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## 7.—Analyses of Western Australian iron meteorites

by  
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### Abstract

All available analytical data on iron meteorites found in Western Australia are presented. The contents of nickel, cobalt, gallium and germanium in 33 of these meteorites was determined using X-ray fluorescence spectrometry, thus enabling these meteorites to be classified structurally and chemically. The new analytical data enabled a number of paired falls to be distinguished.

### Introduction

The first recorded discovery of meteorites in Western Australia occurred in 1884 in the sub-district of Youndeggin, some 110 km east of the town of York. Four pieces were recovered, and a description and chemical analysis of the largest of these specimens was given by Fletcher (1887). The analysis revealed a new type of graphitic carbon which was named cliftonite by Fletcher, who realised that its presence could be a significant clue to the origin and formation of meteorites.

In fact meteorites contain far more information about the early solar system than was once believed (Anders 1971), and analytical data which have accumulated in the past two decades have played no small part in our present understanding of the formation, evolution and chronology of the solar system. The monumental work of Suess and Urey (1956) on the abundances of the elements, depended largely on meteorite abundance data. This work enabled theories of element formation to be formulated, and the work of Burbidge *et al.* (1957) for example, depended to a large extent on the abundance table of Suess and Urey. Meteorite abundance data has continually been refined over the past decade and the recent abundance table of Cameron (1968) draws heavily on this information. It is probably true to say that our present understanding of nucleosynthetic processes in stars would not have been attained if accurate analyses of meteoritic material had not been available.

It is significant that all the early meteorite discoveries in Australia were siderites (irons). The first Catalogue of Western Australian meteorites (McCall and Delaeter 1965) lists 29 irons, 4 stony irons and 15 stones. There were almost twice as many irons as stones, despite the fact that on a world-wide basis the situation is almost the reverse (Mason 1962). This is undoubtedly due to the fact that irons are much more easily recognised than are stony meteorites, and in Australia with its deserts and large

areas of arid land, irons are preserved for a much greater length of time than stony meteorites. Again it is probably significant that the Australian aborigine was not cognisant of the use of metals, and therefore had little interest in iron meteorites which may have been discovered.

Since the publication of the Catalogue in 1965 a number of new meteorites have been reported, and many of these have now been incorporated in the Collection. This has necessitated the publication of a Supplement to the Catalogue (McCall 1968) and a second Supplement is now in preparation.

Many meteorites found in Western Australia have been extensively studied both in Australia and overseas. This interest is partly due to the pioneering work carried out by the late Government Mineralogist, Dr. E. S. Simpson who published a number of papers describing local meteorites over a period of nearly 40 years. Simpson always took great care to analyse the iron meteorites for the major elements—iron, cobalt and nickel, and for the minor elements copper, phosphorus, sulphur and carbon. Many of his results are extremely accurate and have been summarised in this work.

### Analytical method

In this paper an attempt has been made to tabulate all the analyses that have been carried out on Western Australian iron meteorites. It is true that some of the earlier data can no longer be regarded as reliable, but it was felt that a complete record should be made at this time. On the other hand, where a number of analyses have been made by various authors, a recommended value has been given.

The evaluation of analytical data for iron meteorites is by no means a simple task, and, as Moore *et al.* (1969) has pointed out, is sometimes more difficult than for stony meteorites, despite the simpler composition of siderites. In general analysts avoid using samples which include large troilite or schreibersite inclusions. Thus most analyses are not representative of the meteorites as a whole, but only of the metallic phase. For example the sulphur values usually refer to the metallic phase, but this is by no means obvious from many of the original publications. Certainly the sulphur content of the meteorite itself will be significantly different if troilite occurs to any extent. Again iron meteorites are inhomogeneous, and unless adequate sized samples are analysed, there can be no guarantee that the results are typical for the meteorite as a whole.

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A more serious problem is that of evaluating accuracy and precision, particularly when different analysts and analytical techniques are involved. Work on the silicate rock standards G-1 and W-1 has shown that there is an alarmingly wide spread in the results obtained by different analysts, or even by the same analyst at different times. (Fairbairn *et al.* 1951). Lest it be imagined that with the advent of modern methods of analysis such disparities no longer exist, it is instructive to examine the paper of Fleischer (1969) where new analytical data on these standard rocks is summarised.

There is no reason to believe that the situation is any better for iron meteorites than for silicate rocks. In fact the present study reveals large scale discrepancies between analyses carried out on the same meteorite. Cobalt, for example, has invariably been overestimated in the old analyses.

The elements in iron meteorites may be divided into four groups. Firstly, the major constituents of the metallic phases—iron, nickel and cobalt. These three elements usually account for over 99% of the total composition of iron meteorites. Secondly the important trace elements gallium, germanium and iridium on which a chemical classification has recently been devised. Thirdly, the elements found dissolved in the metallic phases and in non-metallic mineral inclusions—carbon, phosphorus, chromium, sulphur and nitrogen. Finally the trace elements such as copper, zinc and the noble metals. In point of fact almost every non-gaseous element occurs in iron meteorites, but unfortunately very few analyses have been made on these trace elements in the Western Australian iron meteorites.

In addition to summarising the analytical data which could be located in the literature, each meteorite was analysed for nickel, cobalt, gallium and germanium as part of the present project. Nickel and cobalt, are major constituents of any iron meteorite, and traditionally have always been regarded as essential analytical data. In point of fact cobalt is not particularly useful in classifying siderites, since its abundance range is very limited. The nickel content of an iron meteorite has long been recognised as one of the essential criteria used in classifying siderites, and it still serves an important role in any structural or chemical classification.

The importance of determining the content of gallium and germanium has been recognised only in recent years. The significance of these elements stems from two main factors. Firstly, gallium concentrations in iron meteorites can vary by a factor of 400, and germanium concentrations by a factor of 14,000. These ranges may be contrasted with cobalt, where the concentrations do not vary by more than a factor of 2, and for nickel where it is unusual for the range in concentration to be greater than 4. Secondly, gallium and germanium concentrations in iron meteorites are highly correlated to each other and to nickel, and in addition are quantised into a number of distinct groups. After

early work by Goldberg *et al.* (1951) and Lovering *et al.* (1957), J. T. Wasson and his associates determined the abundances of gallium, germanium, nickel and iridium in several hundred meteorites in order to elucidate the classification of iron meteorites, (Wasson 1967b, Wasson and Kimberlin 1967, Wasson 1969, Wasson 1970, Wasson and Schaudy 1971).

On the basis of their analytical data, which were determined mainly by neutron activation analysis, eleven resolved chemical groups have been defined. It is believed that the groups may represent different meteorite parent bodies or perhaps regions within a parent body characterised by different chemical or thermal environments (Anders 1964). This chemical classification has been used in the present work.

A Siemen's S.R.S.-1 X-ray fluorescence spectrometer equipped with a molybdenum tube, lithium fluoride crystals and a scintillation detector was used for the analyses. A flat surface on each of the meteorites was polished with successive grades of carborundum paper until a smooth, highly polished surface at least 1.25 cm in diameter was prepared. This surface was exposed to the primary X-ray beam, and peak and background readings were taken for each of the four elements. The spectrometer was calibrated for each element by standard alloys and from a number of siderites with well-established composition. Details of the technique will be presented elsewhere (Thomas and DeLaeter 1972).

The nickel, cobalt, gallium and germanium values measured in the project, must be qualified by error limits of  $\pm 0.02\%$ ,  $\pm 0.05\%$ ,  $\pm 10$  ppm and  $\pm 10$  ppm respectively. These errors represent the 95% confidence limits based on counting statistics of the experiment and the calibration of the instrument. They make no allowance for the heterogeneity of the sample. X-ray fluorescence spectrometry possesses the advantage of being non-destructive, but it suffers from the serious disadvantage of sampling only a very small volume of the specimen. The infinite thickness of an iron meteorite to the X-radiation used in this experiment was only of the order of a few thousandths of a cm, whilst the area of the incident X-ray beam was approximately 1.2 sq cm.

In an effort to overcome this deficiency, each sample was analysed in at least two positions, but this did not alter the fact that the statistical errors stated above are probably less than the possible inhomogeneity errors imposed by the technique itself. The latter errors are certainly worse for the coarse octahedrites than the fine-grained siderites.

## Results

Table 1 lists the classification, specific gravity, cooling rate and contents of the elements nickel, cobalt, gallium, germanium and iridium for the 37 iron meteorites which have been found in Western Australia. Multiple entries have been made for Mount Edith I and II, Premier Downs I and II and the Youndegin meteorites. There

**TABLE 1**

*Classification and major element analyses of iron meteorites*

Name	*Classification		Specific gravity	Cooling rate °C/10 <sup>6</sup> yr.	Ni %	Co %	Ga ppm	Ge ppm	Ir ppm	†References
	Structure	Chemistry								
Avoca (Western Australia)	Om	111A	7.8		8.86	0.52	21.9	48		This work 1
					8.65	0.52				2
					8.76	0.52				Recommended value
Balfour Downs	Om-Og	1	7.8	1.5	8.45	0.50	58.4	194		This work 3
					8.33		56.4	194	2.0	4
					8.39	0.52				5
					8.31	0.51	62.1	194		1
										Recommended value
Ballinoo	Opl	110	7.8	~200	9.84	0.54	41	103		This work 6
					10.06	0.54	44	91	9.0	7
					9.72		39.0	94.4		8
					9.8					9
					8.85	0.74				10
					9.87	0.60				11
							33	100		12
					9.86	0.55	39	95		Recommended value
Dalgaranga			6.8		8.40	0.45	40	59		This work 13
					8.63					Recommended value
					8.45					
Duketon	Om	111A	7.8		7.61	0.49		40		This work 1
					7.25	0.49	21.2			14
Cosnells	Anom.	1-An3	7.6		6.04	0.45	49	252		This work
Gundaring	Om	111A	7.7	4	8.18	0.50	10	50		This work 6
					8.18	0.5				13
					8.32	0.61	19	38		7
					8.22	0.53	16	43		Recommended value
Haig	Om-Og	111A	7.8		6.93	0.49		32		This work 11
					7.36					1
					7.0		16.2			Recommended value
Kimmerina	Opl	110	7.8	~100	9.61	0.54	37	95		This work 3
					9.55					13
					9.69		36.8	93.4	8.1	8
							39.3			1
					9.64		37	91		Recommended value
Landor	Opl									13
Loongana Station (iron)	Om	Anom.	6.9		7.78	0.47	62	179		This work 11
					7.4					Recommended value
					7.7					
Milly Milly	Om	111A	7.8	3.5	7.56	0.49		35		This work 3
					7.45					13
					7.84	0.77				1
							19.9			Recommended value
					7.56	0.50				
Mooranoppin	Og-Ogg	1	7.3	~3.5	6.87	0.45	84	346		This work 6
					6.91	0.50	79	396		7
					7.21	0.88				15
					6.90	0.48	81	370		Recommended value
Mount Doofing	Anom.	1-An3	7.7		6.05	0.45	60	233		This work 7
					6.41	0.48	61	193		4
					6.26		51.5	234	1.2	15
					5.96	0.64				1
							57.8			1
					6.20	0.47	57	225		Recommended value
Mount Edith I	Om	111B	7.5	2						This work 6
					9.40	0.55	15	33		7
					9.45	0.75				15
					9.6		20.1	38.4		16
							20.5	34		12
					9.45	0.625				11
					9.48	0.55				Recommended value

Classification and major element analyses of iron meteorites—continued

Name	*Classification		Specific gravity	Cooling rate °C/10 <sup>6</sup> yr.	Ni %	Co %	Ga ppm	Ge ppm	Ir ppm	†References
	Structure	Chemistry								
Mount Edith II	Om	III B	7.6		9.44 9.18 9.40	0.53 0.66 0.53	27	52		This work 15 Recommended value
Mount Egerton			7.5		6.0 6.38 6.2	0.33	38	112		This work 17 Recommended value
Mount Magnet	D-Opl	Anom.	7.7	50	14.85 14.72 14.56 13.56 14.71	0.57 0.54 0.77 0.56	6.6 6.4 7.53 7.3 7.7 7.3 7.5	8 <1 5.26 5.0 5.3 5.3	0.12	This work 6 7 18 19 12 20 1 Recommended value
Mount Stirling	Og-Ogg	1	7.9	3	6.81 6.93 6.48 6.79 6.72 7.04 6.89	0.45 0.55 0.81 0.44 0.46	93 63 48 86.6 88.6 88	337 409 142 338 350	6.7 1.45 1.45	This work 6 7 8 21 15 22 1 Recommended value
Mundrabilla	Om	Anom.	7.2		7.79	0.48	61 65.1 65	168		This work 1 Recommended value
Murchison Downs	Of	Anom.	7.3		10.0	0.48	20	60		This work
Nuleni	Om	Anom.	7.5		7.1 5.79 7.32 7.2	0.48 0.41 0.48	17.4	54		This work 23 1 24 Recommended value
Premier Downs I	Om	Anom.	7.5		7.72 7.46 7.65	0.48 0.64 0.48	55	179		This work 15 Recommended value
Premier Downs II	Om	Anom.	7.3		7.71 7.58 7.67	0.47 0.89 0.47	56	184		This work 15 Recommended value
Quairading	Og-Ogg	1	7.6		6.73 6.85 6.75	0.45	85	369		This work 11 Recommended value
Redfields	Anom.	Anom.	7.8		6.46 6.65 6.55	0.48 0.48 0.48	41 40.8 40 41	98 93 95		This work 1 25 Recommended value
Roebourne	Om	IIIA	7.7	2.5	7.73 8.04 8.33 7.85	0.51 0.56 0.59 0.53	25 15 19	58 49 53		This work 6 7 10 Recommended value
Tieraco Creek	Of-Om	III B	7.7	1.5	10.33 10.55 10.72 9.66 10.55	0.54 0.60 0.72 0.56	14 13 16.2 16.4 16	28 23 28 28		This work 6 7 16 26 1 Recommended value
Warburton Range	D	IV B	7.9		18.14 18.21 18.20	0.85 0.87 0.86	0.23 0.24 0.24	<4		This work 27 1 28 Recommended value
Wolf Creek	Om	III B	7.2		9.40 8.6 9.23 9.20	0.50 0.4 0.48	27 18.4 20	45 37.3 38	0.04	This work 29 30 Recommended value



Name	*Classification		Specific gravity	Cooling rate °C/10 <sup>6</sup> yr.	Ni %	Co %	Ga ppm	Ge ppm	Ir ppm	†References
	Structure	Chemistry								
Wonyulgunna	Om	111B	7.6	2	8.86 9.05 8.26 8.80	0.51 0.51 0.51	13 21.6 20	43 34 36		This work 6 7 13 1 Recommended value
Yarri	Om	111A	7.8		7.77 8.06 7.91	0.49 0.45 0.47	13	40		This work 24 Recommended value
Youanmi	Om	111A	7.6		7.78 8.08 7.80	0.50 0.87 0.50	20.5	30		This work 13 1 Recommended value
Youndegin I...	Og-Ogg	1	7.85		6.46	0.55	88	312		31 12
Youndegin III	Og-Ogg	1	7.8		6.7 7.01 6.8	0.45 0.93 0.45	87 90.6 90	345		This work 15 1 Recommended value
Youndegin VIII	Og-Ogg	1			6.92	0.49	88	322		7
Youndegin	Og-Ogg	1		~2	6.38 6.94	0.46	90.8	383	2.0	6 4 22

\* The *Structural classification* used is given by Buchwald (Wasson, 1970). The *Chemical classification* adopted is given by Wasson (1967b), Wasson and Kimberlin (1967), Wasson (1969), Wasson (1970) and Wasson and Schaudy (1971).

† *References*—

- |                                 |                                |                               |                                   |
|---------------------------------|--------------------------------|-------------------------------|-----------------------------------|
| 1. De Laeter (1972)             | 9. Hey (1966)                  | 17. McCall (1965)             | 25. De Laeter <i>et al</i> (1972) |
| 2. McCall (1968)                | 10. Ward (1898)                | 18. Wasson & Schaudy (1971)   | 26. Hodge-Smith & White (1926)    |
| 3. Goldstein (1969)             | 11. McCall & De Laeter (1965)  | 19. Simpson (1927)            | 27. McCall and Wiik (1966)        |
| 4. Wasson (1970)                | 12. Smales <i>et al</i> (1967) | 20. Wasson (1967b)            | 28. Schaudy <i>et al</i> (1972)   |
| 5. Wiik & Mason (1965)          | 13. Simpson (1938)             | 21. Wasson (1971)             | 29. Taylor (1965)                 |
| 6. Goldstein & Short (1967)     | 14. Frost (1965)               | 22. Moore <i>et al</i> (1969) | 30. Wasson (1967a)                |
| 7. Lovering <i>et al</i> (1957) | 15. Simpson (1916)             | 23. Simpson (1907)            | 31. Fletcher (1887).              |
| 8. Wasson (1969)                | 16. Wasson & Kimberlin (1969)  | 24. Cleverly & Thomas (1969)  |                                   |

are actually eight separate fragments named Youndegin as detailed by McCall and DeLaeter (1965). Analyses have only been made on Youndegin I, III and VIII. It has not been possible to identify the particular fragment on which analysis by Goldstein and Short (1967), Wasson (1970) and Moore *et al.* (1969) were carried out, and their analyses have therefore been listed under the title "Youndegin".

Two of the 37 meteorites listed are not siderites, but are the metallic pieces of stony-iron meteorites. The first of these, Dalgara, represents material recovered from a meteorite crater and described by McCall (1965) as a mesosiderite with octahedrite nodules. It was one of these nodules which was analysed in the present work. The second, Mount Egerton, has been described by McCall (1965) as a stony iron or possibly an enstatite achondrite usually rich in iron. Cleverly (1968) has examined further recoveries of this meteorite and classified it as an unbrecciated, metal bearing (21%), enstatite achondrite. A piece of the metal phase of Mount Egerton was examined in the present work.

One entry in the Catalogue (McCall and DeLaeter, 1965) is Dowerin, which Simpson (1938) had thought was of meteoritic origin. Only one small 0.35 gm fragment of this "meteorite" was available and when this was subjected

to X ray analysis by Reed (1972) the nickel to iron ratio was found to be <0.2%. It is therefore not a meteorite and has not been listed in the Tables. Another meteorite described by Simpson (1938) as a fine octahedrite is Lander, but as only small fragments were available in the Collection it was impossible to analyse this meteorite except to confirm that it is a siderite.

The structural classification used in this work has been devised by Buchwald (Wasson 1970). This classification has equal logarithmic band width intervals, each octahedrite class corresponding to a range of a factor of 2.5 in kamacite band width. The boundaries have been chosen so that most meteorites belonging to a particular chemical group fall within a single structural class and this procedure minimises the differences between these classes and Tschermak-Prior classes. The chemical classification adopted in Table 1 is based on the nickel, gallium and germanium abundances of the meteorites, as described in the series of papers by Wasson and his associates.

The specific gravities of 32 of the siderites listed in Table 1 were measured as part of the present study. Wherever possible inclusion-free pieces of the meteorite were used for the determinations, although it was not always pos-

sible to be absolutely certain of the absence of troilite or schreibersite inclusions. The weathered outer surface of the meteorites was avoided in determining the specific gravity except for Loongana Station (iron), Murchison Downs, Nuleri and Premier Downs I and II where only the complete meteorites were available. The specific gravity of Mount Egerton has not been recorded since silicate inclusions were contained in the fragment studied, though Cleverly (1968) reports a value of 7.66.

The cooling rates of 13 of the meteorites have also been listed in Table 1. These data are based on electron microprobe measurements of diffusion gradients between gamma and alpha phases of meteoritic nickel iron (Goldstein and Short 1967; Goldstein 1969).

The remainder of Table 1 deals with the abundance data of nickel, cobalt, gallium, germanium and iridium. Only 9 iridium values are quoted, all of which were determined in J. T. Wasson's laboratory.

Table 2 lists all the available data on those minor elements found dissolved in the metallic phases and in non-metallic mineral inclusions. Also listed are a number of trace elements. Zinc and tin have been determined by the stable isotope dilution method using solid source mass spectrometry by Rosman (1972) and DeLaeter and Jeffery (1967) respectively. These data are probably accurate to  $\pm 2\%$  of the quoted values and since at least 1 g samples were dissolved for the experiment, heterogeneity errors should also be minimal. Lovering *et al.* (1957) determined chromium and copper on a number of the samples using emission spectroscopy. Their data should be accurate to  $\pm 5\%$  of the quoted values. The data of Smales *et al.* (1967) on Ballinoo, Mount Edith I, Mount Magnet and Youndegin cover the widest range of trace elements analysed by any of the authors. These data were obtained by neutron activation analysis and the accuracy of the results has been discussed in their paper.

Table 2

Trace element analyses of iron meteorites (in ppm)

Name	C	P	S	Cr	Cu	Zn	As	Mo	Pd	Ag	In	Sn	Sb	†References
Avoca (Western Australia)						1.26								1
Ballinoo		5000 4800 930	300		600									2 3 4 5 6
				59 66	253 233	<1	7.0	8.5	3.8	0.04	<0.01		0.17	
Duketon		2410	300											7
Gundaring				48	156									5
Haig						2.3						0.1		1 8
Kimmerina		920				0.036								4 1 8
												0.7		
Milly Milly	200	2000	100			1.96								9 1 8
												0.15		
Mooranoppin	6700	4200 690		<1	175									10 4 5
Mount Dooling	100	2700	900	28	200 166	12								10 5 1 8
												0.5		
Mount Edith I	200	3500 3200 950	100	<1 5.6	147 147	1.2	12.9	8.5	6.8	<0.01	0.0007		0.11	10 3 4 5 6
Mount Edith II		5000												10
Mount Magnet		500 690		<1 5.3	162 179	<1 <0.4	21.3	4.8	9.3	0.01	<0.01		0.47	11 4 5 6 1 8
												1.2		
Mount Stirling	475 2400	2000 1700	50 60	7.2	145 225	90								12 10 5 1 8
												5.3		



Trace element analyses of iron meteorites (in ppm)—continued

Name	C	P	S	Cr	Cu	Zn	As	Mo	Pd	Ag	In	Su	Sb	†References
Mundrabilla						15.5								1
Nuleri	100	1300												13
Premier Downs I	400	2100	400											10
Premier Downs II	2.47%	3100	Nil		3100									10
Redfields	0.5%		0.1%			0.94								1 8
Rocbourne		1156		44	190									2 5
Tieraco Creek	80	2030	1430	< 1	110	0.92								13 5 1
Warburton Range						< 1 0.026					0.2			6 1 8
Wonyulganna				1.2	118									5
Yarri		1700	40		220									15
Yonanni	500	1500	200		1100									9
Youndegin I		2400 1100												16 4 6
Youndegin II	1500	3000		10.3	14.2	119	36	12	4.9	3.9	0.05	0.012	0.46	10 1 8
Youndegin VI				2.5	155									5
Youndegin	50	2100	300		150									12

† References

- |                              |                                 |                               |                                |
|------------------------------|---------------------------------|-------------------------------|--------------------------------|
| 1. Rosman (1972)             | 5. Lovering <i>et al</i> (1957) | 9. Simpson (1938)             | 13. Simpson (1907)             |
| 2. Ward (1898)               | 6. Smales <i>et al</i> (1967)   | 10. Simpson (1916)            | 14. Hodge-Smith & White (1926) |
| 3. McCall & De Laeter (1965) | 7. Frost (1965)                 | 11. Simpson (1927)            | 15. Cleverly & Thomas (1969)   |
| 4. Reed (1969)               | 8. De Laeter & Jeffery (1967)   | 12. Moore <i>et al</i> (1969) | 16. Fletcher (1887)            |

It is uncertain with what confidence one can quote the pre-1940 analyses of Ward (1898), Simpson (1907, 1916, 1927, 1938), Hodge-Smith and White (1926) and Fletcher (1887). Many of the data given by McCall and DeLaeter (1965) are also pre-1940 analyses performed by a number of analysts, many of whom were employed by the Western Australian Government Chemical Laboratories.

Reed (1969) has analysed a number of the siderites listed in Table 2 for phosphorus, but it should be noted that the analyses refer to the kamacite phase only, and not to the meteorite as a whole. Because of the paucity of analytical information on these minor and trace elements, no recommended values have been given.

Iron was not determined in this study. It is very difficult to determine a constituent making up approximately 90% of a sample with sufficient precision to be comparable with the other measurements. In order to determine an unmeasured component the iron value would have to be precise to four significant figures. Many of the analyses in the literature list iron values, but these were usually determined by difference, and are therefore of doubtful value and have not been included in the tables.

Nichiporuk and Chodos (1959) have analysed the troilite phase of 12 meteorites for 8 elements, but the only Western Australian siderite in the group is Ballinoo. They list the following data for this meteorite: iron 78.5%, nickel 4.82%, cobalt 0.30%, vanadium <13 ppm, chromium 0.12 ppm, copper 771 ppm, zinc <50 ppm and arsenic <50 ppm. The analytical method used was X-ray fluorescence, and the authors have estimated their accuracy limits for each of the elements analysed.

Conclusions

Since the publication of the Catalogue of Western Australian Meteorite Collections in 1965, a large and significant body of analytical data has been published by a variety of authors both in Western Australia and overseas. It is now recognised that the structural classification of iron meteorites depends on the kamacite bandwidth and can not be made simply in terms of the nickel content of the meteorite involved. Many of the older designations have therefore been altered in terms of Buchwald's classifications.

The importance of the gallium-germanium groups has now been recognised as a means of

classifying iron meteorites on a chemical basis, and the groups have been used to infer genetic and environmental relationships between various meteorites. The theory of cooling rate determinations from nickel diffusion profiles has been developed in the last decade and this has enabled the thermal history of meteorites to be investigated with important conclusions as to the size of the meteorite parent bodies.

Another development in recent years has been the use of physical methods of analysis in determining the abundance of elements in a wide variety of materials. Data from neutron activation analysis, X-ray fluorescence spectrometry, stable isotope dilution (using solid source mass spectrometry) and electron microprobe analysis have all been reported in this paper. Prior to 1965, traditional wet chemical analyses and emission spectroscopy were the only methods used in the abundance data included in the Catalogue. Many of the Western Australian meteorites had never been analysed for more than one or two elements, and some of the older data were suspect. The present project has included the analysis of every iron meteorite found in Western Australia for nickel, cobalt, gallium and germanium, including those meteorites discovered since 1965.

One important outcome of the study has been to provide additional information on paired falls. A number of the Western Australian meteorites are believed to be fragments of the same fall masquerading under different names. The most famous case is that of the Youndegin shower. A diagram reproduced by McCall and DeLaeter (1965, page 57) shows the approximate locations of Youndegin I-VIII, Mooranoppin, Mount Stirling and Quairading. This group of 11 meteorites has a restricted geographical distribution, and on the evidence presented in this paper, are members of the same fall. It is hoped to procure additional samples of these meteorites so that a full investigation of all 11 meteorites may be carried out.

Another group of meteorites which are thought to be part of the same fall are Loongana Station (iron) and the Premier Downs meteorites, (McCall and DeLaeter 1965). To these can now be added Mundrabilla, a large iron meteorite tentatively described as being connected to the other meteorites by McCall and Cleverly (1970). All these meteorites come from a restricted locality along the Trans-Australian Railway on the Nullarbor Plain. The chemical evidence presented in this paper supports the concept that these are members of the same meteorite shower.

It is equally important to know which meteorites thought to be paired are, in fact, from separate falls. Mount Edith I and II were found in 1913 and 1914 respectively at locations some 3.2 km apart. They were therefore identified as belonging to the one fall, and the chemical evidence presented in this paper supports this contention.

The data presented in this paper have reinforced the necessity for some type of inter-laboratory comparisons to be made by those

involved in meteorite analyses. It is now customary for laboratories making silicate rock analyses to use the set of standard rocks provided by the United States Geological Survey. The National Bureau of Standards has also been active in producing a variety of standard metal alloys. However no existing metal standards serve the requirements for siderite analyses. It is to be hoped that pieces of a large iron meteorite, which have been tested for homogeneity and absence of significant mineral inclusions, might be distributed among laboratories involved in meteorite research, so that future analyses of iron meteorites might be made with more stringent confidence limits than has been possible in the past.

Acknowledgments.—The author is indebted to Mr. W. W. Thomas for assisting with the X-ray analyses. Most of the meteorite samples were generously supplied by the Western Australian Museum Board to whom appreciation is expressed. The author would also like to thank Dr. G. J. H. McCall, Mr. W. H. Cleverly and Dr. C. Pearson for assisting in many ways.

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# 8.—*Eucalyptus forrestiana* subsp. *dolichorhyncha*, a new taxon from Western Australia

by M. I. H. Brooker<sup>1</sup>

Manuscript received 22 February 1972; accepted 22 August 1972

### Abstract

*Eucalyptus forrestiana* subsp. *dolichorhyncha* is described. Its distribution, historical status and relationship to *E. forrestiana* subsp. *forrestiana* are discussed.

*Eucalyptus forrestiana* Diels subsp. *dolichorhyncha* M. I. H. Brooker subsp. nov. SLOBEB (Pryor and Johnson 1971).

A subspecies typica operculo in rostrum elongatum 1-3 cm longum contracto et alabastris fructibusque plerumque minoribus in pedicellis brevioribus differt.

A subspecies differing from the typical form in the operculum which is abruptly contracted into an elongated beak, 1-3 cm long, and in the buds and fruit which are generally smaller and for shorter pedicels. (Figures 1, 2.)

### Herbarium material

**Holotype:** Grasspatch, Western Australia, J. W. Green 1252, 16.iii.1957.

**Other specimens:** Grasspatch, C. A. Gardner 2225 (NSW, PERTH) 22.v.1924, C. A. Gardner and W. E. Blackall 1070 (PERTH) 15.x.1931, C. A. Gardner (PERTH, FRI.) 31.i.1935, G. H. Burvill (PERTH) 6.viii.1959; Salmon Gums, R. Stamford (PERTH, NSW) 17.vii.1924; south of Grasspatch, J. H. Willis (MEL. 1009877) 1.ix.1947; 2 miles south of Grasspatch, L. A. S. Johnson (NSW) 18.xii.1960; 2 miles south of Red Lake, R. D. Royce 4060 (PERTH) 18.iv.1953; 14 miles north of Gibson, M. E. Phillips (CBG 021991, FRI) 5.xi.1962; 18.7 miles south of Salmon Gums, G. M. Chippendale 180 (FRI, MEL) 13.iii.1967; 532 mile peg between Norseman and Esperance, S. G. M. Carr 639 (PERTH) 1.iv.1968; Gibson, A. Kessell 880 (PERTH) 11.vi.1969; 13.7 miles south of Salmon Gums, M. I. H. Brooker 2501, 2502 (PERTH) 15.ii.1970; 10 miles south of Peak Eleanora, J. S. Beard 5867 (King's Park) 30.iii.1970. General distribution is from Salmon Gums to Gibson on the Norseman-Esperance road.

### Discussion

Subspecies *dolichorhyncha* has been widely referred to in literature and horticulture as *E. forrestiana*. Its limited area of distribution is crossed by the Norseman-Esperance road in a region where to both the west and east, subsp. *forrestiana* occurs over a wide tract of country, which has until recently been largely inaccessible (Beard 1973). Consequently subsp. *forrestiana* has probably been sampled far less frequently than subsp. *dolichorhyncha* and the latter rather than the former, has been regarded as typical. Nevertheless, both forms exist in Australian herbaria and both have been planted for ornamental purposes without taxonomic significance being attached to their differences.

In the original description of *E. forrestiana* (1905), Diels stated that the operculum was pyramidal and illustrated it as such. Maiden (1917) made no reference to any unusual forms of the species and the illustration in the "Critical Revision" (Plate 95, nos. 1, 2), is very close to Diels' original. Maiden (1929) made a further reference to *E. forrestiana* in which he referred to the "long rostrate operculum" of a specimen from Grasspatch (C. A. Gardner 2225), but he did not comment on the significance of the variation. This specimen, illustrated in Plate 283 (no. 6B), is subsp. *dolichorhyncha*.

Gardner (1933) considered that Diels had described an aberrant form in respect of the operculum or alternatively that the beak of the

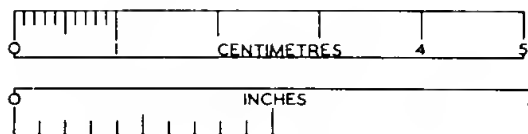


Figure 1.—A bud of *Eucalyptus forrestiana* subsp. *forrestiana*.

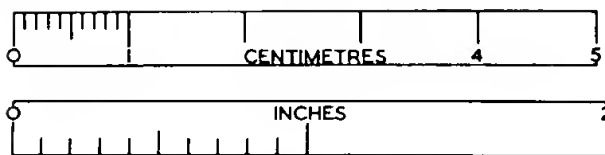


Figure 2.—A bud of *Eucalyptus forrestiana* subsp. *dolichorhyncha*.

<sup>1</sup>Forestry and Timber Bureau, Canberra, A.C.T. 2600

operculum had become detached from Diels' specimen. Evidence from recent field collections and from progeny which have been raised to the bud stage (Beard 1973) show that subsp. *forrestiana* does not produce a long beaked operculum. The bud apex is frequently scarred, however, and it is probably on this feature that Gardner based his suggestion that the beak had become detached. Blakely's redescription of *E. forrestiana* (1934) refers in part to subsp. *dolichorhyncha*.

A specimen of historical interest collected by Diels and Pritzel is Pritzel 479 (Perth) whose buds have opercula intermediate in morphology between those typical for the subspecies. From correspondence with the Director of the Botanisches Museum, Berlin-Dahlem, where it is presumed the type specimen of *E. forrestiana* was lodged and subsequently destroyed, it is not known what the relationship between Pritzel 479 and Diels 5331 (the type) is. If Diels 5331 is not extant we must take Diels' description and drawing as typical of *E. forrestiana* and regard Pritzel 479 as either an intermediate form—a possibility not unlikely between two closely

related forms whose distributions we know to be overlapping in some localities, or an immature bud variant.

*Acknowledgments.*—I wish to thank the Officers-in-Charge of the State herbaria in Perth, Melbourne and Sydney for the loan of specimens, and Dr. J. S. Beard who drew my attention to the two forms of *E. forrestiana*. Thanks are due to Mr. N. Hall for the photographs and to Dr. L. A. S. Johnson for the latin translation.

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# 9.—The ecology and distribution of *Eucalyptus forrestiana* Diels

by J. S. Beard<sup>1</sup>

Communicated by M. I. H. Brooker

Manuscript received 22 February 1972; accepted 21 November 1972

### Abstract

The distribution of the two subspecies of *Eucalyptus forrestiana* has been determined and the range mapped. Altitude, rainfall and associated soil types are described.

### Introduction

Until recently *Eucalyptus forrestiana* Diels had been collected only along the main road from Norseman to Esperance, at the type locality. This was due to the impenetrability of the country on either side which had not then been settled and was covered with dense mallee in which there were few tracks and no roads. The land boom in Western Australian during the decade up to 1970 entailed the penetration of areas of potential farm land by tracks bulldozed for surveyors engaged in soil survey and land assessment, and it was possible to use these for botanical survey also.

### Ecology and distribution

In November 1967 and in March and September 1970 the writer visited this area for purposes of vegetation mapping and traversed many of

the survey tracks. As *E. forrestiana* is a conspicuous species it was readily possible to define its range. The ecology is slightly different on the east and west sides of the Norseman-Esperance road. On the west, from the sea between Hopetoun and Esperance a coastal plain slopes gently upwards for about 40 km. inland to an altitude of about 200 m., where the country levels off to a flat plain stretching for a further 30-40 km. This plain has a mallee soil with a differentiated profile of sand over clay, which is winter-wet due to the flatness of the country, with considerable areas having a gilgai surface. Such country with its special soil conditions carries a distinctive plant association in which *Eucalyptus eremophila* F. Muell. and *E. forrestiana* are the dominants. The area occupied by this association is therefore the range of *E. forrestiana* which it is possible to map with some exactitude from aerial photography on the accompanying diagram (Fig. 1). The range extends for 110 km. to the west of Truslove, and within the hatched area the species is very abundant. It has not been observed outside the area shown, presumably due to close association with the particular soil type.

On the east side of the Norseman-Esperance road the country is in general similar to that to

<sup>1</sup>Royal Botanic Gardens, Sydney, N.S.W. 2000. Present address: 6 Fraser Road, Applecross, W.A. 6153

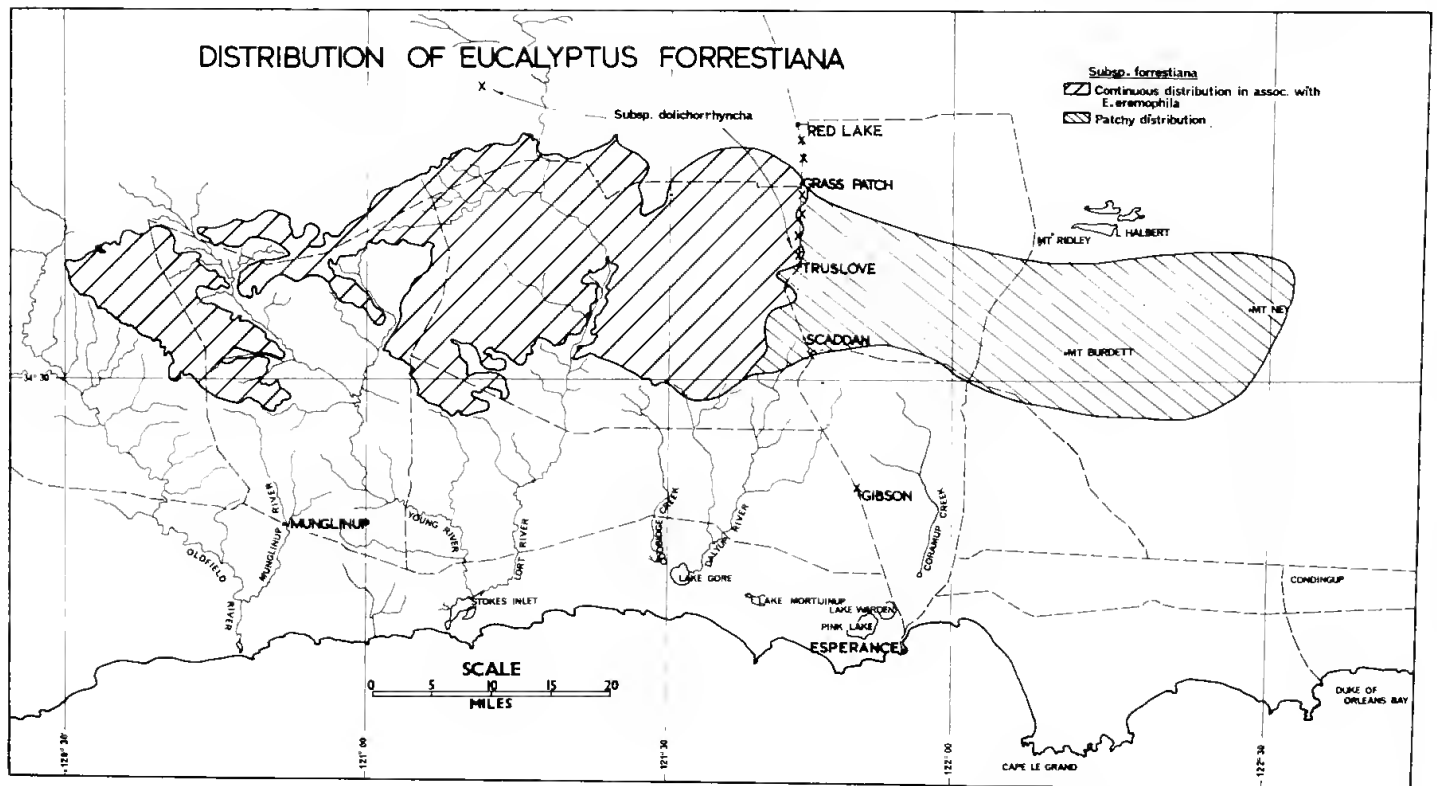


Figure 1.—The distribution of *Eucalyptus forrestiana*.

the west and is likewise covered with dense mallee associations but there are no longer large extensive areas of the soil-type on which *E. forrestiana* occurs. The species appears to be in general less common and to be locally frequent in patches of badly drained or gilgai soil. It was recorded as far east as Mt. Ney (Beard 6388), 65 km. to the east of Truslove, beyond which on equivalent soils it appears to be replaced by *E. dielsii*. In this sector it occupies a belt about the same distance from the coast as its western distribution, indicating some relation to rainfall which averages between 335 and 385 mm. per annum.

The gross distribution mapped is that of *E. forrestiana* subsp. *forrestiana*. Subspecies *dolichorhyncha* M. I. H. Brooker (1973) has been observed only along the Norseman-Esperance main road where it mingles with subsp. *forrestiana*, except for a single instance known; Beard 5867 was collected in a heath association 50 km. west of the main road, on a track 16 km. south of Peak Eleanora. It is possible therefore that subsp. *dolichorhyncha* does extend across the intermediate country between this point and its type locality.

The vegetation of this belt of country is generally described as "mallee" and contains many true mallee species of *Eucalyptus* in which a massive underground rootstock is developed. Following destruction of the top growth by a bush fire the plant sprouts again from the stock with numerous spindly stems. Neither *E. forrestiana* nor *E. eremophila* with which it associates adopts this growth form. Each tree is single-stemmed and originated as a seedling after the last bush fire. These species are killed by fire and do not regenerate by coppice. This behaviour has been described by Beard (1967) in *E. platypus*, which forms "thickets" some 150 km. further west in the Ravensthorpe area where it was noted that *E. annulata* and *E. spathulata* also share this habit. Such small trees, reaching heights of 5 to 10 m. are strictly-speaking not mallees and are known in Western Australia as "marlocks". Technically the formation should be known as low forest.

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# 10.—A progeny trial to obtain evidence of hybridity in two taxa of *Eucalyptus*

by J. S. Beard<sup>1</sup>

Communicated by M. J. H. Brooker

Manuscript received 22 February 1972; accepted 21 November, 1972

## Abstract

A trial was conducted with progeny of *Eucalyptus erythrandra* Blakely and Steedman, and of *E. forrestiana*. Examination of surviving plants after seven years is considered to show that the former taxon is a hybrid form whereas the latter is not.

## Introduction

In November 1962 seed was collected from two individuals of *Eucalyptus erythrandra* Blakely and Steedman on the Ravensthorpe-Esperance road about 30 km east of Ravensthorpe. Another seed collection was made from a population of small trees of *E. forrestiana* Diels near the 540 mile peg on the Esperance-Norseman road between Scaddan and Truslove.

*E. erythrandra* was described by Blakely in 1938 from a specimen collected by H. Steedman at Kundip, west of Ravensthorpe. Gardner, however, in 1933 described the same taxon as a new variety, var. *robusta*, of *E. angulosa* Schau., and later (Gardner, 1940) announced that "I have since received, through the Conservator of Forests, specimens of this plant collected by Mrs. Daniells of Hopetoun, which exhibit a perfect series embracing on the one hand *E. tetraptera* Turcz., and *E. angulosa* Schau. on the other. Amongst the intermediate forms is typical *E. erythrandra*, which I consider to be a hybrid. The evidence in favour of this theory is quite clear."

Progeny were raised from the two seed collections of *E. erythrandra* in the King's Park Arboretum to seek evidence for hybridity. The same was done with the seed collection of *E. forrestiana*.

The taxonomy of *E. forrestiana* has recently been clarified (Brooker 1973). The specimen and seed collected by the writer in 1962 are now correctly referred to as *E. forrestiana* Diels subsp. *forrestiana* and there is no reason to suspect interspecific hybridity. In 1962 however, the name *E. forrestiana* was being incorrectly restricted to a form of the species, occurring in the same locality, which differs in having a long beak to the operculum. This taxon has since been described as *E. forrestiana* subsp. *dolichorhyncha* M. I. H. Brooker.

In 1962 the late Mr. C. A. Gardner considered the writer's collection to be possibly a hybrid between *E. forrestiana* (as then conceived) and *E. stoatei* C. A. Gardn., and the seed was therefore included in the progeny trial.

## Results

Seed from the collections made was sown in the King's Park nursery in summer 1962-1963, as follows:—

*E. erythrandra*. Accession Nos. 2167/62, 2170/62 = voucher specimen JSB. 2283.

*E. forrestiana*. Accession No. 2155/62, voucher specimen JSB. 2343a.

Plots were planted in the arboretum in May 1963 at 12' x 12' (3.45 x 3.45 m.).

2167/62, 4 lines of 9 = 36 plants

2170/62, 4 lines of 9 = 36 plants

2155/62, 9 lines of 10 = 90 plants

Each year thereafter the plants were weeded and watered weekly in summer. An assessment was made in May 1967, when in the 2155/62 progeny (*E. forrestiana*) there were 50 survivors ranging in height from 0.5 to 2 m., the larger ones coming into flower. Of 39 flowering specimens all reproduced the parental characteristic of short operculum and 4-ribbed fruit. In the two plots of *E. erythrandra* both survival and growth were poor. Only 22 plants out of 72 remained and these were mostly small and weak, with few flowering. It was observed however that there was a marked segregation into types resembling both reputed parents of the hybrid, *E. tetraptera* and *E. angulosa* (Gardner 1940).

Final assessment was deferred until April 1970, seven years after planting, with this result—

*E. forrestiana*. 46 survivors, 1.5-3 m tall, all flowering and fruiting copiously but fruits shed prematurely without liberating seed. No apparent differences between individuals in habit of tree or leaf size or shape. Short operculum, 46 (100%). 4 major ribs on fruit, 46 (100%). Indications of minor ribbing on fruit between major ribs, 13 (28%). Slight variations in fruit length and thickness, and in the peduncle, appear but not seeming significant.

*E. erythrandra*. 20 plants of which 2 dead; these still had leaves and were included in the examination. Plants very variable, 12 assessed as resembling *E. angulosa* (upright branching habit, smaller, thinner leaves, compound inflorescences, small fruit of *E. angulosa* type), 5 resembling *E. tetraptera* (straggly and decumbent form, thick large rigid leaves, large solitary 4-angled fruit) and 3 intermediate. There was a difference between the two collections, progeny of 2167/62 having 4 *angulosa*-type, 5 *tetraptera*-type, 0 intermediates, 2170/62 having 8 *angulosa*-type, 0 *tetraptera*-type, 3 intermediates.

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### Conclusions

It is concluded that there is no evidence of hybridity in the progeny of *E. forrestiana* subsp. *forrestiana*, nor of variation to ssp. *dolichorrhyncha*. There was no occurrence of the long-beaked form in the population, nor any intermediates.

On the other hand Gardner's supposition of hybridity in *E. erythrandra* is very clearly supported. The only consideration here lies in the identity of the reputed parents. *E. tetraptera* occurs in the mallee-heath communities, east of Ravensthorpe where *E. erythrandra* forms are found but *E. angulosa* does not, being a coastal species. *E. incrassata*, on the other hand, another member of the "dumosa" group and of which *E. angulosa* has been considered a variety by some authorities, does so, and this is probably the actual parent. It has smaller fruits than *E.*

*angulosa* but is sufficiently close to it not to affect materially the comparisons in the progeny trial.

This paper is presented in order to draw attention to the utility of progeny trials conducted in Botanic Gardens to assist the elucidation of taxonomic problems.

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# 11.—Harris Sandstone-Yindagindy Formation relationships and possible position of permo-carboniferous boundary, Carnarvon Basin, Western Australia

by J. F. Read<sup>1</sup>, P. J. Alcock<sup>2</sup> and P. Hoseman<sup>3</sup>

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## Abstract

This paper describes the stratigraphic relationships between plant-bearing sediments of possible Carboniferous or Permian age and underlying Yindagindy Formation sediments (Lower Carboniferous) exposed in the eastern Carnarvon Basin. The sequence is, in descending order:

3. Lyons Group (Permian),
2. Harris Sandstone, and
1. Yindagindy Formation (Lower Carboniferous).

In the Moogooree area, plant-bearing sandstones previously included in the Harris Sandstone have been assigned to the Lyons Group by White and Condon (1959). The main reasons for the change were that the plant-bearing beds differed lithologically from the Harris Sandstone, and rested with erosional unconformity on a surface of marked relief. Detailed mapping in the Moogooree area indicates that these plant-bearing beds are similar lithologically to the Harris Sandstone and that they are mildly disconformable upon the Yindagindy Formation. An angular unconformity which separates the Permian, Lyons Group from the underlying Harris Sandstone probably represents the Carboniferous-Permian boundary in the area.

## Introduction

This paper describes the stratigraphic relationships between plant-bearing beds of Carboniferous or Permian age and the underlying Lower Carboniferous Yindagindy Formation in the Moogooree area, eastern Carnarvon Basin, Western Australia (Fig. 1).

The "Yindagindi limestone" of Teichert (1950) was renamed Yindagindy Formation by Condon (1954), who considered it to be of Carboniferous age because of its conformable relationship with underlying Carboniferous beds.

Overlying plant-bearing sandstones in the Moogooree area were informally named the "Red Hill sandstone", by Teichert (1950). Condon (1954, p.31) renamed the plant-bearing beds the Harris Sandstone, making the type section approximately 31 km. (19 mi.) north-north west of Moogooree Homestead; at the type section, the Harris Sandstone was considered to conformably underlie the Lyons Group and to disconformably overlie the Yindagindy Formation. Condon (1954, p.34) excluded the Harris Sandstone from the Lyons Group because of lithologic and genetic differences.

Later, the plant-bearing sandstones around Moogooree were included in the Lyons Group as they were considered to be lithologically similar to non-tillitic parts of the Lyons Group and differed lithologically from the Harris Sandstone at the type section (White and Condon 1959, p.58; Condon 1967, p.7). This implied that the Harris Sandstone was absent from the section exposed at Moogooree. Furthermore, Condon (*in* White and Condon 1959, p.58) considered that the plant-bearing beds in the Moogooree area rested unconformably on an erosional surface of marked relief developed on Yindagindy Formation sediments.

In contrast, Dickins and Thomas (1959) considered that the plant-bearing sandstones around Moogooree were equivalent to the Harris Sandstone at its type section as the rocks formed a distinct stratigraphic unit on the basis of lithology, field occurrence and stratigraphic position and that they are distinguishable from the Lyons Group in that they are non-tillitic. In this paper, these plant-bearing sandstones will be referred to as Harris Sandstone.

The Yindagindy Formation is considered to be of Lower Carboniferous age by Thomas (1962). Dickins and Thomas (1959) assign a Lower Permian age to the Lyons Group. However, the age of the Harris Sandstone is at present inconclusive; White (*in* White and Condon 1959) considers that the lepidodendroid plant material could be of Carboniferous or Permian age but Krausel (1961) implies that it is Carboniferous.

## Stratigraphy

Determination of contact relationships between the Lower Carboniferous Yindagindy Formation and the Carboniferous or Permian Harris Sandstone around Moogooree has been hindered by faulting, by poor exposure of Yindagindy Formation-Harris Sandstone contact and Harris Sandstone-Lyons Group contact and by the absence of adequate fossil material for determining age of the Harris Sandstone and basal Lyons Group beds.

The Yindagindy Formation-Harris Sandstone contact at localities 1 to 4 (Fig. 1) was mapped by plane table at a scale of 1:1200; a traverse was run at locality 5. To facilitate mapping, the Yindagindy Formation was divided into 4 units. The sequence in the Moogooree area is, in descending order:

### *Harris Sandstone:*

Thickness at type section, 85 metres (Condon 1967, p. 11).

In the Moogooree area the Harris Sandstone occurs in fault-blocks which form low red hills; local total

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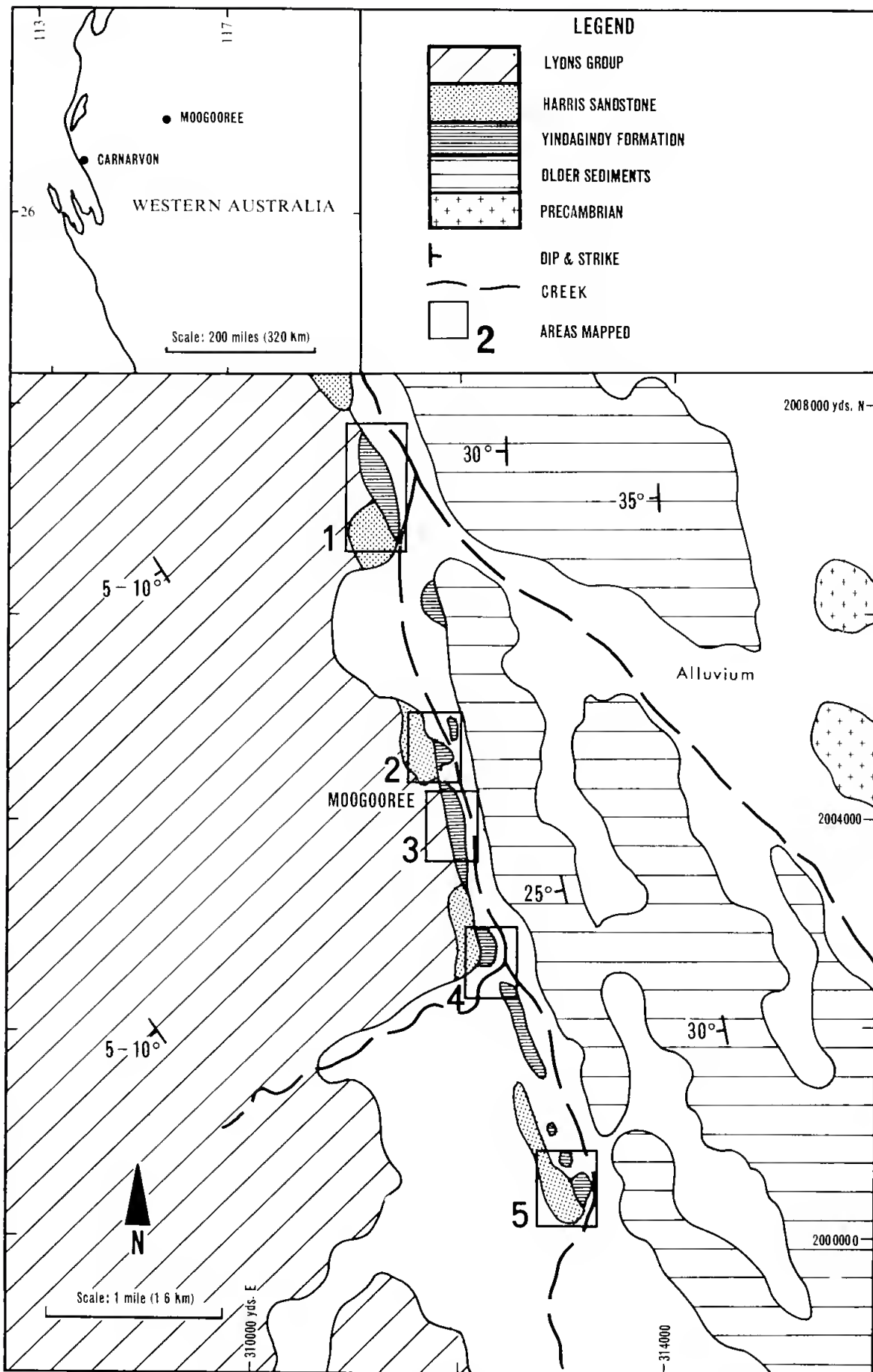


Figure 1.—Locality map and general geology of the Moogooree area: adapted from photogeological map supplied by West Australian Petroleum Pty. Ltd.

thickness of the unit is not known. Contacts between the Harris Sandstone and the overlying Lyons Group are concealed beneath a residual cover of pebbles and boulders from glacial beds of the Lyons Group, together with siliceous laterite fragments. The Harris Sandstone consists of thinly bedded or cross-bedded, well-sorted, medium- to coarse-grained quartz sandstones; the sandstones are clean and free of detrital matrix<sup>1</sup>. Cortical impressions and casts of lepidodendroid stems are common near the base of the formation. The Harris Sandstone disconformably overlies.

**Yindagindy Formation:**

Maximum thickness in the Moogooree area, 68 metres.

*Unit D.*—(20 metres). This unit consists of fine-grained lime mudstones and interbedded, poorly exposed terrigenous sediments. The lime mudstones are laminated and have birdseye structures; they are poorly fossiliferous. The uppermost beds of the Yindagindy Formation are poorly exposed, thin ferruginous quartz sandstones (2 metres thick) and an underlying blue vuggy limestone which forms a distinctive marker bed. The blue vuggy limestone is characterized by abundant subvertical tubes up to 1 cm in diameter which are filled with sparry calcite. Locally where the quartz sandstone has been eroded, the blue, vuggy limestone marks the top of the formation. At locality 1, a limestone pebble conglomerate appears to be laterally equivalent to or overlies the blue, vuggy limestone bed.

*Unit C.*—(38 metres). This unit crops out as a low strike ridge. The unit consists of poor-sorted, medium- to coarse-grained calcareous feldspathic sandstones which are locally cross-bedded, together with poorly exposed siltstones and claystones, and intercalated oolitic limestones. Rare fossils include brachiopods, gastropods, serpulids and algal structures.

*UNIT B.*—(4.5 metres). This unit crops out as a bluff. It consists of brown, thick-bedded, quartzose

skeletal-fragment limestones and minor oolitic and coquinoid limestones. Fossils include brachiopods, crinoids and bryozoans.

*UNIT A.*—(5.5 metres). This unit is generally obscured by a rubble slope flanking the bluff formed by unit B limestones. It consists of fine- to coarse-grained, thin-bedded or cross-bedded, poor-sorted calcareous feldspathic sandstones with two limestone horizons, the lower one marking the base of the Yindagindy Formation; it conformably overlies.

**Williambury Formation:**

Thickness at the type section, 235 metres (Condon 1967, p.69).

Friable, poorly sorted, medium- to coarse-grained feldspathic sandstone.

**Harris Sandstone—Yindagindy Formation Contact**

Contacts between the Harris Sandstone and Yindagindy Formation are typically faulted, and the abundance of faults suggest that the area lies within a fault zone. The faults are evidenced by stratigraphic discrepancy where upper beds of the Yindagindy Formation or lower parts of the Harris Sandstone are missing. Other features associated with the faults are slickensides in sandstones of the Harris Sandstone and Yindagindy Formation, calcite veins in limestones and folding of limestone beds. Relative movement on faults is generally west—block down with variable lateral displacement.

Stratigraphic relationships between the formations were determined where sedimentary contacts have not been obscured by faulting. Such contacts occur in the southern portion of locality 1, in a fault block at locality 2, at the southern end of locality 4 and at locality 5. The stratigraphic succession and probable thickness

<sup>1</sup>All specimens of Harris Sandstone from the Moogooree area examined in hand specimen and thin section were clean quartz sandstones with little or no detrital matrix; Condon (*in* White and Condon 1959, p. 58) described this sandstone as a silty quartz greywacke

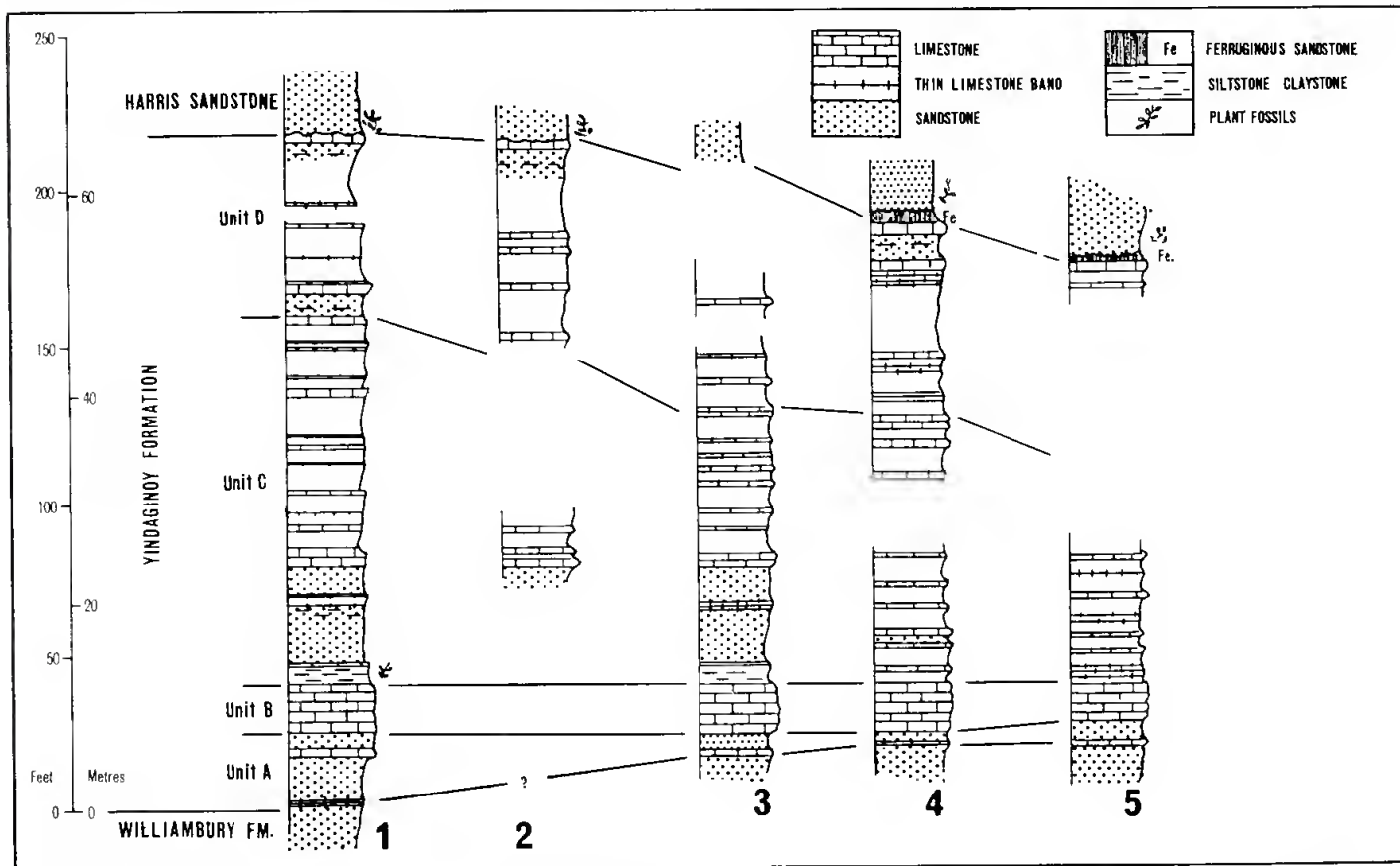


Figure 2.—Columnar sections of the Yindagindy Formation, Moogooree area, localities 1 to 5. Blank pattern denotes soil covered areas.

of the Yindagindy Formation at each locality are shown in Figure 2. Detailed maps of localities 1 to 4 are shown in figs. 3 and 4.

*Locality 1.*—The Harris Sandstone at the southern end of locality 1 rests on blue, vuggy limestone and contains abundant cortical impressions of lepidodendroid stems. Locally, a limestone-pebble conglomerate (up to 1 metre thick) underlies the Harris Sandstone; the conglomerate is probably stratigraphically equivalent to the blue, vuggy limestone. Dips of the Harris Sandstone, and Yindagindy Formation at the contact are flat-lying; dips are unreliable in determining stratigraphic relationships as some beds are displaced by faults.

*Locality 2.*—The Harris Sandstone occurs as low residual mounds up to 3 metres high in a fault block in the central portion of locality 2.

It contains plant fossils and rests upon the blue, vuggy limestone. The contact is well exposed and the sediments are almost horizontal. West of this fault block unit D is exposed as west dipping limestone bands, the topmost band being blue, vuggy limestone. West of this bed the Harris Sandstone crops out as rubble in soil.

*Locality 3.*—The sequence at locality 3 is heavily faulted and formation contacts are concealed beneath soil. A thick section of Yindagindy Formation is exposed at this locality (Fig. 2).

*Locality 4.*—Contacts are well exposed in and around south of a north-east flowing creek in the central portion of locality 4. Here, plant-bearing sandstones rest upon 2 metres of ferruginous, non-fossiliferous quartz sandstone which overlies blue, vuggy limestone. Limestones of unit D are well exposed at this locality. Dips of 20 to 25 degrees above and below the contact suggest conformable or disconformable contacts.

*Locality 5.*—At locality 5, plant-bearing beds overlie thin ferruginous, non-fossiliferous sandstones which rest on blue, vuggy limestone.

Lithological correlations of Yindagindy Formation limestones of unit D indicate that the blue, vuggy limestone is the same stratigraphic horizon in all areas mapped.

### Conclusions

In the Moogooree area, the Harris Sandstone disconformably overlies a thin (2 metres) ferruginous sandstone or (where this has been eroded), a distinctive, blue, vuggy limestone horizon. The ferruginous sandstone and underlying blue, vuggy limestone are the uppermost beds of the Yindagindy Formation in the area. Locally, a limestone-pebble conglomerate (up to 1 metre thick) which is closely associated with blue, vuggy limestone, lies at the top of the Yindagindy Formation.

The ferruginised top of the Yindagindy Formation and the sharp change in lithology from the Yindagindy Formation to the Harris Sandstone indicate a disconformity (Condon 1954, p.30). However, in the Moogooree area,

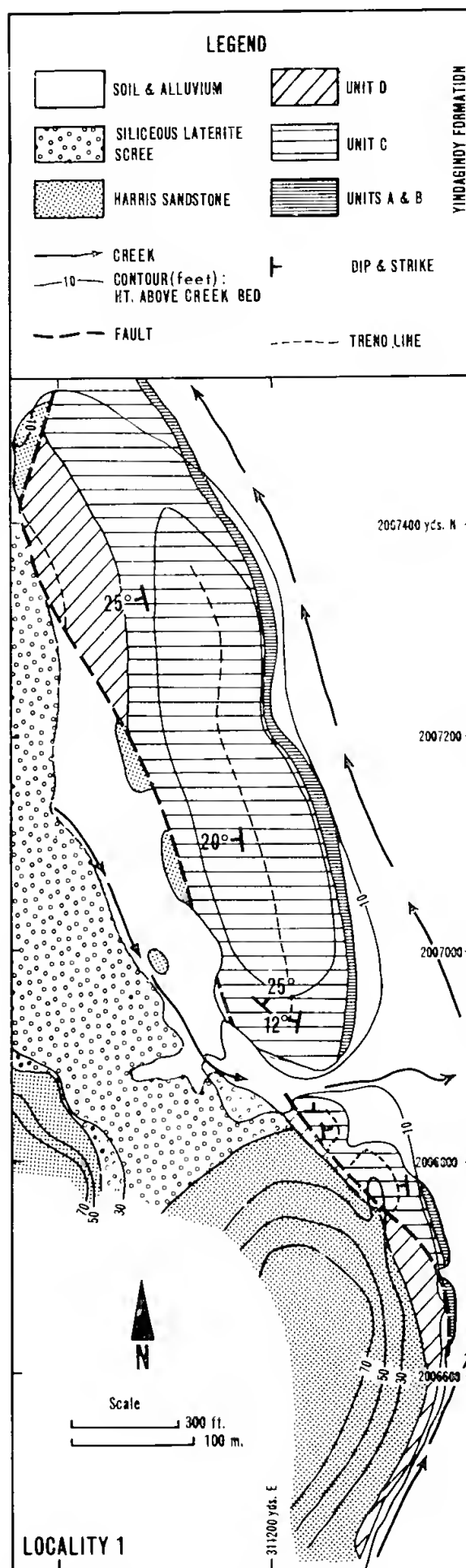


Figure 3.—Geological map, locality 1.

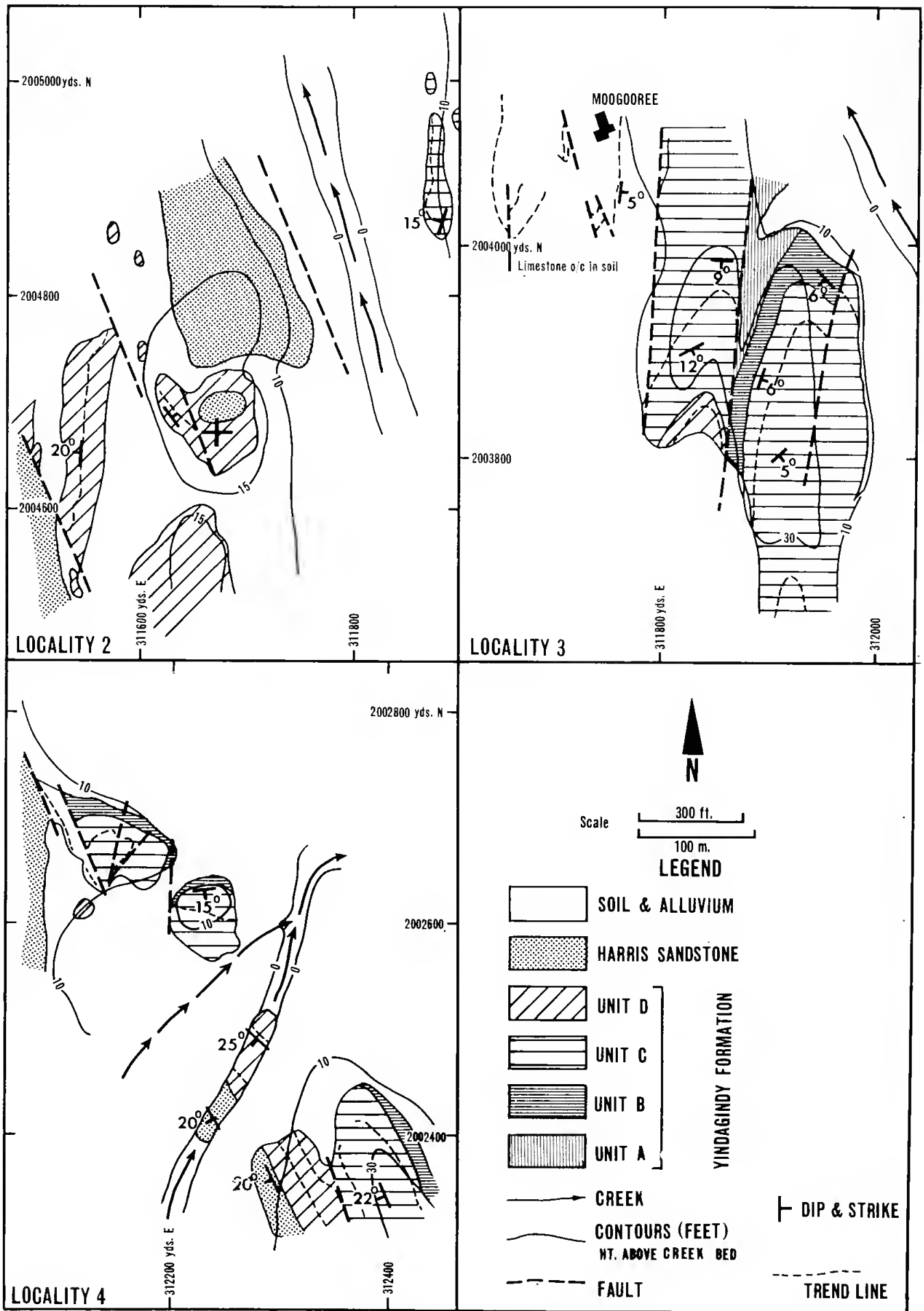


Figure 4.—Geological maps, localities 2, 3 and 4.



the disconformity surface has little relief, probably 2 metres maximum, and is essentially parallel to the underlying Yindagindy Formation beds. There is no evidence for an erosional unconformity of *marked relief* at the base of the plant-bearing sandstones as reported by Condon (*in* White and Condon 1959). Removal of parts of the Yindagindy Formation and Harris Sandstone by later faulting has brought Harris Sandstone or Lyons Group sediments into contact with a truncated sequence of the Yindagindy Formation, simulating an erosional contact of high relief. Lithologically, the sandstones are similar to the Harris Sandstone at the type section, being clean quartz sandstones rather than silty quartz greywackes as reported by White and Condon (1959, p.58). Thus the plant-bearing beds are referred to the Harris Sandstone and not the Lyons Group as White and Condon (1959) and Condon (1962) proposed.

South of Moogooree homestead, the Lyons Group progressively truncates older sediments till it finally rests upon the Precambrian basement rocks (Condon 1962). As the Harris Sandstone is concordant with the underlying Yindagindy Formation, an angular unconformity probably exists between Harris Sandstone and overlying Lyons Group, instead of the conformable contact of Condon (1954). The contact between the Harris Sandstone (Carboniferous?, Krausel 1961) and the Lower Permian, Lyons Group (Dickins and Thomas 1959) may mark the Carboniferous-Permian boundary in the region.

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# 12.—The genus *Ctenotus* (Lacertilia, Scincidae) in the South-West and Eucla Divisions of Western Australia

by G. M. Storr<sup>1</sup>

Manuscript received 20 February 1973; accepted 20 March 1973.

### Abstract

The following 17 taxa are defined and keyed out: *pantherinus pantherinus* (Peters), *pantherinus ocellifer* (Boulenger), *lesueurii* (Duméril & Bibron), *fallens* sp. nov., *severus* Storr, *alleni* sp. nov., *mimetes* Storr, *uber uber* Storr, *atlas* Storr, *impar* Storr, *lancelini* Ford, *labillardieri* (Duméril & Bibron), *gemma* sp. nov., *delli* sp. nov., *catenifer* sp. nov., *schomburgkii* (Peters), and *brooksi euclae* Storr. Lectotypes are designated for *Lygosoma lesueurii* Duméril & Bibron and *Tiliqua australis* Gray.

### Introduction

This is the fourth in a series of regional surveys of the genus *Ctenotus*. Previous papers covered the Eastern Division of Western Australia (Storr 1969), the Northern Territory (Storr 1970), and South Australia (Storr 1971).

This paper is based on material in the Western Australian Museum (registered numbers without prefix) and a few specimens kindly loaned by the National Museum of Victoria (NMV), the South Australian Museum (SAM), Museum of Comparative Zoology (MCZ), Muséum National d'Histoire Naturelle (Paris), and Zoological Museum of Humboldt University (Berlin). The number of specimens examined in each taxon were *p. pantherinus* (20), *p. ocellifer* (1), *lesueurii* (49), *fallens* (162), *severus* (10), *alleni* (2), *mimetes* (7), *u. uber* (6), *atlas* (2), *impar* (45), *lancelini* (5), *labillardieri* (368), *gemma* (25), *delli* (11), *catenifer* (14), *schomburgkii* (25), and *brooksi euclae* (30).

In the descriptions of species quantitative characters are usually expressed as ranges with means in brackets. The term "palpebrals" here applies to the scales along the free edge of the upper eyelid. The term "calli" refers to thickenings of the subdigital lamellae too broad to be called keels. "Presuboculars" are the scales aligned with and immediately posterior to the loreals.

### Key to species and subspecies

1. Dorsal and lateral pattern lacking ocelli ..... 2
- Dorsal and lateral pattern consisting wholly or mainly of black-and-white ocelli—*pantherinus* group ..... 6
2. Dorsal and lateral pattern usually including longitudinal series of spots, blotches, dots and dashes, as well as stripes and lines ..... 3
- Dorsal and lateral pattern consisting solely of alternating longitudinal black and white stripes—*taeniolatus* group ..... 11

3. Subdigital lamellae smooth, callose or obtusely keeled; snout-vent length up to 105 mm ..... 4
- Subdigital lamellae sharply keeled; snout-vent length up to 52 mm—*schomburgkii* group ..... 16
4. Three supraoculars normally in contact with frontal; presuboculars 2 ..... 5
- Usually two supraoculars in contact with frontal; presuboculars 3 *labillardieri* group ..... 12
5. Subdigital lamellae smooth or broadly callose; SVL up to 105 mm—*lesueurii* group ..... 7
- Subdigital lamellae obtusely keeled or narrowly callose; SVL up to 77 mm—*leonhardii* group ..... 10
6. A black vertebral stripe (sometimes incomplete or discontinuous) No vertebral stripe ..... *p. pantherinus*  
*p. ocellifer*
7. A well-defined black vertebral stripe, narrowly edged with white Vertebral stripe absent or reduced to a black line ..... 8  
9
8. Nuchals normally 4 or 5; usually a white line on nape between paravertebral and dorsolateral white lines, extending forward along edge of frontal and backward for varying extent; a series of oblique white bars behind arm; midbody scale rows seldom more than 26; lamellae under fourth toe seldom less than 24 ..... *lesueurii*
- Nuchals normally 2 or 3; no white line between paravertebral and dorsolateral lines; no oblique white bars behind arm; midbody scale rows seldom less than 28; lamellae under fourth toe seldom more than 24 ..... *fallens*
9. White dorsolateral line margined above by broad blackish laterodorsal stripe and separated below from dark upper lateral zone by narrow hiatus of pale ground colour; lamellae under fourth toe less than 25; nuchals 2 or 3 ..... *severus*
- White dorsolateral line margined above by narrow black laterodorsal stripe and in contact below with black of upper lateral zone; lamellae under fourth toe more than 25; nuchals 4 ..... *alleni*
10. Midlateral white stripe well defined; dark laterodorsal stripe not enclosing a series of pale spots ..... *mimetes*
- Midlateral stripe not or barely discernible; laterodorsal stripe enclosing a series of pale spots ..... *u. uber*
11. White stripes totalling 11 (including a vertebral stripe) or 12 (without a vertebral stripe); nasals and prefrontals separated; labials usually 7 ..... *impar*
- White stripes totalling 8 or 10 (no vertebral stripe); nasals and prefrontals seldom separated; labials usually 8 ..... *atlas*
12. White dorsolateral line continuous; abdomen yellow; subdigital calli wide ..... 13
- White dorsolateral line broken into a series of short dashes; abdomen white; subdigital calli narrow ..... 14

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13. Hindleg reddish ..... *labillardieri*  
 Hindleg yellowish ..... *lancelini*
14. Hindleg yellowish brown, boldly  
 marked with black and white;  
 labials 8 ..... *gemma*  
 Hindleg olive-grey, dotted with  
 blackish brown; labials seldom  
 more than 7 ..... 15
15. Back dark brown, unpatterned be-  
 tween narrow black laterodorsal  
 stripes ..... *delli*  
 Back olive grey, strongly patterned  
 (broad blackish laterodorsal stripe  
 often bearing a series of white dots;  
 usually some trace of dark vertebral  
 line) ..... *catenifer*
16. Dorsal ground colour dark (olive  
 grey or olive brown); presuboculars  
 2; plantars opposite fourth toe not  
 differentiated ..... *schomburgkii*  
 Dorsal ground colour very pale  
 (pinkish in life, white in alcohol);  
 one presubocular; plantars oppo-  
 site fourth toe enlarged and keeled *brooksi euclae*

### *Ctenotus pantherinus pantherinus*

*Lygosoma (Htinulia) pantherinum* Peters, 1866, Mber. Akad. Wiss. Berlin 1866: 89. Swan River, Australia.

**Diagnosis.** A large *Ctenotus* whose dorsal and lateral pattern consists mainly of black-and-white ocelli; subdigital lamellae sharply keeled; nasal grooved.

**Distribution.** Northern interior of South-West Division, from the lower Murchison, south to Mt Lesueur, New Norcia and Quairading. Extralimital in far southwest of Eastern Division (16 mi. S of Karalee).

**Description.** Snout-vent length (mm): 36-90 (67.9). Length of appendages (% SVL): tail 152-186 (173), foreleg 22-31 (26.5), hindleg 39-45 (41.1).

Nasals in contact. Prefrontals usually in contact, occasionally separated very narrowly. Supraoculars 4, first three in contact with frontal. Supraciliaries usually 7, occasionally 8, mean 7.2. Palpebrals 9-13 (11.4). Second loreal 0.8-1.4 (1.02) times as wide as high. Upper labials usually 8, occasionally 9, mean 8.1. Ear lobules 4-8 (5.7), obtuse in juveniles, subacute in adults. Nuchals usually 2 or 3, occasionally 1 or 4, mean 2.7. Midbody scale rows usually 32 or 34, seldom 30 or 36, mean 33.4. Lamellae under fourth toe 22-25 (23.6).

Dorsal and lateral ground colour coppery brown, occasionally washed with olive-green. Black vertebral stripe usually extending from nape to base of tail, but sometimes disappearing at midback or becoming broken posteriorly. Usually 5, sometimes 4, longitudinal series of ocelli on each side of body, viz. a paravertebral, a dorsolateral and two or three lateral, each ocellus consisting of a short white bar margined on each side by a short black bar. White bars of dorsolateral and midlateral ocelli in some specimens almost continuous enough to form stripes.

**Material.** South-West Division: Janja Thicket, 16 mi. ENE of Kalbarri (37616); Galena (29627); Binnu (25599); 14 mi. NE of Morawa (17299); Mt Lesueur (11162-3); 7 mi. NE of Miling (17300-5); 7 mi. N of New Norcia (17306); Dangin (17307); near Quairading (2482); Wamenusking (8555); Bruce Rock (21371). Also the holotype (Berlin 5379).

### *Ctenotus pantherinus ocellifer*

*Lygosoma ocelliferum* [Boulenger], 1896, Ann. Mag. Nat. Hist. (6) 18: 342. Broome, W.A. (K. Dahl).

**Diagnosis.** Differing from *C. p. pantherinus* mainly in lacking black vertebral stripe.

**Distribution.** Arid mallee-spinifex zone of Eucla Division. Extralimital in Kimberley, North-West and Eastern Divisions of Western Australia and in Northern Territory and South Australia.

**Description.** See Storr (1969: 99; 1970: 98).

**Material.** 8 mi. E of Fraser Range (30756).

### *Ctenotus lesueurii*

*Lygosoma lesueurii* Duméril & Bibron, 1839, Erpétologie générale 5: 733. Nouvelle Hollande (Péron & Lesueur). *Tiliqua australis* Gray, 1839, Ann. Nat. Hist. 2: 291. Australia. [= *Lygosoma australe* (Gray) of Peters, not *Lygosoma australis* Gray.]

**Diagnosis.** A large member of the *lesueurii* group with a pale-edged vertebral stripe and a dark-edged dorsolateral line. Distinguishable from *C. fallens* by its brighter and more complex pattern (including a pale dorsal line on nape between paravertebral and dorsolateral lines, extending forward along edge of frontal and for varying distances backward; and pale dark-edged oblique ventrolateral bars behind arm), more numerous nuchals (rarely less than 4), fewer midbody scale rows (rarely more than 26), and more numerous lamellae under fourth toe (seldom less than 24).

**Distribution.** West coast and coastal plains south to Augusta, thence east to the Albany district.

**Description.** Snout-vent length (mm): 43-101 (79.8). Length of appendages (% SVL): tail 200-253 (230), foreleg 24-30 (26.0), hindleg 41-53 (46.7).

Nasals separated. Prefrontals in contact (occasionally separated very narrowly or by an azygous scale). Supraoculars 4, first 3 in contact with frontal, second very large. Supraciliaries 6-9 (rarely other than 7; mean 7.0). Palpebrals 10-14 (11.9). Second loreal 1.0-2.2 (1.47) times as wide as high. Upper labials 8 (occasionally 9; mean 8.1). Ear lobules 3-7 (mean 4.7); obtuse in juveniles; acute, subacute or truncate in adults; third mostly largest. Nuchals usually 4, occasionally 5, rarely 3, mean 4.2. Midbody scale rows 24-28 (25.1). Lamellae under fourth toe 23-28 (25.9), smooth or broadly callose.

Dorsal ground colour greyish brown in adults, coppery brown in juveniles. Blackish-brown vertebral stripe from nape to base of tail, much narrower than a paravertebral scale, with a narrow white margin, which in turn is narrowly margined with black. White dorsolateral line from rear of orbit to tail, on which it is suffused with brown; margined above with black (laterodorsal stripe). A dorsal line on nape between black paravertebral line and black laterodorsal stripe, extending forward along outer edges of frontoparietal and frontal. Upper lateral zone blackish brown with a series of white spots or dashes. White midlateral stripe from ear nearly to end of tail, anteriorly breaking up and tending to join with white ventrolateral spots which behind arm are



modified into short oblique bars. A white line curving under orbit. Upper labials edged with brown.

*Remarks.* Of the three extant syntypes of *Lygosoma lesueurii* in the Paris Museum, I choose as lectotype no. 2982, collected by Péron & Lesueur [presumably on the west coast of Western Australia in 1801]; this is the specimen whose measurements are given in the original description.

Mr. A. F. Stimson of the British Museum tells me (*in litt.*, 7 January 1972) that none of their specimens can be certainly identified as type of *Tiliqua australis* Gray. In order to stabilise that name, I designate the lectotype of *Lygosoma lesueurii* Duméril & Bibron as neotype of *Tiliqua australis* Gray.

*Material.* South-West Division: Meanarra Hill, 4 mi. E of Kalbarri (33529); Wittecarra Gully, 5 mi. SE of Kalbarri (33882); 11 mi. SSE of Kalbarri (33784); 1 mi. SSW of Kalbarri (33668-9, 33712); between Cockleshell Gully and Jurien Bay (12695); Favourite Island (17202); near mouth of Hill River (13440, 17205); Green Islets (17208-9); Muchea (462); Scarborough (28925); Mt Yokine (19112, 21714, 21885); Bedford (9121); North Perth (4840); Leederville (8885); Kings Park (17239); Nedlands (6672); South Perth (29652-3, 29772-5, 30252-4, 33384-5, 39085, 39983, 40842-5); Riverton (28330); Gosnells (10978); Mandurah (40847); Augusta (30235); Chorkerup (4538).

#### *Ctenotus fallens* sp. nov.

*Holotype.* R 33780 in Western Australian Museum, collected by Lawrence A. Smith on 6 February 1969 at 11 mi. SSE of Kalbarri, Western Australia, in 27° 52' S, 114° 12' E.

*Diagnosis.* Generally similar to *C. lesueurii*, differing in duller and simpler pattern (*e.g.*, no dorsal pale line between paravertebral and dorsolateral pale lines, and no oblique ventrolateral barring behind arm), fewer nuchals (seldom more than 3), more numerous midbody scale rows (usually more than 26), and fewer lamellae under fourth toe (seldom more than 24).

*Distribution.* Northern half of South-West Division, south to Pinjarra and inland to the Loop (lower Murchison), Balla Tank, Koolanooka Hills and Corrigin; also on Houtman Abrolhos (West Wallabi, Middle, Rat, Helsinki, and Hut Islands), Jurien Bay Islands (Green, Boullanger and Favourite), Wedge Island, Lancelin Island and Rottneest Island. Extralimital in North-West Division.

*Description.* Snout-vent length (mm): 35-95 (68.7). Length of appendages (% SVL): tail 175-261 (218); foreleg 20-32 (25.9); hindleg 35-54 (43.8).

Nasals usually separated. Prefrontals in contact (very narrowly separated in one specimen). Supraoculars 4, first 3 (2 in 2 specimens) in contact with frontal. Supraciliaries 6-8 (mostly 7, rarely 6, mean 7.2). Palpebrals 9-14 (11.3). Second loreal 1.1-2.3 (1.55) times as wide as high. Upper labials 7-9 (mostly 8, rarely 7, mean 8.1). Ear lobules 2-6 (3.8), subacute, acute or truncate in adults, obtuse in juveniles, second or third usually largest. Nuchals 1-5 (mostly 2,

rarely more than 3, mean 2.3). Midbody scale rows 25-33 (28.1). Lamellae under fourth toe 17-26 (22.0), smooth or broadly callose.

Dorsal ground colour dark or pale greyish brown in adults, blackish in juveniles. Blackish brown vertebral stripe from nape to base of tail, narrower than a paravertebral scale, with a narrow white margin, which in turn may be edged with black. White dorsolateral line from above temples to tail, on which it is suffused with brown, broadly margined above with black. Upper lateral zone dark brown with a series of white blotches, spots or dashes. White mid-lateral stripe from behind eye to tail. Lower lateral zone pale grey or pale brown, irregularly spotted with white. Indistinct white line curving under eye.

*Material.* South-West Division: Gee Gie Out-camp, 21 mi. NNW of Murchison House (34039); Kalbarri (29924); The Loop, 22 mi. NE of Kalbarri (33868); Meanarra Hill, 4 mi. E of Kalbarri (33538); 19 mi. E of Kalbarri (33585); Red Bluff (33875, 37643); Lockwood Spring and Hawks Head Lookout, 20 mi. SE of Kalbarri (33847, 33872, 37565-7); 11 mi. SSE of Kalbarri (33776-83); 11 mi. SSW of Kalbarri (33666-7, 33711); Balla Tank, 23 mi. E of Ajana (40850); Koolanooka Hills (29580); Lake Arrowsmith (40849); 40 mi. S of Dongara (19762); Stockyard Gully (26743-5); Green Head (30289); 5 mi. NE of Mt Peron (25284); Mt Lesueur (11161); 5 mi. N of Jurien Bay (17200); 5 mi. NE of Jurien Bay (30478); 5 mi. E of Jurien Bay (30503); Frenchman Bay (17206-7); mainland opposite Green Islets (17210); 10 mi. NE of Lancelin (22282); Lancelin (17214); Ledge Point (33428-31); 7 mi. N of New Norcia (17216-20); Beermullah (4807); between Mougumber and Gingin (30233); Gingin (40036); Culham (17221, 22450-4); Julimar Forest, 15 mi. NW of Toodyay (36332); 3 mi. SE of Bullsbrook (36329); Sorrento (41641-2); Balcatta (14860); North Perth (4838-9); City Beach (17238, 37742; NMV D9798); Cottesloe (7869); Wembley (13111); Gooseberry Hill (24689); 6 mi. E of Kalamunda (34082); Mundaring Weir (14856-7, 16532, 19656, 20594, 21228, 26448, 26475, 40019); 10 mi. SE of Sawyers Valley (22672); Darlington (5987-9, 21263-5); Bickley (13543); Roleystone (17240-5); Karragullen (17246-7); Gosnells (29328); Kelmscott (41177); York (7320, 12663-5); Corrigin (12434); Darling Scarp, between Pinjarra and Dwellingup (25095); West Wallabi Island, Houtman Abrolhos (17253-62, 19602-3); Middle Island, Houtman Abrolhos (27185); Hut Island, Houtman Abrolhos (37518, 41550); Rat Island, Houtman Abrolhos (41535, 41556); Helsinki Island, Houtman Abrolhos (41546); Green Island, 12 mi. N of Jurien Bay (17199, 17201); Favourite Island, Jurien Bay (17203); Boullanger Island, Jurien Bay (17204); Wedge Island (17211-3); Lancelin Island (17215); Rottneest Island (3266-8, 17129, 17222-36; NMV R974-81).

#### *Ctenotus severus*

*Ctenotus severus* Storr, 1969: 101. Galena, W.A. (G. M. Storr).

*Diagnosis.* A medium-sized member of the *lesueurii* group, generally similar to *C. fallens* and differing mainly in colour pattern—black

vertebral stripe absent or reduced to a line on foreback or neck and not white-edged; black laterodorsal stripe broad and sharp-edged; dark upper lateral zone separated from white dorsolateral line by a hiatus of pale ground colour.

*Distribution.* Far northern interior of South-West Division, south to Galena and Gullewa. Extralimital in North-West Division (southern interior) and Eastern Division (southwest).

*Description.* Snout-vent length (mm): 54-91 (68.4). Length of appendages (% SVL): tail 213-224 (218); foreleg 20-27 (23.8); hindleg 36-46 (42.7).

Nasals separated. Prefrontals in contact (narrowly separated in one specimen). Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7 or 8 (7.3). Palpebrals 9-11 (10.4). Second loreal 1.2-1.6 (1.34) times as wide as high. Ear lobules 4-6 (4.8). Nuchals 2 or 3 (2.7). Midbody scale rows 27-32 (29.7). Lamellae under fourth toe 19-23 (21.7).

For further details of coloration, see original description.

*Material.* South-West Division: Galena (17195-6, 19994-6, 25680-3); Gullewa (40848).

#### *Ctenotus alleni* sp. nov.

*Holotype.* R 33602 in Western Australian Museum, collected by Nicholas T. Allen on 17 January 1969 at 11 miles north of Galena, Western Australia, in 27° 41' S, 114° 39' E.

*Diagnosis.* A member of the *lesueurii* group with reduced dorsal pattern, distinguishable from *severus* by its more numerous subdigital lamellae and nuchals, narrower black laterodorsal stripe, and contact between white dorsolateral line and black of upper lateral zone. Superficially similar to *mimetes* but readily distinguishable by wide subdigital calli and by black upper lateral zone enclosing small white spots rather than large rufous rectangular blotches.

*Distribution.* Far northern interior of South-West Division.

*Description* (based on holotype and paratype). Snout-vent length (mm): 87, 78. Length of appendages (% SVL): tail 258, 264; foreleg 25, 24; hindleg 48, 48.

Nasals separated. Prefrontals forming median suture. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7. Palpebrals 12-13. Second loreal 1.3-1.9 times as wide as high. Upper labials 8. Ear lobules 4-6. Nuchals 4. Midbody scale rows 26-28. Lamellae under fourth toe 28-33, each with a moderately wide callus.

Dorsal ground colour olive, darkest on head, palest on tail. Vertebral stripe reduced to a black line on nape. Narrow, clearcut, black laterodorsal stripe from brow to base of tail, about half a scale wide. White dorsolateral line from orbit to base of tail, on which it gradually becomes suffused with ground colour. Black upper lateral zone with one or two series of small white spots or short dashes. White midlateral stripe extending back nearly to end of tail, but barely extending forward to arm. Lower lateral zone blackish brown with one or two irregular series of short dashes.

*Paratype.* South-West Division: 20 mi. NE of Yuna (26499).

#### *Ctenotus mimetes*

*Ctenotus mimetes* Storr, 1969: 103. 12 miles east of Paynes Find, W.A. (D. A. Richards).

*Diagnosis.* A member of the *leonhardii* group with long tail and legs, no vertebral stripe, well-developed white midlateral stripe, black laterodorsal stripe narrow and not enclosing spots, and upper lateral zone consisting of alternating rectangular blotches of black and rufous.

*Distribution.* Northern interior of South-West Division, south and west to Ajana, Carnamah, and Merredin. Extralimital in North-West and Eastern Divisions of Western Australia.

*Description.* Snout-vent length (mm): 33-77 (63.3). Length of appendages (% SVL): tail 212-246 (228); foreleg 22-30 (25.2); hindleg 45-57 (51.3).

Nasals separated. Prefrontals forming median suture. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7. Palpebrals 10-14 (12.2). Second loreal 1.0-1.3 (1.23) times as wide as high. Upper labials 8. Ear lobules 3-5 (4.0). Nuchals 3 or 4 (3.2). Midbody scale rows 26-28 (27.3). Lamellae under fourth toe 23-28 (26.2), each compressed and bearing a dark obtuse keel or narrow callus.

For coloration, see original description.

*Remarks.* A specimen (26499) from the Yuna district was wrongly listed by Storr (1969: 104) under *C. mimetes*; it is actually a specimen of *C. alleni*.

*Material.* South-West Division: 2 mi. W of Ajana (30321); Yuna (8303, 9027); Carnamah (407); Merredin (1265-6).

#### *Ctenotus uber uber*

*Ctenotus uber* Storr, 1969: 102. 22 miles southeast of Yalgoo, W.A. (P. J. Fuller).

*Diagnosis.* A member of the *leonhardii* group, distinguishable from *mimetes* by presence of pale spots in dark laterodorsal stripe and absence of pale midlateral stripe.

*Distribution.* Arid northeast of Eucla Division (Nullarbor Plain). Extralimital in North-West and Eastern Divisions of Western Australia.

*Description.* Snout-vent length (mm): 44-61 (54.3). Length of appendages (% SVL): tail 157-172 (163); foreleg 22-27 (24.8); hindleg 45-53 (47.0).

Nasals normally separated (forming a median suture in one specimen). Prefrontals separated or in contact. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 6 or 7. Palpebrals 10-13 (10.7). Second loreal 1.0-1.4 (1.34) times as wide as high. Upper labials 8. Ear lobules 3-5 (3.6). Nuchals 3-5 (4.0). Midbody scale rows 30-32 (30.5). Lamellae under fourth toe 21-24 (21.8), each with an obtuse keel.

Dorsal ground colour brown, darker and more olive on head, more coppery on tail and hindlegs. Vertebral stripe variably developed (at best a dark line from nape to base of tail; sometimes absent). Dark brown laterodorsal stripe enclosing an indistinct series of pale brown spots. Brownish-white dorsolateral line



sometimes broken into a series of spots. Upper lateral zone dark brown with 3 or 4 longitudinal series of pale brown dots. Lower lateral zone pale brown, spotted or variegated with brownish white.

*Material.* Eucla Division: Seemore Downs (17284-5); 57 mi. NNE of Rawlinna (41592); Forrest (17286); 15 mi. S of Forrest (41594); 24 mi. S of Forrest (41593).

### *Ctenotus atlas*

*Ctenotus atlas* Storr, 1969: 105. 17 miles south of Atley, W.A. (E. & H. Pianka).

*Diagnosis.* A member of the *taeniolatus* group with 8 or 10 pale stripes. Further distinguishable from *impar* by lack of pale vertebral stripe, nasals and prefrontals usually in contact, and upper labials usually 8.

*Distribution.* Arid mallee-spinifex zone of Eucla Division. Extralimital in North-West and Eastern Divisions of Western Australia and in the interior of South Australia and of New South Wales.

*Description.* For further details of coloration and scutellation, see original description.

*Material.* Eucla Division: 11 mi. E of Fraser Range (30765-6).

### *Ctenotus impar*

*Ctenotus impar* Storr, 1969: 105. Tambellup, W.A. (F. R. Bradshaw).

*Diagnosis.* A member of the *taeniolatus* group with 11 (regionally 12) pale lines and stripes, and nasals and prefrontals separated.

*Distribution.* Southern half of South-West Division, north to the Gingin district, but absent from far southwest (i.e. south of Busselton and west of the Fitzgerald). Extralimital in far southwest of Eastern Division.

*Description.* Snout-vent length (mm): 30-66 (51.8). Length of appendages (% SVL): tail 153-200 (176); foreleg 21-31 (25.7); hindleg 37-50 (43.6).

Nasals and prefrontals separated. Supraoculars 4, first 3 (rarely 2) in contact with frontal. Supraciliaries 5-8 (mostly 7, mean 6.9). Palpebrals 8-13 (10.4). Second loreal 0.9-1.5 (1.19) times as wide as high. Upper labials 7 (occasionally 6 or 8). Ear lobules 2-5 (3.7). Nuchals 2-4 (3.1). Midbody scale rows 25-30 (27.7). Lamellae under fourth toe 18-24 (21.7), each with a dark obtuse keel.

For coloration, see original description.

*Geographic variation.* Over most of its range *impar* has eleven pale stripes including a broad whitish vertebral stripe. In the northwestern part of its range, i.e. from the Gingin district south to Pinjarra, the vertebral stripe is divided by a fine dark line, giving a total of 12 pale stripes.

*Material* (additional to that listed in Storr 1969). South-West Division: Wanneroo (31450); Armadale (36676); Yunderup (37748-9); 17 and 18 mi. E of Pingrup (39853-7, 39874-6, 39931-2); Lake Magenta Reserve (39939-42); middle and lower Fitzgerald River (36960, 39004); 10 mi. N of Hopetoun (36248, 36287-9).

### *Ctenotus lanceolini*

*Ctenotus labillardieri lanceolini* Ford, 1969: 69. Lancelin Island, W.A. (J. Ford).

*Diagnosis.* A large pale member of the *labillardieri* group with yellow legs streaked with blackish brown.

*Distribution.* Only known from Lancelin Island, off west coast.

*Description.* Snout-vent length (mm): 68-80 (75.7). Length of appendages (% SVL): tail 189-194 (192), foreleg 20-23 (20.8), hindleg 32-38 (33.4).

Nasals separated (usually narrowly). Prefrontals narrowly separated. Supraoculars 4, first 2 (3 in one specimen) in contact with frontal. Supraciliaries 7 or 8 (7.4). Palpebrals 11-13 (11.4). Second loreal 1.4-1.8 (1.62) times as wide as high. Upper labials 8. Ear lobules 3 or 4 (3.4), subacute or obtuse, second the largest. Nuchals 3 or 4 (3.4). Midbody scale rows 24. Lamellae under fourth toe 22-24 (23.0), each bearing a wide callus.

Dorsally pale brown, irregularly marked with dark brown (markings tending to orientate longitudinally). Poorly defined blackish brown laterodorsal stripe from temples to base of tail, enclosing an irregular series of pale spots. White dorsolateral line from orbit to base of tail. Blackish upper lateral zone enclosing an irregular series of whitish spots and short dashes. White midlateral stripe from ear aperture to base of tail. Dark brown lower lateral zone variably marked with white, including in one specimen a ventrolateral stripe.

*Remarks.* Lancelin Island is so small and close to the mainland that I find it hard to believe with Ford (1969: 74) that *lanceolini* is only an insular representative of *labillardieri*. I think it more likely that *lanceolini* is a northern representative of *labillardieri*, possibly surviving only on Lancelin Island.

*Material.* South-West Division: Lancelin Island (18871-5).

### *Ctenotus labillardieri*

*Lygosoma labillardieri* Duméril & Bibron 1839: 73. New Holland.

*Hinulia greyii* Gray 1845: 76. Swan River.

*Diagnosis.* A member of the *labillardieri* group with reddish legs heavily marked with black. Further distinguishable from *gemmula*, *delli* and *catenifer* by the white dorsolateral line continuous (i.e. not broken into a series of short dashes).

*Distribution.* Humid coasts and near-coastal ranges of South-West and Eucla Divisions, north to the Swan River, east to the Thomas River, and inland to Mt Helena, Boddington, Rocky Gully and the Stirling Range; also on Eclipse and Bald Islands and the Archipelago of the Recherche.

*Description.* Snout-vent length (mm): 25-76 (55.6). Length of appendages (% SVL): tail 142-213 (184); foreleg 20-31 (25.0); hindleg 31-51 (39.4).

Nasals separated (very rarely in short contact). Prefrontals separated (rarely in short contact). Supraoculars 4, first 2 (occasionally

3) in contact with frontal. Supraciliaries 6-9 (7.0). Palpebrals 7-12 (9.6). Second loreal 1.0-2.3 (1.54) times as wide as high. Upper labials 7 or 8 (7.4). Ear lobules 2-6 (3.8), obtuse or subacute. Nuchals 3 or 4 (occasionally 2 or 5, very rarely 6, mean 3.5). Midbody scale rows 24-31 (27.4). Lamellae under fourth toe 20-30 (24.5), each with a dark wide callus.

Coloration in northern Darling Range.—Dorsum brown or olive, without pattern except for narrow black laterodorsal stripe from brow to base of tail (on which it becomes increasingly broken). White dorsolateral line from brow to tail. Black upper lateral zone usually immaculate, extending as a stripe forward through orbit nearly to tip of snout and backward nearly to end of tail. White midlateral stripe from upper lip to distal quarter of tail. Lower lateral zone blackish, enclosing a white ventrolateral stripe. Legs reddish brown, heavily blotched or streaked with black. Abdomen yellow.

Coloration on Bald Island.—Dorsal ground colour olive. Black ragged-edged vertebral stripe usually present. Black laterodorsal stripe very wide, ragged edged, and enclosing a series of small white spots. White dorsolateral line not so straight as in northern specimens. Black upper lateral zone with 1-3 series of white dots. White midlateral stripe wavy, sometimes broken. Lower lateral zone blackish, irregularly spotted or variegated with white.

*Geographic variation.* In most populations the coloration lies between the extremes described above. In the northern Darling Range the pattern is clear-cut and spotting is rare. Going south, the pattern gradually becomes ragged (especially in adults), black pigment increasingly invades the dorsum, the black stripes become dotted with white, and the white stripes become wavy or disjointed.

For full discussion of variation, see Ford (1969).

*Material.* South-West Division: Herne Hill (4908); Mt Helena (1978-9, 25583); Stoneville (27857-8); Greenmount (NMV D7615); Darlington (3340-1, 5985-6, 21262); Glen Forrest (627); Mundaring (8850, 14858, 21229, 26447); Mundaring Weir (26476-7, 30678); 4-7 mi. E of Kalamunda (19492-4, 26816, 34337-8, 37475); Gooseberry Hill (4676); Kewdale (31946); Churchmans Brook (17981-2); Gosnells (4965); Bartons Mill (10262-4); Karragullen and 5 mi. SE (17987-8, 19118); Roleystone (17990); Araluen (31548); Canning Dam (12912); Wungong Brook (17985-6); Byford and 3 and 5 mi. E (17984, 19247, 19803); 4 mi. N of Jarrahdale (17983); Gleneagle (26291, 32470); Serpentine (17977-80); 6 mi. E of Keysbrook (17992-5); Banksiadale (6768, 34252-5); Dwellingup (39958-61, 39979, 40123); Boddington (10708-10); Lake Clifton (17966-8); Collie and vicinity (17969, 19244-6, 22831); Margaret River (17953-5); Mammoth Cave (66); Boranup (13417, 19833-4, 27850, 32465); Karridale (13446); Deepdene (12426, 12776, 36343); 5 mi. N of Augusta (37801-2, 37807); Augusta (30232); Cape Leeuwin (259, 263, 12783, 17956-65); Calgardup (7732); 7 mi. S of Nannup (27847);

10 mi. E of Nannup (21894); Carey Brook, Donnelly River (27848-9, 41039-49); 6 mi. NW of Manjimup (39725-9); Manjimup (5578-9, 5582, 8184, 19039-40, 37819); 7 mi. S of Manjimup (17950-1); Pemberton (5580-1, 37968-9); Northcliffe (19489-91); Mt Chudalup (17970-3); Broke Inlet (26433); Nornalup (11039); Kent River (260-1); Rocky Gully and 6 mi. W (17962, 41050-5); Pardelup (18004); Chorkerup (4514); Denmark, including Rudgyard, Valley of Giants, and Monkey Rock (19853-4, 22460-72, 24692-9, 24942-7, 31188-90, 31984, 37961, 37963-4); Albany (10946); King George Sound (NMV D2735-8); Eclipse Island (6803, 11278); Gidley Brook (27846); Lower Kalgan (19117); Two Peoples Bay (36354-7, 36383-4, 37834-5); Mt Many Peaks (17872-6); Waychinicup River (27845, 29699, 41148-55); Cheyne Beach (17926-47, 19976, 29700, 36010-3, 36015, 36018-9); Bald Island (17903-25, 19972-4, 40815-6); Porongorup Range (21805-8); Mt Toolbrunup (21809-15); Bluff Knoll (17974-5); Mt Bland (36882-5); Boondadup River (36918-9, 37187-94, 37199); east of Mt Barren (17976); Kundip (11005). Eucla Division: Oldfield River (30144); Dalyup River (17949); Dempster Head, Esperance (14948); 6 mi. NE of Esperance (SAM 5952); 5 mi. N of Cape Le Grand (30802-3); Mt Le Grand (22529); mouth of Thomas River (36251-68); Figure of Eight Island (10119; NMV D8247); Boxer Island (NMV D9799, D9805); Thomas Island (10234); Mondrain Island (17901-2; NMV D8240); Middle Island (8684).

#### *Ctenotus gemmula* sp. nov.

*Holotype.* R 29640 in Western Australian Museum, collected by Magnus Peterson and Bryan J. Harty on 8 October 1967 at South Perth, Western Australia, in 32° 00' S, 115° 49' E.

*Diagnosis.* A small member of the *labillardieri* group, distinguishable from *labillardieri* by its broken white dorsolateral stripe and narrower subdigital calli, and from *delli* by its 8 (rather than 7) upper labials and legs boldly blotched (not obscurely dotted) with black.

*Distribution.* Southern half of South-West and Eucla Divisions, north to the Swan River and east to Israelite Bay.

*Description.* Snout-vent length (mm): 31-58 (50.0). Length of appendages (% SVL): tail 163-203 (188); foreleg 21-29 (23.8); hindleg 34-47 (39.8).

Nasals separated (rarely touching). Prefrontals usually narrowly separated, occasionally in short contact. Supraoculars 4, first 2 in contact with frontal. Supraciliaries 6-8 (6.9). Palpebrals 8-12 (10.4). Second loreal 1.1-1.7 (1.34) times as wide as high. Upper labials 8. Ear lobules 2-5 (3.4), acute or subacute in adults, second usually largest. Nuchals 2-4 (3.3). Midbody scale rows 24-28 (24.7). Lamellae under fourth toe 23-27 (24.9), each with a dark obtuse keel.

Dorsally olive grey, unmarked except for narrow black laterodorsal line from brow to base of tail. A dorsolateral series of short white dashes from brow to base of tail. Black upper lateral



zone with or without a series of white spots, extending forward as a broken stripe through orbit nearly to tip of snout and backward on to proximal quarter of tail. White midlateral stripe wavy or broken into series of short dashes. Narrow dark grey lower lateral zone variably marked with white. Legs yellowish brown boldly marked with black and white.

*Paratypes.* South-West Division: South Perth (29595-6, 29639-42, 29651, 29741, 29776-7, 30260, 34396, 37734, 37744-6, 40698, 40748, 40846, 41145, 41567); Rocky Gully (41056); 4 mi. W of Lake Cairlocup (41170); 11 mi. E of Greenshields Soak, Lake Magenta Reserve (39941). Eucla Division: 5 mi. W of Israelite Bay (31102).

#### *Ctenotus delli* sp. nov.

*Holotype.* R 37478 in Western Australian Museum, collected by John Dell on 29 April 1970 at 6 miles east of Kalamunda, Western Australia, in 31° 57' S, 116° 08' E.

*Diagnosis.* A small member of the *labillardieri* group with legs dark olive, finely peppered with black and white. Further distinguishable from *labillardieri* by broken white dorsolateral line, and from *gemma* by upper labials usually 7 (rather than 8).

*Distribution.* The northern Darling Range, from the Helena River to Mt Cooke.

*Description.* Snout-vent length (mm): 34-63 (45.0). Length of appendages (% SVL): tail 156-179 (168); foreleg 24-32 (27.7); hindleg 35-45 (41.1).

Nasals usually separated, occasionally in short contact. Prefrontals separated, usually widely. Supraoculars 4, first 2 in contact with frontal. Supraciliaries usually 7, occasionally 8. Palpebrals 8-12 (9.7). Second loreal 1.3-1.8 (1.52) times as wide as high. Upper labials usually 7, occasionally 8. Ear lobules 3-5 (4.0), obtuse, very small (especially compared to width of aperture). Nuchals 3 or 4 (3.3). Midbody scale rows 28-36 (29.9). Lamellae under fourth toe 23-29 (25.7), each with a dark, narrow callus.

Dorsally dark olive brown, unmarked except for narrow indistinct black laterodorsal stripe from brow nearly to tail. White dorsolateral line from brow to tail (on which it becomes suffused with brown), broken, except anteriorly, into a series of short dashes. Black upper lateral zone from orbit nearly to end of tail, bearing one or more series of white dots. White midlateral stripe broken into series of short dashes, extending forward to below eye and indistinctly backward to about base of tail. Lower lateral zone dark grey flecked with white.

*Paratypes.* South-West Division: 2 mi. SE of Darlington (22582); 4 mi. E of Kalamunda (39982); 6 mi. E of Kalamunda (19120, 34349, 36453, 37476-7, 37985); Karragullen (17989); Mt Cooke (40755).

#### *Ctenotus catenifer* sp. nov.

*Holotype.* R 21819 in Western Australian Museum, collected by Julian R. Ford on 5 November 1963 on hill slopes above Cheyne Beach, Western Australia, in 34° 52' S, 118° 34' E.

*Diagnosis.* A small member of the *labillardieri* group with legs olive brown longitudinally marked with series of black dots. Further distinguishable from *labillardieri* by its broken white dorsolateral line and from *delli* and *gemma* by its heavily patterned back and lack of white midlateral stripe.

*Distribution.* South coast of South-West Division, from West Cape Howe to Cheyne Beach, inland to Chorkerup; with a slightly different population 125 miles to northeast (near Ravenshorpe).

*Description.* Snout-vent length (mm): 33-58 (48.7). Length of appendages (% SVL): tail 168-191 (176); foreleg 21-29 (25.3); hindleg 33-44 (38.1).

Nasals separated. Prefrontals separated, usually widely. Supraoculars 4, first 2 in contact with frontal. Supraciliaries 6-8 (7.2). Palpebrals 8-10 (8.8). Second loreal 1.1-1.4 (1.21) times as wide as high. Upper labials usually 7, occasionally 8. Ear lobules 3-6 (4.2), acute or subacute in adults, obtuse in juveniles, first or second usually largest. Nuchals 3 or 4 (3.5). Midbody scale rows 24-30 (26.7). Lamellae under fourth toe 21-25 (22.7), each with a dark obtuse keel or narrow callus.

Dorsal ground colour olive grey flecked with black. An irregular black vertebral stripe occasionally present. Broad black laterodorsal stripe from brow to tail, ragged edged and bearing a series of pale dots. White dorsolateral line from brow to tail, more or less broken into a series of short dashes. Black upper lateral zone bearing a series of white dots. Dark grey lower lateral zone irregularly flecked with whitish.

*Remarks.* For photograph and description of peculiar specimen from near Ravenshorpe, see Ford (1969).

*Paratypes.* South-West Division: West Cape Howe (21823); Chorkerup (4251); Two Peoples Bay (36375, 36386, 40989-90); Waychinicup River (17877); Cheyne Beach (17935, 17942, 36013-5, 36318); Phillips River, 11 mi. W of Ravenshorpe (18005).

#### *Ctenotus schomburgkii*

*Lygosoma schomburgkii* Peters, 1863, Mber. Akad. Wiss. Berlin 1863: 231. Buchsfield, S.A. (R. Schomburgk).

*Diagnosis.* A member of the *schomburgkii* group, distinguishable from *C. brooksi euclae* by its dark dorsal colouration and two presuboculars.

*Distribution.* Interior of South-West and Eucla Divisions. Extralimital in North-West and Eastern Divisions of Western Australia and in south of Northern Territory, northern South Australia, and western New South Wales.

*Description.* Snout-vent length (mm): 30-49 (40.7). Length of appendages (% SVL): tail 163-214 (188); foreleg 24-32 (27.0); hindleg 43-61 (51.2).

Nasals and prefrontals separated. Supraoculars 4 (rarely 5), with 3 (rarely 2) in contact with frontal. Supraciliaries mostly 7, occasionally 6, rarely 8. Palpebrals 7-10 (9.0). Second loreal 1.2-2.1 (1.68) times as wide as high. Upper labials 7 (occasionally 6 or 8). Ear

lobules 2-5 (3.2), short and obtuse, the first usually much the largest. Nuchals 2-5 (3.6). Midbody scale rows 24-29 (26.1). Lamellae under fourth toe 20-26 (23.0).

Dorsally olive grey or olive brown, unmarked in south, variably marked with black in north (usually with a vertebral, dorsal, and laterodorsal line). White dorsolateral line conspicuous only when margined above with black. Black upper lateral zone enclosing a series of pale vertical bars which may be very narrow or replaced by one or two series of dots; extending as a black stripe forward through orbit to tip of snout and back to about middle of tail. Narrow black lower lateral zone indented or spotted with white. Limbs boldly streaked with black.

*Geographic variation.* In the far southwest of its range, *i.e.* north to the Darling Range and Merredin, *schomburgkii* is completely unmarked dorsally. In the west there is a 75-mile gap between our southernmost striped-back specimen (New Norcia) and our northernmost plain-back specimen (Bartons Mill). In the east there seems to be a gradual change from plain-back to striped-back; for example, two or four specimens from Holt Rock show a trace of the vertebral stripe, and in our single specimen from Salmon Gums this stripe is still more strongly developed.

I treat *schomburgkii* binomially because I now regard *pallescens* of the Northern Territory as a full species.

*Material.* South-West Division: 19 mi. E of Kalbarri (33539, 33553); 12 mi. N of Galena (33621-2); Caron (MCZ 33273); 7 mi. N of New

Norcia (25673); Merredin (1267); Bartons Mill (10267); Boyagin Reserve (22516-7); East Pingelly (28315); Lake Magenta Reserve (39933, 39936-7, 40753); Holt Rock (34407, 34507, 36757, 37491); Lake Varley (29049). Eucla Division: Salmon Gums (30792); 12 mi. N of Seemore Downs (25862-3).

### *Ctenotus brooksi euclae*

*Ctenotus brooksi euclae* Storr, 1971: 14. Eucla, W.A. (W. B. Alexander).

*Diagnosis.* A member of the *schomburgkii* group with whitish dorsal ground colour and a single presubocular.

*Distribution.* Coastal sand dunes of Eucla Division, west to Eyre. Extralimital in far western South Australia.

*Description and material.* See Storr 1971: 14.

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## Obituary

### Sir John Burton Cleland 1878-1971

Emeritus Professor Sir John Burton Cleland, Kt. (created 1964), C.B.E., M.D., Ch.M., F.R.A.C.P., the oldest surviving member of the Royal Society of Western Australia, died in his sleep at Adelaide on August 11, 1971, at the age of 93 years. He was born at Adelaide on June 22, 1878. His father, Dr. W. L. Cleland, Colonial Surgeon of South Australia, put him up as a member of the local Field Naturalists' Group as a youth, and he remained an active member for 80 years, actually contributing an article in its journal, the *South Australian Naturalist*, just prior to his death.

He began his medical training in Adelaide but because of a strike by the honorary teaching staff in 1897 senior medical students were compelled to complete their courses elsewhere. He chose Sydney, because, as he related afterwards, he had heard that opportunities for "birding" were most favourable there! Subsequently he trained in England, at the London School of Tropical Medicine and the London Hospital (as a cancer research scholar), finally becoming Professor of Pathology at his old university, Adelaide (1920). Though he was distinguished in medicine he also became eminent in other fields—in ornithology (he became president of the Royal Australasian Ornithologists' Union), in systematic botany and mycology, and in anthropology. He is credited as "the guiding spirit in the lavish anthropological expeditions to northern South Australia and the lower Northern Territory in the early and middle 1930s" which were organized by the University of Adelaide with the aid of Rockefeller funds.

Though he was resident in this State only between 1906 and 1909, when he occupied the post of Government Pathologist and Bacteriologist, he threw himself actively into the affairs of this Society's predecessor—the West Australian Natural History Society. He was at once elected a member of the council, then presided

over by the Anglican Archbishop of Perth, Dr. C. O. L. Riley, and delivered a lecture to the society on June 26, 1906, on "Demonstrations on some parasites of the blood." This was followed by a paper, "An objection to the direct continuity of the germplasm, with a suggestion as to the part possibly played by hormones in heredity" (September 22, 1908), and a report on "A scientific trip to the north coast of Western Australia," contributed to the same meeting. These were published in the journal of the Society.

He was elected president of the Society for the year 1908-1909 but did not stay out the full term as he left the State and later took up the appointment of Principal Microbiologist in the New South Wales Department of Public Health. His presidential address, "The Australian fauna and flora and exotic invasions" (*J. Nat. Hist. & Sc. Soc.*, 3 (1), 1910: 12-18) was read on his behalf by Bernard H. Woodward, director of the W.A. Museum. In this address Cleland was perhaps the first zoologist in this State to warn on the ecological and medical dangers of alien acclimatisations.

One cannot but speculate as to how much richer the biological scene would have become in this State if Cleland had chosen to remain here. In Adelaide his fame grew and he was the recipient of many awards—the Verco Medal of the Royal Society of South Australia (1933), the Lord Medal of the Royal Society of Tasmania (1939), the Australian Natural History Medallion (1952) and many fellowships. He was a member of many government-appointed boards and committees having to do with scientific and landscape-conservation matters. He was a conspicuous member of that band of "medical naturalists" who added so much to knowledge in Australia during the nineteenth and early twentieth centuries, and has been described as "the last of the old gentlemen-naturalists of the Charles Darwin tradition."

## OBITUARY

### Eileen Ruth Lathlain Johnson M.B.E., B.Sc. (Adelaide), M.A. (Toronto) 1896—1972

Mrs. E. R. L. Johnson, an Honorary Member of the Royal Society of Western Australia, died at her son's home in Melbourne in August, 1972. Mrs. Johnson joined the Society as Miss E. R. L. Reed in 1922. An honours graduate in Botany from the University of Adelaide, she had come to the University of Western Australia to take up an appointment in the Biology Department. When the Botany Department became independent in 1929, Miss Reed was appointed Lecturer-in-Charge, a position she held until her marriage towards the end of 1931. During this period Miss Reed was an active and enthusiastic member of the Society, serving on the Council and being Vice-President in 1932. In 1925-1926 an exchange lectureship was arranged between Miss Reed and Dr. Gertrude Wright of Toronto, who will also be remembered with affection by members of the Society of that period. In Toronto Miss Reed worked for and was granted the degree of Master of Arts of that University.

After her marriage, Mrs. Johnson continued her membership of the Society, though with less time for Society activities. In 1954, after the death of her husband and with her children grown up, Mrs. Johnson rejoined the staff of the

Botany Department of the University of Western Australia, and remained a valued and popular lecturer until her retirement and return to Adelaide in 1965. In view of her scientific contributions and her long and valued association with the Society she was elected an Honorary Member at that time. From 1928 Mrs. Johnson was associated with St. Catherine's College, University of Western Australia, and was Chairman of the College Council from 1956 to 1966; in recognition of this work she was awarded an M.B.E. in 1967. She also spent a three-year term on the University Senate, and was President of the University Women's Association.

During her retirement, Mrs. Johnson was able to continue her botanical work at the Adelaide Herbarium through the courtesy of the Director, Dr. Eichler. The results of an early collecting trip to the Nullarbor Plain were published in the Society's Journal, and a paper on the Western Australian species of *Isoetes* was almost ready for publication at the time of her death. Mrs. Johnson is survived by a daughter, Mrs. John Leslie, and a son, Dr. Andrew Johnson. She will be missed by a large circle of friends.



## INSTRUCTIONS TO AUTHORS

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# 13.—The origin of amphibolite and basic granulite bands in Precambrian gneisses of the south coast of Western Australia

by N. C. N. Stephenson<sup>1</sup>

Manuscript received 22 August 1972; accepted 20 February 1973.

## Abstract.

Evidence provided by chemical variation trends and by field associations suggests that amphibolite and basic granulite bands in the Precambrian gneisses of the south coast of Western Australia have probably been derived from extrusive or intrusive basic igneous rocks, rather than calcareous or dolomitic shales.

## Introduction

Precambrian gneisses with roughly east-west tectonic trends outcrop along the south coast of Western Australia between Point D'Entrecasteaux and Israelite Bay. These rocks are intruded by numerous syn- and late-kinematic granitic plutons also of Precambrian age (Turek and Stephenson 1966), and form part of the Albany-Esperance Block, an arcuate belt wrapped around the southern and southeastern margins of the Archaean Yilgarn Block. The gneisses are predominantly granitic in character, with intercalated basic, pelitic, and minor calc-silicate bands. Migmatitic types are common. The metamorphic grade varies from upper amphibolite to lower granulite facies. Granulite facies rocks from the Fraser Range, at the northeastern end of the Albany-Esperance Block, gave a Rb-Sr age of  $1330 \pm 15$  m.y. (Compston and Arriens 1968, p. 585) and this could be the age of the main metamorphism throughout the Block.

Bands and lenses of amphibolite (hornblende-plagioclase rocks) and basic granulite (hornblende-plagioclase-pyroxene rocks) are common throughout the south coast gneisses.

It is generally recognised that amphibolite and basic granulite may result from the metamorphism of various rock types including extrusive and intrusive basic igneous rocks, basic tuffs, and calcareous or dolomitic shales. The problem of distinguishing between meta-igneous and metasedimentary amphibolites and basic granulites has concerned geologists for many years. The only published study of the amphibolites and basic granulites of the south coast is by Clarke *et al.* (1954) who concluded (p. 54), from a comparison of major element compositions, that they were probably derived from basic igneous rocks. Since publication of this reconnaissance study it has become widely accepted that similarity in major element composition does not necessarily prove derivation from a basic igneous parent and various other approaches to the problem have been tried (e.g., Walker *et al.* 1960; Leake 1964; Shaw and Kudo 1965). It is the purpose of this paper to re-

examine the problem of the origin of the amphibolite and basic granulite bands in the south coast gneisses in the light of recent information.

## Methods

Seven samples of amphibolite and basic granulite have been analysed for 13 major and 13 trace elements. SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, total Fe as Fe<sub>2</sub>O<sub>3</sub>, MgO, CaO, K<sub>2</sub>O, TiO<sub>2</sub>, P<sub>2</sub>O<sub>5</sub>, and MnO were determined by X-ray fluorescence spectroscopy using the techniques for sample preparation and matrix corrections described by Norrish and Hutton (1964, 1969). Seven synthetic standards were used for calibration, and standard rocks G-2, GSP-1, AGV-1, BCR-1, PCC-1, and DTS-1 were analysed to check the accuracy of the method. FeO was determined by titration against standard ceric sulphate solution, and Na<sub>2</sub>O by flame photometry. Total water (H<sub>2</sub>O<sup>+</sup> + H<sub>2</sub>O<sup>-</sup>) was estimated as the ignition loss, with a correction (based on the residual FeO contents of the ignited samples) applied for oxidation of FeO. H<sub>2</sub>O<sup>-</sup> was determined by drying the samples at 110°C. The precision of the analyses at the concentration levels encountered was, with 95% confidence, about  $\pm 1\%$  of the amount present for SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, total Fe as Fe<sub>2</sub>O<sub>3</sub>, FeO, CaO, K<sub>2</sub>O, and TiO<sub>2</sub>, and  $\pm 5\%$  of the amount present for MgO, Na<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, MnO, and H<sub>2</sub>O<sup>+</sup>.

Co, Rb, Sr, Y, Zr, Ba, La, Pb, and Th were determined by X-ray fluorescence spectroscopy using pressed powder samples (Norrish and Hutton 1964; Norrish and Chappell 1967, p. 205). Standard rocks W-1, G-2, GSP-1, AGV-1, BCR-1, PCC-1, and DTS-1 were used for calibration, and the procedure of Hower (1959) was used for matrix corrections. Interferences by FeK $\beta_1$  in Co analyses, RbK $\beta_{1,3}$  in Y analyses, and SrK $\beta_{1,3}$  in Zr analyses were compensated by mathematical corrections based on measurements on samples spiked with known concentrations of the interfering element (Leake *et al.* 1969, p. 63). Li, Ni, Cu, and Zn were determined by atomic absorption spectroscopy. The precision of the analyses at the concentration levels encountered was, with 95% confidence, roughly  $\pm 5\%$  of the reported concentration for Ni, Zn, Rb, Sr, Zr, and Ba;  $\pm 10\%$  for Li, Co, and Y;  $\pm 15\%$  for Cu, La, and Pb. Th was not detected.

Modes were determined by counting 1000 points over a sample area of about 500 mm<sup>2</sup>. Plagioclase compositions were estimated from measurements of the extinction angle X<sup>1</sup>  $\Delta$  010 in sections perpendicular to *x* (Deer *et al.* 1963, Vol. 4, Fig. 55), orthopyroxene compositions

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Table 1

Chemical analyses, C.I.P.W. norms, Niggli values, and modes for amphibolites (analyses 1-5) and basic granitites (analyses 6-11) from the south coast of Western Australia. Average abundances of major elements (Manson 1967, Table VI) and trace elements (Prinz 1967, Table I) for tholeiites (column 12) and alkali basalts (column 13) are listed for comparison.

	Amphibolite						Basic granitite						
	1	2	3	4	5	6	7	8	9	10	11	12	13
	54556	54562	54563	65581	32613	—	16582	20015	56601	56603	56612	—	—
SiO <sub>2</sub>	55.42	49.95	48.95	51.76	50.02	49.99	46.76	48.14	55.71	49.94	49.27	51.2	47.2
Al <sub>2</sub> O <sub>3</sub>	16.82	15.45	15.05	16.88	12.98	18.35	17.94	14.72	16.66	12.49	15.63	15.9	15.8
Fe <sub>2</sub> O <sub>3</sub>	1.40	3.19	2.83	4.97	2.75	2.15	3.16	1.93	1.09	1.47	1.91	2.9	3.2
FeO	6.46	8.31	8.06	6.16	12.16	5.97	8.78	12.92	8.80	12.80	10.48	8.0	8.0
MgO	4.82	6.60	8.33	4.56	6.16	6.19	6.84	6.78	2.46	8.03	5.17	6.2	7.0
CaO	7.69	8.04	9.39	7.22	10.13	10.39	10.22	5.53	6.57	8.35	8.17	9.9	10.1
Na <sub>2</sub> O	3.00	2.50	2.90	2.64	2.04	3.79	2.97	2.26	4.50	2.84	4.00	2.4	3.2
K <sub>2</sub> O	1.89	2.50	1.50	2.44	0.44	0.91	1.46	0.35	1.89	1.02	1.97	0.7	1.4
H <sub>2</sub> O <sup>+</sup>	1.15	1.45	1.52	1.10	1.72	0.92	0.64	0.68	0.48	0.95	1.15	0.8	1.0
H <sub>2</sub> O <sup>-</sup>	0.16	0.14	0.14	0.16	0.03	0.28	0.04	...	0.17	0.17	0.11	1.6	2.4
TiO <sub>2</sub>	0.89	1.06	0.88	1.51	1.42	0.87	0.93	1.44	1.21	0.67	1.57	0.21	0.48
P <sub>2</sub> O <sub>5</sub>	0.22	0.30	0.27	0.56	0.20	0.30	0.23	0.19	0.57	0.11	0.57	0.21	0.48
MnO	0.22	0.48	0.28	0.23	0.29	0.14	0.18	0.24	0.28	0.43	0.27	0.17	0.16
Total	100.17	99.97	99.90	100.19	100.46*	100.48**	100.15	100.18	100.39	99.27	100.27	...	...
Trace Elements (p.p.m.)													
Li	16	21	28	24	...	...	...	...	8	19	36	10	12
Co	32	36	137	34	...	...	...	...	16	37	39	39	42
Ni	86	88	43	80	...	...	...	...	56	148	66	85	101
Cu	10	8	108	59	...	...	...	...	7	8	7	127	108
Zn	100	180	137	134	...	...	...	...	171	288	166	30	51
Rb	136	104	86	137	...	...	...	...	38	38	92	450	774
Sr	487	264	228	570	...	...	...	...	364	172	494	32	30
Y	25	48	31	36	...	...	...	...	73	23	35	108	138
Zr	86	146	81	185	...	...	...	...	461	69	157	244	444
Ba	491	599	198	929	...	...	...	...	2101	490	696	...	...
La	33	39	13	36	...	...	...	...	72	18	46	...	...
Pb	31	17	17	20	...	...	...	...	20	16	18	...	...
Th	<5	<5	<5	<5	...	...	...	...	<5	<5	<5	...	...
C.I.P.W. Norms (wt. %)													
q	5.42	2.99	...	5.13	2.99	5.56	8.90	1.07	1.86	6.02	11.65	...	...
or	11.15	14.75	8.87	14.43	2.62	5.56	17.29	18.86	11.18	24.02	27.52	...	...
ab	25.38	21.15	24.53	22.33	17.26	29.13	30.86	29.19	38.07	18.38	18.87	...	...
an	26.94	23.57	23.62	26.99	24.96	30.51	4.26	...	19.67	...	3.42	...	...
bc	...	...	...	...	...	1.56	15.46	18.50	7.81	12.85	14.90	...	...
di	8.04	11.77	17.23	4.20	19.98	15.51	15.82	7.33	15.91	14.63	15.55	...	...
hy	17.69	12.67	0.83	14.45	23.66	...	...	2.74	2.30	1.26	2.98	...	...
ol	...	7.12	16.73	...	...	11.40	1.82	1.58	2.74	2.13	2.76	...	...
pl	1.68	2.01	1.67	2.86	2.69	1.67	4.64	0.34	2.30	0.25	1.35	...	...
mt	2.02	4.62	4.10	7.21	3.98	3.13	...	...	...	...	...	...	...
ap	0.51	0.70	0.63	1.31	0.46	0.67	...	...	...	...	...	...	...

Niggli Values

al	27.5	22.0	20.1	26.4	18.0	25.6	23.2	19.3	28.5	16.8	22.3
fm	38.3	47.4	44.7	42.1	51.1	37.8	44.3	50.3	35.0	55.1	44.0
c	22.8	20.8	22.8	20.5	25.6	26.5	24.1	25.1	20.4	20.4	21.2
alk	11.4	9.7	8.5	10.9	5.4	10.1	8.4	5.3	16.1	7.8	12.5
mg	0.56	0.37	0.64	0.55	0.43	0.58	0.51	0.45	0.32	0.51	0.46
Quartz	12.6	0.2	...	0.6	A	...	...	...	10.7	...	...
K-feldspar	2.8	4.7	...	...	M	...	M	M	53.6	31.0	42.9
Plagioclase	52.4	30.0	29.7	43.5	M	M	M	M	1.7	6.5	16.6
Biotite	20.7	25.3	21.3	13.0	M	A	M	M	15.8	87.5	28.7
Hornblende	10.3	39.8	58.4	41.2	M	M	M	M	13.4	20.2	2.3
Orthopyroxene	...	...	...	...	...	M	M	M	...	...	...
Chinopyroxene	...	...	...	...	...	M	M	M	...	...	...
Sphene	0.4	...	tr	0.3	A	...	A	A	1.3	tr	0.1
Opauques	0.3	tr	tr	1.2	A	...	A	A	1.3	tr	tr
Others	0.5	tr	tr	0.2	A	...	A	A	...	...	...
Optically Determined Mineral Compositions											
Plag. An%	37	37	38	44-46	35	40	50	50	35	37	34
Opx. Fe <sup>0</sup> %	...	...	...	...	...	...	...	53	75	57	63
Cpx. Ca:Mgr:Fe	...	...	...	...	...	...	...	...	...	44:36:20	39:26:35

Analyses 5-8 are quoted from Clarke *et al.* (1954, Table IV).  
 \* Includes 0.06% CO<sub>2</sub>; 0.06% FeS<sub>2</sub>. \*\* Includes 0.03% FeS<sub>2</sub>; 0.12% Cl; 0.05% Cr<sub>2</sub>O<sub>3</sub>.  
 M—Major constituent. A—Accessory.  
 Specimen numbers refer to the collection of the Geology Department, University of Western Australia.

from measurements of refractive index  $\gamma$  (Deer *et al.* 1963, Vol. 2, Fig. 10), and clinopyroxene compositions from measurements of  $2V_z$  and refractive index  $\beta$  (Deer *et al.* 1963, Vol. 2, Fig. 41).

### Description of the Amphibolites and Basic Granulites

The amphibolite and basic granulite bands range in thickness from less than one metre up to several tens of metres, and are normally conformable with foliation and lithological banding in the surrounding gneisses. One notable exception occurs near Doubtful Island Bay where a discordant band of basic granulite clearly of intrusive igneous origin is well exposed. However, the great majority of basic bands could be interpreted as sedimentary or tuffaceous layers, or as igneous flows or sills.

Most of the basic bands are broadly homogeneous, but some are thinly layered suggesting either metamorphic differentiation or original (sedimentary?) layering. Recrystallisation during metamorphism has completely destroyed original textures, producing granoblastic or foliated fabrics. Hence the parent rock must be deduced from the present chemical composition. In this approach it is necessary to make the assumption, though difficult to substantiate, that metamorphism was isochemical (except for volatiles).

The 11 rock analyses on which this study is based comprise 4 previously presented by Clarke *et al.* (1954, Table IV) and 7 new analyses carried out by the author. The 11 analysed samples are from 5 widely separated localities (Torbay, Albany, Cape Riche, lower Pallinup River, and Point Irby; see Fig. 1) spanning a total distance of 130 km. The samples include representatives of the amphibolite facies and the amphibolite-

granulite transitional facies, and cover all the more common variations in mineral assemblage. Samples showing evidence of metasomatism (usually granitisation; less commonly carbonation or scapolitisation) or of significant retrogression have been carefully excluded from the study.

Chemical analyses, C.I.P.W. norms, Niggli values, and modes for the samples studied are listed in Table 1. There appear to be no consistent differences in major element composition, except perhaps water content, between the amphibolite and basic granulite samples. Hence the basic granulites are believed to be the higher-grade equivalent of the amphibolites. This belief is supported by the fact that these two rock types are generally not associated in the field.

### Discussion

It is evident in Table 1 that the analysed samples are similar in major and trace element composition to average tholeiite and alkali basalt (Manson 1967; Prinz 1967). Following the system of Yoder and Tilley (1962, p. 352), four of the analysed samples may be classified as oversaturated tholeiite (normative quartz and hypersthene), four as undersaturated tholeiite (normative hypersthene and olivine), and three as alkali basalt (normative olivine and nepheline).

However, bulk chemical similarity to basic igneous rocks does not prove an igneous origin. Most authors accept that mixtures of carbonate and shale in appropriate proportions may, after high-grade metamorphism with loss of volatiles, closely resemble basic igneous rocks in bulk composition. Attempts (e.g., by Evans and Leake 1960; Walker *et al.* 1960) to distinguish between meta-igneous and metasedimentary

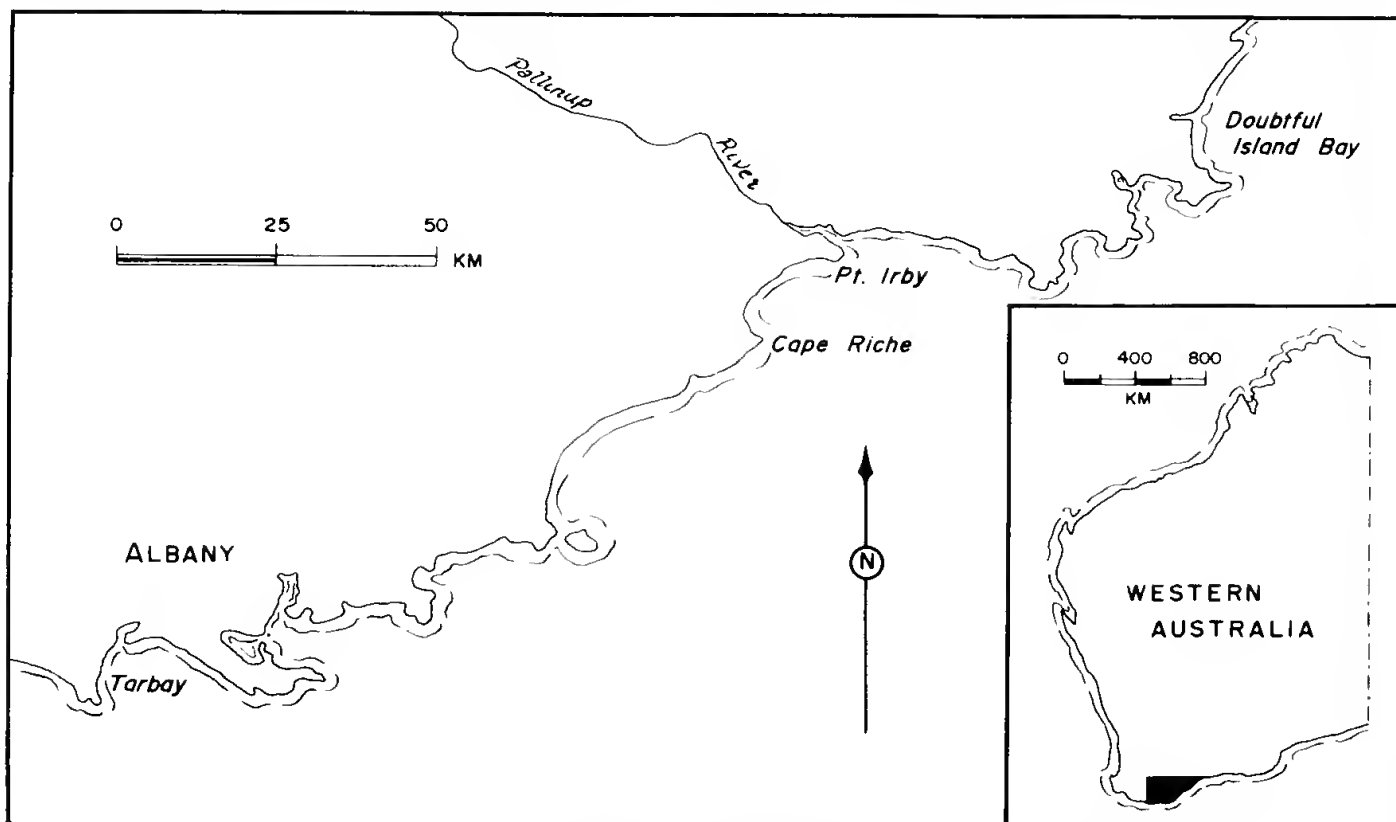


Figure 1.—Locality map.

amphibolites on the basis of abundance levels of certain trace elements have not produced completely diagnostic criteria because observed ranges of trace element concentrations in basalts and in carbonate-shale mixtures greatly overlap.

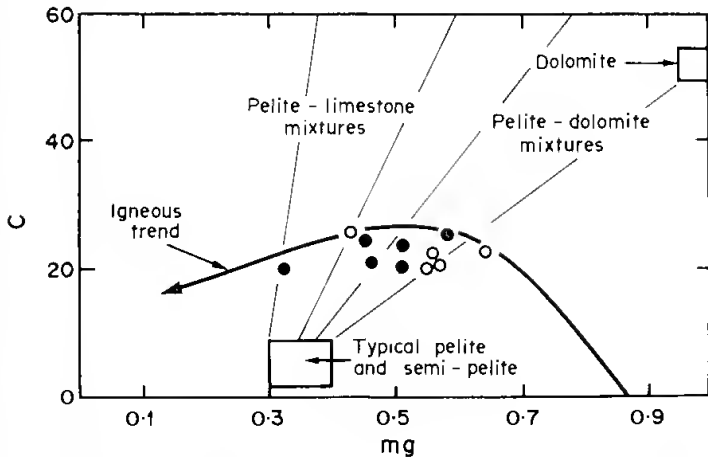


Figure 2.—Niggli c-mg plot for south coast amphibolites (circles) and basic granulites (dots) (after Leake 1964).

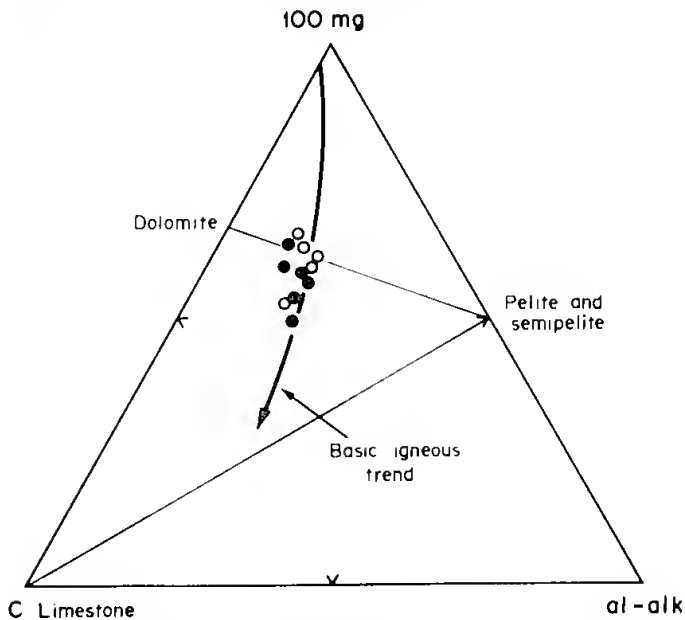


Figure 3.—100mg-c-(al-alk) plot for south coast amphibolites (circles) and basic granulites (dots) (after Leake 1964).

However, Leake (1964) has suggested that chemical variation trends in suites of samples, rather than absolute abundance levels, may be significant, and this approach is followed here. Perhaps 11 analyses are insufficient to reliably define variation trends, but nevertheless some interesting results emerge. Niggli c-mg and 100mg-c-(al-alk) plots of the south coast amphibolites and basic granulites (Figs. 2 and 3, after Leake 1964) closely follow igneous trends, and Ni and Co concentrations appear to increase with increasing Niggli mg values (Figs. 4 and 5) as expected in igneous rocks, but not in carbonate-shale mixtures (Leake 1964). Therefore derivation of the amphibolite and basic granulite bands in the south coast gneisses from extrusive or intrusive basic igneous rocks, or possibly basic tuffs, seems likely.

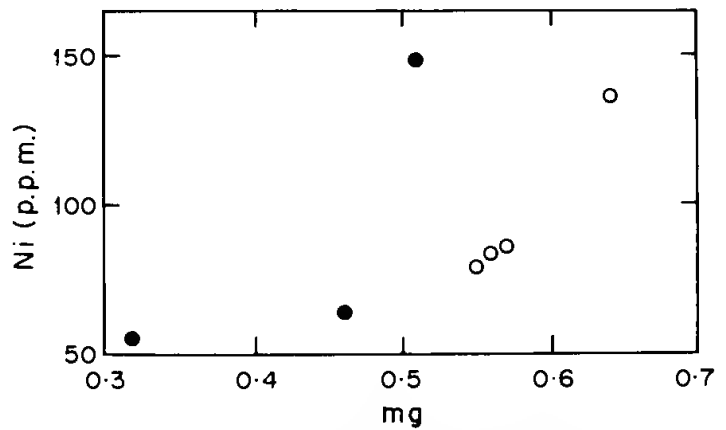


Figure 4.—Ni-mg plot for south coast amphibolites (circles) and basic granulites (dots).

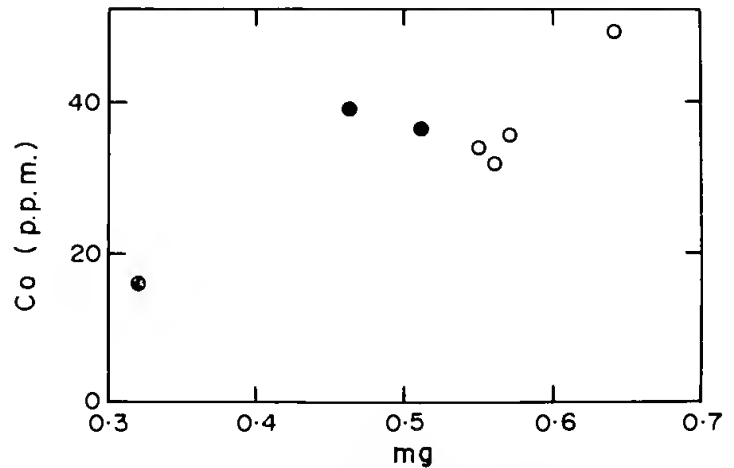


Figure 5.—Co-mg plot for south coast amphibolites (circles) and basic granulites (dots).

However, Orville (1969) has demonstrated that rocks composed largely of hornblende and plagioclase, with relatively small amounts of other minerals, must plot in a limited field along the hornblende-plagioclase tie-line on the ACF diagram, and hence approximate the field of basic igneous rocks (see Fig. 6, after Orville 1969). A consideration of the chemical compositions of hornblende and plagioclase leads to the conclusion that most amphibolites must also plot within the field of basic igneous rocks on c-mg and 100mg-c-(al-alk) diagrams. Orville (1969) has also shown that hornblende-plagioclase rocks can, because of their restricted bulk compositions, represent only a very limited composition range in carbonate-shale mixtures (see Fig. 6). Therefore it can be argued that hornblende-plagioclase rocks, regardless of their origin, might be expected to approximate basic igneous rocks in major element composition, and might be expected to show igneous, rather than sedimentary, trends on variation diagrams based on major element composition.

Because mixtures of carbonate and shale are unlikely to be confined to the restricted range of proportions which yields amphibolite on metamorphism (shale with 20-40% dolomite; see Orville 1969, Fig. 5), it follows that amphibolites derived from carbonate-shale mixtures are likely to be intimately associated in the field with calc-silicate rocks (e.g., plagioclase-diopside grossular rocks) and pelitic gneisses (e.g.,



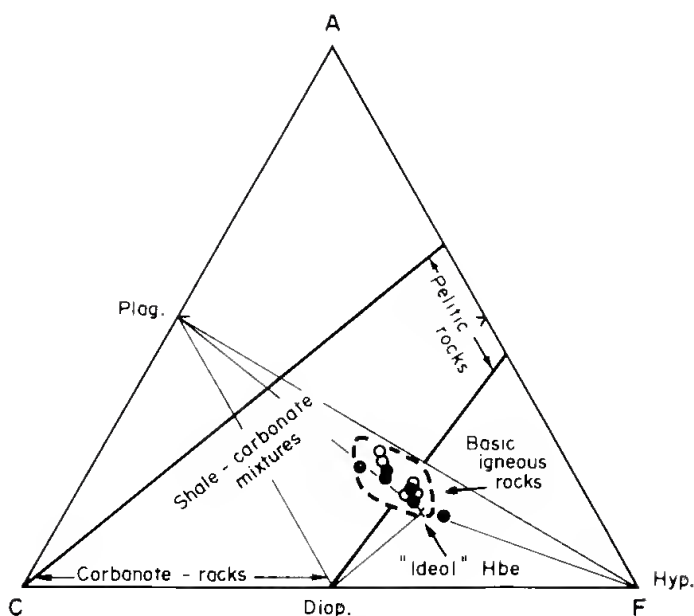


Figure 6.—ACF plot for south coast amphibolites (circles) and basic granulites (dots) (after Orville 1969).

quartz - plagioclase - garnet - biotite - cordierite gneisses), and transitional assemblages. Associations of this type, though not unknown, are uncommon in the south coast gneisses; the amphibolite and basic granulite layers are normally interbanded with granitic gneiss. Furthermore, lithologies representing bulk compositions transitional between amphibolite and pelitic gneiss and between amphibolite and calc-silicate rock are rare in the region in question, so there does not appear to be a continuous variation from calc-silicate to pelitic rock through amphibolite and basic granulite. The amphibolite and basic granulite appear to represent a distinctly defined rock type rather than an intermediate member of a carbonate-shale-derived series. The lack of close association in the field between calc-silicate rocks, amphibolites, and pelitic gneisses also rules out Orville's (1969) model for the genesis of metasedimentary amphibolites involving chemical reaction between adjacent incompatible carbonate and pelitic assemblages.

### Conclusions

It is concluded that amphibolite and basic granulite bands in the gneissic complex of the south coast of Western Australia have been derived mainly from extrusive or intrusive basic igneous rocks rather than calcareous or dolomitic shales because:

- (i) they follow igneous trends on c-mg, 100mg-c-(al-alk), Ni-mg, and Co-mg variation diagrams;
- (ii) they are not usually closely associated in the field with calc-silicate and pelitic gneisses.

Derivation from an igneous parent is further supported by the occurrence at Doubtful Island Bay of at least one band of basic granulite showing discordant, clearly intrusive relations with surrounding rocks. However, the possibility that the parent rocks were basic tuffs cannot

be ruled out in the absence of relict textures, but this is perhaps unlikely in view of the general scarcity of basic tuffs in the geologic column.

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# 14.—The petrology of the Mt Gardner Adamellite, near Albany, Western Australia

by N. C. N. Stephenson<sup>1</sup>

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### Abstract.

The Mt Gardner Adamellite is emplaced in Precambrian amphibolite facies gneisses of the Albany-Esperance Block, about 30 km east of Albany, Western Australia. It is a composite pluton composed mainly of coarse-grained, porphyritic adamellite intruded by dykes of microadamellite and by very minor pegmatite and quartz veins. Field evidence strongly suggests that the pluton was intrusively emplaced as a magma or crystal mush. Chemical data are consistent with derivation of the microadamellite dykes from the porphyritic adamellite magma by concentration of residual liquids, perhaps by filter pressing, during the later stages of crystallisation. The pegmatite and quartz veins are possibly the products of more advanced fractionation. The magma probably originated by anatexis of crustal rock below the present level of emplacement of the pluton during the orogeny responsible for regional metamorphism of the country rocks.

### Introduction

Mt Gardner Adamellite is the name proposed for a granitic pluton situated at the southern end of Two People Bay on the south coast of Western Australia, about 30 km east of Albany

(Figure 1). It is named after Mt Gardner, a prominent topographic expression of the pluton, located at 35° 00'S latitude and 118° 10'E longitude. The Mt Gardner Adamellite is one of a number of granitic plutons emplaced in the Precambrian high-grade metamorphic rocks of the Albany-Esperance Block, and has not been described previously. The purpose of this paper is to discuss the origin of this pluton in the light of new field, petrographic, and chemical data. A geological map is attached (Figure 2).

The chemical and modal analytical methods used in this study have been summarised elsewhere (Stephenson 1973). Mesonorms were calculated using the method of Barth (1962), and plagioclase compositions were estimated from measurements of the extinction angle  $X' \Delta 010$  in sections perpendicular to  $x$  (Deer *et al.* 1963, Fig. 55). Sample numbers refer to the collection of the Geology Department, University of Western Australia.

### Country Rocks

#### Introduction

The basement rocks of the south coast part of the Albany-Esperance Block are Precambrian

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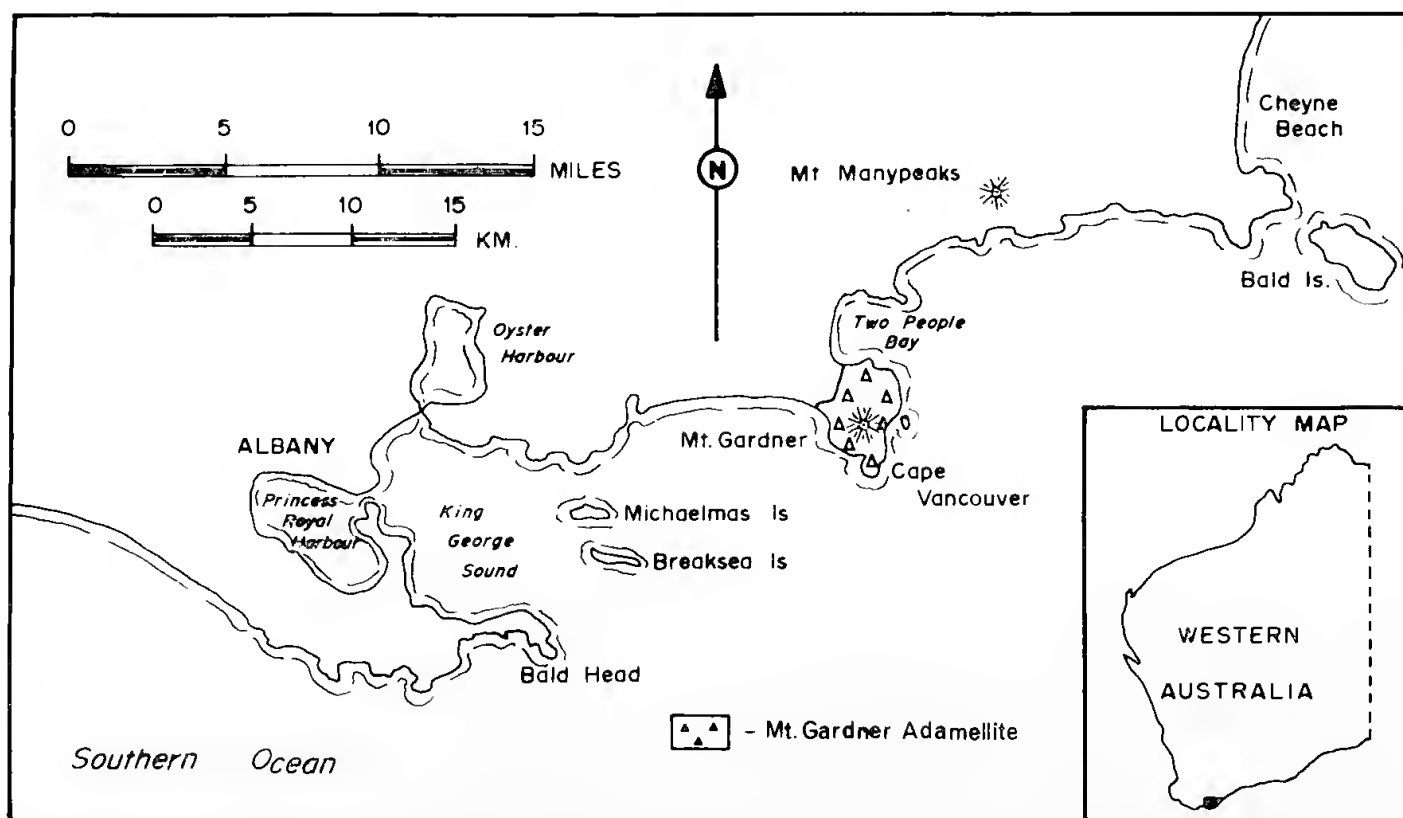


Figure 1.—Map of the Albany district showing the location of the Mt Gardner Adamellite.

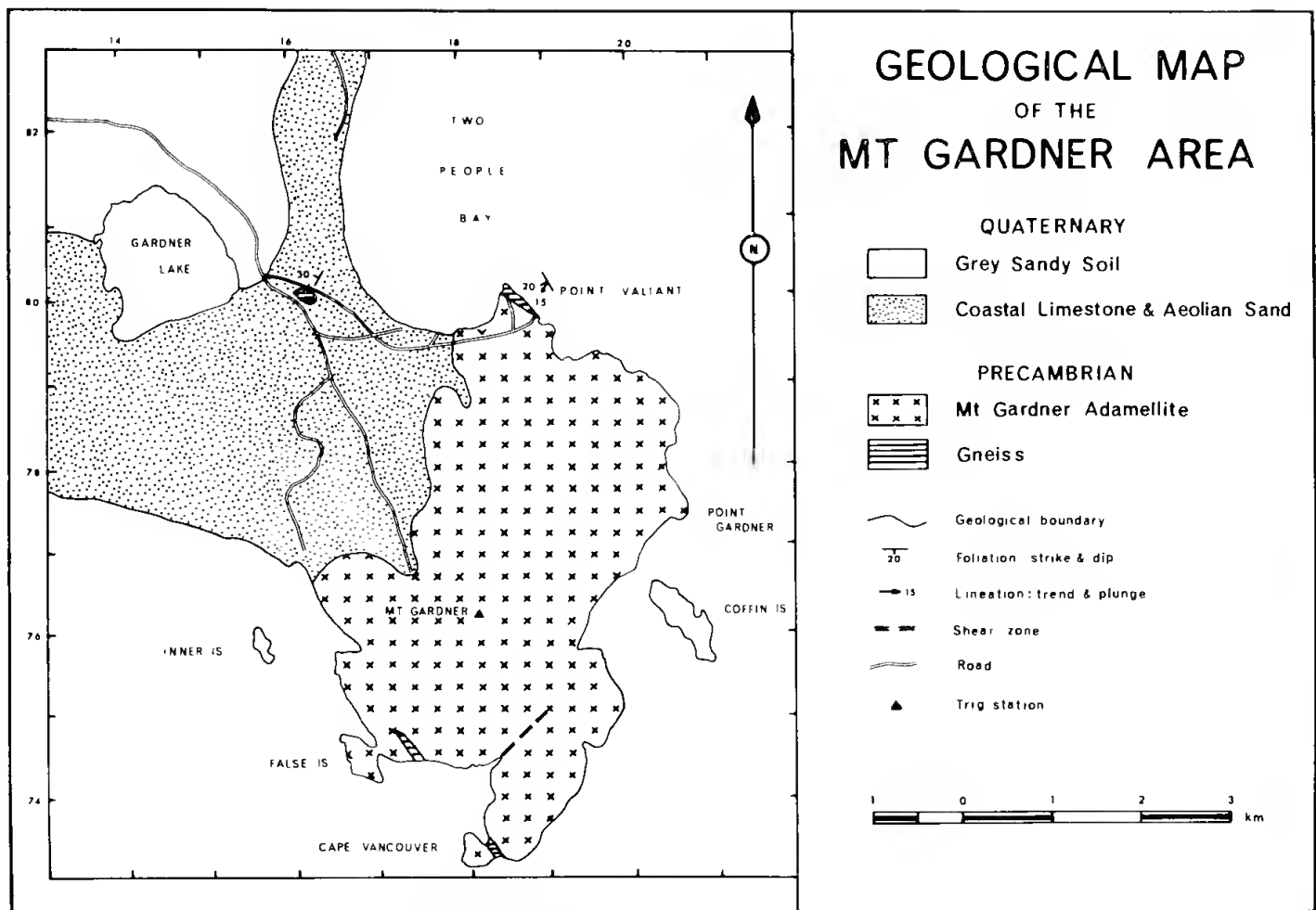


Figure 2.—Geological map of the Mt Gardner area.

gneisses with roughly east-west tectonic trends. These gneisses are predominantly granitic in composition, with intercalated metasedimentary and metabasite bands. Migmatites are common. The metamorphic grade varies from upper amphibolite to lower granulite facies. Granulite facies rocks from the Fraser Range, at the northeastern end of the Albany-Esperance Block, gave a Rb-Sr age of  $1330 \pm 15$  m.y. (Compton and Arriens 1968) and this could be the age of the main metamorphism throughout the block.

The gneissic country rocks surrounding the Mt Gardner Adamellite have been largely obscured by Recent unconsolidated dune sands and by the Southern Ocean. However, they appear to be largely granitic in character, with occasional thin dioritic bands and lenses.

#### Petrography

1. The *granitic gneiss* is poorly foliated, equigranular fine- to medium-grained, and highly leucocratic. Quartz, oligoclase, and microcline in sub-equal amounts are the major constituents. Biotite is the main accessory and a few samples contain a little green hornblende. Minor accessories include magnetite, sphene, epidote, muscovite, apatite, allanite, and zircon. The texture is predominantly granoblastic, commonly modified by the occurrence of biotite either in small streaky aggregates or in well

oriented disseminated flakes. In some samples, especially those collected close to the margin of the Mt Gardner Adamellite, microcline tends to corrode and enclose other minerals, suggesting metasomatic growth. Chemical analyses and modes of four representative samples are presented in Table 1.

2. The *dioritic gneiss* is a fine- to medium-grained, equigranular, dark grey, mesocratic rock composed mainly of andesine, green hornblende, biotite, and quartz. Microcline is locally present. Minor accessories include magnetite, sphene, apatite, allanite, and zircon. The texture is usually weakly foliated due to the preferred orientation of hornblende and biotite. The chemical analysis and mode of a representative sample is presented in Table 1.

#### Metamorphic facies

The mineral assemblages most common in the gneisses around the Mt Gardner Adamellite may be summarised as follows:

1. Granitic gneiss—  
Quartz-plagioclase-microcline-biotite  $\pm$  hornblende.
2. Dioritic gneiss—  
Quartz-plagioclase-biotite-hornblende  $\pm$  microcline.

These assemblages are characteristic of the amphibolite metamorphic facies (Turner 1968).

**Table 1**

*Chemical analyses and modes of granitic and dioritic gneisses from Mt Gardner*

	Granitic gneiss				Dioritic gneiss
	56578	56585	56592	56593	54513
SiO <sub>2</sub> ....	72.26	76.12	77.51	76.15	56.20
Al <sub>2</sub> O <sub>3</sub> ....	12.93	12.21	11.83	12.82	14.98
Fe <sub>2</sub> O <sub>3</sub> ....	2.59	1.22	0.47	1.00	2.35
FeO ....	1.53	1.00	0.70	1.01	5.47
MgO ....	0.52	0.23	0.13	0.42	5.19
CaO ....	2.03	1.21	0.54	1.30	6.68
Na <sub>2</sub> O ....	3.57	3.19	3.25	3.38	3.00
K <sub>2</sub> O ....	3.24	4.30	5.22	4.17	3.29
H <sub>2</sub> O <sup>+</sup> ....	0.36	0.21	0.33	0.22	0.99
H <sub>2</sub> O <sup>-</sup> ....	0.11	0.13	0.10	0.16	0.14
TiO <sub>2</sub> ....	0.34	0.16	0.06	0.15	1.29
P <sub>2</sub> O <sub>5</sub> ....	0.09	0.02	0.01	0.04	0.69
MnO ....	0.06	0.05	0.02	0.03	0.15
Total ....	99.63	100.05	100.17	100.85	100.42
Trace Elements (p.p.m.)					
Li ....	16	10	22	10	18
Co ....	4	<3	3	3	32
Ni ....	26	20	19	24	87
Cu ....	6	5	4	4	49
Zn ....	78	54	44	51	101
Rb ....	137	172	267	143	177
Sr ....	240	101	22	108	593
Y ....	36	42	134	35	42
Zr ....	259	138	97	154	303
Ba ....	1501	1141	277	1696	1667
La ....	67	59	37	48	67
Pb ....	37	37	51	28	32
Th ....	12	12	27	20	22
Modes (vol. %)					
Quartz ....	34.1	35.5	38.4	35.5	10.4
K-feldspar ....	26.1	30.8	35.8	27.0	7.5
Plagioclase ....	33.7	31.5	24.0	34.8	37.8
Biotite ....	4.2	1.4	1.7	tr	14.9
Hornblende ....	.....	.....	.....	2.0	27.7
Rest ....	1.9	0.8	0.1	0.5	1.7
Plag. An% ....	29	19	13	18	34

**Structure**

Determination of the structure in the gneisses around the Mt Gardner Adamellite is difficult because of inadequate outcrop. Lithological banding and foliation in the gneiss appear to be mutually parallel. In isolated outcrops near the northern margin of the pluton these features strike roughly north-south and dip gently (20°-30°) west. This represents a marked local departure from the regional east-west strike in the south coast part of the Albany-Esperance Block. A weak mineral lineation, defined by preferred orientation of elongate biotite flakes, plunges southwest at about 15°-25°. This is assumed to be a *b*-lineation.

**Mt Gardner Adamellite**

*Field occurrence and facies*

The Mt Gardner Adamellite outcrops prominently over an area measuring 6½ x 3½ km, but the actual dimensions of the pluton may be greater because the margins are almost completely obscured by the Southern Ocean or by Recent aeolian sand. The pluton is topographi-

cally expressed as a group of dome-shaped hills which rise steeply from the sea to a maximum elevation of 400 m at Mt Gardner. Two main facies have been recognised:

- (i) Porphyritic adamellite
- (ii) Microadamellite.

*Porphyritic adamellite* constitutes the bulk of the pluton. It is a fairly homogeneous, massive rock with abundant megacrysts of K-feldspar up to 4 x 4 x 2 cm in size set in a medium-grained allotriomorphic to hypidiomorphic granular groundmass.

*Microadamellite* occurs as minor dykes up to a few metres wide within the porphyritic adamellite. It typically shows fine-grained, allotriomorphic granular texture, but the local presence of anhedral megacrysts of K-feldspar up to 2 x 2 x 1 cm in size produces a seriate texture in places.

*Mineralogy*

Both facies of the Mt Gardner Adamellite are composed mainly of K-feldspar, plagioclase, and quartz in order of decreasing abundance, with biotite the main accessory. Minor accessories include magnetite, sphene, muscovite, metamict, allanite, epidote, and zircon. Chemical analyses, mesonorms and modes of representative samples are presented in Table 2.

The K-feldspar is microcline, occurring as anhedral megacrysts and in the groundmass. Larger grains show a strong tendency to corrode and enclose the other minerals, and some megacrysts are strongly poikilitic. Crosshatching may be well developed, rudimentary, or absent, and Carlsbad twinning is common. Perthitic texture is usually conspicuous, with film, string, and patch types most common. The plagioclase is anhedral to subhedral, albite-twinning oligoclase-andesine (An<sub>28</sub>-An<sub>31</sub>), commonly with albite rims on grain boundaries in contact with K-feldspar. Patchy alteration to saussurite or sericite is not unusual. Quartz is anhedral and commonly shows undulose extinction. Biotite is anhedral to subhedral with X = light brown, Y = Z = dark brown. In the porphyritic facies it tends to be concentrated with the minor accessories in wispy aggregates, whereas in the microadamellite it occurs as disseminated flakes commonly showing a preferred orientation. Alteration to chlorite is evident in some samples.

*Textures and crystallisation history*

The crystallisation history of the Mt Gardner Adamellite is not easily determined from grain relations. Apatite and zircon may be included in magnetite and sphene, and all these minerals tend to be euhedral against, and enclosed by, biotite. Biotite and quartz are occasionally enclosed by plagioclase, and these three minerals (especially plagioclase) are commonly corroded and enclosed by K-feldspar. Plagioclase is locally euhedral against quartz, and quartz is commonly interstitial to both feldspars. Hence the order in which the minerals commenced to crystallise appears to be: (i) apatite and zircon;



**Table 2**

*Chemical analyses, mesonorms, and modes of the porphyritic adamellite and microadamellite facies of the Mt Gardner Adamellite*

	Porphyritic Adamellite			Microadamellite		
	56582	65625	65629	65626	65628	65630
SiO <sub>2</sub> ....	66.07	67.74	67.89	69.42	68.88	71.43
Al <sub>2</sub> O <sub>3</sub> ....	16.25	16.18	15.20	15.07	14.87	14.33
Fe <sub>2</sub> O <sub>3</sub> ....	2.25	1.42	1.73	1.51	1.52	1.88
FeO ....	1.43	1.14	1.31	1.52	1.63	1.11
MgO ....	0.90	0.53	0.81	0.71	1.00	0.62
CaO ....	2.68	2.25	1.99	2.14	2.11	1.22
Na <sub>2</sub> O ....	3.71	3.50	3.14	3.29	3.14	2.85
K <sub>2</sub> O ....	5.49	6.00	6.43	5.25	5.56	5.83
H <sub>2</sub> O <sup>+</sup> ....	0.54	0.38	0.47	0.80	0.87	0.62
H <sub>2</sub> O <sup>-</sup> ....	0.08	0.10	0.13	0.09	0.11	0.18
TiO <sub>2</sub> ....	0.64	0.38	0.54	0.49	0.52	0.43
P <sub>2</sub> O <sub>5</sub> ....	0.24	0.20	0.19	0.13	0.18	0.11
MnO ....	0.06	0.05	0.06	0.05	0.05	0.03
Total	100.34	99.87	99.89	100.47	100.44	100.64
Mesonorms (mol. %)						
Q	17.63	19.10	20.35	24.70	24.17	28.75
Or	29.93	33.85	35.87	28.61	29.68	33.11
Ab	33.52	31.71	28.58	29.92	28.59	25.98
An	9.59	8.64	6.87	8.19	7.58	3.93
C	0.79	0.89	0.65	1.12	1.04	2.13
Bi	4.31	3.10	4.27	4.53	5.83	2.94
Mt	2.36	1.49	1.83	1.59	1.60	1.99
Sp	1.34	0.79	1.14	1.02	1.09	0.90
Ap	0.50	0.42	0.40	0.27	0.38	0.23
Trace Elements (p.p.m.)						
Li	19	13	21	17	19	16
Co	7	4	5	3	4	6
Ni	33	33	19	33	18	19
Cu	6	8	5	6	9	5
Zn	79	68	70	70	68	65
Rb	187	211	222	208	196	221
Sr	754	641	606	533	469	218
Y	56	49	66	18	77	18
Zr	456	336	409	353	490	364
Ba	3789	3818	3962	2747	2949	1448
La	179	115	106	182	191	136
Pb	44	48	49	45	41	38
Th	23	18	25	39	39	52
Modes (vol. %)						
Quartz	19.1	19.6	19.7	23.0	23.6	27.4
K-feldspar	39.5	43.6	44.8	36.9	39.1	41.2
Plagioclase	34.7	28.9	28.9	31.2	30.6	24.4
Biotite	4.2	5.1	4.1	6.8	5.4	5.5
Rest	2.5	2.8	2.5	2.1	1.3	1.5
Plag. An%	28-30	28-30	28	28	31	29-30

(ii) magnetite and sphene; (iii) biotite; (iv) plagioclase; (v) K-feldspar. The position of quartz in the crystallisation sequence is regarded as doubtful. There was probably a large overlap between the crystallisation ranges of the felsic minerals.

Several textural features of the Mt Gardner Adamellite give rise to speculation regarding certain aspects of the petrogenesis of the pluton. The tendency for biotite and minor accessory minerals to occur in aggregates suggests that these minerals may be refractory remnants of parent rock or xenoliths rather than products of magmatic crystallisation. The preferred orientation of disseminated biotite flakes in the

microadamellite parallel to intrusion margins is probably a primary flow structure. The strong tendency of K-feldspar to corrode, enclose, and replace the other minerals suggests a post-magmatic (autometasomatic) phase of K-feldspar growth. Perthite and albite rims on plagioclase are believed to have developed by subsolidus reorganisation of albite exsolved from K-feldspar (see Phillips 1964). The common occurrence of undulose extinction in quartz and K-feldspar, and occasional fractured feldspar grains and bent biotite flakes suggest some post-consolidation deformation of the pluton.

*Chemical analyses*

A comparison of the analyses in Table 2 shows that the porphyritic adamellite and microadamellite facies of the Mt Gardner Adamellite are very similar in composition. The microadamellite tends to be slightly richer in SiO<sub>2</sub> and Th, and slightly poorer in Al<sub>2</sub>O<sub>3</sub>, P<sub>2</sub>O<sub>5</sub>, Sr, and Ba than the porphyritic adamellite.

*Minor intrusions*

Both major facies of the Mt Gardner Adamellite are cut by occasional small veins of pegmatite and quartz a few centimetres in width. The relative ages of the pegmatite and quartz veins are not known.

The pegmatite is a coarse-grained, hypidiomorphic-textured rock composed mainly of quartz, oligoclase, and microcline, with minor magnetite and biotite. The quartz veins are coarse-grained, allotriomorphic-textured, and composed almost entirely of quartz.

*Xenoliths*

Xenoliths are fairly common in the porphyritic adamellite. They occur as clearly defined, angular blocks up to about 20 m across, showing little evidence of assimilation. The lithologies represented are restricted to those found in the nearby country rocks, with xenoliths of granitic gneiss outnumbering those of dioritic gneiss by at least ten to one. Chemical analyses and modes of representative samples are presented in Table 3 for comparison with the analytical data for the country rock gneisses listed in Table 1. The xenoliths generally show random orientation of their internal foliation, and therefore appear to have been rotated during their incorporation in the pluton.

The microadamellite dykes contain few xenoliths, mostly of porphyritic adamellite.

It is concluded that the xenoliths in the Mt Gardner Adamellite have been rafted from the adjacent wall and roof rocks. Their nature is consistent with intrusive magmatic emplacement of the pluton, rather than metasomatic emplacement, but there is no evidence to suggest that they have been transported from significantly greater depth.

*Contact relations*

Contacts between the Mt Gardner Adamellite and surrounding gneisses are mostly obscured, either by the Southern Ocean or by superficial deposits. The sole exception occurs at the north-

**Table 3**

*Chemical analyses and modes of granitic and dioritic gneiss xenoliths in the Mt Gardner Adamellite*

	Granitic gneiss		Dioritic gneiss
	56583	65631	65627
SiO <sub>2</sub> .....	71.45	78.91	56.19
Al <sub>2</sub> O <sub>3</sub> .....	13.66	10.79	13.44
Fe <sub>2</sub> O <sub>3</sub> .....	1.57	1.16	1.87
FeO .....	1.24	0.50	5.05
MgO .....	0.42	0.15	7.55
CaO .....	1.24	0.49	5.93
Na <sub>2</sub> O .....	2.86	1.98	2.37
K <sub>2</sub> O .....	5.90	6.01	4.60
H <sub>2</sub> O <sup>+</sup> .....	0.57	0.28	0.95
H <sub>2</sub> O <sup>-</sup> .....	0.13	0.13	0.10
TiO <sub>2</sub> .....	0.33	0.07	1.05
P <sub>2</sub> O <sub>5</sub> .....	0.08	0.02	0.72
MnO .....	0.04	.....	0.14
<b>Total</b> .....	<b>99.49</b>	<b>100.49</b>	<b>99.96</b>
<b>Trace Elements (p.p.m.)</b>			
Li .....	14	2	35
Co .....	5	<3	37
Ni .....	31	15	204
Cu .....	6	5	7
Zn .....	61	27	113
Rb .....	238	191	188
Sr .....	249	219	1136
Y .....	25	8	29
Zr .....	297	88	216
Ba .....	1454	1330	3913
La .....	316	<6	84
Pb .....	51	34	33
Th .....	78	<5	16
<b>Modes (vol. %)</b>			
Quartz .....	27.3	43.7	13.4
K-feldspar .....	35.6	40.7	14.9
Plagioclase .....	31.2	14.2	23.5
Biotite .....	4.0	0.4	21.7
Hornblende .....	.....	.....	25.0
Rest .....	1.9	1.0	1.5
Plag. An % .....	28	20	31

ern margin where about 600 m of the contact is exposed at Point Valiant. Here the contacts are sharp in detail, but the pluton margin is somewhat indefinite, being defined by a wide zone in which gneiss and adamellite are intermingled. Porphyritic adamellite is interbanded with the gneiss in lit-par-lit fashion on a large scale, and irregular discordant intrusions of porphyritic adamellite and microadamellite into gneiss are common. Small veins of quartz and pegmatite are also fairly numerous. The gneiss in this contact zone locally shows development of K-feldspar porphyroblasts, suggesting K-metasomatism, but there is no evidence of major thermal effects in the contact rocks, nor is there any sign of marginal chilling in the adamellite.

It is concluded that the contact relations are consistent with intrusive magmatic emplacement of the Mt Gardner Adamellite, rather than metasomatic emplacement.

**Discussion**

*Petrogenesis of the Mt Gardner Adamellite*

Contact relations and the nature of xenoliths strongly suggest that the Mt Gardner Adamellite was intrusively emplaced as a magma or crystal mush. The spatial association and simi-

larity in composition between the porphyritic adamellite and microadamellite facies suggest a close genetic relationship between them. The nature of this relationship is investigated below.

Despite the strong similarity in bulk chemical composition it is evident in Table 4 that K/Rb, Ba/K, Ba/Rb, and Sr/Ca ratios are slightly lower in the microadamellite than the porphyritic adamellite. Consideration of the substitution behaviour of Ba and Rb for K, and of Sr for Ca during progressive fractional crystallisation of granitic magma (Taylor 1965) suggests that these results are consistent with the microadamellite dykes being the residual product of fractional crystallisation of the porphyritic adamellite magma. The pegmatite and quartz veins are possibly the product of more advanced fractionation.

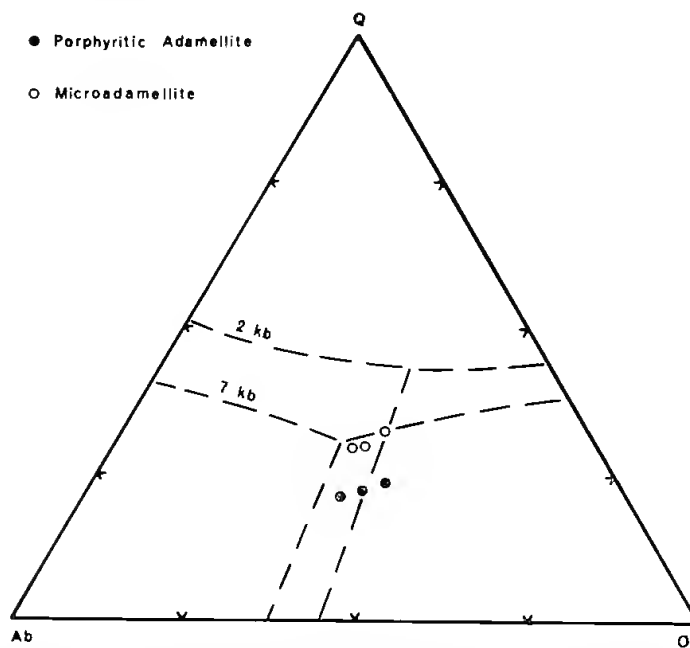


Figure 3.—Mesonormative Ab-Or-Q proportions for the Mt Gardner Adamellite samples compared with the cotectic lines for the system An-Ab-Or-Q-H<sub>2</sub>O where Ab/An = 3.8, for water vapour pressures of 2 kb (from von Platen 1965) and 7 kb (inferred from von Platen 1965, and von Platen and Höller 1966).

In Figure 3 (after von Platen 1965, and von Platen and Höller 1966) the Mt Gardner Adamellite samples are compared with phase relations in the system An-Ab-Or-Q-H<sub>2</sub>O for the appropriate Ab/An ratio of 3.8. The microadamellite samples approximate the minimum melting composition for water vapour pressures around 7kb, whereas the porphyritic adamellite samples plot significantly further from the Q-corner. Consideration of the crystallisation behaviour of melts in the system An-Ab-Or-Q-H<sub>2</sub>O (see von Platen 1965) shows that these results support the contention that the microadamellite dykes are the residual product of fractional crystallisation of the porphyritic adamellite magma, and suggests that fractionation occurred at a water vapour pressure of 7 kb or less.

Filter pressing resulting from tectonic disturbance of the pluton during the later stages of crystallisation is seen as a likely fractionation mechanism.

### Origin of the magma

Stephenson (1973 in prep.) has argued that similar granitic plutons nearby are the product of anatexis of crustal rocks during the orogeny responsible for the high-grade metamorphism of the country rocks. A similar origin for the Mt Gardner Adamellite magma seems likely, although there are no radiometric or Sr isotope data available to confirm or refute this suggestion.

The country rocks in the vicinity of the Mt Gardner Adamellite belong to the amphibolite facies, and hence may have attained a temperature high enough to cause substantial anatexis. Furthermore, the country rocks are composed mainly of granitic gneiss and therefore could yield large amounts of granitic magma on partial melting. Thus it is possible that the Mt Gardner Adamellite may be the product of anatexis more or less *in situ*. However, this possibility can be ruled out on chemical grounds. It is reasonable to assume that elements concentrated in the final stages of fractional crystallisation of magma should also be concentrated in early-formed anatectic melts. Hence a magma formed by partial melting should show lower K/Rb, Ba/K, Ba/Rb, and Sr/Ca ratios

Table 4

Element ratios for the Mt Gardner Adamellite and the gneissic country rocks

	K/Rb	Ba/K x10 <sup>3</sup>	Ba/Rb	Sr/Ca x10 <sup>3</sup>
<b>Porphyritic Adamellite</b>				
56582	294	83	20	39
65625	284	77	18	40
65629	290	74	18	43
<b>Microadamellite</b>				
65626	252	63	13	35
65628	284	64	15	31
65630	264	30	6.6	25
<b>Granitic Gneiss</b>				
56578	196	56	11	17
56585	208	32	6.6	12
56592	163	6.4	1.0	5.7
56593	242	49	12	12
<b>Dioritic Gneiss</b>				
54513	154	61	9.4	13

than the parent rock (see Taylor 1965). Comparison of these ratios for the Mt Gardner Adamellite with those for the granitic and dioritic gneiss country rocks (Table 4) suggests that the pluton cannot have been formed *in situ* by partial or complete melting of the country rocks. Therefore an origin at greater depth is assumed.

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## 15.—A preliminary investigation of the Yilmia Meteorite

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### Abstract.

The meteorite found at Yilmia Hill in Western Australia has been shown by optical and electron microprobe analysis to be an enstatite chondrite of type II (or class E6). It is characterised by relatively abundant sinoite and tridymite. Several criteria indicate a low value for the temperature of final equilibration although the phase assemblage is beginning to be affected by weathering.

### Introduction

Only sixteen meteorites of the enstatite chondrite type were reported by Mason (1966). They were subdivided by Keil (1968) into two types (I and II) with two intermediate stones, on the basis of the iron content and other mineralogical characteristics which will be further noted below. A new find was made on Australian Selection (Pty) Limited ground at Yilmia Hill near Spargoville, W.A., late in 1969 by Mr. G. Coulson, but was unrecognised until June 1971. At this time a second occurrence was discovered only about 400m south of the first. The two occurrences were designated Yilmia I and Yilmia II.

It was not possible for the present authors to carry out the extensive statistical work required for a complete analysis of the meteorite. However, sufficient mineralogical and electron microprobe data have been accumulated to place it unequivocally into Type II of the enstatite chondrites and to point out some of its peculiarities. A limited point count on a representative field of view showed that the percentage of metallic nickel-iron was above average, and of silicates below average, for this type of meteorite. The class symbol according to the Prior-Mason system as modified by Keil (1969) would be Ce<sub>2</sub>, while the Van Schmus and Wood (1967) group would be E6. The analytical data presented in the section on mineralogy are only given as approximate figures, since in view of the variability of the phases, individual analyses are almost meaningless.

### Description of the find

Both masses occurred on flat, soft, lateritic soil which is underlain at a depth of about 30 cm with a hard laterite. The absence of outcrop in this area accounts for the ease with which the meteorites were found. The two masses were discovered three km north north-east of Yilmia Hill Trig Station at latitude 31° 12' and longitude 121° 31' (Figure 1).

The meteorites were partially exposed with the lower portions buried about 8 cm deep. A scatter pattern of smaller fragments (Figure 2A), perhaps thrown off on impact, northwards of the

Yilmia I mass, together with the fact that the two impact sites lie on a north-south line, suggests that the meteorites came in on a south-north trajectory. Unfortunately the Yilmia II site was disturbed before the position of the loose fragments relative to the main mass could be recorded.

The scatter patterns represent something of a mystery, for this type of meteorite should have sufficient metal to resist fragmentation on impact, especially in soft soil. The alternative suggestion that fragmentation is the result of weathering does not explain the scatter over a distance of one metre or the relatively unweathered state of the exposed surfaces.

Although the lateritic area surrounding the sites was searched carefully, no further discoveries were made.

The main mass of Yilmia II (figure 2 B and C) is the best preserved and roughly arrow shaped, the blunt point being originally directed towards the north. The side that faced south is almost flat. The buried fragments of Yilmia I, when pieced together, indicate a roughly similar shape.

The buried portions were severely weathered to a rusty yellow brown colour. The weathered lower side of Yilmia II is strongly exfoliated or layered, unlike the exposed upper half which is apparently devoid of layering. The exposed surfaces are dark brown, fairly smooth and undulose. Irregular and pentagonal crack patterns were seen on some of the more weathered surfaces. Freshly cut surfaces had a bluish colour which became oxidised upon exposure within a matter of days.

Yilmia I weighed 16.2 kg of which the main mass weighed 8.6 kg. Yilmia II weighed 23.8 kg, the weight of the main mass being 11.3 kg. The greater part of these finds are preserved as samples 13192 and 13197 respectively at the Western Australian Museum. Almost 100 gm at the Kalgoorlie School of Mines have sample numbers 10951.1 and 10951.2. Small samples exist at CSIRO Laboratories, Perth, and in the Geology Department, University of Melbourne.

All the mineralogical data in this paper refer to the find Yilmia I (see Figure 2A). Analyses were carried out on an MAC-400S microprobe analyser operating at 20 kV for all elements except carbon, nitrogen and oxygen, which were analysed at 8 kV. For the most part metallic standards were used, although comparison was made with other oxides, sulphides and silicates. Apatite was used as a phosphorus standard.

### Mineralogy

From the mineral assemblage shown in Table 1, and the detailed composition of the phases,

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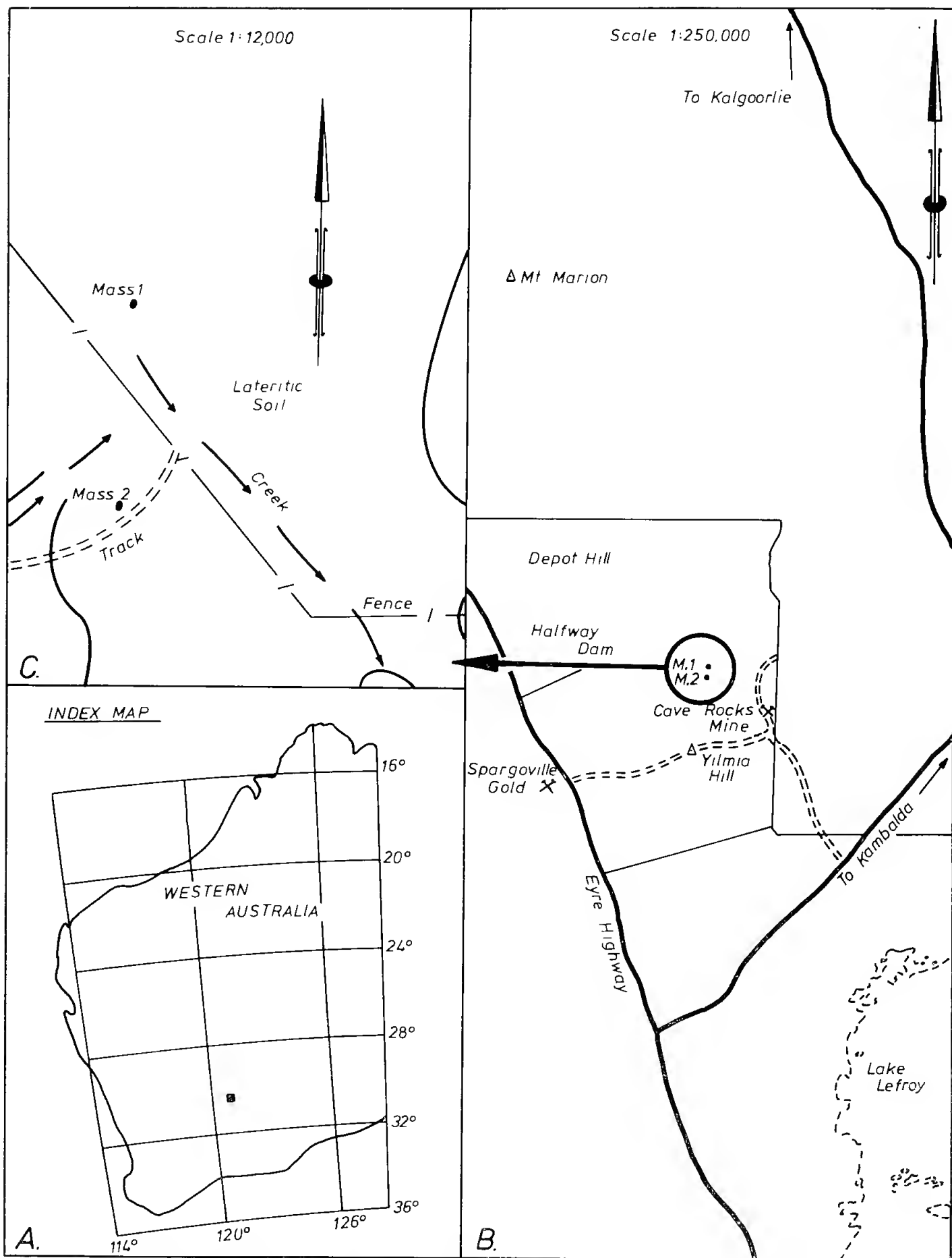


Figure 1.—Location map for the Yilmia Hill meteorite discovered about 10 km West of Kambalda.



INCHES 0 6 12 18 24 APPROXIMATELY  
 CM 0 10 20 30 40 50 60

A

WEST FACE



EAST FACE

B

WEST FACE



EAST FACE

C



Figure 2.—(a) Scatter pattern of mass Yilmia I, north being to the right of the photograph. The white card marks the spot from which came the portion of the meteorite described in this paper. It is possible that this portion was moved to this spot after discovery of the site.  
 (b) Main mass of Yilmia II, showing smooth surfaces exposed to the air, and the layered buried portion. The pointed (northern) side is towards the viewer.  
 (c) Yilmia II viewed obliquely from above relative to position as found. The right hand side was facing north.

Table 1

Phases Present in the Yilmia Hill Meteorite

## Opaque Phases:

Phase	Ideal Composition	Minor Elements Present (Approximate %)
native iron*	$\alpha$ Fe	2.4 Ni, 0.4 Co, 0.2 Cr, 0.1 Ti
kamacite	$\alpha$ Fe (< 7.5% Ni)	5-7½ Ni, ~1 Si, 0.3-0.6 Co, ~0.1 Zn
taenite	$\gamma$ Fe (8-55% Ni)	12-16 Ni, ~1 Si, 0.4 Co
troilite	FeS	1-1½ Cr, ½-1 Ti, 0.1 Mn, 0.1 V, ~0.1 Zn, .05 Co
alabandite	MnS	Up to 21 Fe, 2 Mg, 0.1 Cr, <0.5 Ca, ~0.1 Zn
daubréelite	FeCr <sub>2</sub> S <sub>4</sub>	3 Mn, ~.15 Zn
oldhamite	CaS	2 Fe, 0.6 Mn, 0.3 Si
schreibersite	Fe <sub>3</sub> P	23-26 Ni, 0.15 Co, some S, ~.05 Zn
pentlandite*	(Fe, Ni) <sub>9</sub> S <sub>8</sub>	Co
graphite	a-C	

\* May be an alteration product.

## Transparent Phases:

Phase	Ideal Composition
enstatite	MgSiO <sub>3</sub>
oligoclase	(Na, Ca) (Al, Si) <sub>4</sub> O <sub>8</sub>
tridymite	SiO <sub>2</sub>
sinoite	Si <sub>2</sub> N <sub>2</sub> O
clinopyroxene	(Fe, Mg, Ca) SiO <sub>3</sub>

the meteorite is a Type II enstatite chondrite. In thin section some relict chondrules can be distinguished. A feature of the sections is the segregation into metal-rich and sulphide-rich regions (Figure 3 A and B) and into oligoclase-rich and enstatite-rich regions, on a scale of a few mm. Although the sections studied were fairly fresh, and most of the phases were unaltered, much of the oldhamite had been weathered away, and no good section of this mineral was exposed. In some areas, kamacite and alabandite were partly altered to an oxide phase (Figure 3C). Even where the original phase was kamacite, sulphur was present in the product. Some of this has undoubtedly been introduced in the weathering solutions, but there also seems to be a thin rim (~1 $\mu$ m) of sulphide surrounding many kamacite grains, and in some cases this is left unaltered by the mild weathering, showing the outline of the original grain. One weathered grain was apparently after schreibersite. Analysis of these regions is not possible on a quantitative basis, because they are heterogeneous on a micron scale. However, many microprobe traverses show the presence of nickel-rich regions in which Ni may exceed iron by as much as five to one, and the total metal counts may exceed those from a monoxide. Sulphur is sometimes present, and the example shown in Figure 4 could be interpreted as a very small grain of pentlandite, containing some enrichment of cobalt. These phases are evidently not in equilibrium.

## Siliceous Minerals

*Enstatite*—This phase is an enstatite of low manganese content. Its iron and calcium contents are as expected for Type II, but its aluminium content is lower than usual. Full quantitative data were not obtained. *Oligoclase* and *tridymite* are also present; probe data were

obtained only for identification purposes, so no minor element trends can be quoted. The SiO<sub>2</sub> phase was not obvious in our thin section, and a few grains were removed from the polished section for Debye-Scherrer analysis. It was clearly identified as tridymite and was quite abundant. *Sinoite*, Si<sub>2</sub>N<sub>2</sub>O occurred in several large grains in the polished section. It forms hard, columnar crystals, which normally fluoresce strongly under electron bombardment. Some areas, however, fluoresced only weakly, and it is evidently dangerous to take the fluorescence as the major diagnostic criterion for this mineral.

## Opaque minerals

*Kamacite* is, as usual, the most abundant opaque phase. It contains 5-7½% nickel, 0.3-0.6% cobalt, and up to 1% silicon. Apart from the even lower silicon content, these figures are typical of kamacite from Type II enstatite chondrites, although some zinc (up to 0.1%) also seems to be present in the Yilmia material. One grain of native iron was observed adjacent to troilite and the more typical kamacite; when carbon coated, its colour was distinctly different from that of the latter. This contained only 2.4% nickel and no silicon. The minor elements present included 0.4% Co, 0.2% Cr, and 0.1% Ti, figures which suggest that it may have been formed by weathering from the adjacent troilite, since the phase assemblage is still highly reducing. Ni and Co would need to be contributed from kamacite and taenite.

*Graphite* is generally associated with the kamacite.

*Taenite* occurs in several grains, usually adjacent to kamacite, and was recognised by its high nickel content. This is then the third enstatite chondrite to contain taenite, and the second of Type II. The nickel content of 12-16%

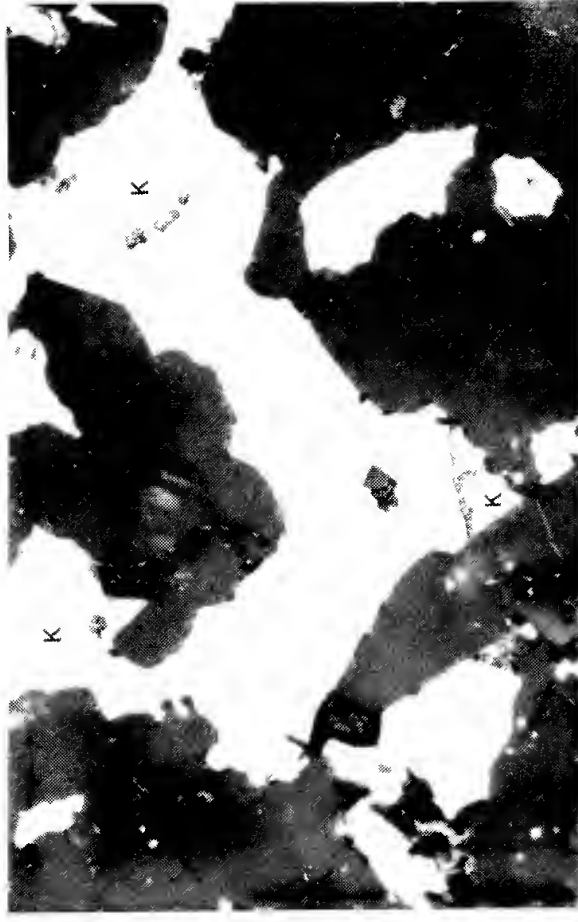
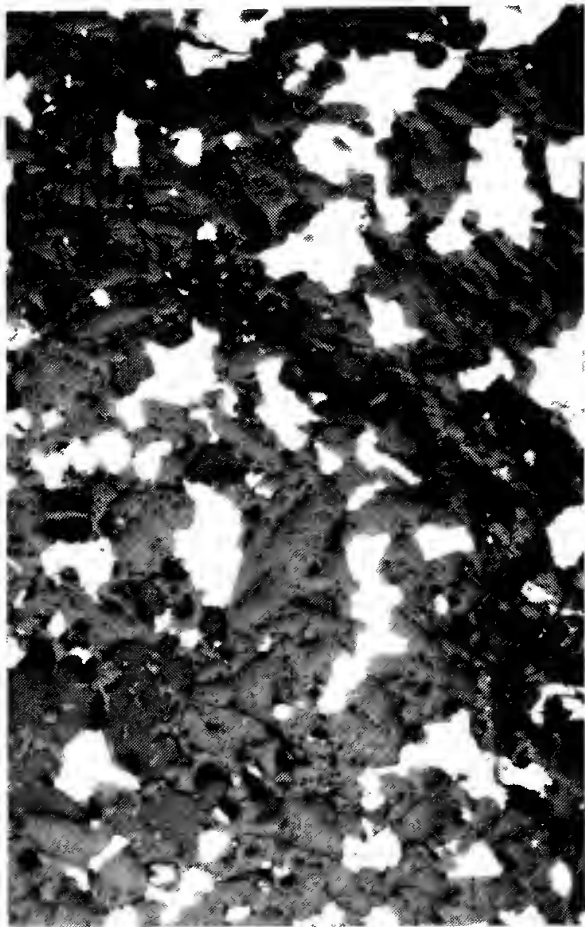
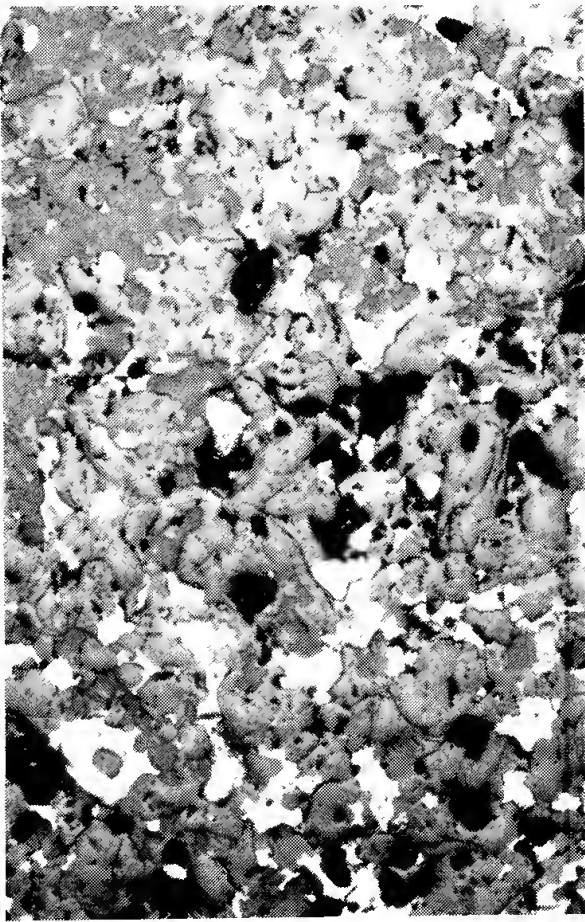


Figure 3.—Micrographs of the Yilmia I Meteorite. (a, top left) A metal rich region. The light phases are taenite and kamacite. Only two grains of sulphides are visible in this field. Width of field 2.2 mm. (b, top right) A sulphide rich region. The light areas are mainly troilite, alabandite, and daubréelite, with some schreibersite and a few metallic grains at the right hand edge. Oldhamite is present in some of the dark pits. Width of field 2.2 mm. (c, lower left) Alabandite altering along cracks to an oxide phase. The white area is troilite. Width of field 140 $\mu$ . (d) Large schreibersite complex (white areas). Width of field 560 $\mu$ . Kamacite grains marked K.



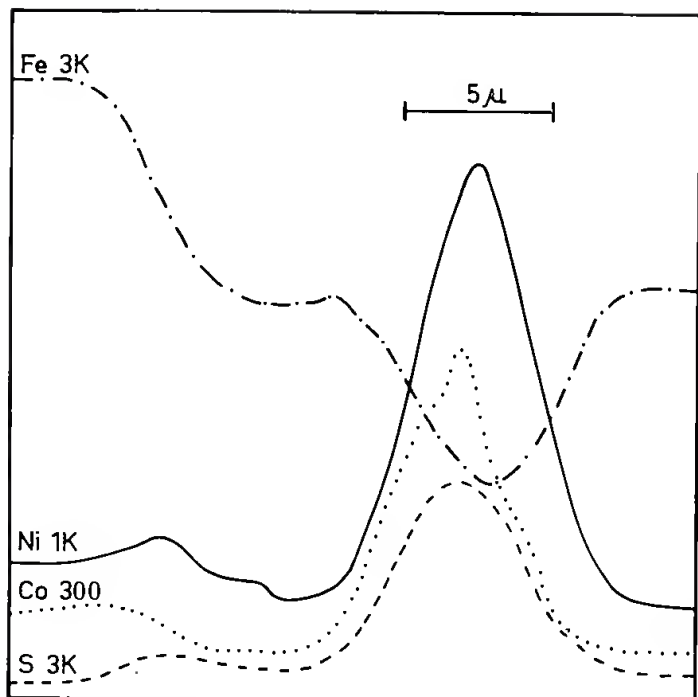


Figure 4.—Traverse across weathered region using the electron microprobe. The sulphide grain is apparently pentlandite containing some cobalt. It is not possible to say whether the pentlandite is an original meteorite phase, or a product of weathering. The symbol identifying each trace indicates the element and the full vertical scale in counts per second.

is considerably higher than that in Adhi-kot and Hvittis. Its cobalt and silicon contents ( $\sim 0.4\%$  Co and up to  $1.1\%$  Si) are similar to those of kamacite. The high nickel content may correspond to a lower temperature of formation of the Yilmia meteorite, since the two-phase region between kamacite and taenite increases considerably as the temperature is reduced.

The *troilite* seems typical of the Type II enstatite chondrites, containing  $1-1\frac{1}{2}\%$  chromium,  $\frac{1}{2}-1\%$  titanium,  $\sim 0.1\%$  manganese and zinc, up to  $0.1\%$  vanadium, about  $0.05\%$  chromium, and sometimes traces of nickel, copper and silicon. As usual, troilite is finely intergrown with daubréelite; where small areas are isolated in the latter, titanium values may be anomalously high.

*Oldhamite* was present, but as it did not polish well (see above), its composition could not be determined categorically. In addition to calcium and sulphur, the following elements were measured: Fe to  $2\%$ , Mn to  $0.6\%$ , Si to  $0.3\%$ , and traces of Mg, Cu, Ni and Co. It is likely that these will be maximum figures (errors being due to the presence of accessory minerals and weathering products), so this oldhamite is unusually low in manganese, and probably also in magnesium.

*Manganoan daubréelite* is close to the ideal composition  $\text{FeCr}_2\text{S}_4$ , with somewhat less than  $3\%$  manganese replacing iron. There are sometimes trace amounts of Si and Ti. Zinc is usually about  $0.1$  to  $0.2\%$ , although in a few grains the amount may reach  $0.5\%$ . The polish-

ing relief between troilite and daubréelite makes it difficult to analyse narrow lamellae of the latter; they often give spuriously high iron counts.

*Ferroan alabandite* is quite variable in composition; as stated in Keil (1968) there is a tendency for calcium to increase and for sulphur and manganese to decrease as the iron content increases. One grain had a very low Mn/Fe ratio of 2.1/1. There was usually about  $2\%$  magnesium,  $0.1\%$  chromium,  $0.1\%$  zinc, and up to  $0.45\%$  calcium.

*Schreibersite* may occur as small grains in association with kamacite, or as large structures such as that shown in Figure 3D. The nickel content is high ( $\sim 23-26\%$ ) in common with all other type II enstatite chondrites, and cobalt is low at about  $0.15\%$ . Silicon was not always present, but sulphur and zinc were consistently slightly above background.

## Discussion

This work was done concurrently with that described by El Goresy and Lovering (1972), and by Buseck and Holdsworth (1972) at the 35th Annual Meeting of the Meteoritical Society. Both of these groups of workers used material from the main mass of Yilmia II. Our results are consistent with their abstracts, although we have been unable to find osbornite or the new zinc-containing sulphide mineral described by the last-named authors, in spite of careful search in the likely areas.

If the low manganese and magnesium counts in the oldhamite are real, the curves of Skinner and Luce (1971) would suggest a very low minimum temperature of formation (below  $600^\circ\text{C}$ ), which agrees well with the value obtained from the calcium content of the alabandite, and the high nickel content of the taenite. Arguments of Larimer (1968) in the case of the Jajh deh Kot Lalu meteorite, which falls closest to Yilmia on Skinner and Luce's curves, also indicate a possibly low temperature of formation ( $720 \pm 140^\circ\text{C}$ ) based on the activities of Si, Fe and  $\text{CaSiO}_3$ , which are unlikely to be very different in the two meteorites. The presence of tridymite indicates a much higher temperature at some stage in the meteorite's history.

Sufficient work has been reported here for classification purposes, and for a comparison of many properties with other enstatite chondrites. A full analytical coverage is still required, together with a comparison of the two masses, Yilmia I and II.

The meteorite phase assemblage is most similar to that observed in Jajh deh Kot Lalu, but the composition of the phases is different enough to make it unlikely that both falls were due to a single meteoritic event. Probably the most significant difference would be the higher free silica and sinoite, the low magnesium content of the alabandite and odhamite, and the presence of taenite in the Yilmia meteorite.

*Acknowledgements.*—We wish to thank Dr. J. A. Hallberg and Mr. R. C. Morris for their help with the thin section, and Dr. R. A. Binns for helpful advice.

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## 16.—Remains of a thylacine (Marsupialia : Dasyuroidea) and other fauna from caves in the Cape Range, Western Australia

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### Abstract.

Occurrences of thylacine and other vertebrate remains from cave deposits in the Cape Range are reported. Some of these records appear to lie outside the known modern distributions of the species. Aboriginal shell artefacts are also reported from one of the sites.

### Introduction

Between 1960 and 1970, several collections of animal remains from cave deposits in the Cape Range, Western Australia (Figs 1 and 2), were presented to the Western Australian Museum. This material has now been analysed. In naming mammals, we follow Ride (1970).

Cave reference numbers, for example CR 4, are those of the Western Australian Speleological Group (W.A.S.G.) and should not be confused with the deep wells (Cape Range 1 to 4) drilled in the area by West Australian Petroleum Pty. Ltd.

The geology of the Cape Range district has been described by Condon et al. (1955). The caves occur in gently folded marine limestones of Miocene age. Maps of the region include the Ningaloo (SF 49-12), Onslow (SF 50-5), and Yanrey (SF 50-9) sheets, Australia, 1:250,000 series.

The specimens, on which this report is based, are Western Australian Museum fossil vertebrates 62.9.1-22, 66.4.17-84, 67.7.2, 68.5.28-32, 68.7.53 and 68.7.54, 68.7.56-111, 69.6.403, 69.7.411-431, 69.7.757-762, 71.6.44, 71.6.56-157, 71.7.121, 71.9.1-4, 71.10.197-207; fossil invertebrates (land snails) 71.996-998, 71.1003-1008. The numbers of zoological and archaeological specimens are cited in the text.

### History of collecting

The earliest collections known to us from cave deposits in the Cape Range were made in April 1962 by Messrs. D. L. Cook and T. Fry, both members of the Western Australian Speleological Group (W.A.S.G.). Cook (1962) reported on the results of the visit. Two of their localities, Owl Roost Cave (CR 4) and Cave CR 7, are represented by Samples 1 and 2 in Table 1, which reidentifies several of their specimens.

In August 1962, Messrs. P. Cawthorn (Western Australian Museum) and P. Symons (W.A.S.G.) collected fossils from Owl Roost Cave (CR 4), from Caves CR 43, CR 44 and four other caves, listed as Samples 3 to 9, Table 1. Of these seven caves, only the location of Owl Roost Cave is known with confidence and two others, CR 43 and CR 44 are known approximately.

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The other four have not yet been allocated reference numbers because of uncertainty as to their location. Cawthorn (1953) reported on zoological collecting in the district but not on cave deposits.

In May 1965, a Western Australian Museum party comprising Mr and Mrs G. E. J. Hitchin and G. W. Kendrick collected from five fossiliferous sites, Caves CR 18, CR 19, CR 6, CR 20 and Monajee Cave (CR 21) listed under Samples 10 to 14, Table 1. For part of the time, they were assisted by Messrs A. J. Saar (W.A.S.G.) and D. G. Bathgate (Honorary Associate, Western Australian Museum), Mrs E. F. Saar and Mr T. Butler. A short account of the expedition was prepared by Kendrick (1968).

In April 1966, Mr D. G. Bathgate collected from Cave CR 42. This material is listed as Sample 15, Table 1.

In April 1968, Mr P. J. Bridge and eight other members of the W.A.S.G. collected fossils from Caves CR 29, probably CR 36 and from Owl Roost Cave (CR 4), listed under Samples 16 to 18, Table 1. An account of the expedition was prepared by Bridge (1968).

### Localities

The following locality details of known fossiliferous caves in the Cape Range have been compiled from field records and catalogue entries relating to specimens in the fossil collection of the Western Australian Museum, from published reports of field parties (Cook 1962; Kendrick 1968; Bridge 1968) and from information kindly provided by Mr P. J. Bridge.

1. Owl Roost Cave, CR 4. The name was first used by Cook (1962). The location is approximately 15 km from Learmonth along the track to the Cape Range No. 3 deep well. The sink hole, about 3 m in diameter, lies about 30 m east from the track and is marked by a fig tree (*Ficus platypoda* Hook.). The chamber beneath the solution pipe contained owl pellet remains and bones of larger animals. In our records, three different parties have collected from this cave.

2. Cave CR 7. The location is near Central Hill beside the track from Learmonth to the Cape Range No. 4 deep well and approximately 9 km south of the fork in the track which leads away to the No. 3 deep well. The cave was "a single cavern with a rectangular entrance halfway up a cliff on the west side of the track" (Cook 1962).

3. Unregistered cave, Sample 3, Table 1. On original labels, the location is described as "Soln.

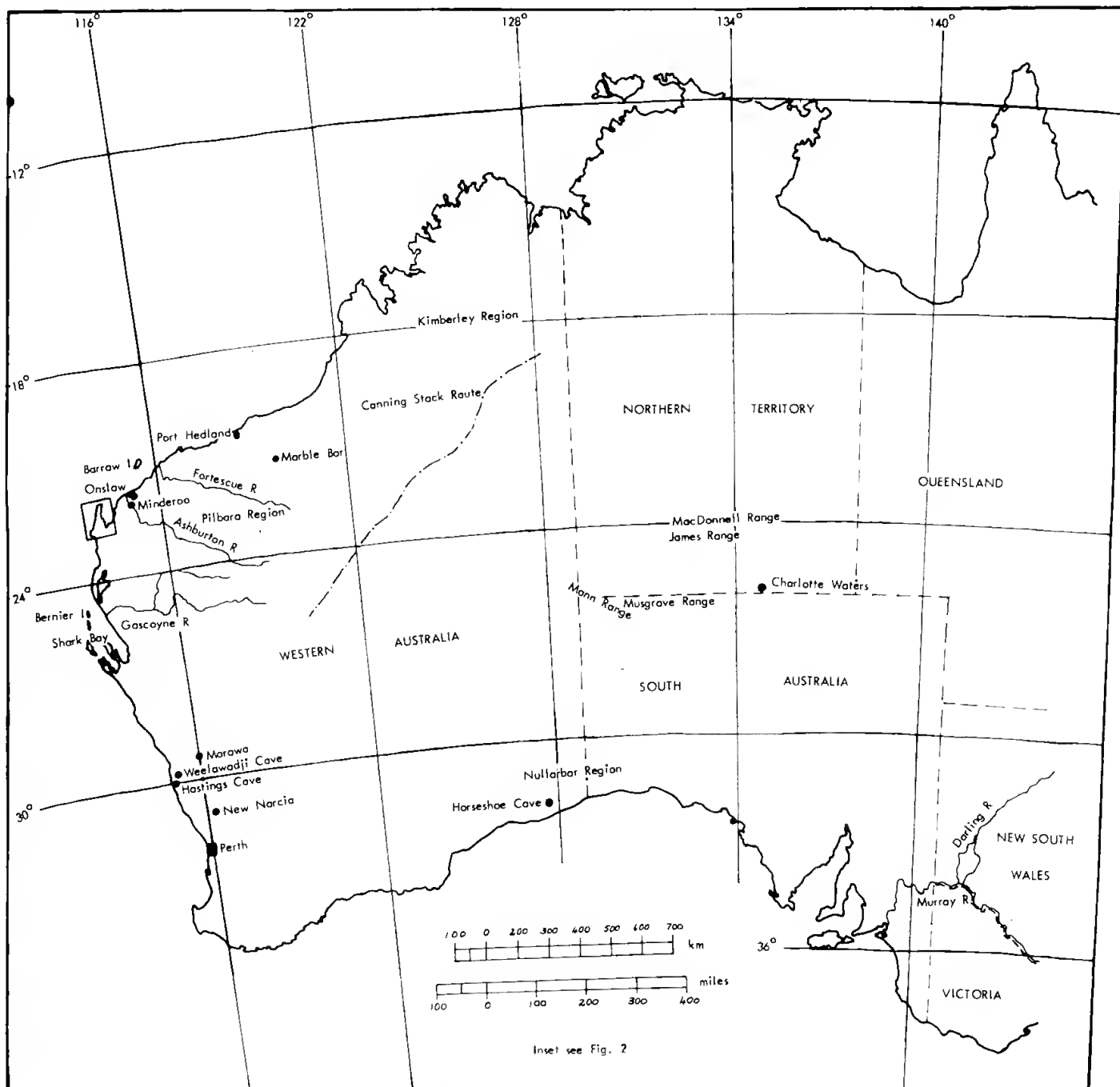


Figure 1.—Locality map: Australia.

pipe and cave 70' deep 130 yards S of No. 3 track, at 7.9 mls". We assume this to mean 7.9 miles (12.7 km) from Learmonth along the track to the Cape Range No. 3 deep well.

4. Unregistered cave, Sample 4, Table 1. On original labels, the location is described as "Sinkhole and cave 8 yards W of No. 3 track at 7.3 mls". We assume this to mean 7.3 miles (11.8 km) from Learmonth along the track to the Cape Range No. 3 deep well.

5. Unregistered cave, Sample 5, Table 1. On original labels, the locality is described as "Soln. pipc 100' deep, 1½ mls NE of No. 2 well".

6. Unregistered cave, Sample 6, Table 1. On original labels, the location is described as "Sinkhole 120' deep, 100 yards W of Learmonth road at 7.4 mls". We assume this to mean 7.4

miles (11.9 km) from Learmonth along the track to the Cape Range Nos. 3 and 4 deep wells. The track forks, northward to the No. 3 well and southward to the No. 4 well within a few kilometres from the position of this cave.

7. Cave CR 43. On original labels, the location is described as "Sinkhole and undercut 2/3 ml. N of Mt. King".

8. Cave CR 44. On original labels, the location is described as "Small cave near Bunbury Cave, 5 ml bore, Yardie Creek Station".

9. Cave CR 18 (in field notes, WAM Cave 1). The location is 1.0 km and bearing 354° from the Cape Range No. 2 deep well. At the surface, the cave had a large, undercut collapse opening, into which a gully would discharge water after rain. The cave floor lay about 40 m below the



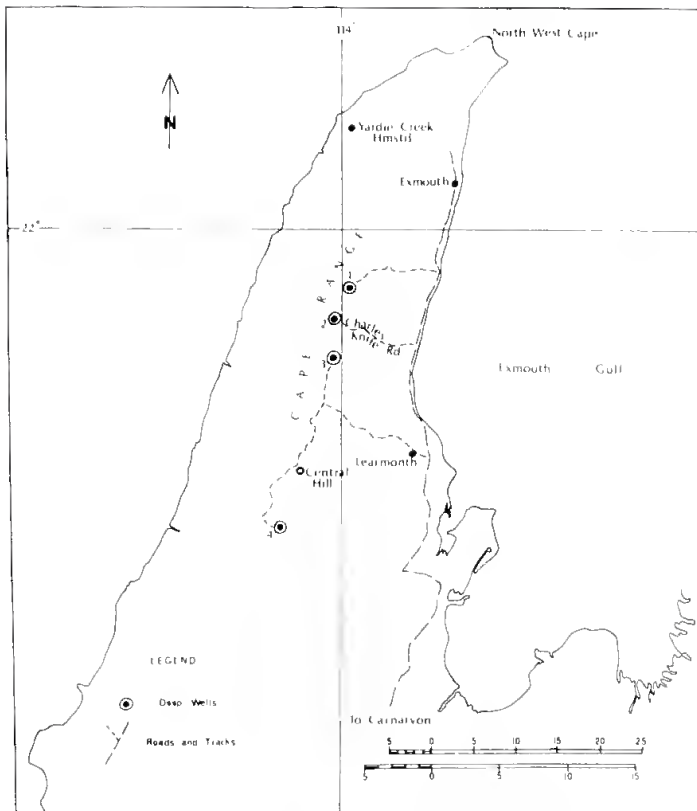


Figure 2.—Locality map: Cape Range. Bar scales in km (upper) and miles (lower).

surface, rising to the west and descending to the east within a large chamber. A few minor "cave earths", probably water deposited, were sampled from along the sides of the chamber but, apart from a single skull picked up from the floor, no vertebrate remains were found. Located from aerial photographs, this cave attracted attention because of its large size but it proved to be a very poor fossil site.

10. Cave CR 19 (in field notes, WAM Cave 3). The location is 0.7 km and bearing  $38.5^\circ$  from the Cape Range No. 2 deep well. A sinkhole about 3 m wide at the surface descended to a rubble floor at a depth of 19.5 m. A side passage continued down beneath a wedged boulder; about 3.6 m further below was a small chamber with a descending, spiral passage leading down about a further 4 m, and floored with bone-rich rubble and sand. The lowest part of the cave was the richest in bone material.

11. Cave CR 6 (in field notes, WAM Cave 4). This cave was noted but not entered by Cook and Fry (Cook 1962). The location is close to the eastern side of the track from Learmonth to the Cape Range No. 4 deep well, about 21 km from Learmonth. A solution pipe, about 3 m wide at the surface, widened considerably below ground, passing down to a chamber with a rubble floor and a sand deposit at a depth of 30 m. A bone-rich "cave earth" was found in a lower part of the chamber floor. Earthworms collected from humic soil in this chamber have been described by Jamieson (1971). Insects and other arthropods were seen but not collected.

12. Cave CR 8 (in field notes, WAM Cave

5). The location is about 3 km west of Learmonth on the escarpment of the Cape Range and a little south of Charles Knife Road. Cook (1962) described it as "An open, well-illuminated single chamber containing much weathered calcite formation. It is situated in the base of a cliff and has apparently been exposed after a collapse of a section of the cliff". Poorly fossiliferous "cave earths" were sampled by Hitchin and Kendrick in 1965. This cave was listed under the reference number CR 20 by Kendrick (1968).

13. Monajee Cave, CR 21 (in field notes, WAM Cave 6). The name was first used by Kendrick (1968). The location is 3.6 km and bearing  $46^\circ$  from Central Hill. The cave entrance, an open sinkhole about 2 m wide at the surface, lay within a small depression on a ridge of rocky, broken ground. A large fig tree covered the opening. The cave is discussed in further detail below in connection with the discovery there of thylacine remains.

14. Cave CR 42. The location is in a canyon 1.6 km north east of the Cape Range No. 2 deep well. It is described as "a small cave".

15. Bell Cave, CR 29. The name was first used by Bridge (1968), who describes the location as "Airphoto 5297, Ref. 5.9 cm S and 6.7 cm E of the photo centre point". The cave is a bell-shaped hole 20 m deep, with two surface openings. At the bottom, a horizontal tunnel leads off for a short distance.

16. Cave CR ?36. There is some uncertainty as to whether the fossil material came from this cave or from CR 41, but Mr P. J. Bridge (personal communication, January 1972) considers that the source was more likely to have been CR 36. The location is approximately 2.9 km beyond the fork in the track from Learmonth, proceeding toward the Cape Range No. 3 deep well. It is close to the eastern side of the track. Cave CR 41 is located about 0.4 km south east of Cave CR 36 and about 0.2 km east of the track.

#### Thylacine and associated remains from Monajee Cave (CR 21)

One of the caves located by the 1965 Museum expedition, initially referred to in field records as WAM Cave 6, was subsequently named Monajee Cave, for reasons which are discussed below. The name is derived from the Aboriginal word for "conch shells used as utensils" in the Gascoyne-Ashburton districts and was obtained from the manuscripts of Mrs Daisy Bates by Dr I. M. Crawford of the Western Australian Museum (Kendrick 1968).

Monajee Cave comprised a more or less vertical but somewhat twisted solution pipe about 2 m wide and 21 m deep, which opened into a chamber a further 3 m deep and about 10 m across at the widest part. The total depth from surface to floor was 24 m. Fig tree roots covered much of the walls of the shaft and several of these continued down from the chamber roof into the floor below. The abrupt transition from vertical shaft to laterally developed chamber suggests that the roof of the lower cave lies at or near the contact of the Tulki

Table 1

Vertebrates present in samples from cave deposits of the Cape Range  
Numbers in the columns represent the minimum number of individuals represented in each sample

Collectors and Year of Visit	Cook & Fry, 1962		Cawthorn and Symons, 1962					Hitchin, Kendrick et al., 1965				Bathgate, 1965		Bridge et al., 1968				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample Numbers	CR 4	CR 7	...	...	...	...	CR 4	CR 43	CR 44	CR 18	CR 19	CR 6	CR 8	CR 21	CR 29	CR 4	CR 4	
Cave Numbers	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
<b>MARSUPIALS</b>																		
<i>Dasyurus hallucatus</i>	2										1	2		3				1
<i>Antechinus rosamundae</i>											2	1		1				
<i>Antechinus macdonnellensis</i>	2										2	1		2				
? <i>Platypus</i> sp. or ? <i>Sarcophilus</i> sp.	2										1	1						
<i>Sarcophilus laingianus</i>											1	1						
<i>Sarcophilus</i> sp.											1	1						
<i>Phascogale calura</i>											1	1						
<i>Thylacinus cynocephalus</i>											1	1						
<i>Perameles</i> sp.	7			2							9	8						
<i>Isacanthus</i> sp.	1				1	1				1	1	2						
<i>Trichosurus</i> sp.											1	1						
<i>Palorchestes platyops?</i>											3	5						
<i>Bettongia lesueur</i>		1			1	1	2				1	1						
<i>Petrogale</i> sp.											1	1						
<i>Macropus</i> (some identified as <i>robustus</i> )	1										1	1						
<b>EUTHERIANS</b>																		
<i>Rattus tunneyi</i>	12			7							10	1		7				
<i>Rattus rattus</i>											1	1		1				
<i>Mesembriomys uacerrus</i>	1										1	1		2				
<i>Leperidillus apicalis</i>	1			1							1	1						
<i>Nelumbo</i> ( <i>Macropodulatus</i> ? <i>sumplius</i> )	1										1	1						
<i>Nelumbo</i> sp.	2										1	1						
<i>Zarogomys pedunculatus</i>	1										1	1		4				
<i>Zarogomys</i> probably <i>pedunculatus</i>	22										27	1		10				
<i>Pseudomys bernardusbergensis</i>	1										1	1		3				
<i>Pseudomys ?praeceus</i>	1										1	1		1				
<i>Pseudomys desertor</i>	1										3	3		3				
<i>Pseudomys nanus</i>	1										2	2		1				
<i>Canis familiaris</i>	1										1	1		1				
<i>Felis catus</i>											1	1		1				
<i>Ovis aries</i>											1	1		1				
<b>OTHER VERTEBRATES</b>																		
Bird	1										2	3		1				
Lizard	?1										1	1		1				
Python											1	1						
Shark (teeth)											1	1						

Limestone and the Mandu Calcarenite (Cook 1962). A prominent dripstone pillar, no longer growing, descended from the chamber roof and had been sharply truncated about midway between the roof and the present floor of the cave. This probably represented a column, severed by subsidence of the floor on which it had once stood.

Bone-bearing samples were collected from deposits in six different parts of Monajee Cave. One of these was a lithified "cave earth", remnants of which were attached to the limestone walls up to about 1.8 m above the present floor and up to about the same level as the base of the truncated roof pillar. Several large pieces of lithified "cave earth" were found on the floor and the largest of these, from which bones were seen protruding, was collected. The lithified "cave earth" appeared to be the oldest remaining deposit present within the cave.

Unlithified "cave earths" were sampled from other parts of the chamber, including a bank about 1 m high along the eastern wall. Other bone material was gathered from the present floor surface.

When the party returned to Perth, G. E. J. Hitchin used dilute acetic acid to extract a portion of a pelvis from the large block of lithified "cave earth". This was identified as dog (*Canis familiaris*, presumably dingo) and the occurrence recorded by Merrilees (1968), who cited the cave under its informal name of "WAM Cave 6".

In a recent re-examination of the samples collected from Monajee Cave, one of us (J.K.P.) noticed several vertebrae and a single calcaneum representing the thylacine (*Thylacinus cynocephalus*). The vertebrae (No. 71.6.137) came from the same piece of lithified "cave earth" as the dingo pelvis and appeared to be from an animal of small size, the age of which we could not judge. The calcaneum (No. 71.6.103) was found in the bank of unlithified "cave earth" along the eastern side of the chamber and was from the right "heel" of a small but apparently adult animal. The deposit containing the calcaneum appeared to be geologically younger than that from which the vertebrae and the dingo pelvis came but we have no radio metric dates or other means of absolute age determination. The possibility that the calcaneum was reworked from a pre-existing deposit, such as the lithified "cave earth", could not be ruled out.

This record is the first known occurrence of thylacine remains from the north west of Western Australia, though Wright (1968, 1972) has reported Aboriginal rock engravings from the Pilbara region which apparently depict thylacines. It is of interest that the next most northerly occurrence of thylacine remains in this State is also a calcaneum. The specimen (No. 67.11.25) was noticed by Mr J. M. Clark in a sample collected from Weelawadji Cave, Eneabba district, by a Museum party which included Mr and Mrs Hitchin.

Other vertebrates found in association with the thylacine and dog remains in the piece of lithified "cave earth" were a bandicoot (*Isodon* sp.), macropods (*Petrogale* sp. and *Macro-*

*pus* sp.), a rat (*Rattus* sp.) an unidentified murid and a bird.

Land snail shells were common in all of the deposits sampled in Monajee Cave. Those collected represented species of *Themapupa*, *Australbinula*, *Discocharopa*, *Eremopeas* and *Rhagada*; *Pleuroxia ruga* Cotton (Cotton 1953) and a minute punctid of undetermined genus were also collected. All of the species recovered are probably living in the vicinity of the cave at the present time. A living *Eremopeas* was found in aestivation with epiphragm intact on a ledge in the solution pipe of Monajee Cave about 10 m below the ground surface. This specimen (No. 4677-68) is now in the modern mollusc collection of the Western Australian Museum.

#### Aboriginal artefacts in Monajee Cave

The modern floor of Monajee Cave was found to be strewn with numerous pieces of large marine shells, mostly fragmentary, but one large specimen was almost entire. Forty eight pieces were picked up from the floor surface and another piece was found in an excavation a few centimetres below the surface. In addition, a piece of shell was found firmly embedded in flowstone on the wall of the chamber at about 0.8 m above the present floor. This specimen was not collected.

The shells from Monajee Cave were sufficiently well preserved to permit identification and represent the gastropod species *Syrinx aruanus* Linnaeus and *Melo amphora* (Solander), both of which are common along the beaches and intertidal shallows along both sides of North West Cape. Shells of these two species were once widely utilized by the Aboriginal people of the region to make utensils (McCarthy 1967) and the shapes of some of the pieces collected indicate that they were fashioned for this purpose. The quantity of shell material recovered from Monajee Cave suggests that, for a long time, the Aboriginal people of the district had made a practice of discarding such objects into the opening of the solution pipe.

These specimens (Nos. A 15913 and A 22117) are now in the archaeological collection of the Western Australian Museum.

#### Apparent range extensions of mammals

Several of the mammalian occurrences listed in Table 1 imply extensions of range when compared with modern and fossil distributions hitherto recorded. In each case, comparisons were made with modern distributions given by Ride (1970) and with fossil specimens in the collection of the Western Australian Museum. Fossil distributions recorded by Lundelius (1957, 1960) were also taken into account. In assessing these apparent range extensions, it should be kept in mind that the living fauna of the Cape Range is not well known.

*Sminthopsis longicaudata* is represented by four individuals, two from Owl Roost Cave (CR 4) and two from Monajee Cave (CR 21). This little known species is recorded from the vicinity of Marble Bar and ? Central Australia (Ride 1970) and also from "the Pilbara" and

Marble Bar. Thus all extant and well localized records of this species from Western Australia are from the north eastern part of the Pilbara region, about 600 km east from the Cape Range.

A single specimen representing *Antechinus rosamondae* from Owl Roost Cave (CR 4) appears to be the first fossil record for the species and also suggests a slight extension of range. Ride (1970) records it from the Port Hedland district to Onslow on spinifex grassland. A modern specimen (No. M 6534) collected 20 miles (32 km) south east of Minderoo station homestead, lower Ashburton district, is in the collection of the Western Australian Museum.

Two specimens from Cave CR 19 represent a small phascogaline dasyurid. The material is incomplete but may possibly be either a species of *Planigale* or a known but as yet undescribed dasyurid of uncertain generic status from the Pilbara region.

A single tooth from Cave CR 19 appears to represent *Phascogale calura*. This species has been recorded in historic time from the inland south west of Western Australia, the MacDonnell Range of the Northern Territory and elsewhere in eastern Australia (Ride 1970). Lundelius (1957) recorded fossil specimens from the southern Nullarbor region and subsequently (Lundelius 1960) from "Drover's Cave" (really Hastings Cave) Jurien Bay district (see Merrilees 1968).

For determinations and comments on the above four dasyurid species, we are indebted to Mr M. Archer (personal communication, September, 1971).

A single molar tooth (No. 68.7.102) from Cave CR 6 appears to represent *Potorus platyops* (Butler and Merrilees 1971).

Cook (1962) recorded *Mesembriomys macrurus* from Owl Roost Cave (CR 4), and subsequent collecting has confirmed the presence of the species among the fossils from the Cape Range. Modern records of *M. macrurus* are unknown from south of the Fortescue River (Ride 1970). The fossil occurrences are located a further 250 km to the south west.

*Leporillus apicalis* has been recognized from two localities in the Cape Range, indicating a considerable extension of range to that established from modern records. Ride (1970) records the species from Central Australia as far west as the Mann and Musgrave Ranges, South Australia to western New South Wales and parts of Victoria. Lundelius (1957) found it to be abundant in fossil deposits from caves in the Nullarbor region. Other specimens have subsequently been collected by Mr A. Baynes from the surface of small cave deposits in the Shark Bay district (e.g. No. 71.7.5) and from a depth of 2.98 to 3.10 m in Hastings Cave, Jurien Bay district (e.g. No. 72.12.5). In addition, Mr J. White has collected a single specimen of this species (No. 68.1.47) from the surface of a small deposit near Morowa. These fossil records suggest that *L. apicalis* is or was more widely distributed than do the modern records.

One maxilla of a species of *Notomys* from Owl Roost Cave (CR 4) may represent either *N. longicaudatus* or *N. amplus*. The sole record

of *N. longicaudatus* from Western Australia in historic time was from the New Norcia district; other modern records are from the southern part of the Northern Territory and north western New South Wales (Ride 1970). Apart from this uncertain Cape Range specimen, *N. longicaudatus* is not represented in the collections of the Western Australian Museum. Modern *N. amplus* is known only from the vicinity of Charlotte Waters, Northern Territory (Ride 1970) and is not otherwise represented in the collections of the Western Australian Museum.

*Zyzomys pedunculatus* was collected from four separate localities in the Cape Range and these are at present the only examples of the species in the collection of the Western Australian Museum. Modern records are from the MacDonnell and James Ranges of Central Australia (Ride 1970).

Specimens representing seven individuals of *Pseudomys desertor* were collected from three Cape Range localities. Modern records are from the Canning Stock Route and Bernier Island in Western Australia, from the Northern Territory, South Australia and the vicinity of the Murray and Darling Rivers (Ride 1970). Fossil specimens (e.g. No. 71.10.114) have been collected from Horseshoe Cave (N 59) in the southern Nullarbor region by Mr M. Archer (personal communication, September 1971).

Mr A. Baynes has kindly provided us with the following personal communication (October 1971) concerning other specimens of *Pseudomys* in these deposits.

*Pseudomys nanus*, which is understood to include *P. ferculinus* following Ride (1970), may be identified with confidence in the Cape Range fossil material and is also found living in the region on Barrow Island. However the identification of the very similar species *P. praeconis* is not as certain. Using characters which have been found to distinguish *P. praeconis* from *P. nanus* from deposits in the Shark Bay district, two Cape Range specimens (Nos. 71.6.92 and 71.6.144) are identifiable as *P. praeconis*. The uncertainty arises because the known modern specimens of *P. nanus* from the north of Western Australia appear to approach the characters of *P. praeconis* in the form of the maxilla, which is used for this identification. Thus, with only a small number of specimens, it is not possible to determine whether the Cape Range *P. nanus* show an anatomical form similar to *P. praeconis* from Shark Bay, or whether, as seems more likely, there are indeed two species represented in the Cape Range material.

Subject to confirmation, the presence of *P. praeconis* in the Cape Range would indicate an extension of range of about 300 km northward from known modern occurrences in the Shark Bay district (Ride 1970). *P. praeconis* has recently been reported from cave deposits in the lower south west of Western Australia, indicating a further substantial extension from the known modern range (Archer and Baynes 1972).

The shark teeth collected from Cave CR 19 are believed to have been derived by erosion



from the marine limestones of Miocene age in which the cave is formed.

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## 17.—Identity of the Hart Range and Boxhole iron meteorites

by J. R. de Laeter<sup>1</sup>

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### Abstract

A detailed examination of the geographical location, microstructure and chemical composition of the Hart Range and Boxhole iron meteorites has established that they are a paired find. It is not certain whether human transport or atmospheric break-up is responsible for the separate locations of the two meteorites, though it is probable that the Hart Range meteorite was transported by human agency. It is recommended that the name Hart Range be deleted from future meteorite catalogues. Similar studies of the iron meteorites associated with the Henbury and Wolf Creek craters have shown that all three craters were formed by separate events, thus substantiating the conclusion of Wasson (1967,a).

### Introduction

In 1937 a meteorite crater was recognised on Boxhole Station, which is 185 Km north-east of Alice Springs in Central Australia at latitude 22° 37' S and longitude 135° 12' E. A number of siderites were found in the immediate vicinity of the crater, and they proved to be medium octahedrites, (Madigan and Alderman, 1940). The Boxhole meteorites resembled the siderites associated with the Henbury meteorite crater (Alderman 1932 a, 1932 b). The Henbury crater, which was found in 1931, is located some 121 Km south-west of Alice Springs near Henbury Station in Central Australia, at latitude 24° 34' S and longitude 133° 10' E.

The Boxhole and Henbury craters therefore lie about 300 Km apart, and this is far greater than the linear dimensions of the largest well-documented meteorite shower, the Allende chondrite, which is scattered over an ellipse 50 Km long and approximately 300 Km<sup>2</sup> in area (Clarke et al. 1970). A recent study by de Laeter et al (1973) of two Western Australian siderites, Gosnells and Mt. Dooling, has shown conclusively that they are a paired fall, although they were found 400 Km apart. Although it was concluded that the Gosnells meteorite was probably transported by human agency the evidence was not definitive, and the opportunity of examining the relationship between meteorites from two locations of undisputed origin was therefore welcomed.

Wasson (1967, a) examined the possibility that the Boxhole and Henbury craters had a common origin, and also investigated the medium octahedrites associated with the Wolf Creek crater. The Wolf Creek crater, which was discovered in 1947 (Taylor, 1965), is situated some 850 Km north-west of the other two craters at latitude 19° 11' S and longitude 127° 48' E. Wasson (1967 a) studied the chemical composi-

tion of representative samples of the irons associated with the 3 craters and concluded that they were each formed by a separate event.

In May 1944 Mr. J. S. Foxall presented the Geological Survey of Western Australia with a 608 g iron meteorite. It was obviously a fragment of another meteorite, and the broken surface revealed a definite octahedrite structure. The meteorite was named Hart Range by McCall and de Laeter (1965), who classified it as a medium octahedrite. The exact location of the find was not known, except that it came from the Harts Range area in Central Australia, latitude 23° S and longitude 135° E. The locations of the meteorites are shown in Figure 1, whilst Figure 2 is a photograph of the Hart Range meteorite, and clearly reveals the octahedrite structure where it has broken off the main mass.

Dr. B. Mason of the Smithsonian Institution, Washington D.C., U.S.A. suggested that the Hart Range meteorite was in fact part of the Boxhole fall. It was therefore decided to test this hypothesis by examining the microstructure and chemical composition of the two meteorites. It was also decided to independently assess the conclusions of Wasson (1967, a) with respect to the Boxhole, Henbury and Wolf Creek meteorites.

### Structure

A sample of each meteorite was obtained from the collection of the Western Australian Museum, and a suitable face cut on each of the 4 meteorite specimens. After polishing, the smoothed surfaces were etched with dilute nitric acid to reveal the Widmanstätten pattern. Photomicrographs of the etched surfaces were taken and two of these, Hart Range and Boxhole, are reproduced as Figure 3a and 3b respectively.

The structures revealed in the micrographs are remarkably uniform. The main constituent is the nickel-iron alloy kamacite, in regular well-defined plates arranged parallel to the faces of a regular octahedron. The width of the plates vary from 0.75 mm to 1.25 mm with an average width of 1 mm. The two meteorites should therefore be classified as medium octahedrites on Buchwald's classification (see Wasson, 1970). The similarity of the Widmanstätten patterns imply that the samples of Hart Range and Boxhole could be pieces of the same meteorite.

The Widmanstätten pattern for Henbury has a kamacite band width which varies from 0.6 mm to 0.9 mm, with an average width of 0.75 mm. Thus although Henbury is still classified as a medium octahedrite it has a narrower kamacite band width than Boxhole or Hart Range, though

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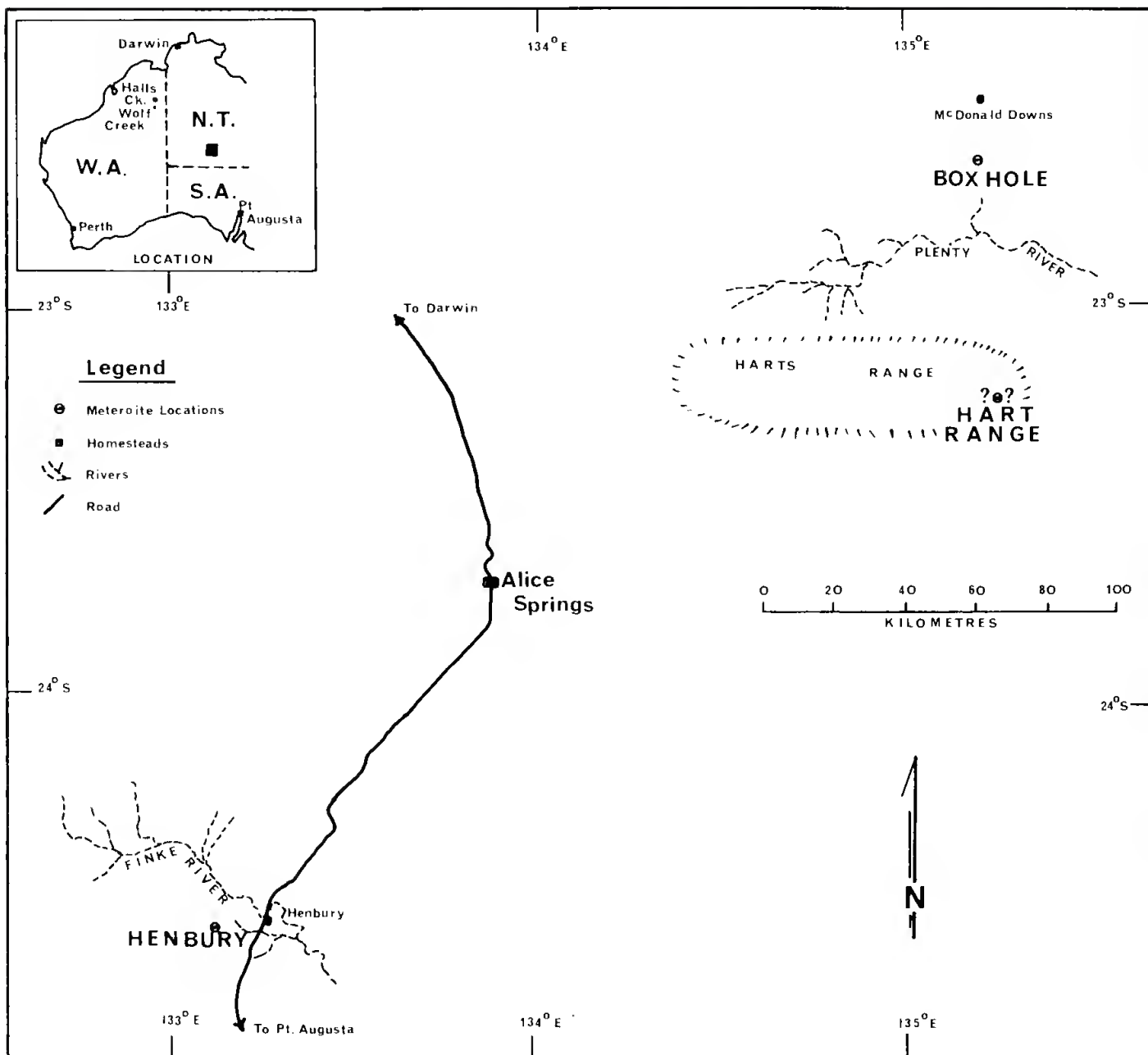


Figure 1.—Location of the Boxhole, Henbury and Wolf Creek craters.

the difference is probably not significant. Alderman (1932 b) states that the average kamacite band width is 1 mm in some specimens and up to 1.5 mm in others. Wolf Creek has an average kamacite band width of 0.9 mm. Polished and etched sections of this meteorite have been illustrated by Taylor (1965).

#### Chemical composition

J. T. Wasson and his associates have carried out a series of investigations during the past 6 years to elucidate the chemical classification of iron meteorites, primarily in terms of their gallium-germanium grouping (Wasson, 1967 b; Wasson and Kimberlin, 1967; Wasson, 1969; Wasson, 1970; Wasson and Schaudy, 1971; Schaudy et al, 1972). On the basis of accurate analytical data on some 450 iron meteorites, eleven chemical groups have been defined.

A considerable amount of analytical data is available for Henbury and Boxhole, whereas Wolf Creek has only been analysed by Taylor (1965) and Wasson (1967 a). As far as can be ascertained Hart Range has never been analysed at all.

In order to classify the four meteorites into one of the eleven chemical groups defined by Wasson and his associates, it was decided to analyse the four meteorite samples non-destructively for nickel, gallium and germanium by X-Ray fluorescence spectrometry. The cobalt abundance was also determined since, together with iron and nickel, it is one of the major constituents of iron meteorites.

A Siemen's SRS-1 spectrometer equipped with a molybdenum tube, a lithium fluoride crystal and a scintillation detector was used for the analyses. A flat, highly polished surface approxi-

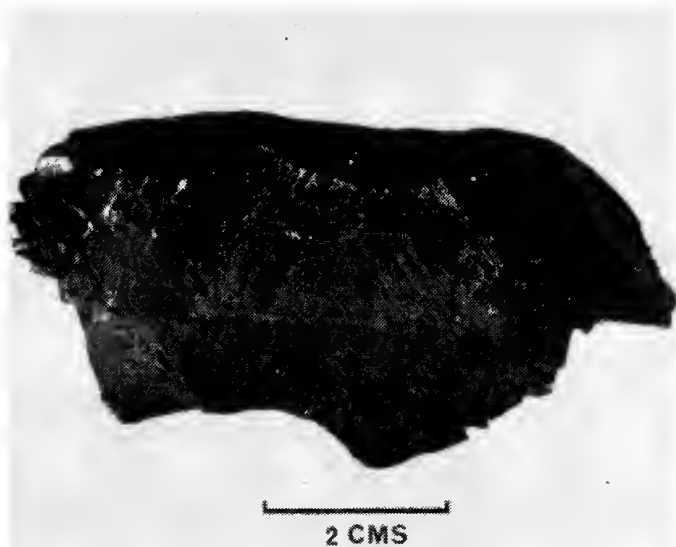


Figure 2.—The Hart Range octahedrite.

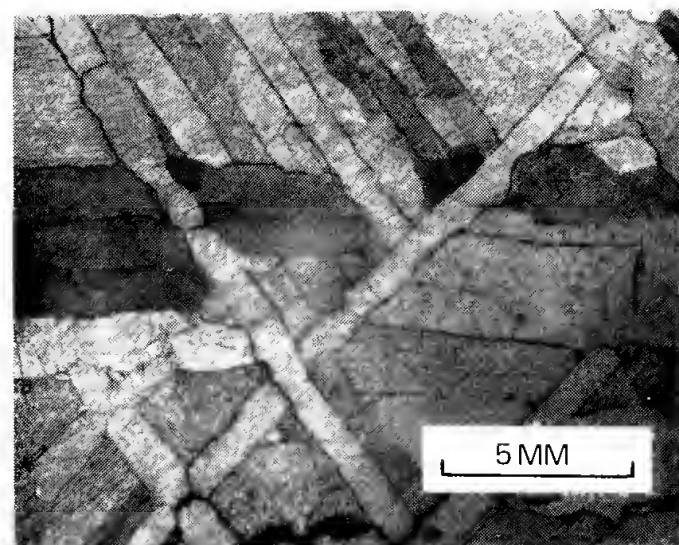
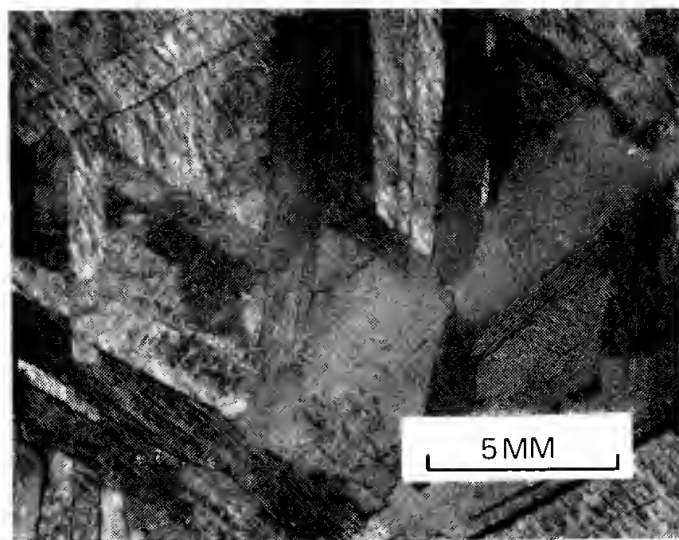


Figure 3.—Polished and etched sections of (above) Hart Range and (below) Boxhole siderites.

mately 1.25 cm in diameter was prepared. This surface was exposed to the X-Ray beam, and peak and background readings were taken for each of the four elements. The spectrometer was calibrated for each element by standard alloys, and from a number of siderites with well established compositions. Full details of the X-ray spectrometry are given by Thomas and de Laeter (1972).

The results of the determinations for the four elements are given in Table 1. The errors quoted with the values have been evaluated on the basis of counting statistics and calibration uncertainties, and are expressed as standard deviations. The analytical work of other authors for these elements have also been listed in Table 1. A number of analyses for Henbury have been omitted from Table 1 since they have been made on mislabelled specimens, (see Smales, 1967).

An examination of the data listed in Table 1 shows that within experimental error, the abundance of cobalt, nickel, gallium and germanium in Boxhole and Hart Range are identical. This supports the structural evidence that Hart Range and Boxhole are pieces of the same meteorite.

Wasson and Kimberlin (1967) define Chemical Group IIIA as having nickel values ranging from 7.4% to 8.7%, germanium values in the range 33 to 46 ppm and a range in gallium from 18 to 22 ppm. In addition the gallium and germanium are positively correlated with nickel. The III A irons are also characterised by regular kamacite bands of average width 1 mm in thickness, and by the paucity of inclusions. Boxhole and Hart Range can therefore be classified as Group III A meteorites.

The analytical data for Henbury also classifies it as a member of Chemical Group III A, whereas the high nickel value of Wolf Creek enables it to be classified as a Group III B meteorite. Group III B is defined by Wasson and Kimberlin (1967) as having a range in nickel, germanium and gallium of 9.2 to 10.7%, 28 to 40 ppm and 16 to 20 ppm respectively. Wolf Creek is therefore unrelated to the Henbury or Boxhole craters and was clearly formed by a separate event.

Henbury is much more difficult to distinguish from Boxhole. Apart from the fact that they are both Group III A meteorites, their abundances of cobalt, gallium and germanium are identical within the limits imposed by experimental error. One has also to note that sample inhomogeneities occur within the same meteorite and it is therefore not surprising to find small variations in elemental abundance between samples from the same meteorite fall. This is particularly true for large meteorite falls, and certainly for those whose impact has produced craters. Wasson (1967 c) has analysed numerous siderite samples from the Canyon Diablo crater and has found that the nickel concentrations range from 7.0 to 8.2% whereas the range in germanium and gallium on the same samples is from 317-332 ppm and 79-83 ppm respectively.

The X-Ray fluorescence spectrometry data of the present study as listed in Table 1 indicates that the nickel content of Boxhole and Hart



Table 1

Analytical data for the four meteorites

Sample*	Cobalt (%)	Nickel (%)	Gallium (p.p.m.)	Germanium (p.p.m.)	Reference
Boxhole 2/1872	0.48 ± 0.005	7.59 ± 0.02	18 ± 2	38 ± 4	1
	0.48	7.66	....	....	2
	....	7.64	18.1	37.2	3
	....	7.68	18.1	37.2	4
	0.50	7.72	13.0	31.0	5
	0.41	7.67	....	....	6
	....	7.1†	....	....	7
Hart Range 2/2851	0.48 ± 0.005	7.60 ± 0.02	20 ± 2	38 ± 4	1
Henbury	0.47 ± 0.005	7.44 ± 0.02	18 ± 2	35 ± 4	1
	....	....	18.8	....	8
	0.47	7.62	....	....	2
	....	7.44	17.4	34.2	3
	....	7.47	17.4	34.2	4
	....	....	15.0	36.0	9
	0.70	7.59	17.2	....	10
	0.30	7.40	....	....	11
	0.37	7.54	....	....	12
....	6.7†	....	....	7	
Wolf Creek 12680	0.50 ± 0.005	9.38 ± 0.02	22 ± 2	42 ± 4	1
	....	9.23	18.4	37.3	3
	0.4	8.6	....	....	13

\* Sample numbers refer to the W.A. Museum Collection.

† Kamacite phase only

## References

- |                               |                           |
|-------------------------------|---------------------------|
| 1 This Work                   | 8 de Laeter (1972)        |
| 2 Lewis & Moore (1971)        | 9 Smales et al. (1967)    |
| 3 Wasson (1967 a)             | 10 Goldberg et al. (1951) |
| 4 Wasson & Kimberlin (1967)   | 11 Spencer (1933)         |
| 5 Lovering et al. (1957)      | 12 Alderman (1932 b)      |
| 6 Madigan and Alderman (1940) | 13 Taylor (1965)          |
| 7 Reed (1969)                 |                           |

Range is significantly different from its abundance in Henbury. However the stated errors do not take into account sample inhomogeneities. Some recent work by de Laeter (1973) on the Younegin meteorite shower, using identical analytical procedures as in this paper, give a range of nickel values from 6.47% to 6.92% over 10 meteorite samples, which are believed to be from the one meteorite fall. Thus under the circumstances, the nickel value of 7.44% for Henbury as compared to 7.59% for Boxhole, cannot conclusively differentiate the two meteorites as unique events. The nickel values obtained by Wasson (1967, a) and Wasson and Kimberlin (1967) using atomic absorption spectroscopy confirm the data obtained in the present study, and in fact all the nickel values for Boxhole listed in Table 1 show a tight range from 7.59% to 7.72%, with an average value of 7.65%. The nickel values for Henbury on the other hand range from 7.40% to 7.62% with an average of 7.50%. The data implies that the nickel value of Boxhole is significantly higher than for Henbury, and this conclusion is streng-

thened by the kamacite values of Reed (1969). Reed also found that the rhabdite abundance in Boxhole was significantly greater than in Henbury. However the interpretation of the nickel data is not definitive, and it was therefore decided to examine additional evidence in the hope of confirming the uniqueness of the Boxhole and Henbury craters.

Table 2 lists some additional analytical data for the Boxhole and Henbury siderites. The quoted errors represent the standard deviations of the respective measurements. Much of the data does not allow any definitive conclusions to be drawn, but this is to be expected since both are medium octahedrites and members of the same chemical group. It is therefore likely that the two meteorites have a similar genetic origin (Wasson and Kimberlin, 1967).

The phosphorus values determined on the kamacite phase by Reed (1969) are different, but not definitively so, although the bulk phosphorus values are approximately the same. The carbon values of Lewis and Moore (1971) are markedly

Table 2

*Analytical data for Boxhole and Henbury meteorites*

Element	Boxhole	Reference	Henbury	Reference
Phosphorus	0.08%	1	0.08%	4
	0.11%	2	0.09%	2
	*1020 ± 180 p.p.m.	3	*840 ± 80 p.p.m.	3
Carbon	....		0.13%	4
	0.013%	2	0.007%	2
Iridium	9.1 ± 0.5 p.p.m.	5	15 ± 0.8 p.p.m.	5
	....		12 ± 0.6 p.p.m.	6
	....		14 ± 0.3 p.p.m.	7
Copper	133 ± 16 p.p.m.	8	156 ± 16 p.p.m.	9
	....		180 ± 5 p.p.m.	7
Chromium	62 ± 7 p.p.m.	8	58 ± 6 p.p.m.	9
Zinc	....		2.04 ± 0.02 p.p.m.	10
	1.9 ± 0.05 p.p.m.	11	1.2 ± 0.05 p.p.m.	11
	....		< 1 p.p.m.	9
Cadmium	7 ± 2 p.p.b.	11	8 ± 2 p.p.b.	11

\* Kamacite phase only

*References*

- |                             |                          |
|-----------------------------|--------------------------|
| 1 Madigan & Alderman (1940) | 7 Cobb (1967)            |
| 2 Lewis & Moore (1971)      | 8 Lovering et al. (1957) |
| 3 Reed (1969)               | 9 Smales et al. (1967)   |
| 4 Alderman (1932 b)         | 10 Rosman (1972)         |
| 5 Wasson (1967 a)           | 11 This work             |
| 6 Wasson & Kimberlin (1967) |                          |

different, but one can not be sure that the difference in the values have not been caused by varying amounts of cohenite in the particular samples analysed. The chromium and cadmium values are also identical within experimental error.

A careful evaluation of the iridium, copper and zinc data show that the values are significantly different for the two meteorites in terms of the experimental errors. This supports the primary nickel abundance data, and reinforces the hypothesis that Boxhole and Henbury are distinct and separate meteorites.

The cadmium and zinc analyses carried out as part of this study have been determined by the stable isotope dilution technique using solid source mass spectrometry. Experimental details will be published elsewhere (Rosman and de Laeter, 1974).

**Conclusions**

The evidence set out in this paper establishes the fact that the Hart Range and Boxhole meteorites are a paired find. Although the Hart Range meteorite is reported to have been found some 60 Km from the Boxhole crater, the information is inconclusive, and the specimen may well have been found closer to Boxhole than is

indicated in Figure 1, or have been transported by human agency to Harts Range from the Boxhole crater area. The microstructure and chemical composition of the two meteorites are practically identical, and both meteorites may be classified as medium octahedrites belonging to Chemical Group III A. It is suggested that the name Hart Range be deleted from future meteorite catalogues.

The analytical data for a siderite associated with the Wolf Creek crater confirms that it is a member of Chemical Group III B, and it is therefore chemically distinct from the other 3 meteorites. The Wolf Creek crater was therefore a separate event. The uniqueness of the event which formed the Henbury crater is more difficult to establish, as the microstructure and compositional data is very similar to that of the Boxhole meteorite. It is also a medium octahedrite, belonging to Chemical Group III A. However the separation in location of the two craters, small dissimilarities in microstructure, and more particularly the differences in nickel, iridium, copper and zinc abundances, confirm the conclusion of Wasson (1967 a) that Henbury is not associated with the Boxhole meteorite fall.

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