

# WOLLASTONITE IN SOUTH AUSTRALIA

REPORT BOOK 99/00016

by

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**PRIMARY INDUSTRIES  
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**PRIMARY INDUSTRIES AND RESOURCES  
SOUTH AUSTRALIA**

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## PRIMARY INDUSTRIES AND RESOURCES SOUTH AUSTRALIA

REPORT BOOK 99/00016

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# WOLLASTONITE IN SOUTH AUSTRALIA

A F CROOKS

Wollastonite is a mineral with an increasing range of industrial applications. The main producer is China. At Ethiudna, in South Australia's northeast, wollastonite occurs associated with diopside marbles of the Palaeoproterozoic, Willyama Supergroup. These are limestones, metamorphosed in response to high heat flows adjacent to the Crookers Well Granites.

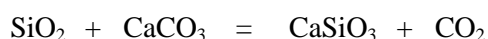
A mining lease (ML 5780) over the main Lady Katherine occurrence, has an Indicated Resource of 600,000 tonnes and is currently held by Minerals Corporation Ltd.

## MINERALOGY

Wollastonite, named in honour of the English chemist and mineralogist W.H. Wollaston (1766-1828), is a naturally occurring calcium metasilicate. Theoretical, pure wollastonite is  $\text{CaSiO}_3$  but generally there is some substitution of Fe and Mn, and to a lesser extent Mg, into Ca lattice sites. Wollastonite is a pyroxenoid with two well-developed cleavages at 84 degrees giving rise to elongate aggregates of white, bladed to needle-like crystals, with a vitreous to pearly lustre. It has a hardness of 4.5 to 5 on the Moh scale, a specific gravity of 2.87 to 3.09 and a melting point of about  $1503^\circ\text{C}$ . It is also largely chemically inert and has a high natural pH (9.9 in a 10% water slurry).

## GENESIS

Wollastonite is formed by both igneous and metamorphic processes, usually involving carbonate rocks. Two types of deposits are recognised. Most significant are skarn deposits involving thermal metamorphic and metasomatic alteration of impure limestone during either regional deformation or in the contact aureoles of intrusive granites. Wollastonite is formed by the following reaction:



Gangue minerals differ from deposit to deposit, with each assemblage reflecting the original composition of the rock or subsequent metamorphic or igneous history. Wollastonite + garnet + diopside, wollastonite + calcite + graphite and wollastonite + quartz + diopside are three commonly recorded assemblages associated with skarn deposits.

The second, and less common wollastonite deposit type, is wollastonite crystallised directly from carbonatite magma. These are usually lower grade than skarn deposits but are potentially economic.

## PRODUCT SPECIFICATIONS

Because of its cleavage properties, wollastonite breaks down during crushing and grinding into needle-shaped particles. The aspect ratio, or ratio of needle length to needle diameter, is a measure of the acicularity of the wollastonite product and is a key market specification. High aspect ratio product in the 15:1 to 20:1 range is suitable for specialised uses such as reinforcing in thermoplastics and thermoset polymer compounds, as a safer replacement for asbestos and in fibreglass. Low aspect ratio product (milled grade with aspect ratios from 3:1 to 5:1) is suitable as a general filler.

Brightness controls the suitability for use in certain ceramic and filler applications. Pure wollastonite is brilliantly white, but impurities may colour it cream or grey. Commercial grade wollastonite is usually in the brightness range of 85 to 95 against a brightness standard of 100.

Loss on ignition (LOI), a measure of the amount of volatile material driven off when the mineral is heated to 1000 °C, is another key specification controlling marketability. In general, the higher the measured LOI, the higher the potential for shrinkage. This may be significant in some applications. LOI, for commercial grade wollastonite products, is in the range of 0.5 to 2.0%.

## USES

Wollastonite has a wide range of uses.

**Ceramics** - Particularly wall tiles and dinnerware. Wollastonite has a brilliant permanent white colour and offers the following advantages over kaolin, talc, etc. :

- improved bonding through drying and pressing
- high strength in both green and fired stages
- Low moisture expansion of fired body
- less firing time
- specific shapes for electrical insulators such as spark plugs can be produced by either dry or wet pressing.

**Glazes** - *Wollastonite based glazes :-*

- improve spraying characteristics owing to lower viscosity of glaze
- flow over the body with minimum interaction because fusion point of the glaze is below the maximum firing temperature of the body
- avoid crazing, coefficient of expansion of glaze approximates that of body
- are high compression glazes
- have no harmful gas emissions, ignition loss being less than 1%.

**Plastics** - Wollastonite's use as a functional filler in plastics and rubber is based on good electrical and dielectric properties and favourable flexural and tensile strength, impact resistance and flex modulus.

**Paints** - Wollastonite is used as an extender in both oil and water-based exterior emulsion paints and in latex paints, road marking paint and caulking compounds because of the following properties :

- pure white colour.
- acicular nature provides good flattening qualities.
- low oil absorption reduces the amount of binder required.
- alkalinity of suspension gives better colour dispersion, makes steel less susceptible to corrosion and neutralises any acids formed by decomposition of polyvinyl chlorides.

**Asbestos replacement** - Asbestos fibres have been recognised as a potential hazard to health which has resulted in its replacement by wollastonite in some applications, such as :

- vinyl-asbestos systems, particularly caulking compounds
- sealants
- friction products (brakes and clutches)
- casting plaster
- roofing compounds.

**Abrasives** - High thermal shock resistance and low coefficient of expansion enable up to 20% wollastonite to be included in ceramic bonded abrasives, particularly wheels, stones, emery paper and industrial pumice.

Wollastonite replaces whiting as a source of CaO in silicon carbide wheels; being a silicate it does not react with the silicon carbide grains.

**Glass** - Wollastonite may replace limestone and sand as a source of lime and silica and is included in fibre glass to improve the surface. In glass making, wollastonite requires significantly less heat than limestone to produce the same amount of melt.

**Other uses** - Wollastonite can reduce raw material cost with no detrimental effect on the finished product in the following applications:-

- asphalt and vinyl floor tiles
- polyesters
- epoxy resin compounds
- mild scouring agents and dental cleaners
- replacing phosphates as a lining material in the fertiliser industry
- substitute for alpha cellulose and wood flour in the manufacture of plywood

- safety elements in matches
- certain adhesives
- cold-setting insulating foams
- load bearing refractories
- wall-board requiring good acoustical and fire resistant properties.

## WORLD PRODUCTION

Estimated world production of wollastonite was between 450 kt and 500 kt in 1997 (Industrial Minerals, 1999). China was the largest producer accounting for 41 - 43% of the world total supply. USA accounts for 30%, while India (17%), Mexico (6%) and Finland (5%) are also significant contributors to world production (Virta, 1999). Based on 1990 figures (Bauer *et al.*, 1994), USA and India were the major suppliers of high aspect ratio product with around 90% of total sales. USA and Finland supplied 95% of the world demand for chemically treated grades; this is a wollastonite product which has been surface modified to improve performance in resin-based applications. The USA consumes 35% of world production with Europe accounting for about 25% and Asia 30%.

### U.S.A.

NYCO Minerals Inc in New York State is the world's largest producer, producing 70 to 100 kt per annum from its Willisboro plant. In 1989 NYCO had total in-ground ore reserves of over 9 Mt grading 45%-49% wollastonite in several deposits. NYCO also produces significant garnet as a co-product.

The R T Vanderbilt Company, also of New York State, produces 40kt per annum of finished product from an ore body with an estimated 900kt of reserves. R T Vanderbilt also exports crushed ore to a processing plant in The Netherlands to produce a higher aspect ratio product.

### CHINA

In 1990, China was producing 70 to 100 kt of wollastonite from three mines in Jilin and Hubei

Provinces, making it the world's second ranked producer. In 1989, a new deposit with an estimated 100 Mt of reserves was discovered in Yunnan Province.

By 1997 production from these mines had increased to an estimated 200 to 250 Kt per annum, overtaking the USA as the world's major producer.

### INDIA

In 1997, the Belka Bahar wollastonite deposit in Rajasthan State produced 80 kt. 1975 estimates of reserves were 50Mt proven and 200 Mt probable.

### FINLAND

The Lappeenranta deposit in SE Finland is the world's fourth largest wollastonite operation, with a 1997 production 23 kt. Here, an elliptical Archaean limestone body, with a wollastonite + calcite bearing core, is mined principally as a raw material for cement manufacture. Wollastonite is produced as a co-product of its calcite for paper coatings operation. 1990 reserves were estimated to be about 4 Mt but a new deposit, approximately 30 km south of the current mine, has an estimated 20 Mt reserves grading 25 to 30% wollastonite.

### MEXICO

In 1990, annual production of wollastonite was about 15 kt, mostly for the domestic and US market. This has been significantly boosted by the opening up of a mine and mill at Hermosillo, northwestern Mexico. This mine, operated by NYCO Minerals Inc, the operators of the Willisboro mine has a production capacity of 240 kt per year.

### OTHERS

Two major mines, one in Canada at Lac St Jeans and one in Spain in Salamanca, with an anticipated combined capacity of 150 kt per annum are currently under development. Chile, Czech Republic, Kenya, Namibia, New Zealand, North Korea, Pakistan, Japan and Turkey are, or have been, minor producers. Uzbekistan also has a small ceramics industry based on local wollastonite mined at its Koytash deposit.

## Major World Wollastonite Producers (excluding China) (after Bolger, 1998)

<i>Country/Company</i>	<i>Mine/Location</i>	<i>Capacity (tpa)</i>
<i>Canada</i>		
Orleans Resources Inc.	Lac St Jean Quebec	50 000 *
<i>Finland</i>		
Partek Industrial Minerals	Lappeenranta	23 000
<i>India</i>		
Wolkem India Ltd	Belkar Pahar, Sirohi and Kura district of Udaipur	80 000
<i>Mexico</i>		
Minera NYCO SA de CV	Hermosillo	240 000
<i>Spain</i>		
Comapnia Minera Ilustracion	Salamanca	100 000 **
<i>USA</i>		
NYCO Minerals	Willsboro, NY	150 000
RT Vanderbuilt	Gouverneur, NY	40 000

\* currently inactive

\*\* planned capacity

## Major Chinese Wollastonite Producers (after Bolger, 1998)

<i>Company</i>	<i>Region</i>	<i>Capacity(tpa)</i>
Faku Wollastonite Mine	Liaoning	20 000
Jiangxi Shanggao Wollastonite Co	Jiangxi	NA
Lishu Wollastonite Co	Jilin	80 000
Panshi Jianye Non-Metal Group	Jilin	35 000
Sanyi Mining Development Co	Liaoning	60 000
Tiefa Wollastonite Mining Group	Liaoning	35 000
Zhejiang Changxing Wollastonite Mine	Zhejiang	25 000

## PRICES

Quoted US prices per ton (Industrial Minerals, 1999), ex works acicular in US dollars were \$180 for –200 mesh material; \$224 for -325 mesh material; and \$248 for – 400 mesh material. For high aspect ratio acicular material, prices were \$308 and \$620 for ground (10 micron) product. Prices per ton f.o.b plant, bulk, were \$170 for –200 mesh and \$214 for –325 mesh.

Quoted prices should be used only as a guideline because actual prices depend on the terms of the contract between seller and buyer.

## WOLLASTONITE IN SOUTH AUSTRALIA - THE ETHIUDNA DEPOSIT

### MINERAL TENURE

The Ethiudna wollastonite deposit (fig.1) is currently held under license by Minerals Corporation Ltd, (ML 5780) with a small part of the lease over the Lady Katherine area “authorised for mining”. The lease area is 75 hectares and expires on the 9<sup>th</sup> of January, 2006 with a right of renewal.

## GEOLOGICAL SETTING OF THE ETHIUDNA DEPOSIT

Ethiudna wollastonite occurrences are 4 km east of Ethiudna Hill, and 47 km NNW of Manna Hill in the northeast of the State. They occur in Palaeoproterozoic, Willyama Supergroup metasediments of the Curnamona Province.

The sequence is interpreted as a series of shallow water, siliciclastic sediments deposited in an active volcanic rift setting with a possible evaporitic component by Cook and Ashley (1992). Dating on volcanoclastics from lower in the same sequence at Abminga homestead gave a U-Pb age of  $1699 \pm 10$  Ma (Ashley *et al.*, 1995).

These sediments are overlain by (sag phase?) pelites, now graphitic, mica schists.

This setting is similar to the sequence mapped elsewhere in the Olary Domain and the Broken Hill Domain to the east. In the correlation table, figure 2, the calcsilicate suite of the Olary Block is correlated with the upper part of the Thackaringa Group and/or the basal Broken Hill Group including, in part, the Ettlewood Calcsilicate Member (Clarke, 1986). At Ethiudna, the wollastonite occurs within the carbonate rocks of the calc-silicate suite/Ettlewood Calcsilicate Member and the Bimba Formation. These units represent a transition from shallow-water conditions, mixed carbonate-pelite environment to deeper water, marine sedimentation.

Laminations within the sequence are considered to be primary bedding features. These features parallel broad compositional zoning of the metamorphic assemblages implying they too are essentially primary in origin.

The development of wollastonite appears to be associated with a pervasive infiltration of  $H_2O$ -rich fluids during prograde metamorphism (Grguric, 1992) i.e.

calcite + quartz  $\Rightarrow$  wollastonite + diopside + carbon dioxide.

Thus, impure limestones are converted to wollastonite, diopside marbles.

This fluid is also considered the medium for the metasomatic remobilisation of Cu – Co – W mineralisation and its subsequent deposition,

replacing pyrite in the Bimba Formation. These metal sulphides were the basis for small scale mining operations from a series of shafts in the vicinity, known collectively as the Ethiudna Copper Cobalt field (Brown, 1908), (Campana and King, 1958), (Waterhouse, 1971), (Esso, 1981) (Grguric, 1992).

The heat source and fluid source for this metasomatic alteration and skarn development appears to be genetically linked to the intrusion of the Crockers Well Granite at about  $1579.2 \pm 1.5$  Ma (Ludwig and Cooper, 1984). This granite is sodic to trondhjemitic, probably indicating inherited characteristics, in particular, soda from the sedimentary host.

This excess soda is interpreted to be derived from the evaporitic component in the sediments (Cook and Ashley, *op. cit.*)

The intrusion of the Crockers Well Granite is considered causal to the formation of the wollastonite as no other occurrences in either the Olary Block or Broken Hill Block are known. A second retrograde metamorphic fluid infiltration event, particularly along zones of structurally-induced, high permeability, has resulted in the destruction of some wollastonite by the reaction :-

wollastonite + microcline  $\Rightarrow$  grossular  
+ quartz +  $K_2O$  (aqueous)

Quartz – garnet assemblages are common at the Ethiudna East copper workings, and associated with wollastonite at the Lookout Mine 2.5km to the south.

The wollastonite occurrences lie within a multiply deformed terrain (Flint and Parker, 1993). The first deformation ( $D_1$ ) involved flat lying macroscopic isoclinal folds associated with interpreted, major nappe structures. This involves elongate, fold limbs parallel to bedding so that the axial plane schistosity formed by this  $F_1$  folding event ( $S_1$ ) is parallel to bedding ( $S_0$ ), except in fold closures. A second deformation ( $D_2$ ), possibly a continuation of  $D_1$ , involves a NW-SE compression and created a series of upright, isoclinal folds ( $F_2$ ) with NE-SW and vertical to over turned fold axial planes. This deformation event probably just predated the intrusion of the 1579 Ma, regional granite and coincided with interpreted peak metamorphism.

A third deformation (D<sub>3</sub>), gave rise to a series of broad-scale, upright, open folds (F<sub>3</sub>). This manifests itself in the double plunge of the F<sub>2</sub> folds and the resulting synclinal keels of the calc-silicate. Later deformational events have in turn deformed the F<sub>3</sub> fold axial plane.

## EXPLORATION HISTORY OF THE ETHIUDNA DEPOSIT

Initial interest in the area centred on the discovery of Cu-Co-W mineralisation, with tremolite being recorded in the calc-silicates (Campana and King, 1958). Subsequently, J.E. Johnson (former field assistant, S.A.D.M) recognised wollastonite at these localities. The economic potential of the wollastonite was first noted by Olliver (Olliver, 1978), drawing attention to the similarity with operating mines in USA and Finland.

Wollastonite-bearing beds crop out at four separate localities viz., Main Shaft, immediately south of the Central Workings, Pipers Shaft and a minor occurrence at the Lookout Hill copper mine 2.5 km to the south.

Originally the wollastonite-bearing calcsilicates were thought to be confined to the cores of antiforms, however, more detailed work in the 1980's, particularly by Adelaide Wallaroo Fertilizers (1985) and later by Adelaide Chemical Co. (1990), led to a reinterpretation as synformal keels. Exploration included the drilling of upwards of 20 diamond drill holes, focussing attention on the northern most synclinal keel around the Main Shaft. Here, Esso Exploration (1981) identified a resource, amenable to open cut methods, of around 1 Mt of 40% wollastonite at 6 000 t/m from a measured body 120 m x 60 m. This has been referred to as the Lady Katherine deposit.

Subsequent detailed work in this area demonstrated an Indicated Resource of 600,000 tonnes with a cut off grade of 20% and an average wollastonite content of 35% (Minerals Corporation, 1996). Approximately 50% of this tonnage could be extracted by open pit methods. There is also potential for further reserves as the body is open ended to the east. Metallurgical testing of samples has demonstrated a recovery rate of 70.3% with a product purity of 67.8% wollastonite from a feed with average grade of 33% wollastonite.

An alternative metallurgical technique involving on-site pre-concentration by photometric sorters is currently under consideration and could have important economic advantages.

## MINERALOGY OF THE ETHIUDNA DEPOSIT

Wollastonite from Ethiudna is colourless to pale grey and predominates in the brown layers of the calc-silicate beds. The wollastonite crystals are stumpy to elongate and xenoblastic to subidioblastic prisms. Associated minerals are, in approximate order of abundance, quartz, microcline, diopside, and calcite with accessory minerals apatite, plagioclase, sphene, iron oxides/hydroxides, zircon and epidote. In 1974 samples were collected for detailed evaluation. The results from one hand-selected, surface sample, P488/74, presented in Olliver (1978), are reproduced here.

*Petrology Report :* Sample P488/74, TS33284; PS34018

*Location :* To the east of and within 30 m of the Main Shaft, Ethiudna Mines.

*Rock name :* Wollastonite (hand selected sample)

*Hand specimen :* This sample consists essentially of pale grey prismatic crystals of wollastonite. These are up to several centimetres long and are interlocked and slightly lustrous on broken surfaces. Externally the sample is dark coloured with iron and manganese oxide/hydroxide staining and is pitted and corroded with cavities up to several millimetres deep.

*Thin section :* An optical estimate of the constituents gave the following:

	<u>Per cent</u>
Wollastonite	80-90
Carbonate (calcite)	10-20
?Quartz and amorphous silica	6-8
Epidote	tr
Opakes (iron oxides and hydroxides)	tr

This sample consists of large, interlocked prismatic crystals of wollastonite. The largest crystals are 0.5 to 1 cm across and about 3-5 cm long. The wollastonite is altered/replaced along cleavage



planes/fractures and grain boundaries by carbonate (calcite) and ?quartz, ?epidote and opaques (principally iron oxides/hydroxides) associated with the wollastonite.

*Chemical Composition* :- the selected sample of wollastonite from Ethiudna was compared with

average commercial grade material produced from Willisboro, New York State, U.S.A. and Lappeenranta, Finland (Andrews, 1970), together with theoretical pure wollastonite. In Table 2, the mineral content of this Ethiudna sample, P488/74, was recalculated based on the results of chemical analyses.

Table 1  
Chemical Analyses of Wollastonite  
(per cent)

	Ethiudna P488/74	Willisboro U.S.A	Lappeenranta Finland	Theoretical
SiO <sub>2</sub>	47.23	50.9	47.79	51.7
Al <sub>2</sub> O <sub>3</sub>	0.06	0.78	0.62	-
Fe <sub>2</sub> O <sub>3</sub>	0.23	0.64	0.47	-
FeO	0.21	n.d.	n.d.	-
CaO	44.22	46.82	45.07	48.3
MgO	0.12	0.85	0.71	-
Na <sub>2</sub> O	0.01	0.08	0.05	-
K <sub>2</sub> O	0.03	n.d.	0.05	-
TiO <sub>2</sub>	0.01	0.08	n.d.	-
MnO	0.30	0.20	n.d.	-
P <sub>2</sub> O <sub>5</sub>	0.06	n.d.	n.d.	-
H <sub>2</sub> O <sup>+</sup>	0.97	n.d.	n.d.	-
H <sub>2</sub> O <sup>-</sup>	0.15	n.d.	n.d.	-
CO <sub>2</sub>	6.40	n.d.	n.d.	-
Total	99.99	100.35	93.75	100.0

Table 2  
Recalculated Mineral Content  
(per cent)

Mineral	CaO	SiO <sub>2</sub>	CO <sub>2</sub>	Weight
Wollastonite	36.1	38.6	-	74.7
Quartz and amorphous silica	-	8.6	-	8.6
Calcite	8.1		6.4	14.5
Total	44.6	47.2	6.4	97.8

The presence of calcite and silica were confirmed by electronprobe micro-analysis

*Specific Gravity* : 2.91 (determined by pyconometry in tetrachloroethylene  
Theoretical range is 2.87 to 3.09 (Andrews, 1970).

*Hardness* : 5 on Moh's scale using a scratch test.  
Theoretical range 4.5 to 5 (Andrews, 1970).

*Brightness* :- The only published data is for a single sample, ground to -0.075 mm and measured against standard MgO.

R457	66.9 per cent
R570	74.5 per cent

Yellowness	7.6 per cent
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This sample was collected from outcrop, but wollastonite encountered in drillcore has a significantly higher brightness (Sue Border, *pers. com.*).

Brightness for the material with 99 per cent passing 0.045 mm is reported as 92.96 per cent G.E. reflectance rating for commercial grade wollastonite (Andrews, 1970).

*Fusibility* : During determination of pyrometric cone equivalent, the sample disintegrated at cone 14 following high shrinkage due to decarbonation of calcite which is intimately associated with the wollastonite. Removal of the calcite would be required before the wollastonite would be suitable for ceramic purposes.

## **WOLLASTONITE IN SOUTH AUSTRALIA - THE MINBRIE OCCURRENCE**

Olliver (1978) reported a second South Australian wollastonite occurrence from section 116, Hundred of Minbrie near Cowell on Eyre Peninsula. Attempts to relocate this occurrence have been unsuccessful, with only tremolite being identified (Olliver, *pers. Com.*, 1998).

## **ACKNOWLEDGEMENTS**

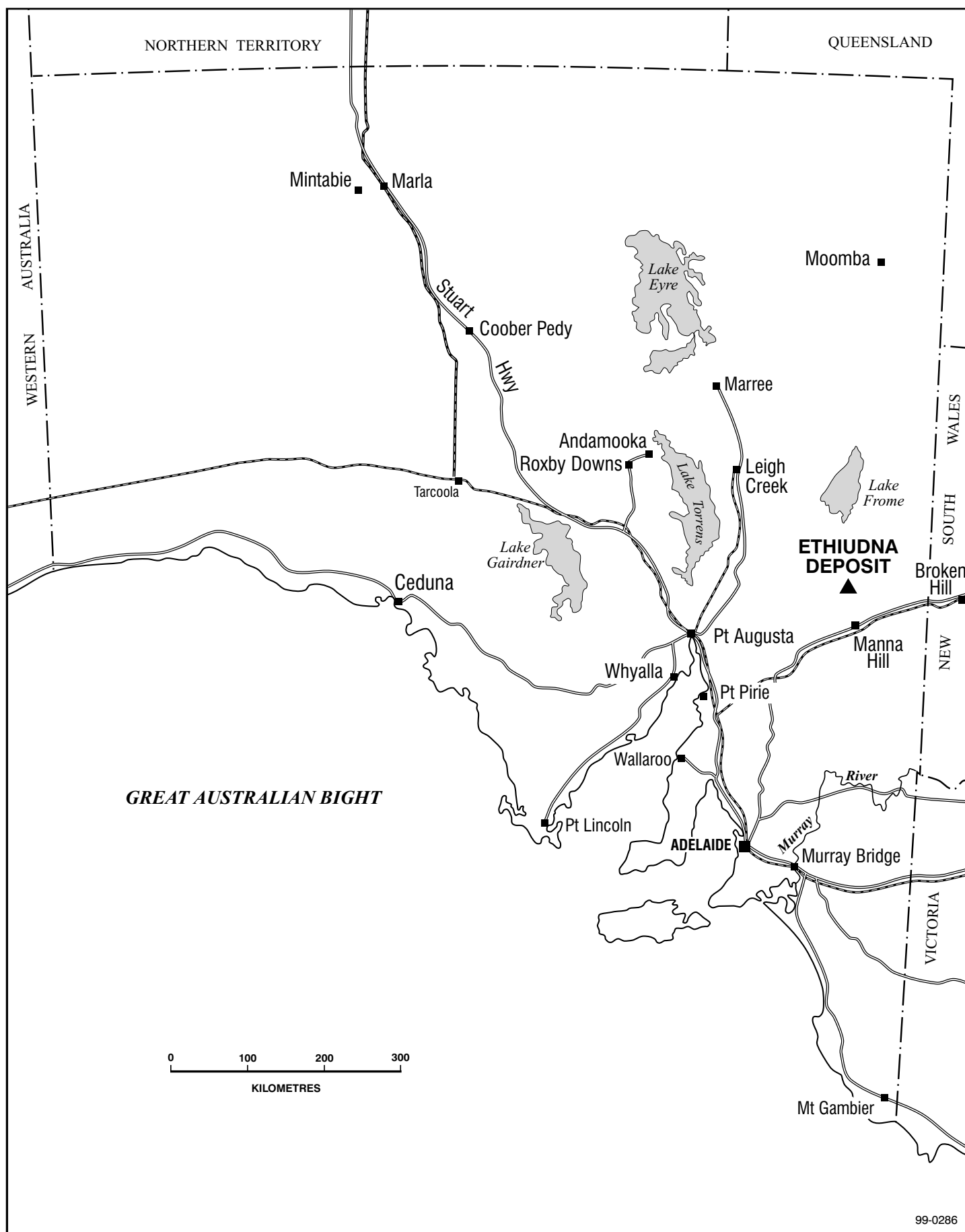
The author would like to acknowledge the assistance of Sue Border, Geos Mining, in the preparation of this report.

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August 1999.

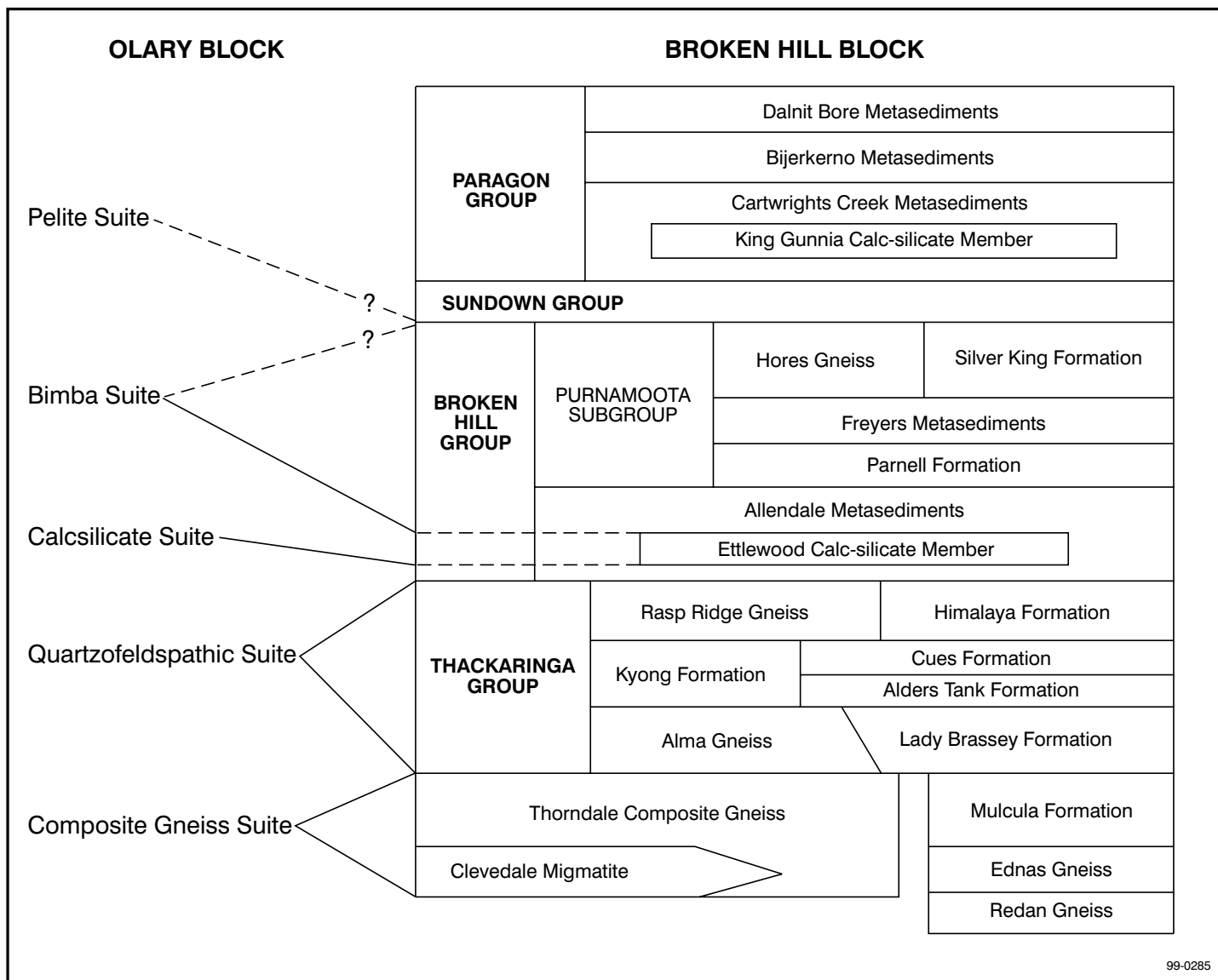
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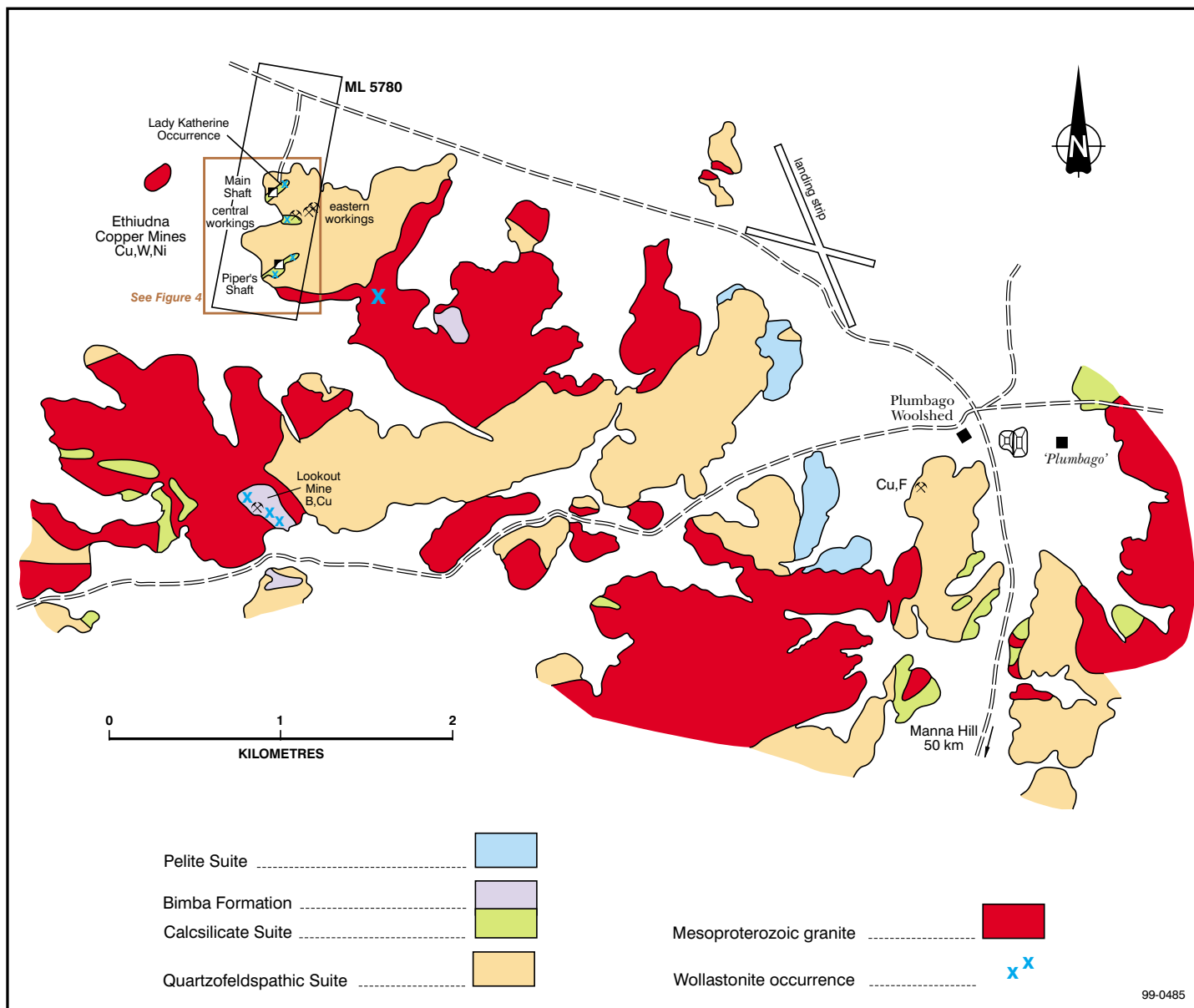
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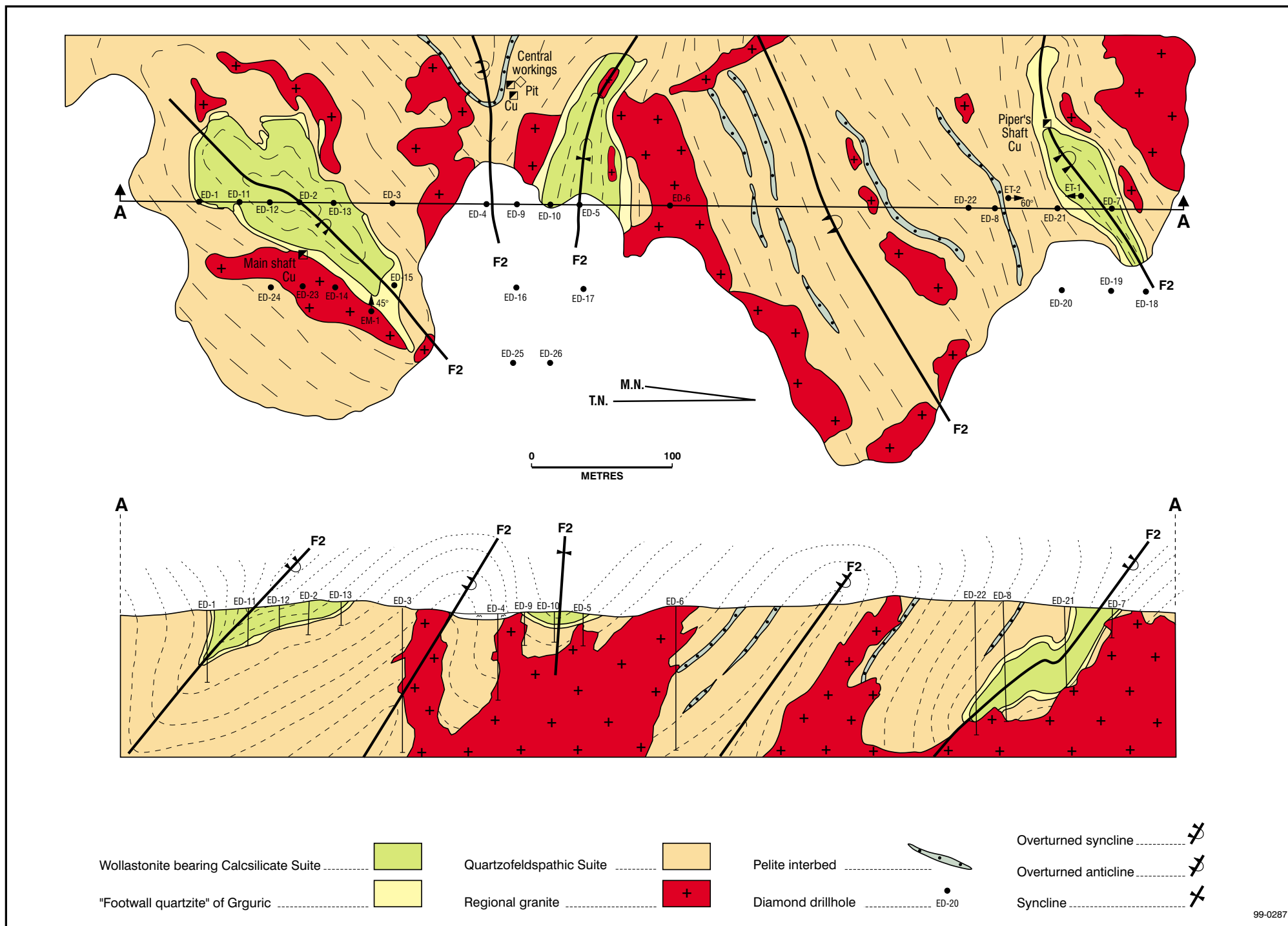
**Fig. 1** Location of Ethiudna Wollastonite deposit.



**Fig. 2** Correlation of Willyama Supergroup in Broken Hill and Olary Blocks (after Ashley et.al., 1995).



**Fig. 3** Ethiudna Wollastonite deposit. Generalised regional geology and locality plan (after Carnie, 1992).



**Fig. 4** Detailed geology of the Ethiudna Mines area (after Grguric 1992).





PHOTO 1: Deformed wollastonite marbles, Lady Katherine occurrence, Ethiudna. (Photo 046835)

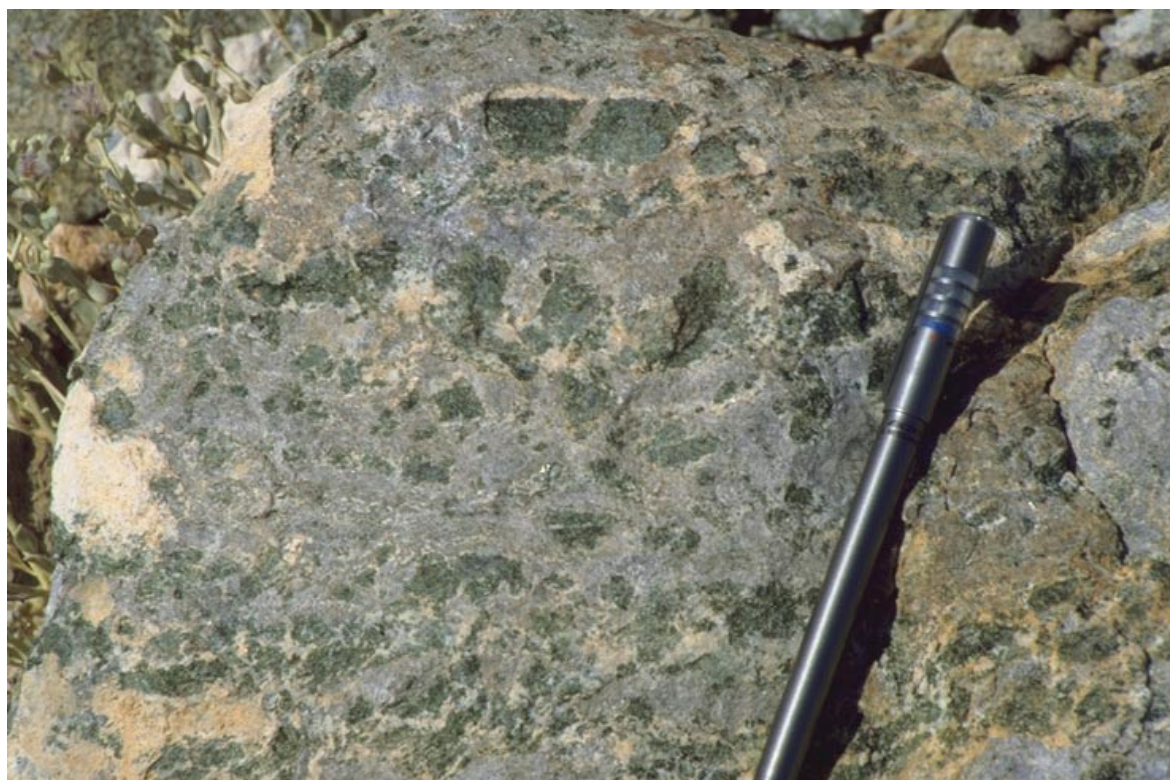


PHOTO 2: Wollastonite, diopside marble, Lady Katherine occurrence, Ethiudna. (Photo 046836)