.615	p
W1141	Clp$_Y$?	–	1.658							
W1142	Clg below Cls	d	1.658	1.517	41°					
W1143	Clg below Clp$_{5a}$	–	1.658	1.517	45°	1.489	1.505			
W1147	Clpz	–	1.658					1.751		p
W1147a	Clpz	–						1.752	1.617	p
W1147b	Dms	–	1.658							
W1151	Clw	a							1.615	p
W1155	Dld	–				?altered-agg. pol. $n=1.53$				
W1167	Clg below Clp$_{10}$	a						1.755		p

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[1] "–" indicates data on type not recorded in field-book.
[2] Also contains chlorite and muscovite.
[3] Axinite present as follows: R967, $\beta=1.680$; W956, $\beta=1.684$.
Heulandite present in W111, $\beta=1.502$, W700, $\beta=1.505$; W1114, $\beta=1.497$.
Pumpellyite present in R965, and in R966; $\beta=1.690$–1.700.

MINERALOGY

The following minerals have been encountered in the veins, and will be discussed in order:

- carbonates
- laumontite
- stilbite
- heulandite
- prehnite
- pumpellyite
- epidote
- axinite
- chlorite
- muscovite
- quartz
- albite
- bytownite

Carbonates: Calcite is by far the most common carbonate, and is remarkably pure. It is usually white en masse, and colorless and transparent in crushed fragments. Thirty-seven determinations give $\omega = 1.658 \pm 0.002$. In one case (W160*a*) optically anomalous carbonate occurs with calcite. This shows $\beta = 1.632 \pm 0.002$, $\gamma = 1.640 \pm 0.002$ and 2V(−) *ca.* 10°. It has wavy extinction, and the anomalous optics are apparently due to strain.

In only two cases have carbonates other than calcite been encountered. These are W876 from Member 9 of the Pyramid Hill Arenite (a brown carbonate) and W402 from the Yarrimie Formation. These have

W876 $\omega = 1.704 \pm 0.003$ (occurs with calcite)

W402 $\omega = 1.682 \pm 0.002$.

Both are uniaxial negative. The refractive index determinations suggest dolomite.

Carbonate occurs throughout the sequence, having been encountered as far down as the Silver Gully Formation.

Laumontite is also widespread, usually in bedding veins or faults. It occurs as silky white columnar prismatic crystals, showing good cleavage, and often forms acicular clumps. It is usually associated with calcite. Twenty-three determinations give $\beta = 1.514$ to 1.520, 2V(−) ca. 30°.

The extinction angle ($Z\Lambda c$) varies between 10° and 53°. Usually the central parts of grains give lower values, about 16°, whilst the margins give values about 42°. The junction between the optically different materials is irregular, but sharp. At times the two types of material are arranged so as to simulate complex twinning, giving a patchy extinction.

This variation in optical properties has been discussed by Coombs (1952) with whose data the present data are in good agreement. He has shown that the variation is due to the laumontite becoming modified to leonhardite by loss of water. Laumontite is characterized by higher refractive indices and a much smaller extinction angle than its leonhardite equivalent. In this study the mineral is termed laumontite in general discussion, regardless of its state of hydration, following Coombs (1952, p. 819), who points out that the hydration state of the mineral may vary with the weather.

Laumontite extends down the sequence to the upper part of the Yarrimie Formation, but is most common in the upper parts of the sequence.

Stilbite occurs as regular aggregates of pink, or rarely white, columnar crystals in joint planes, the aggregates being oriented with their long axes perpendicular to the joint surfaces. It rarely has associated minerals.

Stilbite has one good cleavage parallel to the optic axial plane, and as the mineral tends to lie on this cleavage in the crush, determination of 2V or β is well-nigh impossible without resorting to a U-stage. In cases where rough estimation has been possible 2V(−) is small. Refractive indices (12 determinations) give: α: 1.489 ± 0.002 to 1.494 ± 0.002; γ: 1.503 ± 0.002 to 1.506 ± 0.002.

Stilbite is almost completely restricted to the upper part of the sequence, although an isolated occurrence in the Baldwin Formation has been noted.

In the Drik Drik Formation, joints are filled with a pink mineral of similar morphology to the stilbite. Optical examination (W1155) however shows it to be an aggregate polarizing mass with low D.R. and $n = ca.\ 1.53$. An x-ray powder photograph suggests albite.

Heulandite occurs in joints, usually as salmon pink to red plates lying on the joint surfaces. Only three examples have been noted.

Since heulandite has one good cleavage normal to the optic axial plane ($\perp$ to Z), most grains give good Bx_a figures. Data obtained are: 2V(+) small, $\beta = 1.497 \pm 0.002$, 1.502 ± 0.002, 1.505 ± 0.002.

Because of the few occurrences, the stratigraphic distribution of heulandite is rather ill-defined. The lowest occurrence is below the Scrub Mountain Conglomerate Member.

Prehnite occurs as dull white usually fibrous masses often associated with quartz. It is largely confined to veins of type (*a*).

Refractive index values (10 determinations) range from $\beta = 1.615 \pm 0.003$ to 1.634 ± 0.003, indicating a somewhat variable composition with an upper limit of about 3% Fe_2O_3. Birefringence is moderate to low with 2V(+) large and straight extinction. Cleavage is good; absorption is variable and may be strong.

In one case (R966) optically anomalous prehnite (cf. Winchell, 1951, p. 360) was encountered. This has $\beta = 1.634 \pm 0.003$, 2V(+) small, $r < v$ strong, and wavy extinction. Other parts show anomalous blue interference colors, 2V(+) *ca.* 30° and $r > v$ very strong.

Prehnite in megascopic veins extends from near the horizon of Member 6 of the Pyramid Hill Arenite to below the Scrub Mountain Conglomerate Member, with an isolated occurrence in the Tamworth Group. Evidence from microveins, however, extends this distribution to range from Member 3a of the Pyramid Hill Arenite to the upper part of the Silver Gully Formation.

Pumpellyite has been encountered only in three veins in the middle of the sequence.* One is in a sheared dyke above the Gowrie Sandstone Member (R966). The others are in veins of type (*a*), one megascopic, the other microscopic, from lower in the sequence. The mineral is deep green, and occurs in granular aggregates of small subhedral crystals.

Pumpellyite from R966, accompanied by prehnite, quartz, and later laumontite and calcite, gives:

X = almost colorless $\gamma-\alpha=$ ca.0.018
Y = bright green $\beta=1.690-1.700$, apparently variable
Z = almost colorless
2V(−)large $r>v$ strong, wavy extinction
fine prismatic crystals (0.02×0.004 mm.) elongated parallel to *b*, Y‖*b*.

These data suggest a pumpellyite containing 6–7 wt.% of Fe_2O_3, using the graphs of Coombs (1953, p. 131).

An *x*-ray powder photograph of this pumpellyite gave data which agree closely with the pumpellyite examined by Coombs (1953, p. 121) from Calumet, Michigan.

Epidote characteristically forms apple-green granular aggregates associated with quartz, and usually occurs in veins of type (*a*).

X = Z = colorless $\beta=1.748\pm0.004$ to
Y = pale yellow green 1.764 ± 0.004
2V(−) ca.70° to 2V(+) large $r>v$, slight.

The refractive indices suggest a range of from 25 mol.% to 35 mol.% of $HCa_2Fe_3Si_3O_{13}$. In one case (W1104), possible zoisite was encountered.

Epidote ranges downwards from below Member 10 of the Pyramid Hill Arenite, and has been encountered as low as the Wogarda Argillite.

Axinite occurs as purple plates in veins in spilites in the Tamworth Group at Bowling Alley Point (cf. Benson 1913, p. 577). Data follow:

2V(−) ca.70°; $r<v$ strong, $\beta=1.680\pm0.004$, again 1.684 ± 0.002, D.R. low; pleochroic: pale violet (fast) to colourless (R967, W956).

Axinite from Bowling Alley Point was described crystallographically by Anderson (1906, p. 133). The exact stratigraphic position of the local-

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* This was the first known recognition of pumpellyite in Australia. It has since been recognized by Wilshire (pers. comm.) in the Prospect Lopolith near Sydney, and elsewhere.

ity is uncertain, but it is close to the junction of the Yarrimie and Silver Gully Formations.

Chlorite occurs rarely in veins of type (*a*). Three occurrences, two in microveins, of pale green chlorite have been noted in the Tamworth Group.

Muscovite: One example of this, associated with epidote, quartz, calcite, prehnite and chlorite, occurs in a vein in the Tamworth Group.

Quartz occurs as milky white aggregates, usually unstrained and without crystal form. Veins of type (*a*) are the most common. It is distributed through the sequence from below Member 5*a* of the Pyramid Hill Arenite downwards, although traces occur in a vein above Member 4 of the same unit (W174). This accords reasonably with the observations of Carey (1937, p. 339), and Engel (1954, p. 20) who noted that quartz veins in the areas examined by them (northwest of the present area) are restricted to the Barraba Mudstone (*i.e.* the lower parts of the Parry Group, herein). They did not examine the Tamworth Group.

Albite has been noted only in microveins in the Tamworth Group. It occurs as small, albite-twinned laths often associated with quartz (R921, 937) or calcite (R919, 921, 933) and occasionally prehnite or chlorite. Both lithic and feldspathic labile graywackes may carry these veins.

Bytownite: R957, a hornfelsed argillite from the Hawk's Nest Beds, contains a thin quartz-bytownite-amphibole vein of type (*a*) with minor sphene and apatite. The bytownite is clear, with multiple twinning and moderate relief, $\beta = 1.576 \pm 0.002$ giving a composition of An_{82} (mol.%) derived from the graph of Poldervaart (1950).

PARAGENESES OF VEIN MINERALS

Determinations of parageneses on several multicomponent veins are shown in Table 3. Sequences have been determined by noting the order of deposition in the case of open space fillings, and also by the relationships between the minerals shown in the case of intersecting veins. Development of crystal facies has also been used as a criterion. In some cases contemporaneous deposition appears to have occurred. The most common sequence of deposition follows: epidote, pumpellyite, prehnite, quartz, stilbite, laumontite, calcite. This paragenetic sequence is similar to the major trend observed for the cement in the sediments (Crook, 1961*c*), except that quartz in the vein paragenetic sequence is somewhat later. In the vein paragenetic sequence, as in the cements, the earliest minerals to form are those characteristic of the lower portions of the stratigraphic sequence.

Two veins amongst those described deserve further comment. W1155,

TABLE 3. PARAGENESES OF VEIN MINERALS

			—— Order of deposition ——→				
epidote,		prehnite, muscovite, chlorite,		quartz,			calcite
epidote,				quartz			
	pumpellyite,	prehnite,		quartz,		laumontite,	calcite
		prehnite,					calcite
				quartz			calcite
						laumontite,	calcite
					stilbite,	laumontite,	calcite
			heulandite,	quartz			
					stilbite,		calcite, laumontite
		prehnite,	calcite,	quartz			
quartz, epidote,			calcite				
	pumpellyite			quartz		prehnite	calcite

Underlined pairs represent contemporaneous deposition.

which bears probable albite pseudomorphous after stilbite, occurs as a joint-filling, an occurrence unknown for albite elsewhere in the sequence It may have formed as a stilbite vein, and later been metasomatized by the addition of NaAl and loss of Ca, SiO_2 and H_2O, during the period of formation of the laumontite facies veins in the upper part of the sequence (see below).

R957 bears the extraordinary assemblage quartz-bytownite-amphibole and occurs in the contact aureole of the post-orogenic Mt. Ephraim Granite in a biotite-actinolite hornfels. This vein can scarcely be genetically related to the granite magma. The most likely origin would seem to lie in thermal metamorphism of a pre-existing laumontite-chlorite vein. At temperatures characteristic of the albite-epidote hornfels facies, laumontite will form anorthite-quartz according to the reaction:

$$\underset{\text{laumontite}}{CaAl_2Si_4O_{12}\cdot 4H_2O} \rightarrow \underset{\text{anorthite}}{CaAl_2Si_2O_8} + \underset{\text{quartz}}{2SiO_2} + 4H_2O$$

As laumontite usually bears some Na, the resultant plagioclase will not be pure anorthite. The amphibole could have formed from a chlorite by the usual metamorphic reaction.

STRATIGRAPHIC DISTRIBUTION OF THE VEIN MINERALS

Figure 2 shows the stratigraphic distribution of the more common vein minerals. Carbonate occurs throughout. Laumontite, stilbite and heulandite tend to be confined to the middle and upper portions, pumpellyite to the middle portions, quartz and prehnite to the basal-upper portions and below, epidote to the lower-middle and lower portions, and albite to the lower portions.

Comparison of these results with the results obtained for the same species (or related species) occurring as diagenetic modifications (Fig. 3) (see also Crook, 1961*c*) is instructive. In each, calcite occurs throughout the sequence. Prehnite, epidote and albite have roughly the same distribution in each, and quartz has a distribution resembling that of the quartz cement in the feldspathic labile arenites, but appears slightly higher in the sequence. Pumpellyite apparently occurs slightly higher in the sequence as veins, but data are meager.

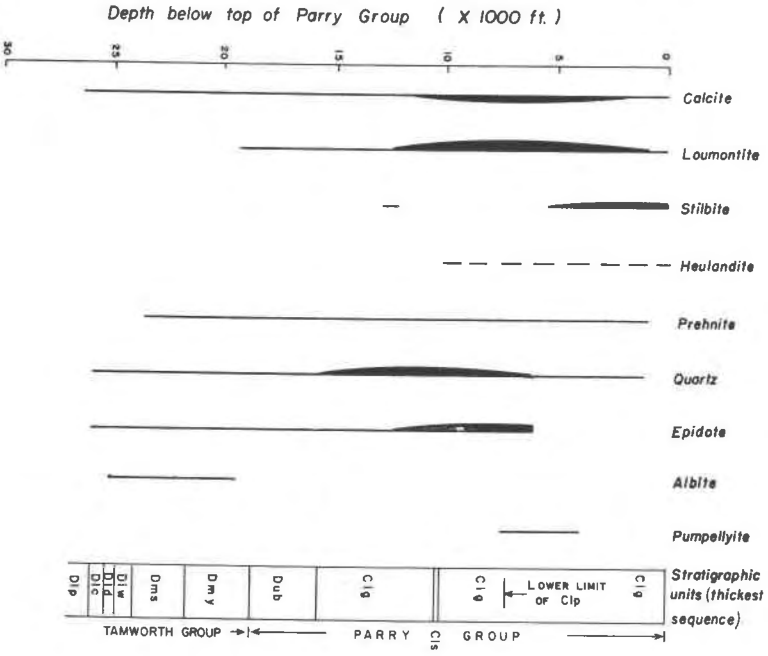

FIG. 2. Stratigraphic distribution of vein minerals.

The zeolites show the most noticeable differences. In comparison with the zeolitic modifications of the detrital feldspar, which range further downward than zeolitic cements, the vein laumontite, heulandite, and and possibly also the stilbite range still further downward, extending into the Yarrimie Formation in the case of laumontite.

MINERAL FACIES REPRESENTED

Analysis of Table 2 and the data from microveins shows that the following assemblages can be recognized in the veins:

1. stilbite ± calcite (+quartz)
2. heulandite (+quartz)
3. laumontite ± calcite (+stilbite, quartz)
4. prehnite ± pumpellyite ± quartz ± calcite
5. epidote ± quartz ± calcite (+prehnite)
6. axinite ± epidote ± calcite
7. albite ± quartz ± calcite (+prehnite, chlorite)
8. calcite ± quartz
9. quartz

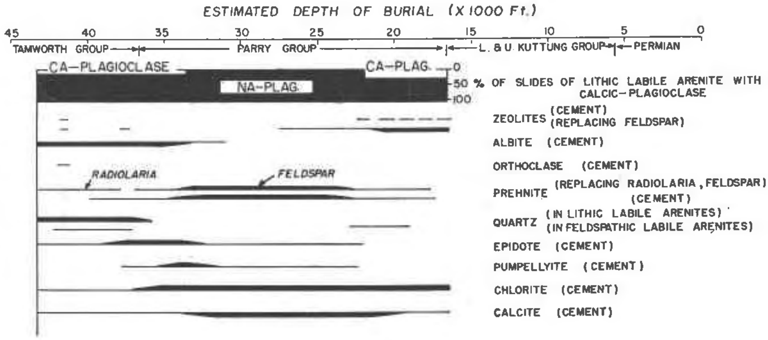

FIG. 3. Stratigraphic distribution of diagenetic minerals.

In the above list species which appear in brackets occur rarely. Some veins listed in Table 2 bear laumontite and calcite together with either prehnite or epidote. In these cases the laumontite and calcite is clearly later, and the veins may be considered as a combination of assemblages 3 and 4 or 5.

The above assemblages may be divided into four groups: 1–3 which represent the zeolite facies of Coombs *et al.*, (1959); 4 representing the prehnite-pumpellyite mineral facies; 5 and 6 representing the albite-epidote mineral facies; and 7–9 which do not bear diagnostic minerals. The two stages of the zeolite facies described by Coombs *et al.* (1959) are present: 1 and 2 represent the heulandite-analcite stage (or subfacies) and 3 the laumontite stage.

The minerals of assemblages 4 to 7 occur in veins of type (2) which are pre-deformational. They are also the early minerals in the paragenetic sequence. Their stratigraphic distributions are similar to those of the same species occurring as diagenetic modifications. There seems little doubt, therefore, that the veins of the albite-epidote and prehnite-pumpellyite mineral facies are of diagenetic origin. As noted by Ellis and Fyfe (in Coombs *et al.*, 1959), quartz becomes a prominent component in the veins only in the prehnite-pumpellyite and higher-grade facies.

The veins representing the zeolite facies are of types (*b*), (*c*) and (*d*), and are syn- or post-deformational. Their minerals come late in the paragenetic sequence, and have stratigraphic distributions different from those of the same species occurring as diagenetic modifications. Veins of this facies, therefore, are probably not related to the diagenesis of the sequence, but to a later, and different, P-T regime.

Veins of the heulandite-analcite subfacies are of type (*b*), and are older than those of the higher grade laumontite subfacies, which occurs as veins of types (*c*) and (*d*). This indicates a reversal of the trend towards lower-grade modifications, and it apparently occurred during and after folding, as the bedding and fault veins (*c* and *d*) formed at this time.

Ellis and Fyfe (in Coombs *et al.*, 1959, p. 83) have pointed out that where $P_{load} = P_{H_2O}$ in the rock, decrease in water pressure in open fissures due to osmotic conditions enables the formation of higher grade assemblages in the fissures than those being formed in the rock. In the Tamworth Trough sequence the vein minerals are either of the same facies as those formed in the rock, or of lower-grade facies. This suggests that, whatever the P-T conditions operating during vein formation, they could not have arisen simply by lowering of P_{H_2O}; temperatures must have dropped as well.

In summary the veins in this sequence indicate the following history. After modification at the temperatures and pressures obtaining during diagenesis (see Crook, 1961*c*), there was a decrease in temperature, and probably of water-pressure also, allowing the deposition of minerals of the heulandite-analcite subfacies on the joints in the sediments. Later, during folding, and particularly during subsequent faulting, there was an increase in water-pressure, or in temperature, or both, permitting the deposition of the veins of the laumontite subfacies along bedding planes and in faults.

CaAl-silicates in veins cutting diagenetically modified sediments and other rocks are probably of common occurrence, although they are not often noted. Niggli *et al.*, 1940, p. 576 record prehnite and later laumontite in the "Alpine Cleft" deposits of Switzerland. The author has noted heulandite, analcite, and laumontite-bearing veins filling joints and fractures in Cretaceous and Lower Tertiary labile sandstones in the Rocky Mountains Foothills of Alberta. Coombs (Coombs *et al.*, 1959) has described prehnite, pumpellyite, laumontite and stilbite veins in New Zealand sediments, pointing out that they are later than the metamorphic maximum, and have a retrogressive significance being correlated "with the filling of fractures under conditions of progressively decreasing load and temperature during denudation." The Tamworth Trough zeolite-facies veins also have a retrogressive significance, but show a reversal of the trend to lower P and T, in that the higher grade laumontite postdates the stilbite.

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REFERENCES

ANDERSON, C. (1906), Mineralogical Notes: No. III—Axinite, petterdite, crocoite and datolite. *Aust. Mus. Rec.*, **6,** 132–144.

BENSON, W. N. (1913), The geology and petrology of the Great Serpentine Belt of New South Wales. Part II. The geology of the Nundle district. *Proc. Linn. Soc. N.S.W.*, **38,** 569–596.

CAREY, S. W. (1937), The Carboniferous sequence in the Werrie Basin. *Proc. Linn. Soc. N.S.W.*, **62,** 341–376.

COOMBS, D. S. (1952), Cell-size, optical properties and chemical composition of laumontite and leonhardite with a note on regional occurrences in New Zealand. *Am. Mineral.*, **37,** 812–830.

——— (1953), The pumpellyite mineral series. *Mineralog. Mag.*, **30,** 113–135.

———, ELLIS, A. J., FYFE, W. S., AND TAYLOR, A. M. (1959), The zeolite facies; with comments on the interpretation of hydrothermal syntheses. *Geochem. Cosmochem. Acta*, **17,** 53–107.

CROOK, K. A. W. (1960a), Petrology of Tamworth Group, Lower & Middle Devonian, Tamworth-Nundle district, New South Wales, *J. Sedim. Petrol.*, **30,** 353–369.

——— (1960b), Petrology of Parry Group, Upper Devonian-Lower Carboniferous, Tamworth-Nundle district, New South Wales. *J. Sedim. Petrol.*, **30,** 538–552

——— (1961a), Stratigraphy of the Tamworth Group (Lower and Middle Devonian), Tamworth-Nundle District, N.S.W. *J. Proc. Roy. Soc. N.S.W.*, **94,** 173–188.

——— (1961b), Stratigraphy of the Parry Group (Upper Devonian-Lower Carboniferous), Tamworth-Nundle district, N.S.W. *J. Proc. Roy. Soc. N.S.W.*, **94,** 189–207.

——— (1961c), Diagenesis in the Tamworth and Parry Groups (Devonian and Lower Carboniferous), Tamworth-Nundle district. In preparation.

ENGEL, B. A. (1954), The geology of the south-eastern portion of the County of Darling. B.Sc. Honours Thesis, University of New England.

NIGGLI, P., KOENIGSBERGER, J., AND PARKER, R. L. (1940), Die Mineralien der Schweizeralpen. Bd II., 307–661, Wepf and Co., Basel.

POLDERVAART, A. (1950), Correlation of physical properties and chemical composition in the plagioclase, olivine and ortho-pyroxene series. *Am. Mineral.*, **35,** 1067–1079.

VOISEY, A. H. (1959), Tectonic evolution of north-eastern New South Wales, Australia. *J. Proc. Roy. Soc. N.S.W.*, **92,** 191–203.

WINCHELL, A. N. AND WINCHELL, H. (1951), Elements of optical mineralogy. Part II. Description of minerals. 4th ed. J. Wiley and Sons, New York.

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