DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY
ENVIRONMENT & RESOURCE DIVISION

WILLUNGA SLATE DEPOSITS

A REVIEW OF THE HISTORY, GEOLOGY & MINING OF THE ROOFING SLATE INDUSTRY OF SOUTH AUSTRALIA

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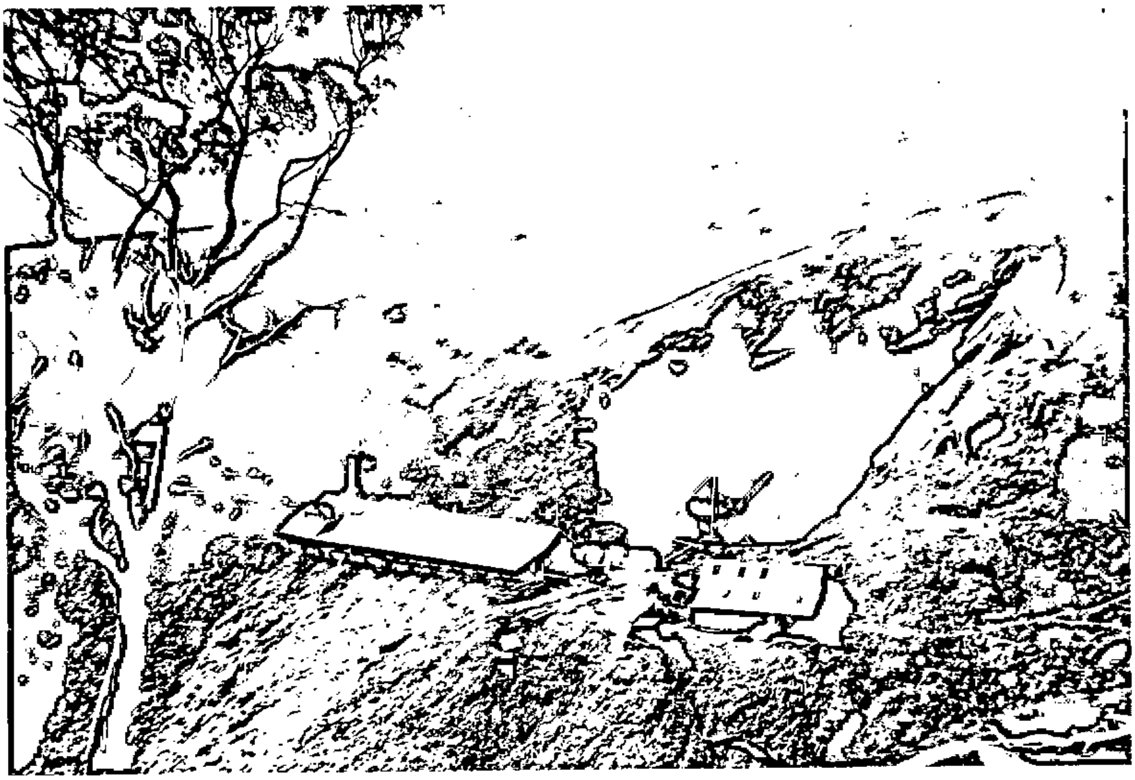
25th February, 1976

Rept.Bk.No. 76/23
G.S. No. 5700
D.M. No. 584/74

The Bangor Quarry (Australian Slate Quarries Ltd.) Willunga, circa 1920 (neg.482)

postdates reopening in 1921.

The Bangor Quarry July 1974(neg.26652)



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PLANS ACCOMPANYING REPORT

DEPARTMENT OF MINES
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ABSTRACT

The Willunga Slate Quarries have been the only significant source of roofing slate in Australia. Since operations began in 1840, an estimated 22 million roofing slates (about 68 000 tonnes) and more than 60 000 tonnes of paving, walling and mill stock have been produced. In recent years, output has been limited to small quantities for paving and walling.

The physical, chemical and weathering properties of Willunga slate are being investigated for light weight aggregate and as a filler. The waste dumps could be used for these purposes.

The slate comprises finely laminated calcareous and dolomitic siltstone within the Tapley Hill Formation. Slaty cleavage coincides with bedding. Roofing slate was obtained from particular bands in the sequence where cleavage planes are closely spaced. Selective mining of these zones exposed in the existing quarries will provide further quantities of roofing slate.

The renewal of roofing slate production will provide a local source of slate from a site of considerable significance in the history of South Australia.

INTRODUCTION

Good quality roofing slate is required for the restoration of historically significant buildings in South Australia.

The Willunga Slate Quarries have been the main source of roofing slate in Australia. In recent years, production has been confined to walling and paving stone.

Following an inspection by officers of the Department of Mines and the Public Buildings Department on 5th June, 1974, the abandoned quarries were mapped and sampled by the authors in July, 1974. Twenty two samples comprising 13 selected samples and 9 chip samples were submitted to the Australian Mineral Development Laboratories (AMDEL) for chemical analyses.

These results together with previous analyses are listed in Appendix B.

The petrographic descriptions of the 13 selected samples comprise Appendix A.

The co-operation of Mr. M. Dunstan in providing access to his comprehensive records and to Mr. C. Reed of Willunga for background information on the slate industry at Willunga is gratefully acknowledged.

LOCATION

The four Willunga Slate Quarries, about 46 km by road south of Adelaide, are located in the Sellicks Hill Range, 1 km to 3 km south of Willunga Township (see Fig. 1 and Fig. 3) within the hundred of Willunga, county Adelaide.

Details of section number and access from Willunga for each quarry are listed in Table 1 and shown in Fig. 2.

TABLE 1

Location and access

Quarry	Section	Distance(km)	Off	Via
Delabole	1150	0.5	Delabole Road	gazetted road
Bangor	756	1.5	Range Hill Rd.	gazetted road and right of way
Bastian's	1008,1242	1.2	St. Johns Rd.	gazetted road
Martin's	1008	1.0	St. Johns Rd.	gazetted road

All quarries lie within the District Council of Willunga in the Hills Face Zone as defined by the Metropolitan Development Plan Hills Face Zone Planning Regulations 1971, which were gazetted on 16th December, 1971.

The northwestern face of Sellicks Hill Range is a major fault scarp which extends from the coast at Sellicks Hill 36 km north easterly to Mt. Bold Reservoir (see Fig. 1). The highest point in the area is Mt. Terrible which rises 386 m above sea level (see Fig. 3). Numerous deeply incised creeks drain north westerly onto the plains of the Willunga Sub-basin.

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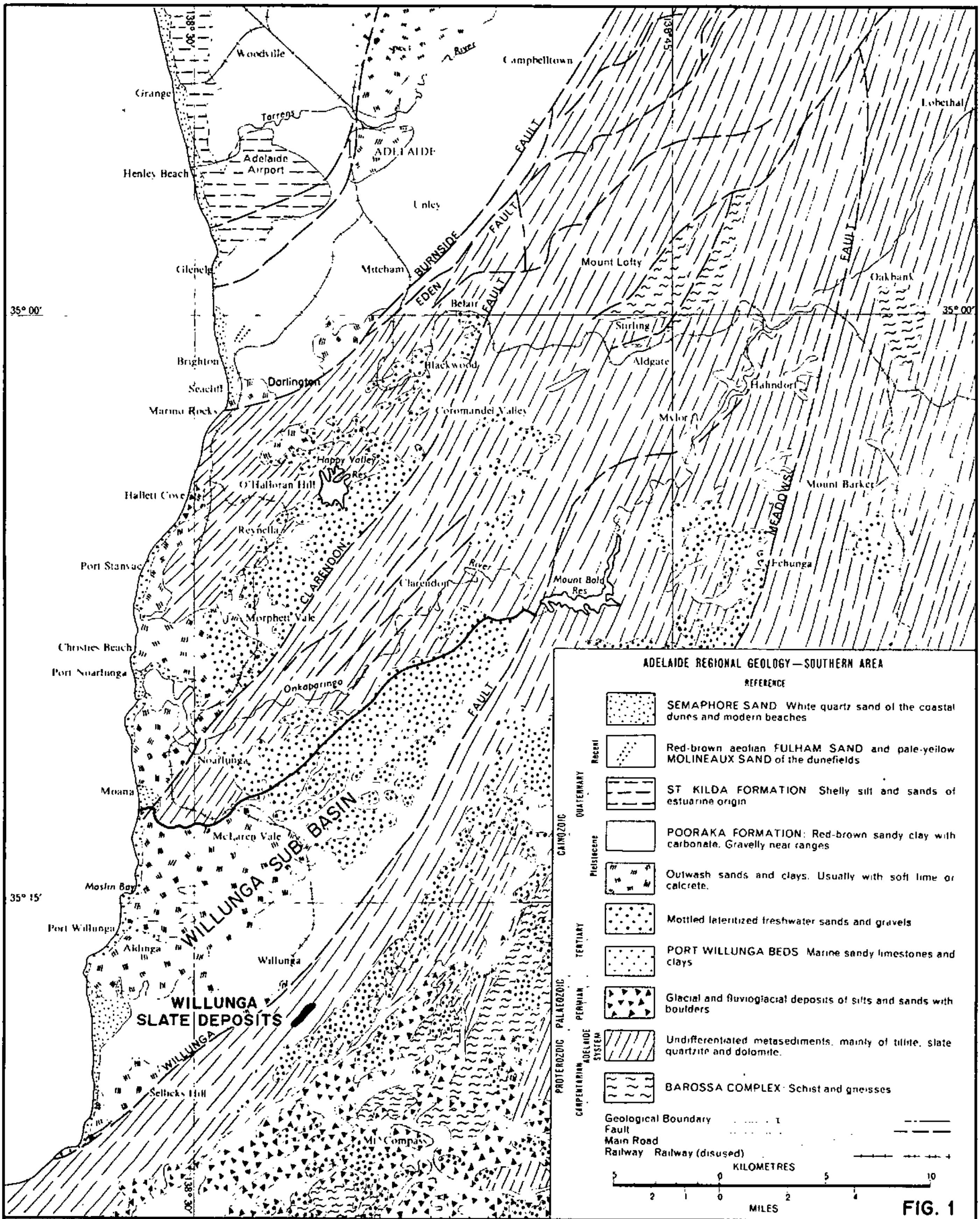


FIG. 1

INDUSTRIAL MINERALS SECTION	DEPARTMENT OF MINES—SOUTH AUSTRALIA	Scale: 1:250,000
Compiled: J.G.O.	WILLUNGA SLATE DEPOSITS	Date: NOV.'75
Drn. / Ckd.	LOCATION AND REGIONAL GEOLOGY	Drg. No. S12002
Geology from Adelaide and Barker 1 250,000 Geological Atlas Series		

PF No S9893 6H

In general, the slate quarries are not visible from the plains to the north and west. Delabole and Bangor Quarries can be seen from the lookout being constructed at the bend in Delabole Road at Delabole Hill.

The present use of the land in Fig. 2 is grazing. Trees have been cleared from all but the top of the scarp 300 m to 600 m south and east of the quarries.

HISTORICAL REVIEW

Delabole Quarry, originally operated by Cornishmen, was named after the famous slate quarry in Cornwall; Bangor was named after a slate quarry in Wales.

The slate industry at Willunga has experienced long periods of depression between intervals of high activity as summarised below.

1840 Outcrop of slate discovered by Edward Loud whilst quail shooting. Operations began with Mr. Dawe as Manager. Superior slate located by Dawe on his property and Delabole Quarry established. Other quarries opened 2 km to northeast.

1842 Willunga Slate Quarry (Bangor) opened by Thomas Williams.

1846 Three quarries operated - Dawe and Polkinghorne on land covering Martins Quarry; and Sampson Bastian at Bastians and Williams at Bangor. Slate carted to Aldinga by bullock dray and transferred to ships at anchor by lighter.

1853 Record 241 000 roofing slates exported from Willunga.

1854 Jetty built at Port Willunga, but not suitable for loading slate.

1860 Delabole Slate Company formed in Adelaide, village established at Delabole Quarry in next few years for 100 people (see Plate 1).

1868 New jetty built at Port Willunga, 0.4 km south-west of old jetty. Many problems still experienced in loading slate. Four quarries operated - Delabole, Kernick's (now Bangor), Bastian's and Martin's.

1873 Demand for roofing slate in excess of supply due to want of experienced labour. Approximately 60 men employed in 4 quarries. An average of 80 tons of paving and roofing slate sent to Melbourne each month.

1891 Peak production, two vessels despatched weekly from Port Willunga carrying 20 000 slates.

1893 Rapid decline, only 18 men employed in three quarries.

1903 Delabole Quarry closed.

1912 Willunga Bangor Company managed by Williams, went into liquidation after several months of operation.

1917 Tender for Bangor Quarry won by John Dunstan and The Australian Slate Company Ltd. formed.

1919 Government of South Australia offers bonus of £1 000 for first 1 000 slates of satisfactory quality.

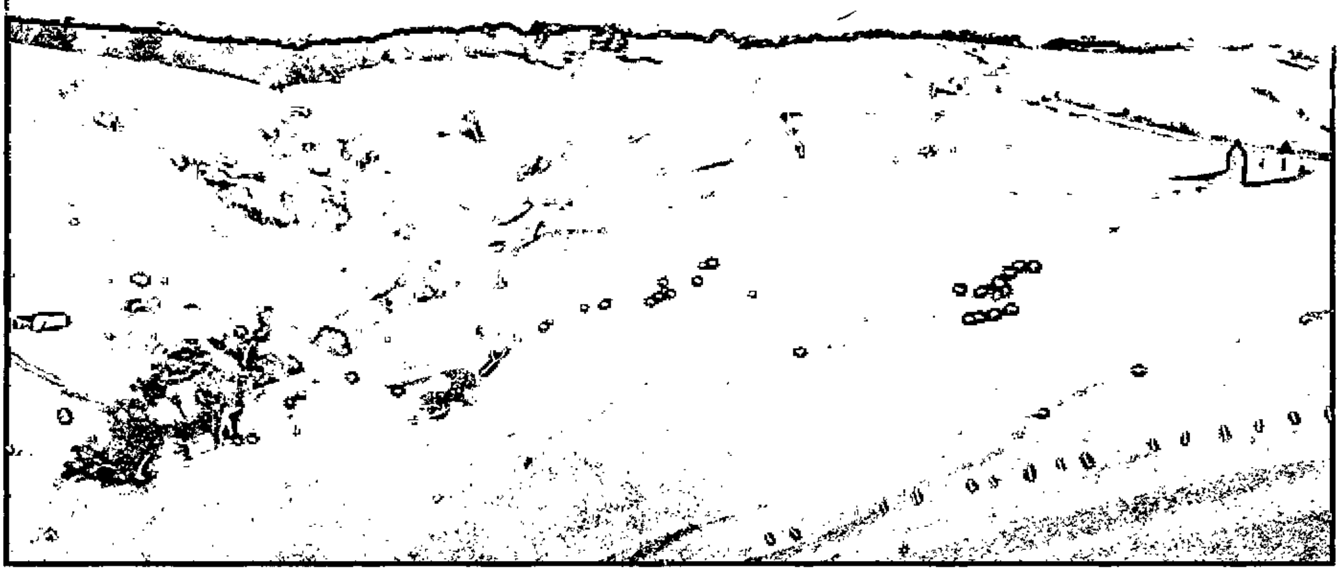
John Dunstan succeeded as Manager by his son Basil Dunstan; 47 men employed.

1921 Official opening of new plant at Bangor Quarry.

1928 Name changed to Australian Slate Quarries Ltd. Availability of cheaper terra-cotta tiles caused final decline.

1937 Bangor Quarry transferred to B.G. Dunstan.

1949 Decline continued with numerous changes in operating company and manager at Martin's - Bastian's and Bangor Quarries. Since 1949, only walling and paving stone has been produced.



DELABOLE QUARRY

Plate 1, (Neg. 26649). Quarry and benches in left centre. At extreme left are ruins of pug houses built in 1860 by the Delabole Slate Company of Adelaide for its employees, many of whom were slate tradesmen from Cornwall. The community erected the small Wesleyan Chapel at extreme right using slate from the quarries.

DEFINITIONS

Slate is defined as a fine grained, metamorphic rock derived from argillaceous sediments and characterised by an excellent parallel cleavage independent of bedding. This slaty cleavage, which allows the rock to split into relatively thin laminae, results from changes both in mineralogy and texture induced by temperatureand pressure.

In contrast, shale and siltstone are fine grained argillaceous sediments which split along original bedding planes.

Slate is confined generally to regions of crumpled and broken strata which have been subjected to considerable folding. Geologically, slate is common and widely distributed. However, sites where commercial roofing slate can be obtained are not widespread. In rocks possessing slaty cleavage, the original bedding is often obliterated. Traces may remain, generally as banding of colour or texture. However, cleavage and bedding can coincide as at the Empire Slate Quarry, Granville, New York, U.S.A. (Howe, 1910). This is also the case at Willunga. Also Delabole Quarries Cornwall (Howe, 1910)

In the petrographic descriptions in Appendix B and hereafter the term <u>slate</u> is used where cleavage is persistent and along the bedding. Cross-cutting joints and fractures are widely spaced. In this report, silt rock is used where parting either does not correspond to the bedding or is not persistent or the sample breaks irregularly. Roofing slate cannot be produced from siltrock.

USES

Originally, the principal use of slate was for thin roofing shingles (see Plate 2). Slate is durable, attractive and fireproof but has the disadvantages of cost and weight compared to alternate materials such as galvanised iron, terra cotta tiles, concrete tiles and asbestos shingles.

PLATE 2 (IFAC 013) BANGOR QUARRY, July, 1974

Closeup of roof of old processing shed showing method of fixing slates and overlap.

Although there is evidence that Welsh deposits were worked during the Roman occupation of Great Britain, the earliest record of a slate roof is a chapel at Stratford-on-Avon in England, built in the 8th centrury (Bowles, 1934). However, it was not until the 18th century that slate from both Wales and France attained wide acceptance.

The first roofing slate quarry in U.S.A. was opened in 1734 in Pennsylvania. The industry grew steadily and reached a maximum production valued at U.S.$5,186,167 in 1908 (Currier, 1960), but declined thereafter.

The various uses of slate are described below.

1. ROOFING

a. Standard Slate - must have a straight, uniform and smooth cleavage. Colour should be either permanent or colour aging should be uniform without deterioration. Sizes range from 150 mm by 230 mm to 400 mm by 730 mm. Thickness is from 5 mm to 6 mm.

Buildings in Adelaide roofed with Willunga Slate include Bonython Hall, Royal Adelaide Hospital (Plate 3), St. Francis Xavier's Cathedral, St. Peter's College Memorial Hall, and various suburban telephone exchanges. The use of Willunga Slate was widespread in the region near the quarries e.g. Old Church, McLaren Vale (Plate 4).

b. Architectural Slate - is used, particularly in U.S.A. to provide a rugged appearance. Surfaces can be rough and uneven, and colour variable. Thickness varies from 25.4 mm to 63.5 mm and length from 0.6 m to 1.2 m.

For large structures, heavier slates are placed near the eaves with smaller and thinner slates towards the ridge.

c. Other uses - slabs are set in mastic for use on flat roofs, roof promenades and terraces.

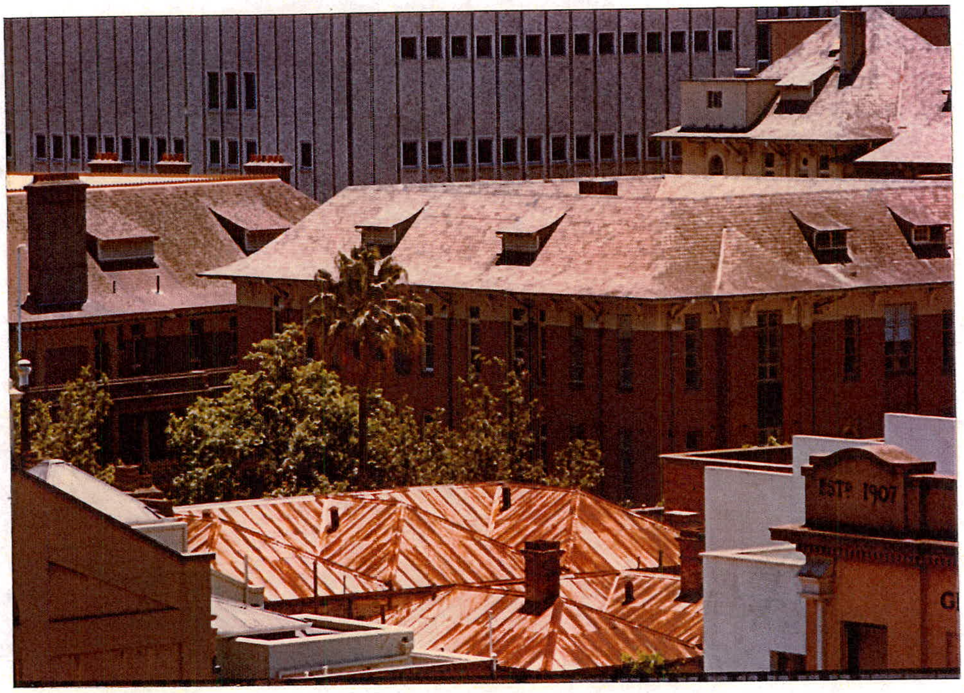


PLATE 3 (IFAE 006) SLATE ROOFS, November, 1974

The charm of slate roofs on buildings at Royal Adelaide Hospital, North Terrace contrasts with nearby galvanised iron. The buildings at centre and at right are roofed with Willunga slate. Bice Building is off the plate to the right.

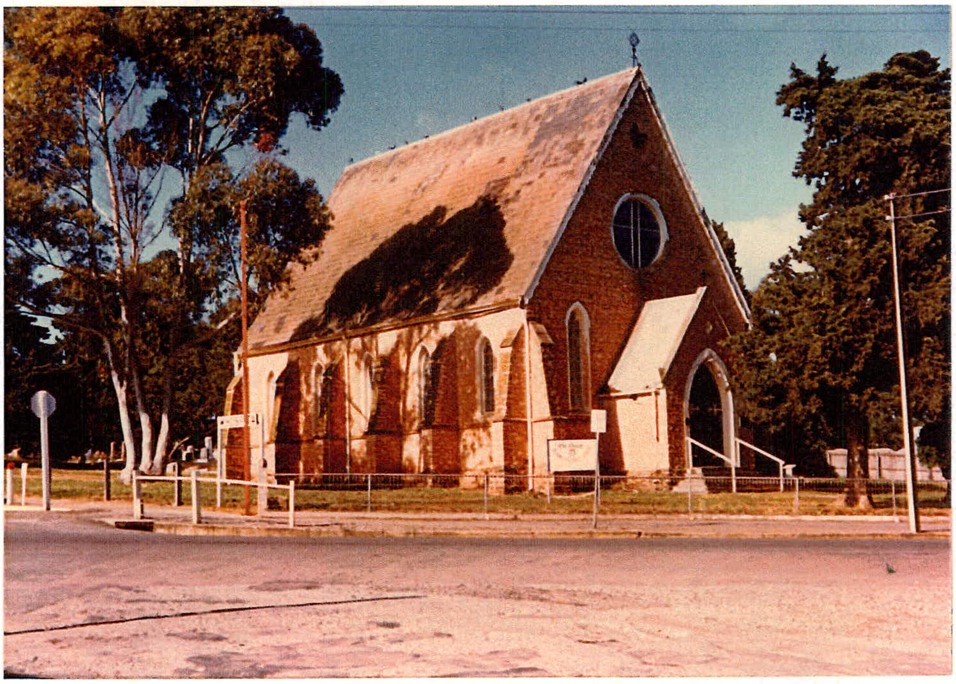


PLATE 4 (IFAE 019) OLD CHURCH, McLAREN VALE, November, 1974

An example of the use of local stone with a roof of Willunga slate.

2. MILL STOCK

a. Blackboard and School Slate - no real demand nowadays. Slate should be soft and uniform in colour and texture. Most of the world's production was obtained from the "soft vein" region of Pennsylvania, U.S.A. (Bowles, 1934).

b. Structural Slate - included mantles, floor tiles, steps, risers, skirting, window sills, billiard and other table tops, head stones, damp courses, vats up to 1000 gallons (made of slabs bolted together), sinks, shelves, bins, kerbing and culverts. A soft even grained slate is preferred that is not highly fissile. Siliceous interbeds from Willunga were widely used although Mintaro flagstone is generally superior, particularly for billiard table tops.

3. PAVING

Slabs may be either rectangular for formal pavements in city buildings or irregular for crazy paving. Mintaro flagstone is preferred to Willunga, as the latter has a tendency to flake under constant wear. Buildings paved with Willunga flagstone include the Old Legislative Council Building in Adelaide and the Melbourne G.P.O. Slabs from Willunga were also used locally for cricket pitches.

4. WALLING

Vertical slate panels were used in both external and internal walls in "Glantowie", erected in Willunga township in 1924-1925 as the residence for the quarry manager (Plate 5). The ceiling was also of slate. Although this type of house is common in Wales and U.S.A. "Glantowie" is reputedly the only one in Australia.

In contrast, horizontal walling is popular today particularly in garden and feature walls, fire place surrounds and as external walling (Plate 6).

PLATE 5 (IFAE 029) "GLANTOWIE", WILLUNGA, April, 1975

The home of the late B.G. Dunstan, former Manager of Australian Slate Quarries Ltd., erected in 1924-25. Vertical panels of Willunga slate were used for external and internal walls. Floors, ceilings, lintels, shelves, washtroughs etc. were all of slate as well as the roof.

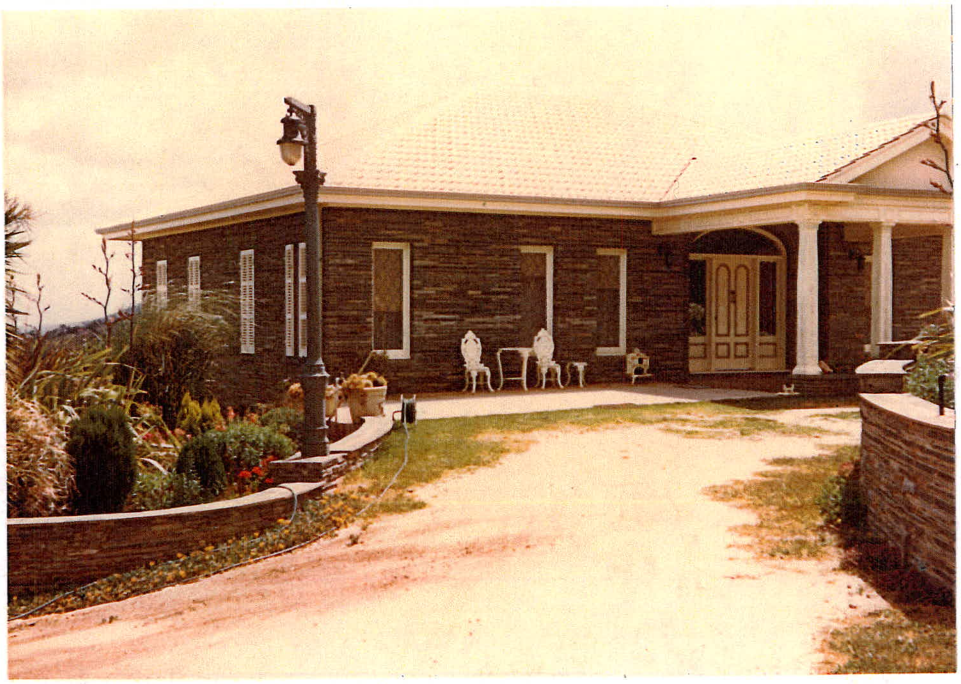


PLATE 6 (IFAE 022) RESIDENCE, COACH RD., SKYE, December, 1974

Willunga flagstone laid horizontally in external walls of house and feature walls in garden.

5. ELECTRICAL SLATE

Certain slate is low in magnetite and carbon and has a high dielectric strength. Electric panels and switchboards can be manufactured from slate, that can be cut and drilled easily without scalling. Selected material from Willunga was used for this purpose.

6. GRANULES

Crushed slate was once widely used in U.S.A. for slate "surfaced composition" and for tennis courts and playgrounds. There was no significant consumption of Willunga slate for this purpose.

7. SLATE POWDER

Following testing in 1920 and 1921, the U.S. Bureau of Mines found that finely pulverised slate, which is inert and has a low weight to a given volume (approximately equal to limestone but slightly superior to Portland cement - Bowles, 1934) could be used as a filler in

- paints
- road asphalt - surface mixtures and asphalt bonded briquettes
- roofing mastic
- mechanical rubber goods but not higher grades of rubber such as car tyres
- linoleum and oil cloth
- window shades except when white
- plastic roofing and flooring

A low fusion point also indicated potential for use in glazes.

Laboratory evaluation by AMDEL is proposed to test the large quantities of waste material at the Willunga quarries (Plate 15). A trial parcel of 10 tonnes has been obtained from the waste dumps at Delabole for milling by Jarvis Minerals. Samples will be tested by AMDEL.

8. LIGHTWEIGHT AGGREGATE

A sample of waste slate from the dumps at Martin's Quarry was included in the evaluation of materials for lightweight aggregate near Adelaide (Nichol, 1975). Although, the sample bloated well within the range 1150 - 1180°C and appearance was reasonable, strength was lacking and it was not selected for follow-up testing.

Waste material from Mintaro bloated very well and produced a very good product in pilot scale trials. As Mintaro flagstone is similar both mineralogically and chemically to Willunga slate further testing of the latter is warranted. Flash firing of samples from dumps at the other quarries is recommended.

MINING AND PROCESSING

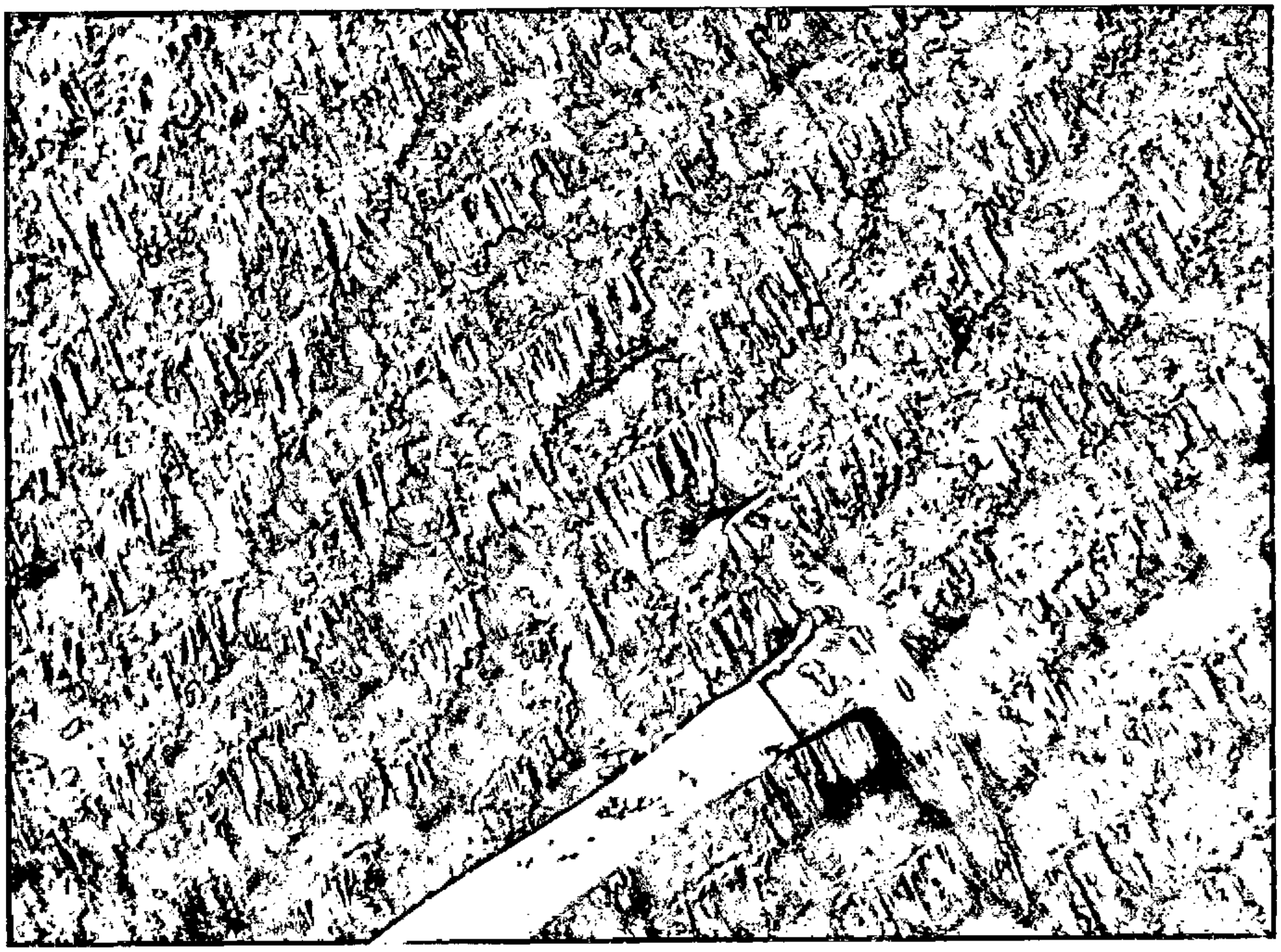
The traditional techniques used in the Welsh and Cornish quarries were brought to Willunga by immigrant slate miners and craftsmen.

In the 19th century, the "opening-in" was accomplished by prising a large slab of slate from the quarry face either by hand chisels (see Plate 7) or the judicious use of explosives in a joint or fracture plane.

At Bangor quarry after 1919, jack hammer drills or pneumatic chisels (called channellers) were used (Jack, 1923).

Sheets were wedged from the slab using plug and feathers. These sheets were hauled away from the working face by winches and later, at Bangor quarry, by a steam driven crane of 5 ton capacity with a 60 feet jib (Jack, 1923; see frontispiece).

At Delabole Quarry, the slabs were transported to the edge of the quarry floor, tipped over and allowed to slide down to the next level for sawing into convenient sizes and splitting by hand chisel to the required thickness. The slate was cut to the appropriate size, as marked by a notched gauge, using a special chopper.



DELABOLE QUARRY

Plate 7, (Neg. 26650). Close up of worked face at centre quarry showing pattern of chiselling used to remove large slabs (4 — 5 cm thick) which were then cut and split into the required sizes for roofing slates.

At Bangor (see frontispiece and Plates 9, 14 and 15), the slabs were left to weather for several days before transporting by rail truck to the splitting shed. Inside the shed, splitting to required thickness was still done by hand chisel. However, the slate was trimmed to size using a machine akin to a lawn mower with a curved blade rotating about a horizontal axis.

Equipment in the shed in 1924 comprised

- an underfired multi-tubular boiler
- a direct coupled steam driven air compressor with a capacity of 450 cu ft per minute
- 30 h.p. mill engine
- 18 h.p. workshop engine
- 9 slate dressing machines
- sand sawing plant for cutting flagstones
- rubbing machine for smoothing surfaces.

The quarry face at Bangor reached a height of 60 m, but the floor has been filled with waste and the face is now only 26 m high.

PRODUCTION

Production data are incomplete and poorly recorded, particularly prior to 1924 (Vaughan, 1973). There is no documentation in the Statistical Record of output for some years in the 19th century when slate is known to have been shipped to Melbourne and Sydney.

A total of 2.77 million roofing slates valued at £30,325 is recorded as having been exported interstate from 1841 to 1892. With some years not listed and no data on local consumption, 4 million roofing slates appear a reasonable total for 1840-1899. Flagging worth £33,272, assumed to be 10,000 tonnes, was exported from 1883 to 1894. Local usage probably accounted for a further 10,000 tonnes.

Output was minor from 1900 until 1917 when Bangor Quarry was reopened. From 1917 to 1944, 12.25 million roofing slates were produced at Bangor and 5,000 tonnes of flagging, paving and walling stone. The last major order for roofing slate was in 1933 for Bonython Hall.

The only known production at Delabole Quarry since the initial closure in 1903 was 1,000 tonnes of paving and walling stone during 1955 to 1957 and occasional small quantities thereafter.

Production from Bastian's and Martin's Quarries in returns lodged with the Department of Mines is as follows:

ballast - 17,000 tonnes from 1925 to 1947

flagging - 31,000 tonnes from 1938 to 1974

roofing - 5 tonnes in 1949.

The overall estimate of production from Willunga, as summarised in Table 2, is based on a search of records in the Archives and the Department of Mines, numerous newspaper reports and discussions with residents at Willunga.

Substantial quantities of waste used for fill or road metal are not included.

TABLE 2

Production, 1840-1975

		Roofing slate		Flagging, paving & walling
		millions	tonnes	tonnes
1840-1899	Export	4	13,000	10,000
	Local	5	17,000	10,000
	Total	9	30,000	20,000
1900-1974		13	38,000	40,000
	Total	22	68,000	60,000

1,000 standard slates weigh approximately 3 tonnes.

PRICES AND IMPORT DUTY OF ROOFING SLATE

In the 19th century, Willunga slate had to compete with slate imported from England and America which was sold in Melbourne for £12 per 1 000. In comparison, Willunga slate cost £17 per 1 000 delivered to Melbourne which included £3 for freight charges from the quarries to Aldinga. The price for 1 000 slates in Adelaide was £10/10/-.

In 1914, best quality Welsh slate was £18 per 1 000 compared with £9 for Willunga slate in Adelaide. Prices rose considerably during the next few years with the import of 25% duty on slate from Wales and 35% duty on slate from U.S.A. In 1921, price ranges were as follows:-

Welsh slate - £36/10/- to £56/10/- delivered on trucks in London.

Willunga slate - £17 to £27 on rail trucks at Willunga.

In 1975, import duty on slate from overseas was dependent on source as follows:-

New Zealand	- nil
Great Britain and favoured nations	- 18%
Developing countries	- 23%
U.S.A. and other general countries	- 33%

Current prices for imported slate delivered in Melbourne vary from \$450 to \$600 per thousand. At present, slate is imported to Adelaide via Melbourne at a cost of approximately \$800 per thousand.

Demand for roofing slate has increased to such an extent that W.H. Martin & Co. are arranging to import slate direct to Adelaide.

MINERAL TENURE

The land at Willunga is freehold with minerals reserved to the Crown.

However, where a person was divested of his property in minerals under the Mining Act, 1971-1975, an area so determined may be declared by proclamation to be a private mine provided application was made within three years after July, 1972 (Section 19(1)).

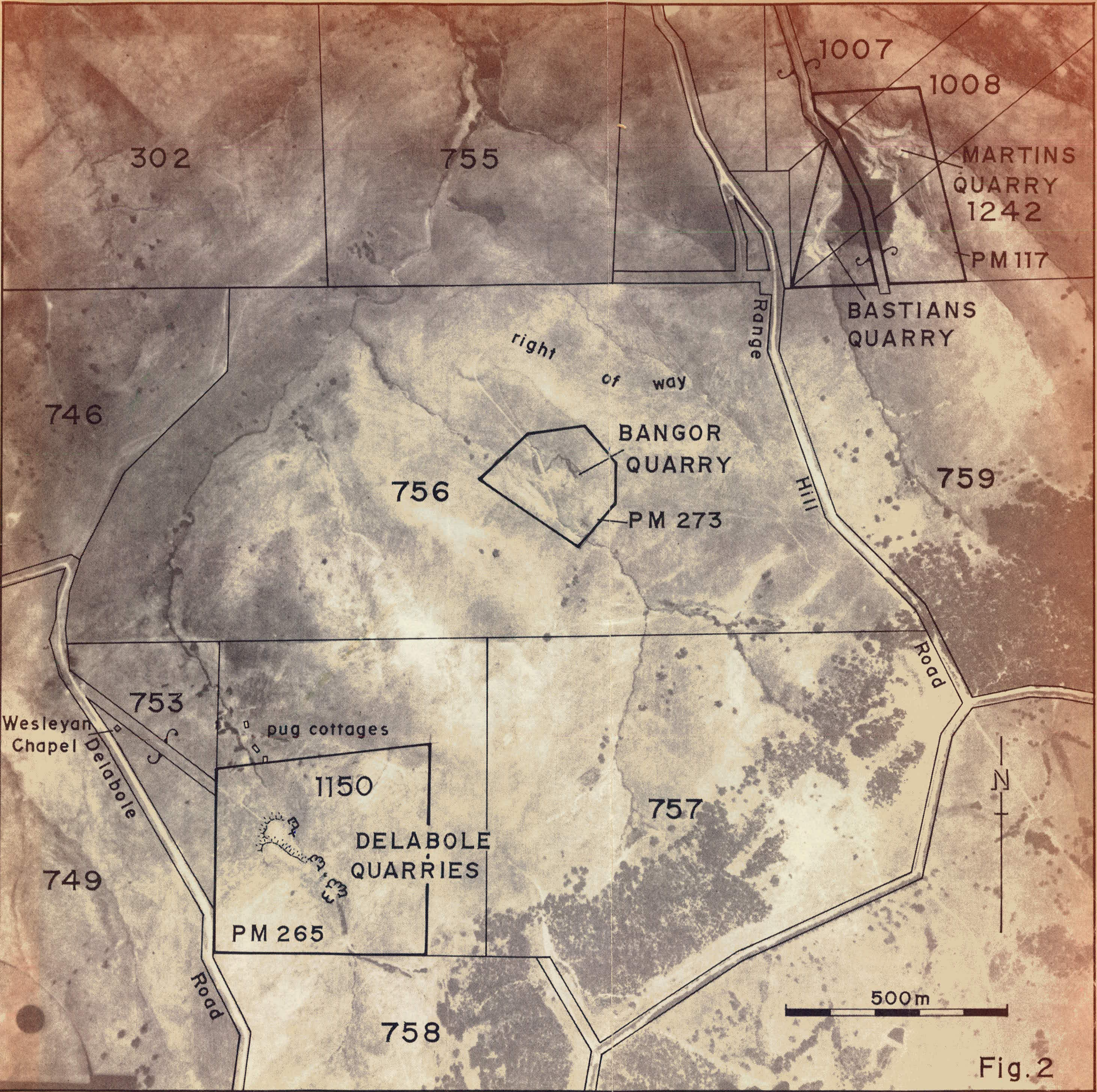


Fig. 2

INDUSTRIAL MINERALS SECTION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	Scale: 1:10 000
Compiled: D.A.Y.	WILLUNGA SLATE DEPOSITS	Date: 19·8·75
Drn: J.G. Ckd: R.A.	HD. WILLUNGA	Drg. No:
PHOTOGRAPHY Svy. 1370 No. 061	PRIVATE MINES AND QUARRIES	75–761

The current tenements over the slate quarries are detailed in Table 3 and the areas involved are shown on Fig. 2.

TABLE 3

Mining Tenements, Willunga Slate Quarries (January 1976)

Quarry	Private Mine	Hectares	Proclaimed	
Delabole	265	15.9	28.11.74	N.F. & D.C. Morse transferred to Tower Hill Pty. Ltd.
Bangor	273	4.3	13.2.75	Tantalite Pty. Ltd., under agreement with the Estate of B.G. Dunstan.
Martin's & Bastian's	117	10.1	24.5.73	Edwards Bros. under agreement with J.C. Sparrow & Co. Ltd.

Mining in the Hills Face Zone is subject to the Restriction or Prohibition of Surface Mining Operations Regulations under the Mines and Works Inspection Act, 1920-1970 (see Appendix C) and is also a consent use under the Hills Face Zone Regulations prepared under the Planning and Development Act, 1966-1971.

The distance and direction to the nearest occupied house from each quarry is listed in Table 4.

TABLE 4

Nearest Occupied House (as at January, 1976)

Quarry	Direction	Distance(km)
Delabole	southeast	1.0
Bangor	north	1.4
Bastian's	north	1.0
Martin's	north	0.7

GEOLOGICAL SETTING

The regional geology as shown on Fig. 1 and Fig. 3 is adapted from Milang (Horwitz & Thomson, 1960), BARKER (Thomson & Horwitz, 1962) and ADELAIDE (Thomson, 1969).

The slate deposits at Willunga belong to the calcareous and dolomitic siltstones of the Tapley Hill Formation and lie about 600 m to 900 m stratigraphically below the lenticular Brighton Limestone. These sediments are units of the Umberatana Group of Sturtian age, part of the Adelaidean sequence forming the Mt. Lofty and Flinders Ranges.

In comparison, the Parachilna deposit occurs near the top of the Tapley Hill Formation (Olliver & Scott, 1974) whereas the Mintaro flagstone deposit lies within the Mintaro Shale, a stratigraphically older bed in the Burra Group near the base of the Sturtian sediments (see Table 5). At Darlington, 30 km north of Willunga, the Tapley Hill Formation is non-fissile and was quarried extensively for blocks to provide dimension stone for many early buildings in Adelaide.

At Willunga, two structural blocks are separated by the steep northwesterly dipping slightly arcuate Willunga Fault (see Fig. 3). On the eastern or upthrown side a sequence of Cambrian sediments, not differentiated in Fig. 3, rest unconformably on Upper Precambrian sediments, as described in Table 6. These beds which are on the limb of a major syncline are overturned and dip steeply to the east. Remnants of mottled lateritized freshwater sands and gravels veneer Precambrian bedrock east of the scarp.

			WILLUNGA (BARKER 1:250000)	MINTARO (BURRA 1:250000)		PARACHILNA (PARACHILNA 1:250000)
PRECAMBRIAN	ADELAIDEAN	MARIN-OAN			UMBERATANA GROUP	ETINA LIMESTONE
		STURTIAN	BRIGHTON LIMESTONE	PEKINA FORMATION		
			- - - - - - -			- - - - - - -
						TAPLEY HILL FMN. WOCKERAWIRRA DOLOMITE MBR.
			TAPLEY HILL FMN	TAPLEY HILL FMN		
				TINDELPINA SHALE MEMBER		TINDELPINA SHALE MEMBER
			- - - - - - -	- - - - - - -		- - - - - - -
			STURT TILLITE	APPILA TILLITE		WILYERPA FMN.
				BRAEMAR IRON FMN		HOLOWILENA IRONSTONE (Boulder beds)
		BELAIR SUB-GROUP	(Unnamed)	BURRA GROUP: KADLUNGA SLATE		(Unnamed)
				GILBERT RANGE QTZ'E		
				- - - - - - -		
				MINTARO SHALE		
				LEASINGHAM QTZITE		
		TORREN-SIAN	GLEN OSMOND SLATE	SADDLEWORTH FMN.		

Approximate position of Slate or Flagstone deposit........ - - - -

TABLE 5

DEPARTMENT OF MINES — SOUTH AUSTRALIA

INDUSTRIAL MINERALS SECTION	Drn. J.G.O	STRATIGRAPHIC SEQUENCE AT WILLUNGA, MINTARO AND PARACHILNA	SCALE:
	Tcd. A.F.		S10949
J.G. Olliver	Ckd. A.F.		MG
SEN. GEOLOGIST	Exd.		DATE: 14 August 1974

500-2,69 665

TABLE 6

Stratigraphic Sequence, East of Willunga Fault

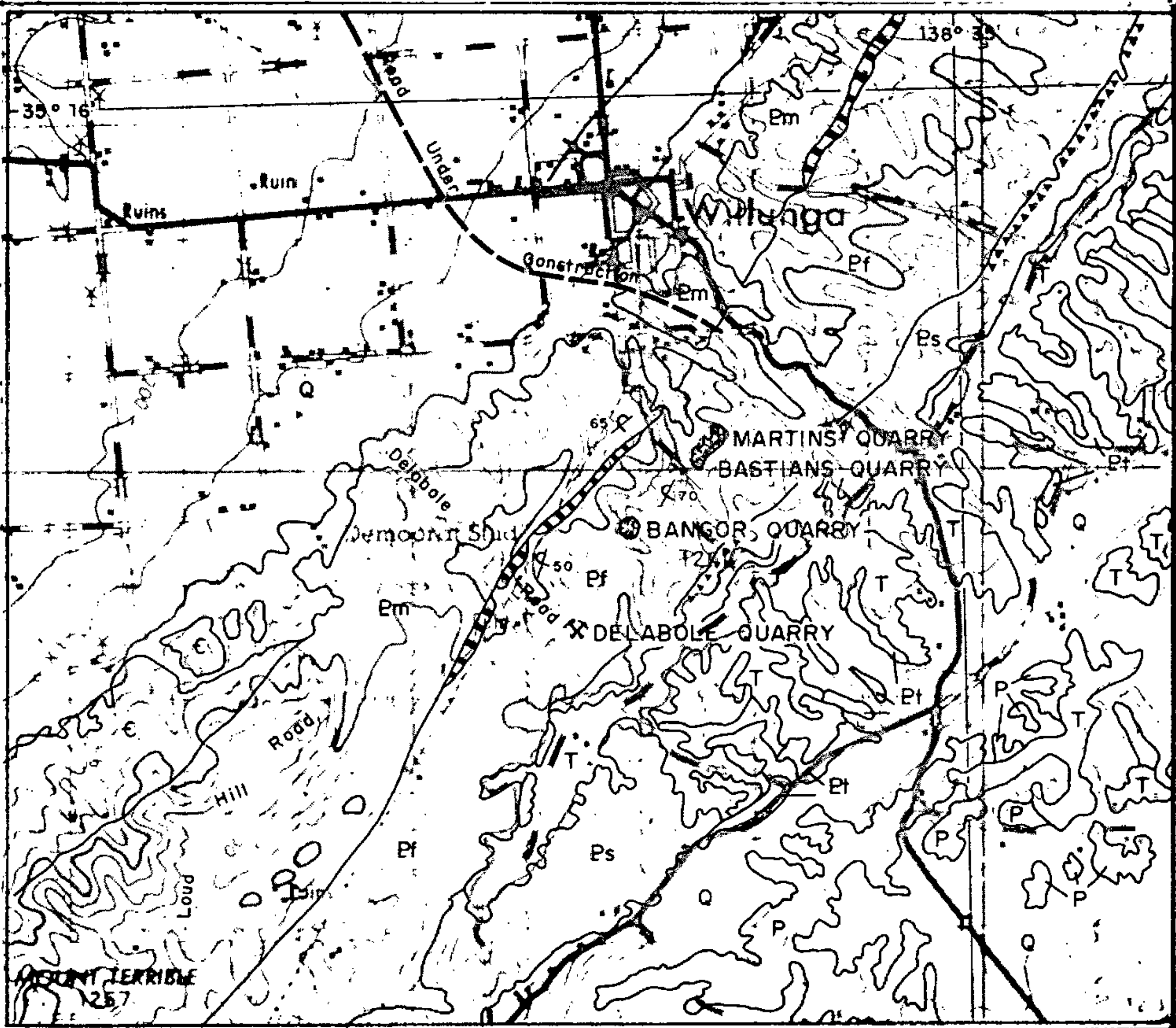
Cambrian		Heatherdale Shale - Mottled shale with phosphatic nodules.
		Fork Tree Limestone - calc dolomite with Archeocyatha
		Sellick Hill Limestone - argillaceous limestone
		Wangkonda Limestone - quartzite and oolitic limestone
		Mt. Terrible Formation - shale, sandstone, arkose, pebbly at base.
Upper Precambrian	Marinoan	- Laminated purple or green shale
		- Quartzite, impure quartzite and greywacke
		- Brown siltstone, laminated pyritic phyllite and greywacke
		- Limestone and marble
		- Gravel, tillitic grit, quartzite
		- Green and brown siltstone with sandy beds grading to greywacke.
	Sturtian	Brighton Limestone - blue oolitic dolomite and limestone
		Tapley Hill Formation - grey slaty calcareous siltstone and dolomite. Grey ferruginous shale at base.
		Sturt Tillite - tillite, feldspathic quartzite, siltstone and shale.

On the western or downthrown side, the Willunga Sub-basin, a shallow tectonic valley approximately 160 square km in area, extends westerly to Gulf St. Vincent (see Fig. 1). Orientation is due to movement along major faults in the late Tertiary. This basin is filled with Permian fluvioglacial clays overlain by a Tertiary sequence of non-marine and marine sediments obscured by Recent and Pleistocene sands, silts, clays, scree, outwash and slope deposits.

6697-III

S.A. DEPARTMENT OF MINES

WILLUNGA SLATE DEPOSITS
LOCAL GEOLOGY



REFERENCE

QUATERNARY

Q — RECENT TO PLEISTOCENE
Alluvium, scree and slope deposits.

TERTIARY

T — PLIOCENE
Lateritised deposits - cross-bedded silts and sands.

PERMIAN

P — Glacial and fluvio-glacial deposits - crossbedded silts and sands.

CAMBRIAN

€ — Shales, limestones with quartzites and arkoses.

Strike and dip of overturned beds (50)

PRECAMBRIAN
ADELAIDEAN

Pm — MARINOAN
Shales, quartzites, siltstones, gravels and grits.

STURTIAN
BRIGHTON LIMESTONE: Oolitic, flaggy and dolomitic limestones.

Pf — TAPLEY HILL FORMATION: Blue-grey laminated siltstones and slates

STURT TILLITE: Boulder tillite.

Ps — BELAIR SUBGROUP: Quartzites and arkoses, siltstones and shales.

Pt — TORRENSIAN
Siltstones, greywacke, quartzites and phyllites

SCALE

kilometres 0 — 3 kilometres

1:50000

S12001 FIG. 3

SAMPLING

The twenty two samples collected during 1974 are described in Table 7 and locations are shown on Figs. 4-8. Delabole Quarry comprises three openings (see Plate 8), Bangor one (see Plate 9), Bastian's two and Martin's three.

TABLE 7

Description of Samples (refer to p. 6 for definitions)

Sample No.	Dept. No.	Type	Description
Delabole Northern Quarry			
WS1	A247/74	Selected	Siltrock. Light grey to medium grey, finely laminated, cross cleaved siltstone, parting along cleavage at 35-40^{o} to the bedding. Bedding up to 3 mm.
WS2	A248/74	Selected	Siltrock. Light grey to medium grey, siltstone with lensoid carbonate rich beds up to 200 mm weathering yellowish brown. Parting oblique to bedding.
Delabole Middle Quarry			
WS3	A249/74	Selected	Slate. Finely laminated siltstone beds up to 4 mm, light grey carbonate rich bands and medium grey silt bands. Parting along bedding planes marked by very fine mica flakes.
WS4	A259/74	Chip	Slate, zone 3.2 m wide.
WS5	A250/74	Selected	Siltrock. Partly weathered interbedded medium dark grey shale generally 1 mm but up to 3 mm and very pale brown, to yellow sandy and silty lensoid beds up to 7 mm. Poor parting along bedding and incipient oblique cleavage.
WS6	A251/74	Selected	Slate. Medium dark grey to dark grey very finely laminated siltstone and shale. Well developed bedding plane parting. Slight sheen.

Sample No.	Dept. No.	Type	Description
Delabole Southern Quarry			
WS7	A260/74	Chip	Slate, zone 8.5 m wide.
WS8	A252/74	Selected	Slate. Medium grey to medium dark grey finely laminated siltstone and shale. Slight sheen on well developed bedding plane parting. Minor calcite on joint planes.
WS9	A253/74	Selected	Siltrock. Finely laminated medium grey to medium dark grey, siltstone with thicker bands of very pale brown silty fine sandstone - from a zone with regular jointing forming blocky slabs.
Bangor Quarry			
WS10	A254/74	Selected	Roofing slate off former processing shed at quarry. Medium light grey, finely laminated siltstone with well developed bedding plane parting. Grain! → Vague ripple marks on upper surface.
WS11	A255/74	Selected	Slate. Medium light grey finely laminated siltstone with slight sheen on moderately well developed bedding plane parting. Finely disseminated pyrite on several bedding planes. Grain! → Vague ripple marks on some bedding planes.
WS12	A256/74	Selected	Siltrock. Massive medium grey carbonate siltstone, a few laminations on edge of sample.
WS13	A261/74	Chip	Siltrock, 16.0 m wide, north of slate zone.
WS14	A262/74	Chip	Slate, zone 11.5 m wide.
WS15	A263/74	Chip	Siltrock. 23.0 m wide, south of slate zone.
Bastian's Quarry			
WS22	A76/74	Selected	Slate from stockpile of paving slabs.
WS16	A264/74	Chip	Slate, zone 6.5 m wide.
WS17	A257/74	Selected	Slate. Finely laminated medium grey siltstone with layers varying from light grey to medium dark grey. Slight sheen on well developed bedding plane parting.

Sample No.	Dept. No.	Type	Description
Martin's Quarry			
WS18	A265/74	Chip	Slate, zone 8.0 m wide, southern quarry.
WS19	A266/74	Chip	Slate, zone 15.0 m wide, middle quarry.
WS20	A267/74	Chip	Siltrock. Deeply weathered siltstone 10 m wide, northern quarry.
WS21	A258/74	Selected	Siltrock. Weathered laminated medium grey and white to yellow and brown siltstone to fine sandstone, lensoid in places. Weathering has produced irregular mottling.

The following 13 samples as well as the 2 earlier samples from Bangor collected in 1919 and 1922 represent slate or potential roofing slate -

Delabole Quarry	WS3, 4, 6, 7 and 8
Bangor Quarry	WS10, 11 and 14
Bastian's	WS16, 17 and 22
Martin's	WS18 and 19.

Although WS9 was classed as a slate in Appendix A jointing is too prevalent in the zone for roofing slate to be obtained.

All samples of slate are characterised by a sheen on bedding planes caused by alignment of platy minerals.

PLATE 8 (IFAD 003) DELABOLE QUARRY, July 1974

The three quarries at Delabole, looking north easterly along strike of beds.

PLATE 9 (IFAC 005) BANGOR QUARRY, July, 1974

General view looking northwards. Pay Office on entrance track at left and processing shed centre left with waste dumps below.

GEOLOGY OF THE SLATE QUARRIES

1. ROCK SEQUENCE

The sequence exposed in each quarry face is described below from west (younger) to east (older).

a. Delabole Southern Quarry (Fig. 4)

Width(m)	Description
4.5	Siltrock. Interbedded siltstone and fine grained sandstone. Poor parting along widely spaced bedding planes. Occasional calcite-quartz veins up to 15 mm wide.
0.5	Transition zone, sandstone beds decrease to east. Specks of pyrite in sandstone.
8.5	Slate. Finely laminated dark grey to black siltstone. Well developed parting along closely spaced bedding planes. Moderately calcareous. Occasional yellow sandstone up to 10 mm wide. Highly weathered in places. WS7 is chip sample across zone and WS8 a selected sample.
27.0+	Siltrock. Interbedded siltstone and fine grained sandstone - WS9 selected sample with poor parting, widely spaced.

b. Delabole Middle Quarry (Fig. 5)

Width(m)	Description
3.0	Siltrock. Siltstone with yellow brown sandstone interbeds, parting along bedding widely spaced.
0.5	Slate, dark grey, moderate to slightly calcareous.
3.0	Siltrock. Laminated siltstone with poor parting. Bedding buckled near quartz lens.
3.0	Slate, dark grey to light grey, moderate to slightly calcareous, WS6 is a selected sample.
3.5	Siltrock. Grey siltstone widely spaced parting along bedding with prominent band of green sandstone 90-130 mm wide and other thinner sandstones.
1.2	Siltrock. Interbedded siltstone and sandstone, non calcareous. Sandstone bands up to 10 mm moderately spaced parting. Lensoid bands common. WS5 is a selected sample.

Width(m)	Description
0.4	Transition zone.
3.2	Slate, dark grey with lighter sandstone bands up to 5 mm decreasing in abundance to east. Selected sample WS3 and chip sample WS4 across zone.
0.4	Transition zone.
23.0+	Siltrock. Finely laminated siltstone with abundant sandstone interbeds up to 100 mm wide. Ripple markings common on bedding planes of siltstone.

c. Delabole Northern Quarry (not mapped)

Interbedded flaggy calcareous siltstone and sandstone (siltrock) which are typically lenticular. Parting along bedding planes is poorly developed and widely spaced. Cross cleavage is strongly developed in places. No potential for roofing slate but paving and walling stone abundant due to high sandstone content (WS1 and WS2).

d. Bangor Quarry (Fig. 6)

Width(m)	Description
2.5	Siltrock. Interbedded siltstone and sandstone with widely spaced parting.
2.5	Zone of quartz-calcite veins. Bedding contorted (see Plate 10).
0.5	Slate, slightly buckled in places.
1.0	Siltrock. Yellow brown siltstone with dark interbeds.
1.0	Zone of quartz-calcite veins, bedding contorted.
16.0	Siltrock. Finely laminated siltstone, but poor bedding plane parting. Occasional sandstone bed up to 50 mm in eastern 3 m. Chip sample WS13.
11.5	Slate, with some lighter bands of sandstone and limestone. Moderately high carbonate content overall. Chip sample WS14.

PLATE 10 (IFAC 016)   BANGOR QUARRY, July, 1974

Bedding planes contorted about white quartz-calcite veins.

Width(m)	Description
2.0	Zone of fracturing, with calcite veinlets up to 10 mm wide.
2.5	Slate. Selected sample WS11 contains weathered pyrite grains.
0.5	Transition zone, proportion of slate decreases eastwards. Selected sample WS12.
23.0+	Siltrock. Grey laminated siltstone, moderate to widely spaced parting along bedding. Chip sample WS15.

e. Bastian's Southern Face (Plate 13)

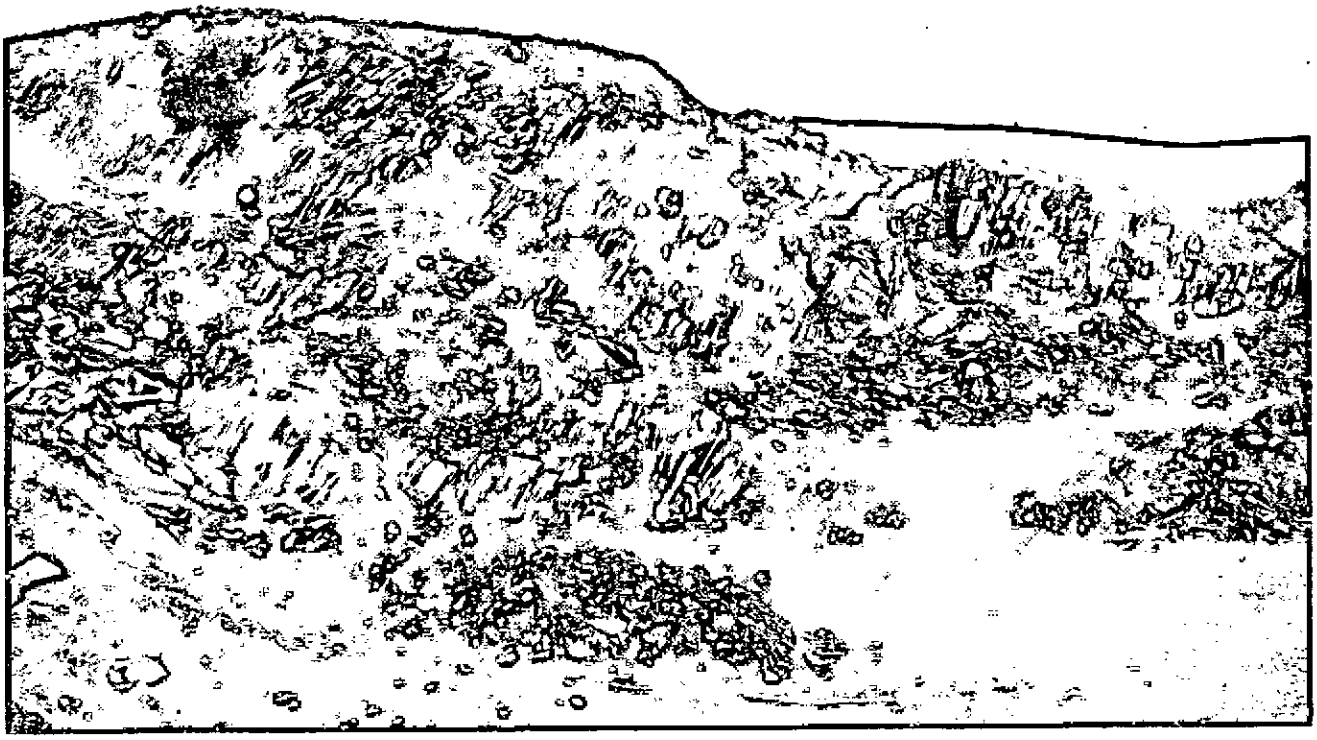
Not mapped due to overhanging face.

f. Bastian's Northern Face (Fig. 7)

Width(m)	Description
5.0	Siltrock. Siltstone, weathered, with yellow brown sandstone bands of up to 30 mm. Some lensing of beds. Moderately spaced parting.
0.5	Transition zone.
6.5	Slate, with occasional sandstone bands. Less calcareous eastwards. Chip sample WS16. Minor jointing. Selected sample WS17.
3.0	Transition zone.
3.0	Siltrock. Siltstone, widely spaced parting.
1.5	Slate.
1.0	Siltrock. Siltstone, widely spaced parting.
0.5	Slate.
4.0+	Siltrock. Siltstone, with concordant quartz lens, more calcareous to east. Ripple marking on bedding planes.

g. Martin's Southern Face (Fig. 8 - units refer from right to left)

Width(m)	Description
10.0+	Siltrock. Siltstone. Calcite - quartz veins in siltstone with contorted bedding.
8.0	Slate, chip sample WS18.



Above:

MARTINS QUARRY

Plate 11, (Negs. 26646, 26647, 26648).

Central face looking south.

deep below floor as quarry is high

Right:

MARTINS QUARRY

Northern workings.

Plate 12, (Neg. 26645).

Left:

BASTIANS QUARRY

Plate 13, (Neg. 26654). Southern face.

Width(m)	Description
29.0	Siltrock. Interbedded siltstone and sandstone, bedding buckled in places with thin calcite veins.
4.5	Slate, calcite veins up to 40 mm along bedding in eastern 1.0 m.
6.0	Siltrock. Interbedded siltstone and calcareous sandstone up to 130 mm wide. Widely spaced parting.

h. Martin's Middle Face (Plate No. 11)

Approximately 15.0 m of slate in centre of face with 25.0 m and 20.0+ m of siltrock west and east respectively. Samples WS19 was chipped from slate zone.

i. Martin's Northern Face (Plate No. 12)

Deeply weathered light grey, brown to white finely laminated siltstone with a high proportion of interbedded sandstone with little if any slate WS20 was chipped from face and WS21 a selected sample.

The proportion of slate in each quarry is summarised in Table 8.

TABLE 8

Proportion of slate exposed in quarry

Quarry		Width of face (m)	Slate Zone (m)	Slate Zone %
Delabole	South	40.5	8.5	21
	Middle	41.2	6.7	16
	North	not mapped	-	-
Bangor		63.0	14.0	22
Bastian's	South	not mapped	-	-
	North	25.0	8.5	34
Martin's	South	57.5	8.0	14
	Middle	60.0	15.0	25
	North	not mapped	-	-
TOTAL		287.2	60.7	(Average) 21

This might be primary cleavage →
(not secondary) being refracted by coarser grained sediments

Actual yield of slate from the six quarries is expected to be considerably less than 21% as rejection of thin interbeds of sandstone is required as well as loss due to joints, thin calcite veins and cross cleavage.

i.e. as low as 2-5 % yield.

2. BEDDING

22° 35°

In general, strike varies from 202 deg. to 217 deg. and dip from 60 deg. to 70 deg. to the east. There is local contortion near major cross fractures or zones of quartz-calcite intrusion.

3. CLEAVAGE

At Willunga, slaty cleavage coincides with the bedding. All samples of slate exhibit a well defined bedding plane cleavage produced by the alignment of the flaky minerals - muscovite, chlorite and biotite (see Appendix A). As well, most quartz grains are elongated in the direction of cleavage and even calcite and dolomite grains tend to be slightly elongated in the same direction.

The finer grained more phyllitic layers are completely fissile to thicknesses of a fraction of a mm, whereas the cleavage planes are more widely spaced in layers with relatively high quartz or carbonate contents.

Secondary cleavage is poorly developed except in Delabole North. Strike varies from 202 deg. to 217 deg. with dips of 45-46 deg. to the east, and hence cuts bedding at an angle of 15-25 deg. Thin calcite veins often intrude along the cleavage e.g. in zones up to 1.0 m wide at Martin's South.

4. JOINTS

Two main joint sets have developed, approximately at right angles to bedding, and three other sets as follows:

(a)	strike 165-240 deg.	dip 16-69 deg. north-west
(b)	265-316 deg.	82 deg. south through vertical to 70 deg. north
(c)	137-207 deg.	63-84 deg. north-east
(d)	205-225 deg.	47-56 deg. east
(e)	115 deg.	0-5 deg. south

Set (a) was used as a floor during quarrying.

5. WEATHERING

In the old workings the uppermost 5-10 m was rejected - this material was deemed to be weathered and unreliable for roofing slates (pers. comm. Mr. C. Reed). Deeper weathering is also associated with some of the joints and fractures.

Upon weathering, fine grained pyrite, where present, reacts with carbonate minerals causing the slate to "feather" and soften.

In periods of high production at Willunga, some roofing slates of inferior quality were produced from weathered zones or layers rich in pyrite. These slates deteriorated rapidly and led to the poor reputation of Willunga slates in some quarters (Pittman, 1912). However, there are some roofs in Adelaide of high quality Willunga slate still in good condition after many years e.g. Bice Building at Royal Adelaide Hospital has been in service 52 years. At Willunga, some roofs are more than 100 years old.

PETROLOGY

All 13 samples examined petrographically are bedded, indurated, carbonate bearing siltstones which split along bedding to varying degrees (see Appendix A). Grain size of individual minerals varies from 0.01 mm to 0.1 mm. The range in content of the main minerals is listed in Table 9. Accessory minerals include feldspar, opaques, carbonaceous matter, tourmaline, zircon, apatite and pyrite.

TABLE 9

Mineral Content - Estimated Optically

Mineral	Range (percent)
Quartz	30-55
Dolomite	Tr-10
Calcite	Tr-25
Phyllosilicates	
Biotite	less than 5
Muscovite	5-30
Chlorite	10-30

Quartz grains, up to 0.06 mm, vary from equant to elongate parallel to bedding. Margins are generally irregular and xenoblastic with the enclosing phyllosilicates. Carbonates occur as equant to slightly elongate xenoblastic grains up to 0.05 mm.

Phyllosilicates are aligned generally subparallel with the bedding. Both chlorite and muscovite are significcant but only occasional brown pleochroic flakes of biotite are present. Chlorite flakes are irregular, wispy and pale green, or brown. Muscovite is colourless as flakes up to 0.08 mm or aggregates of flakes. Muscovite that is crumpled and distorted is probably detrital whereas regular flakes closely associated with chlorite and biotite are probably secondary having replaced the other phyllosilicates.

Laminations, which are often emphasized by a concentration of organic matter, are produced by an alternation of light bands either quartz-rich or carbonate-rich and dark phyllosilicate-rich layers. Individual laminae vary in thickness from a fraction of a mm to 4 mm. In the 7 samples of slate (WS3, 6, 8, 10, 11, 17 and 22) laminae are regular in thickness, generally less than 1 mm, with closely spaced planes of parting. This fissility is more pronounced in phyllosilicate-rich layers. Closely spaced cross cutting joint planes, foliation planes or veins are absent.

Material not classed as slate is characterised by one or a combination of the following properties.

(1) Lensoid laminae - layers wedge out over relatively short distances (WS5)

(2) Deficient in phyllosilicate layers (WS5, 12 and 21).

(3) Well developed cleavage oblique to bedding plane (WS1 and 2).

(4) Relatively closely spaced jointing (WS5 and 9).

Weathering produces a softer, more friable rock (WS9) and eventually irregular yellow and brown iron oxide staining and a removal of carbonate (WS21).

this should be 38% →
as per Newbigin (1967)

The general fine grain size, carbonate content, the presence of carbonaceous matter and pyrite indicate deposition in a shallow marine environment.

PHYSICAL PROPERTIES

Prior to 1965, published data on Willunga slate was limited to testing of 4 samples for modulus of rupture, breakage resistance and hardness (Jack, 1923).

During 1966 and 1967, the Bureau of Mineral Resources tested nine "slates" from Australia including Willunga, Mintaro and Wistow from South Australia. Willunga slate is regarded as useful as internal or external paving stone or as external cladding stone on the results as detailed in Newbigin (1967) and summarised in Table 10.

TABLE 10

Results of Testing of Willunga Slate, Newbigin (1967)

Property	Value	Comment
Bulk Specific Gravity	2.70	Normal
Water adsorption	0.68 percent	Low
Crushing Strength		
Dry	40 150 p.s.i.	Adequate
Wet	31 400 p.s.i.	Adequate, loss on saturation not more than 30 percent.
L.A. Value for Abrasion	28 percent	Fairly resistant to abrasion.
Sodium Sulphate Test		
No. of cycles	13/15	Fairly durable
Percentage wt. loss	negligible	

As part of a programme to evaluate natural building stones in South Australia, a bulk sample of slate from Bangor Quarry is being tested by AMDEL for the following properties.

1. Water Absorption - A.S.T.M. C121-48 (1970)
2. Modulus of Rupture - A.S.T.M. C120-52 (1970)

3. Slipperiness of wet slab
4. Degree of polish
5. Oil Absorption
6. Modulus of elasticity - A.S.T.M. C120-52 (1970)
7. Curvature & flatness - A.S.T.M. C406-58 (1970)
8. Maximum slab size
9. Minimum splitting thickness
10. Abrasion resistance (Taber Abraser)
11. Simulated atmoshperic attack
12. Abrasion hardness - A.S.T.M. C241-51 (1970)
13. Depth of softness - A.S.T.M. C217-58 (1970)
14. Acid resistance - A.S.T.M. C217-58 (1970)

CHEMICAL COMPOSITION

The results of chemical analyses of the 24 samples from Willunga are summarised in Table 11 from data in Appendix B and compared with the following:-

- Average of 4 samples from Mintaro.
- Average of 3 samples from Parachilna (Olliver & Scott, 1974).
- Average of 2 samples from Quorn (Olliver, 1975).
- An imported grey slate from the roof of Adelaide Gaol.
- Black slate from Lehigh County, Pennsylvania, the slate richest in carbonate in U.S.A.
- General average of 8 varieties of slate from New York, Vermont and Pennsylvania, U.S.A.
- Roofing slate from Frankenburg, Prussia, the slate richest in carbonate of 14 varieties in Europe.
- Very dark banded roofing slate from Llansantfraid, North Wales, the richest in carbonate of 6 Welsh slates.
- Green roofing slate from Vehenhelli, Wales, containing least carbonate of 6 Welsh slates.

TABLE 11. Summary of Chemical Analysis

	SOUTH AUSTRALIA							OVERSEAS				
	Willunga			Mintaro	Para-chilna	Quorn	Wales?	U.S.A.	U.S.A.	Prussia	Wales	Wales
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
SiO_2	48.22-63.66	52.49-56.54	53.85	54.63	50.57	55.05	54.23	56.38	61.51	59.35	56.71	63.06
Al_2O_3	10.29-14.90	11.54-14.90	12.61	13.07	9.08	11.16	23.48	15.27	15.39	13.56	14.43	18.03
Fe_2O_3	0.60- 5.47	0.64- 1.59	1.13	0.68	0.75	1.27	1.06	1.67	2.21	1.10	1.98	2.24
FeO	0.64- 4.87	3.65- 4.87	4.36	4.45	3.21	3.56	6.67	3.23	4.08	4.75	3.65	4.07
CaO	0.37-13.29	4.61- 8.11	6.87	5.80	13.94	8.74	0.47	4.23	1.47	5.20	3.83	0.81
MgO	2.79- 5.44	4.18- 5.44	4.74	6.15	3.32	3.72	1.70	2.84	3.23	3.60	3.47	2.21
Na_2O	1.06- 1.90	1.06- 1.57	1.37	1.24	1.37	1.61	0.52	1.30	1.22	1.48	2.59	1.51
K_2O	2.16- 3.22	2.51- 3.02	2.76	2.73	2.35	2.41	4.71	3.51	3.90	1.77	2.61	3.07
CO_2	0.10-12.40	4.75- 8.10	6.89	7.66	11.80	7.45	0.15	3.67	1.55	4.45	3.71	nil
CaO:MgO	0.13- 3.54	0.89- 1.88	1.45	0.92	4.20	2.40	0.28	1.49	0.46	1.44	1.10	0.37

(a) Range for 24 samples of slate and siltrock.

(b) Range for the 15 samples classed as slate.

(c) Average of the 15 samples.

(d) Average of 4 samples.

(e) Average of 3 samples.

(f) Average of 2 samples.

(g) Slate from roof at Adelaide Gaol.

(h) Black slate, Lehigh County, Pennsylvania, U.S.A.

(i) General average of slates from Vermont, New York and Pennsylvania, U.S.A.

(j) Frankenberg, near Goslar, Prussia.

(k) Dark banded slate, Llansantfraid, North Wales.

(l) Green slate, Velenhelli, Wales.

The last 5 analyses have been obtained from Dale et al. (1914).

The 24 samples from Willunga range from WS2, rich in carbonate (12.40% CO_2) to WS21 with minor carbonate (0.10% CO_2). However, the 15 samples of <u>slate</u> from Willunga are restricted to the relatively narrow range of 4.75% to 8.10% CO_2 with an average of 6.89% CO_2. Overall, these slates are generally calcareous rather than dolomitic as ratio of CaO to MgO averages 1.45. Only WS3 and WS22 have a ratio less than 1.0.

There is no significant difference in chemical content between siltrock WS13 and WS15 and the adjacent slate zone WS14 at Bangor Quarry. Most of the iron in the deeply weathered sample WS21 (only 0.88% FeO) had been oxidized in comparison to all other samples.

Elsewhere in South Australia, in comparison to Willunga, Mintaro is slightly more dolomitic, Quorn more calcareous and Parachilna appreciably more calcareous.

The sample from Willunga with least carbonate (4.75% CO_2) was collected from Bangor Quarry in 1919 and is similar in composition to slate from Frankenburg, Prussia. However, most other overseas slates are low in carbonate, and in particular the roof at Adelaide Gaol contains only 0.15% CO_2.

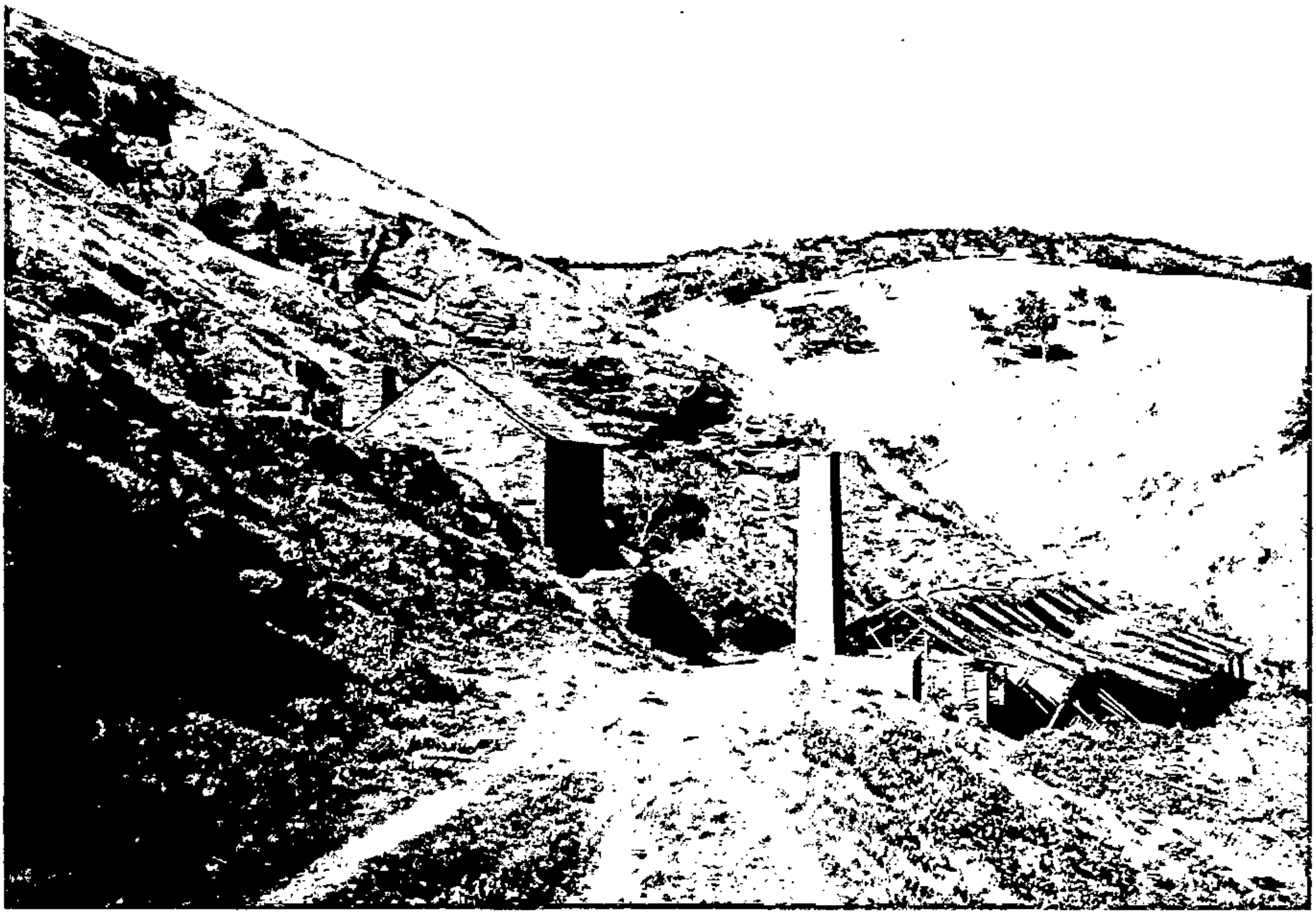
RESERVES

The slate deposits extent over a strike length of 2.3 km in a zone about 300 m wide. Although the establishment of the quarries was preceded by intense prospecting, other favourable bands probably exist. Trenching would be required to expose fresh rock below the weathered zone, as apart from creek beds, outcrop conditions are poor.

Quarrying at Bangor Quarry had reached a depth of 60 m prior to backfilling to the present floor level.

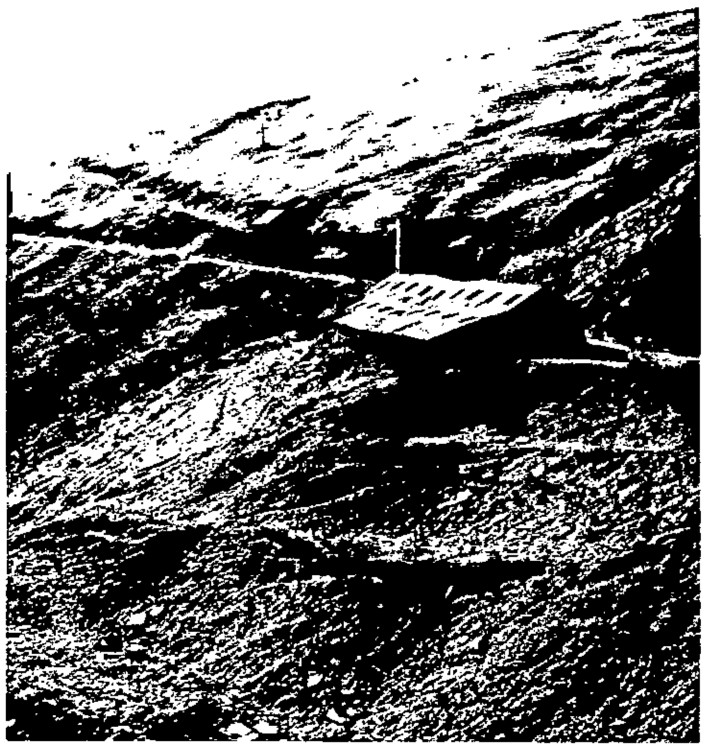
Yield of roofing slate was estimated at 10% of total material quarried.

probably less – down to 5%



BANGOR QUARRY

Above: Plate 14, (Neg. 26651). The approach to the quarry looking south-easterly. Buildings erected by Australian Slate Quarries Ltd. are, at left the slate walled and roofed office and at right , the boilerhouse and splitting shed.



Right: Plate 15, (Neg. 26653). Huge waste dumps below the splitting shed.

As slate of similar quality is expected to persist between the quarries, reserves are adequate to sustain large scale operations.

CONCLUSIONS

Since operations began in 1840, the slate industry at Willunga has experienced several periods of high activity followed by long intervals of stagnation.

An estimated 22 million roofing slates, equivalent to 68,000 tonnes, have been produced with at least another 60,000 tonnes for paving and other purposes.

The current popularity of natural stone for walling and paving, together with the need for roofing slates to renovate historic buildings has renewed interest in the Willunga slate deposits. As well, the use of the large amounts of waste material in light weight aggregate and as a low cost filler are under investigation. The physical properties of Willunga slate are being determined by AMDEL as part of a programme to evaluate all natural building stones in South Australia.

Willunga slate splits readily and cleanly along cleavage planes which are coincidental with the bedding.

The deposits are part of the Tapley Hill Formation, a unit of the Umberatana Group of Precambrian age. The slates are finely laminated siltstones which contain up to 20% calcite and up to 10% dolomite. Chemical content averages 6.87% CaO, 4.74% MgO and 6.89% CO_2, all of which are higher than analyses recorded for overseas slate.

Large reserves of material are readily available.

Roofing slate will only be obtained from the relatively well defined slate zones at each quarry.

The re-establishment of the roofing slate industry at Willunga should be encouraged, not only to supply a commodity no longer produced in Australia, but as an operation of historic significance with considerable tourist appeal.

25th February, 1976

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A P P E N D I X   A

PETROGRAPHIC DESCRIPTIONS

extracted from

AMDEL Report MP3436/74 by Dr. R. Davey

and

AMDEL Report MP486/75 by R. Cooper

Sample WS1 A247/74; TS 32630

Location: Hundred of Willunga, section 1150, Delabole Slate Quarry.

Rock Name: Indurated and foliated carbonate-bearing siltstone.

Hand Specimen:

This sample is grey, fine grained, and finely laminated, the thickness of the laminae varying from a fraction of a millimetre to several millimetres. There is a weak cleavage in the rock parallel to the bedding and a far more pronounced cleavage/joint system at an angle of approximately 45° to the bedding. The hand specimen has slabbed parallel to this latter cleavage/joint system but the broken surfaces are highly irregular (stepped) due to the effects of the bedding plane cleavage. Minor irregularities in the hand specimen include a vein, 1 - 2 mm wide, which is aligned neither parallel to the bedding, nor to the cross-cutting cleavage/joint system, and there are also minor bedding irregularities and dislocations.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	30-40
Dolomite	5-10
Calcite	8-12
Biotite	less than 5
Muscovite	5-15
Chlorite	15-25
Feldspar	less than 5
Opaques	less than 5

This sample is composed principally of quartz, with minor amounts of dolomite, calcite, muscovite, and chlorite and trace amounts of biotite, feldspar, and opaques. The constituent grains are all less than 0.06 mm across. The dominant foliation does not follow the bedding but is at an angle of approximately 40°. However the bedding is still quite clear because of the different proportions of quartz and phyllosilicates in the different layers, deformation with the development of cleavage planes being more pronounced in the phyllitic layers. In fact the foliation plane varies according to the amount of quartz and the degree of incompetence of the bedding laminae, being at a greater angle to the bedding in the ~~incompetent~~ competent ? quartzose layers and nearly coinciding with the bedding in the ~~competent~~ incompetent phyllosilicate-rich layers.

Individual quartz grains have been elongated by the deformation the rock has undergone, are up to 0.05 mm long, and have complex angular/xenoblastic margins with surrounding carbonate and phyllosilicate grains. Both calcite and dolomite are present, and these carbonates form equant to slightly elongate xenoblastic grains up to 0.05 mm across. The dominant phyllosilicate appears to be a green to green-brown chlorite, which forms irregular wispy flakes. The largest flakes of chlorite are usually closely associated/intergrown with a brown pleochroic biotite. Muscovite occurs as flakes of varying size up to 0.08 mm long. Some of these are crumpled and evidently of detrital origin unlike the chlorite which appears to be secondary and to have formed in part through the replacement of the other phyllosilicates present. A few grains of feldspar were detected microscopically, and the sample contains opaque grains up to 0.04 mm across.

This sample is an indurated carbonate-bearing siltstone which parts principally along a cleavage that is at a marked angle to the bedding. However, the bedding is still quite distinct and the poor and irregular nature of parting rules this material out for slate making. The rock contains no obvious easily weathered minerals and could perhaps be utilized for flagstones.

Sample WS2 A248/74: TS 32631

Location: Hundred of Willunga, section 1150, Delabole Slate Quarry.

Rock Name: Indurated, irregularly cleaved, carbonate-bearing siltstone.

Hand Specimen:

This sample is grey, fine-grained, faintly bedded, with bedding units up to several millimetres thick, and weakly and irregularly cleaved. Instead of parting readily along the bedding plane cleavage the sample breaks in a highly irregular fashion.

Thin Section: An optical estimate of the constituents gives the following:-

	%
Quartz	30-40
Dolomite	4- 8
Calcite	15-25
Biotite	Trace
Muscovite	10-20
Chlorite	10-20
Feldspar	<5
Opaques (including carbonaceous material)	<5

This sample is fine-grained and composed principally of quartz, calcite and phyllosilicates. Quartz and carbonate-rich layers up to 1 cm thick with a grain size of 0.02 to 0.03 mm are interspersed with phyllosilicate-rich layers, up to 2 mm thick, which have an average grain size of less than 0.02 mm. The cleavage in the rock is more pronounced in the phyllosilicate-rich layers and is at an angle of approximately 10 to 20° in the bedding. As the phyllosilicate-rich layers constitute 20% or less of the rock, this sample is somewhat coarser-grained than the other sample in the suite. Both calcite and dolomite are present and this sample contains the greatest proportion of carbonate among the samples submitted. It also has a higher calcite:dolomite ratio than the other samples. Opaques occur as small equant grains up to 0.02 mm across and some are thought to be pyrite. In the well-cleaved phyllosilicate-rich layers the cleavage planes appear to be filled with opaque material. This may be an optical effect caused by the fine grain size of the material but is more likely due to the presence of small amounts of either iron oxides/hydroxides or carbonaceous material. The phyllosilicates in this sample consist principally of chlorite and muscovite.

This is a relative coarse grained, carbonate-bearing, indurated siltstone which contains an irregular and impersistent cleavage which is at an angle of 10 to 20 degrees to the bedding. Because of the nature of the cleavage the rock tends to break/fracture in a highly irregular fashion and material such as this is unlikely to be suitable for the manufacture of slates or even flagstones.

Sample WS3 A249/74: TS 32632

Location: Hundred of Willunga, section 1150, Delabole Slate Quarry.

Rock Name: Indurated well cleaved carbonate-bearing siltstone (slate)

Hand Specimen:

This sample is grey, fine grained, well bedded, with the bedding laminations varying in thickness from a fraction of a millimetre to several millimetres. The rock parts readily along the bedding plane and there are no closely spaced joint or foliation planes/systems cross-cutting the bedding.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	30-40
Dolomite	5-10
Calcite	5-10
Biotite	less than 5
Muscovite	5-15
Chlorite	15-25
Feldspar	less than 5
Opaques	less than 5

This sample is composed principally of quartz and phyllosilicates with a lesser amount of carbonate. The grain size is of the order of 0.01-0.02 mm with the largest grains being less than 0.06 mm.

The rock is strongly foliated, the foliation planes being parallel to the bedding, and the more phyllitic laminae in the rock are more strongly foliated.

Quartz grains are up to 0.06 mm long and have been elongated in the direction of foliation. They have irregular xenoblastic margins with the surrounding phyllosilicate and carbonate grains. The phyllosilicates include muscovite, biotite, and chlorite of which the latter mineral predominates. It is pale green-brown and forms wispy flakes up to 0.06 mm long. Chlorite is sometimes seen closely associated with/surrounding muscovite and biotite flakes and it is possibly replacing these latter minerals. The muscovite is colourless and occurs in flakes up to 0.06 mm long. A proportion of the muscovite flakes are crumpled and distorted and probably are of detrital origin. Biotite is brown, pleochroic, and occurs as small irregularly shaped flakes up to 0.04 mm across. Both calcite and dolomite are present in this sample and occur as equant xenoblastic grains up to 0.05 mm across. There are a few opaque grains in this rock, the largest being less than 0.01 mm across, and also rare grains of feldspar.

This is an indurated carbonate-bearing siltstone with a well developed bedding plane cleavage which is better developed in the more phyllitic laminae. There are no obvious easily weathered minerals present and it should be possible to produce slate from rock such as this.

Sample WS5 A250/74: TS 32633

Location: Hundred of Willunga, section 1150, Delabole Slate Quarry.

Rock Name: Weathered indurated siltstone.

Hand Specimen:

This sample has a weathered appearance being mostly pale brown with only a few narrow grey laminae. The laminae are between 1 and 4 mm thick with the brown laminae having a gritty, fine sandstone, feel and the grey laminae appearing to be more phyllitic. The sample has split along an irregular joint system which is at a high angle to the bedding and there does not appear to be a well developed bedding plane cleavage. There are minor bedding irregularities with grey laminae wedging and feathering out into the brown laminae.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	40-50
Feldspar	2- 4
Muscovite	20-30
Biotite	less than 5
Chlorite	5-15
Calcite	2- 4
Dolomite	2- 4
Opaques	5-10
Accessories: tourmaline, zircon, etc.	trace

This sample consists of grains of quartz, carbonate, feldspar, opaques, in a matrix of strongly aligned phyllosilicate flakes. The quartz grains are equant to elongate in shape, up to 0.06 mm long, and have irregular/xenoblastic margins with surrounding phyllosilicate flakes. Carbonate grains are equant in shape and up to 0.04 mm across. A microchemical staining technique showed that some of the carbonate was calcite and the rest is thought to be dolomite. The dominant phyllosilicate is muscovite, which occurs as wispy flakes, and aggregates of flakes, up to 0.08 mm long. Lesser amounts of pale green chlorite and pale brown, pleochroic biotite are also present. Distinguishing the phyllosilicates is not easy as they are closely intergrown with/associated with iron oxides/hydroxides. The iron oxides/hydroxides are present mostly as minute granules and less commonly as grains up to 0.04 mm across. A few grains of twinned feldspar, and the accessory minerals tourmaline and zircon are present.

This is a weathered sample of siltstone which although quite schistose in texture does not possess a well defined or regular cleavage. The hand specimen has broken along a set of irregular joints which are orientated at a high degree to the bedding and if this fracture system is at all prominent in the area of the quarry from which the sample came rock from that area would be unlikely to make satisfactory flagstones or slate.

Sample WS6 A251/74: TS 32634

Location: Hundred of Willunga, section 1150, Delabole Slate Quarry.

Rock Name: Slate

Hand Specimen:

This sample is grey, fine grained, and finely laminated, the laminae being regular in size and less than 1 mm in thickness. There is a fairly well defined bedding plane cleavage and the rock has broken regularly along this.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	30-40
Feldspar	less than 5
Muscovite	15-25
Biotite	less than 5
Chlorite	15-25
Calcite	8-12
Dolomite	3- 6
Opaques (including ? carbonaceous material)	approx. 5
Accessories: tourmaline	trace

This sample is fine grained and strongly foliated, the foliation planes being opaque in transmitted light and concentrated in the finer grained, more phyllitic laminae. The principal minerals are quartz, muscovite, chlorite and carbonate. The quartz occurs as elongate grains, the largest of which are up to 0.05 mm long. The margins of the quartz grains are irregular against surrounding carbonate and phyllosilicate grains. The principal phyllosilicate minerals are muscovite and chlorite and there are also minor amounts of biotite present. The muscovite is colourless, the chlorite a pale green, and the biotite a brown colour. These minerals occur as wispy flakes up to 0.08 mm long, which are in subparallel alignment and define the foliation in the rock. The carbonate forms equant xenoblastic grains up to 0.05 mm across. A microchemical staining test showed that calcite was present and the other carbonate is thought to be dolomite. Opaques occur as idiomorphic (cubic) grains the largest of which are 0.03 mm across. An opaque substance, possibly carbonaceous material, lines many of the foliation planes. A few grains of feldspar are present and there are also rare grains of tourmaline and zircon.

This sample is an indurated carbonate-bearing siltstone, which unlike the previous sample, has a well defined cleavage parallel to the bedding and is probably suitable for the manufacture of slates and flagstones. Other than the small amount of opaques which are possibly pyritic, this sample contains no obvious easily weathered minerals.

Sample WS8 A252/74: TS 32635

Location: Hundred of Willunga, section 1150, Delabole Slate Quarry.

Rock Name: Slate

Hand Specimen:

This sample is grey, fine grained, finely laminated with most of the laminae being less than 1 mm thick and shows a pronounced tendency to part readily and evenly parallel to the laminae.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	30-40
Feldspar	less than 5
Muscovite	15-25
Biotite	less than 5
Chlorite	15-25
Calcite	10-15
Dolomite	3- 6
Opaques (including ? carbonaceous material)	approx. 5
Accessories: zircon-apatite	trace

This sample is fine grained, closely foliated, and composed principally of quartz, muscovite, chlorite, and carbonate. The foliation planes are closely spaced and anastomose with each other; the finer grained, more phyllitic laminae, are completely cleaved/fissile over widths up to several millimetres whereas in the slightly coarser, more quartzose layers, the cleavage traces are sometimes separated by as much as 0.3 mm, but are generally much closer. The quartz grains are equant to slightly elongate in shape, are up to 0.06 mm long, and have irregular corroded margins with surrounding phyllosilicate and carbonate grains. The carbonate occurs as equant xenoblastic grains up to 0.08 mm across. A microchemical staining test revealed that some of the carbonate was calcite and the rest is thought to be dolomite. The phyllosilicates occur as fine wispy flakes and are often difficult to resolve. Muscovite flakes are colourless and up to 0.04 mm long. The chlorite is a pale green, whereas the biotite is brown and weakly pleochroic. These two phyllosilicates are closely associated and form wispy flakes up to 0.08 mm long. Opaques occur as small grains, up to 0.03 mm across, and the cleavage planes are mostly opaque and are possibly lined with carbonaceous material. A few grains of feldspar and the accessory minerals zircon and apatite, are present in this sample.

This sample is an indurated carbonate-bearing siltstone with a well developed cleavage parallel to the bedding and it should be suitable for the manufacture of slates and flagstones.

Sample WS9 A253/74 TS 32636

Location: Hundred of Willunga, section 1150, Delabole Slate Quarry.

Rock Name: Weathered slate.

Hand Specimen:

This sample is grey, fine grained, and finely laminated with the laminations being generally less than 1mm thick. The sample cleaves readily parallel to the laminae. Unlike the previous two samples, which this closely resembles, this sample is weathered, some laminae being weathered to a brown colour and the exposed ends of the laminae tending to fritter readily.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	40-50
Feldspar	trace
Muscovite and probably clay	15-25
Biotite	trace
Chlorite	20-30
Calcite	2- 4
Dolomite	trace-2
Opaques (including carbonaceous material)	less than 5
Accessories: zircon	trace

Weathering with the dispersion of iron oxides/hydroxides and ?clay has resulted in much of the texture and mineralogy of this rock as seen in thin section being obscured. The principal minerals are quartz, muscovite/clay, and chlorite and the clastic sedimentary texture is dominated by the closely spaced bedding plane cleavage that is present throughout the rock. The quartz grains are equant to slightly elongate in shape, up to 0.03 mm long, and have irregular corroded margins with surrounding phyllosilicate flakes. The proportion of carbonate in this rock which is slightly weathered is considerably less than in the fresh examples of this rock. The carbonate occurs as equant grains up to 0.03 mm across and a microchemical staining test showed that calcite is present as well as another carbonate which is thought to be dolomite. The exact proportions of the phyllosilicate are uncertain because they have been stained/altered/replaced by iron oxides/ hydroxides and possibly altered to clay.

The principal phyllosilicates are a pale green-brown chlorite and colourless muscovite which occur in flakes up to 0.05 mm long. Brown, semi-opaque grains of iron oxides/hydroxides, typically less than 0.03 mm across, occur throughout the rock. The cleavage planes are semi-opaque, and may well be lined with carbonaceous material. Present in trace amounts are flakes of biotite, grains of feldspar, and accessory minerals such as zircon.

This sample, A253/74, is a weathered equivalent of the preceding two samples, A251/74 and A252/74, and it is noticeable that with weathering the rock has become softer, more friable and the amount of carbonate present has been sharply reduced. The pronounced bedding plane cleavage and the lack of any cross-cutting irregularities such as joints, would suggest that fresh examples of rock similar to this would be suitable for the manufacture of slates and flagstones. However, the durability of slates made from such rock would always be suspect considering the susceptibility to weathering that the carbonates in this sample have shown.

<u>Sample WS10 A254/74: TS 32637</u>

Location: Hundred of Willunga, section 756, Bangor Slate Quarry.

Rock Name: Slate

Hand Specimen:

This sample is grey, fine grained, and finely laminated with the laminae being less than 1 mm thick. This sample is actually part of a roofing slate and it is apparent why the rock was chosen for it contains a pronounced bedding plane cleavage and no cross cutting irregularities such as veins or joints.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	30-40
Feldspar	<5
Muscovite	15-25
Biotite	<5
Chlorite	15-25
Calcite	8-12
Dolomite	3- 6
Opaques (including ? carbonaceous material)	∿5
Accessories: zircon, apatite	trace

The dominant textural feature of this rock is the closely spaced bedding plane cleavage. The cleavage planes are spaced a fraction of a millimetre apart and anastomose with each other. The principal mineral is quartz, and there are also significant amounts of muscovite, chlorite, and carbonate. The quartz grains are mostly elongated in the direction of the cleavage, are up to 0.05 mm long, and have irregular corroded margins with surrounding carbonate and phyllosilicate flakes. The carbonate grains are equant or slightly elongate in the direction of cleavage, are up to 0.06 mm long, and are xenoblastic in shape. A microchemical staining test showed that some calcite is present and the remaining carbonate is thought to be dolomite. The phyllosilicates occur as wispy flakes up to 0.08 mm long, and include colourless muscovite, pale green chlorite, and pale brown biotite. The chlorite has low, almost anomalous interference colours. There is some mineral segregation in the rock and the cleavage planes are more closely spaced in phyllitic laminae than they are in laminae with a relatively high quartz and carbonate content. Opaques occur as grains up to 0.04 mm across which are present throughout the rock and most of the cleavage planes are opaque, possibly because they are lined with carbonaceous material. Present in trace amounts are grains of feldspar and accessory minerals such as zircon and apatite.

This rock is a carbonate-bearing siltstone with a sufficiently well defined and regular bedding plane cleavage that is has been used as a roofing slate.

Sample WS11 A255/74: TS 32638

Location: Hundred of Willunga, section 756, Bangor Slate Quarry.

Rock Name: Slate

Hand Specimen:

This sample is grey, fine grained, and finely laminated with the laminae being less than 1 mm thick. There is a well defined bedding plane cleavage along which the rock breaks readily. One lamina, approximately 1 mm thick, in this hand specimen, is appreciably pyritised.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	30-40
Felspar	less than 5
Muscovite	15-25
Biotite	less than 5
Chlorite	15-25
Calcite	8-12
Dolomite	3- 6
Opaques	approx. 5
Accessories: zircon, apatite	trace

The dominant textural feature in this rock is the closely spaced cleavage planes which in much of the rock are spaced at intervals of less than 0.01 mm apart and they tend to obscure the mineralogy. The rock is extremely finely crystalline and X-ray diffractometry shows that the rock consists principally of quartz, with lesser amounts of chlorite and mica, and minor to trace amounts of dolomite, calcite and feldspar.

This is an extremely fine grained rock, with a well developed cleavage which should be suitable for the manufacture of slates.

Sample WS12 A256/74: TS 32639

Location: Bangor Slate Quarry, hundred of Willunga, section 756.

Rock Name: Indurated, weakly cleaved carbonate-bearing siltstone.

Hand Specimen:

This sample is grey, fine grained, and over a width of approximately 7 cm is completely unlaminated except for a narrow band at one edge which is approximately 0.5 cm wide. Unlike the previous two samples from this quarry there is not a pronounced bedding plane cleavage in this sample, the rock tending to break into irregular rocky fragments rather than into slabs/sheets.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	35-45
Dolomite	4- 8
Calcite	10-15
Biotite	less than 5
Muscovite	15-25
Chlorite	10-20
Feldspar	less than 5
Opaques (including ? carbonaceous material)	less than 5

This rock is composed principally of quartz, phyllosilicates, and carbonate. The rock has a grain size of approximately 0.05 mm and is strongly foliated. However, individual cleavage planes anastomose and 'feather' out over distances up to 1 mm and a persistent cleavage is lacking. Quartz grains are subangular to subrounded in shape, in some places definitely elongated parallel to the foliation in the rock and it is not uncommon to see individual grains with highly corroded margins adjacent to carbonate and phyllosilicates. Carbonate occurs as small angular grains up to 0.08 mm across and a microchemical test showed that both calcite and another carbonate thought to be dolomite, are present in the rock. The amount of carbonate present and the ratio of calcite to dolomite has, for this sample, been calculated/estimated mainly from the chemical analyses. Flakes of muscovite, up to 0.1 mm long, are present throughout the sample and are generally in subparallel alignment with the foliation although there are many flakes of muscovite present which are oriented at high angles to the cleavage. Chlorite flakes are commonly intergrown with the muscovite and similar green-brown biotite, with low interference colours, are also present as small patches throughout the body of the rock. Opaques are present as small equant grains, up to 0.03 mm across, and there are minor traces of staining by iron oxide/hydroxides. Many of the cleavage planes appear to be filled with semi-opaque material and this is probably in part an optical effect and in part due to the presence of an opaque phase and it is not unlikely that small amounts of carbonaceous material are present along some of the cleavage planes.

This rock is mineralogically similar to the other samples examined; however, it lacks a persistent cleavage and is unlikely to be suitable for the manufacture of slates.

Sample WS17 A257/74: TS 32640

Location: Hundred of Willunga, section 1008, Bastian's Slate Quarry.

Rock Name: Slate

Hand Specimen:

This sample measures 8 cm x 12 cm x 0.4 cm, is grey, fine-grained, and has parted along a distinct and persistent cleavage. In the sample there are no signs of joints/veins or other dislocations that could cause irregularites in cleavage.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	35-45
Dolomite	4- 8
Calcite	10-20
Biotite	<5
Muscovite	15-25
Chlorite	10-20
Feldspar	<5
Opaques (including ? carbonaceous material	<5

This rock is composed principally of quartz, phyllosilicates, and carbonate, and has a well developed persistent cleavage with prominent cleavage planes or zones of cleavage at intervals of 0.3 mm or closer. Throughout the rest of the rock there is a weak cleavage/bedding which is at a slight angle to the more prominent cleavage just described. Quartz occurs as subrounded to subangular grains that are up to 0.05 mm across and not uncommonly elongate in the direction of the cleavage. The margins of the quartz grains are typically highly irregular/corroded when in contact with surrounding carbonate and phyllosilicate crystals. The carbonate occurs as equant xenomorphic grains up to 0.07 mm across. A microchemical test revealed that calcite and another carbonate are present and from inspection of the chemical analysis it is fairly certain that it is dolomite. The phyllosilicates consist principally of chlorite and muscovite, with traces of biotite as well. The chlorite is green-brown, has low interference figures and occurs as flakes in sub-parallel alignment with the foliation. The muscovite is very similar in appearance to the chlorite but is distinguishable because of its high interference colours. Opaques occur as equant, idiomorphic (cubic) grains and granular aggregates, the largest of which are up to 0.08 mm across. Many of the cleavage traces appear to be lined with opaque material and the exact composition of this is not certain but it possibly contains some carbonaceous matter.

Of the samples submitted this sample, along with sample A254/74, are the most slate-like.

Sample WS21 A258/74: TS 32641

Location: Hundred of Willunga, section 1008, Martin's Slate Quarry.

Rock Name: Weathered, moderately cleaved, laminated siltstone.

Hand Specimen:

This rock is fine grained, finely laminated, and coloured brown or grey depending on its date of weathering/alteration. This weathering (brown rock) has been controlled by the fine laminations/cleavage in the rock. Layers of brown altered rock less than 1 mm wide, penetrating for several centimetres into the grey unaltered rock.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	45-55
Dolomite	less than 1
Calcite	less than 2
Biotite	trace
Clay/muscovite	20-30
Chlorite/clay	10-20
Feldspar	less than 5
Opaques	5-10

This sample is composed principally of quartz and phyllosilicates/clay, and unlike most of the other samples there is virtually no carbonate. Anastomosing foliation planes are present throughout the rock but more persistent foliation planes, or groups of foliation planes, along which the rock would readily cleave are spaced at intervals between 0.2 and 0.5 mm apart. The quartz grains are up to 0.05 mm across, are elongate in the direction of the cleavage and have irregular/corroded margins with surrounding phyllosilicate flakes. The phyllosilicates include green/brown chlorite and a colourless phase, either muscovite or clay, which are present as wispy aligned flakes up to 0.05 mm long. Small equant xenomorphic opaque grains, up to 0.03 mm across, are present throughout this sample as is yellow-brown iron oxide/hydroxide staining. Carbonate is virtually absent but it was possibly originally present and was replaced at an early stage in the alteration/weathering of the rock.

Except for the alteration/weathering this sample is very similar in texture and appearance to the other samples submitted in this suite. It lacks a really persistent and pronounced cleavage like sample A257/74 and presumably if fresh would not cleave so well or so readily into slates.

Sample WS22 A76/74: TS 31834

Location: Hundred of Willunga, section 1008, Bastian's Slate Quarry.

Rock Name: Slate

Hand Specimen:

A thinly bedded, well laminated fine-grained, blue-grey rock, which has a tendency to break into thin sheets. However, the exposed fracture surfaces show irregular steps up to 1.5 mm high.

Thin Section: An optical estimate of the constituents gives the following:

	%
Quartz	30-40
Dolomite	30
Carbonaceous material	5
Pyrite	1
Muscovite	5
Calcite	1- 2
?Perovskite	trace
Chlorite) Clay)	20-30
Tourmaline	trace
Leucoxene	trace

The rock is composed of approximately equal proportions of silt-sized quartz and dolomite together with a slightly lesser amount of chlorite/clay. It contains numerous partings defined by thin, bifurcating or lensoid trains of micaceous or chloritic and carbonaceous material and these are spaced from about 0.1 mm to 0.5 mm apart.

The rock is very evenly textured with the maximum grain size of 0.08 mm and most of the grains are within the size range 0.03-0.05 mm. Quartz, where elongate, and muscovite grains lie parallel to the partings, though quartz and dolomite both tend to be equant. Some calcite has replaced dolomite in a few places at a late stage in the rock's development.

The main lines of weakness are the carbonaceous and micaceous partings. There appears to be the one main direction but the thin section shows the possibility of a second cleavage direction at a low angle to the compositional layering. This 'cleavage' is shown by a tendency for the limbs of lenses to develop a sub-parallel alignment with one common direction dominant. Examination of the hand specimen shows that there is, in fact, no indication of cleavage in this second plane. However, the micaceous and carbonaceous partings are not single layers but occur in close packed zones and any splitting will tend to give slight surface irregularities. Rough step fracturing is likely (and is present in the hand specimen), between the main parting zones. The maximum expected single step is that of the distance between the partings and is expected to be about 1.5 mm.

The trace of pyrite in the rock may cause brown staining on oxidation but the quantity present does not appear to be high enough to seriously affect the quality of the rock.

The rock has been compacted and partly recrystallised during either diagenesis or very low level metamorphism.

A P P E N D I X   B

CHEMICAL ANALYSIS

extracted from

AMDEL Report MP 3436/74 by Dr. R. Davey

AMDEL Report MP 486/75 by R. Cooper

DELABOLE QUARRY

Sample No.	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9
Dept. No.	A247/74	A248/74	A249/74	A259/74	A250/74	A251/74	A260/74	A252/74	A253/74
percent									
SiO_2	54.72	48.22	54.99	53.00	53.31	53.70	52.49	53.12	60.20
Al_2O_3	12.55	10.29	13.25	11.54	13.59	12.80	12.03	12.11	13.95
Fe_2O_3	0.75	0.60	1.11	1.02	2.88	1.19	1.18	1.39	2.73
FeO	4.86	3.36	4.86	4.36	3.59	4.60	4.11	4.04	3.54
CaO	6.07	13.29	4.89	7.88	3.47	6.00	7.81	7.06	1.88
MgO	5.04	3.75	5.44	4.71	4.28	5.11	4.87	5.04	4.58
Na_2O	1.50	1.88	1.37	1.57	1.90	1.38	1.41	1.37	1.70
K_2O	2.73	2.16	2.94	2.51	2.77	2.81	2.67	2.69	3.10
TiO_2	0.84	0.64	0.91	0.83	0.87	0.85	0.81	0.81	0.92
MnO	0.08	0.14	0.08	0.11	0.07	0.08	0.11	0.10	0.10
P_2O_5	0.19	0.20	0.23	0.21	0.24	0.20	0.19	0.20	0.20
H_2O+	3.62	2.61	3.67	3.37	3.90	3.74	3.55	3.61	4.13
H_2O-	0.06	0.05	0.07	0.09	0.14	0.14	0.08	0.07	0.57
CO_2	6.30	12.40	5.60	8.10	3.05	6.50	7.85	7.60	1.90
TOTAL	99.31	99.59	98.81	99.29	99.18	99.10	99.18	99.21	99.49
$CaO:MgO$	2.21	3.54	0.90	1.67	0.81	1.18	1.60	1.40	0.41

BA[illegible] QU[illegible]

Sample No.	MR31	Bull 10	WS10	WS11	WS12	WS13	WS14	WS15
Dept. No.	(1919)	(1922)	A254/74	A255/74	A256/74	A261/74	A262/74	A263/74
percent								
SiO_2	53.64	52.86	54.01	55.64	55.15	53.66	53.89	54.35
Al_2O_3	14.90	13.78	12.63	12.65	11.53	11.78	12.34	12.40
Fe_2O_3	0.64	0.72	1.01	1.46	0.75	1.84	1.39	1.05
FeO	4.87	4.51	4.45	4.43	4.34	3.43	4.04	4.22
CaO	6.46	7.36	6.76	5.11	7.10	8.39	7.71	7.01
MgO	4.60	4.58	4.81	4.78	4.87	4.01	4.48	4.61
Na_2O	1.06	1.42	1.39	1.27	1.37	1.20	1.36	1.42
K_2O	3.02	2.75	2.74	2.94	2.57	2.69	2.78	2.75
TiO_2	0.75	0.79	0.79	0.74	0.77	0.73	0.77	0.79
MnO	0.06	0.05	-	0.07	0.08	0.07	0.08	0.07
P_2O_5	0.37	0.17	0.19	0.20	0.19	0.18	0.19	0.19
H_2O+	4.65	3.12	3.48	3.82	3.27	3.99	3.78	3.65
H_2O-	0.14	0.16	0.06	0.12	0.05	0.21	0.16	0.11
CO_2	4.75	7.79	6.70	5.55	7.35	7.45	7.25	7.20
TOTAL	99.91	100.06	99.02	98.77	99.39	99.63	100.21	99.83
CaO:MgO	1.40	1.61	1.41	1.07	1.46	2.09	1.72	1.52

	BASTIAN'S QUARRY			MARTIN'S QUARRY			
Sample No.	WS22	WS16	WS17	WS18	WS19	WS20	WS21
Dept. No.	A76/74	A264/74	A257/74	A265/74	A266/74	A267/74	A258/74
percent							
SiO_2	56.54	53.57	53.71	54.41	52.74	55.90	63.66
Al_2O_3	13.15	11.98	11.65	12.42	11.97	12.45	14.17
Fe_2O_3	1.02	1.36	0.90	1.59	1.01	1.82	5.47
FeO	4.87	3.99	4.20	3.65	4.36	3.90	0.88
CaO	4.61	8.11	7.88	7.85	7.53	6.31	0.37
MgO	5.19	4.31	4.48	4.18	4.54	4.34	2.79
Na_2O	1.42	1.35	1.33	1.45	1.38	1.50	1.75
K_2O	2.84	2.68	2.56	2.76	2.65	2.75	3.22
TiO_2	0.85	0.78	0.78	0.78	0.76	0.83	0.96
MnO	0.08	0.08	0.08	0.07	0.08	0.09	0.01
P_2O_5	0.20	0.20	0.18	0.19	0.18	0.21	0.19
H_2O+	3.56	3.85	3.44	3.90	3.77	3.86	4.06
H_2O-	0.01	0.13	0.08	0.10	0.07	0.14	1.42
CO_2	5.60	7.60	7.80	7.10	7.55	5.95	0.10
TOTAL	99.94	99.99	99.07	100.45	98.60	100.05	99.05
CaO:MgO	0.89	1.88	1.76	1.88	1.66	1.45	0.13

APPENDIX C

Extract from South Australian
Government Gazette, July 5, 1973
"Regulations under the Mines and
Works Inspection Act, 1920-1970"

Regulations under the Mines and Works Inspection Act, 1920-1970

At the Executive Council Office, at Adelaide, this 5th day of July, 1973

BY virtue of the provisions of the Mines and Works Inspection Act, 1920-1970, and all other enabling powers, I, the Governor of the State of South Australia, with the advice and consent of the Executive Council, hereby make the following regulations.

M. L. OLIPHANT, Governor

Regulations under the Mines and Works Inspection Act, 1920-1970

1. These regulations may be cited as "The Restriction or Prohibition of Surface Mining Operations Regulations".

2. These regulations shall apply to the area or areas of the State specified in the schedule hereto.

3. (1) No person shall, in an area to which these regulations apply, commence or extend any mining operation, or any operation or practice incidental thereto, which interferes with the surface of any land, without the written consent of the Minister being first obtained.

(2) Subject to Regulation 4 of these regulations, the Minister may grant his consent either unconditionally or subject to such conditions as he thinks fit, or may refuse his consent.

(3) Subregulations (1) and (2) of this regulation shall not apply to mines lawfully existing at the time these regulations come into operation and which are being worked in conformity with the requirements of the Mines and Works Inspection Act, 1920-1970, and all regulations made thereunder.

4. The Minister may refuse his consent or impose conditions upon his consent if such refusal or conditions are necessary or desirable:—

(*a*) to reduce or prevent any impairment of the amenity of any area or place by mining operations or practices, or

(*b*) in order to ensure or encourage the orderly mining of mineral deposits in such a manner or in such stages that the amenity of any area or place is either preserved or the impairment thereof is reduced as much as is reasonably possible.

5. (1) Any person who commences or extends any mining operation, or any operation or practice incidental thereto, in contravention of Regulation 3 of these regulations shall be guilty of an offence against these regulations.

(2) Any person who conducts any mining operation or any operation or practice incidental thereto in contravention of Regulation 3 of these regulations shall be guilty of an offence against these regulations for each day upon which such mining operation or operation or practice incidental thereto is conducted.

(3) Any person guilty of an offence against these regulations shall be liable to a penalty not exceeding, for a first offence, $40.00 and for a subsequent offence, $200.00.

THE SCHEDULE

1. Sections 140, 141, 142, 143, 150, 151, 152 and 153 of the Hundred of Willunga.

2. The Hills Face Zone as defined by the Metropolitan Development Hills Face Zone Planning Regulations, 1971, which were made on the 16th day of December, 1971, and published in the *Government Gazette* on the same day at page 2513.

And the Honourable the Minister of Development and Mines is to give the necessary directions herein accordingly.

S.P.O., 93/1972 K. FLEMING, Acting Clerk of the Council

6627-III

REFERENCE

Jointing .... —J—
Upper limit of fresh rock .... - - - - -
Selected sample .... ∘ WS
Chip samples .... ←WS→
Location peg ....
Photo negative number 26656

metres 0 — 5 metres
Approximate Scale

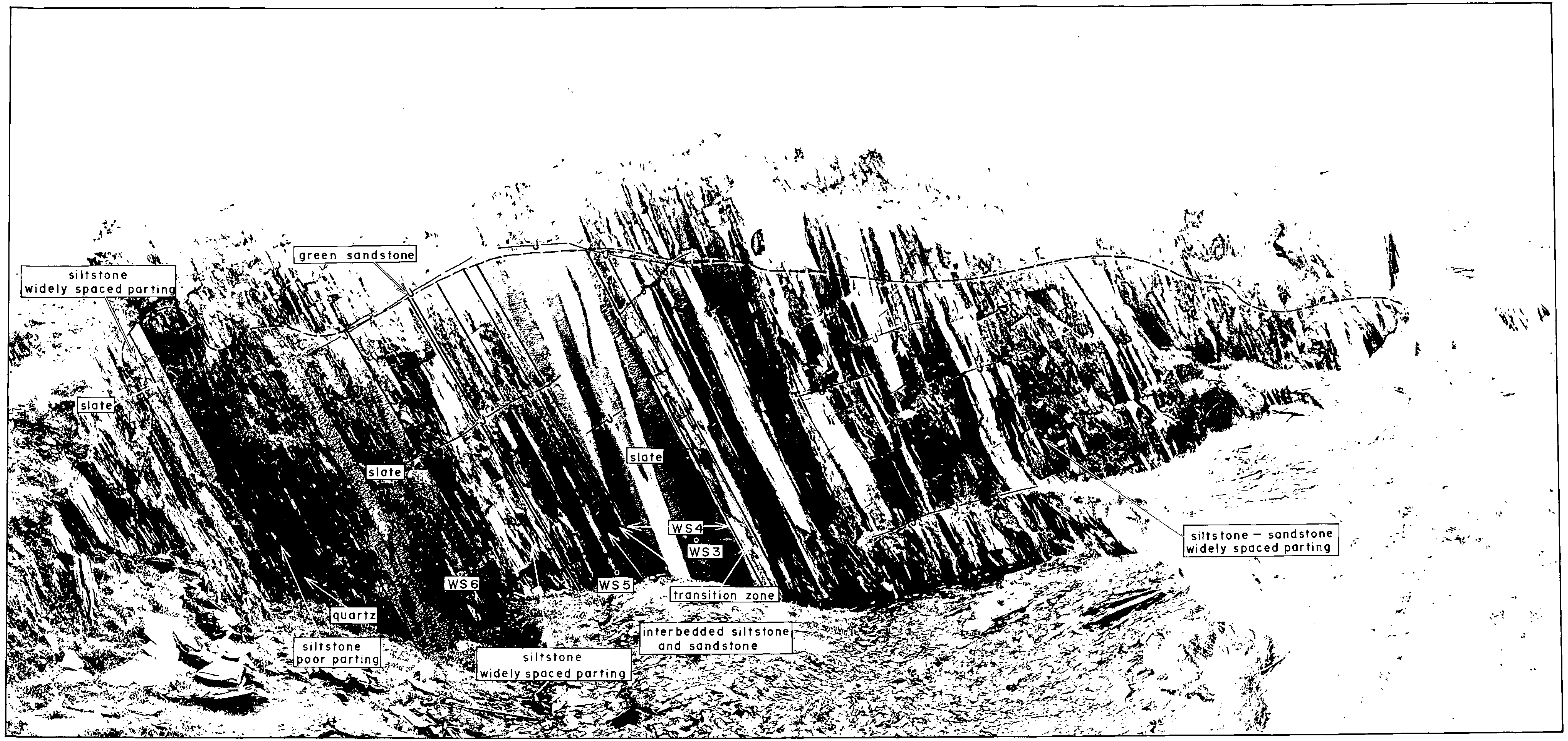
S.A. DEPARTMENT OF MINES

WILLUNGA SLATE DEPOSITS
DELABOLE - SOUTHERN QUARRY

D.C. SCOTT Geologist

FIG. 4

75-999



REFERENCE

Jointing	—J—
Upper limit of fresh rock	— — — —
Selected sample	∘ WS
Chip samples	←WS→
Location peg	
Photo negative numbers	26657 26658

metres 0 — 5 metres

Approximate Scale

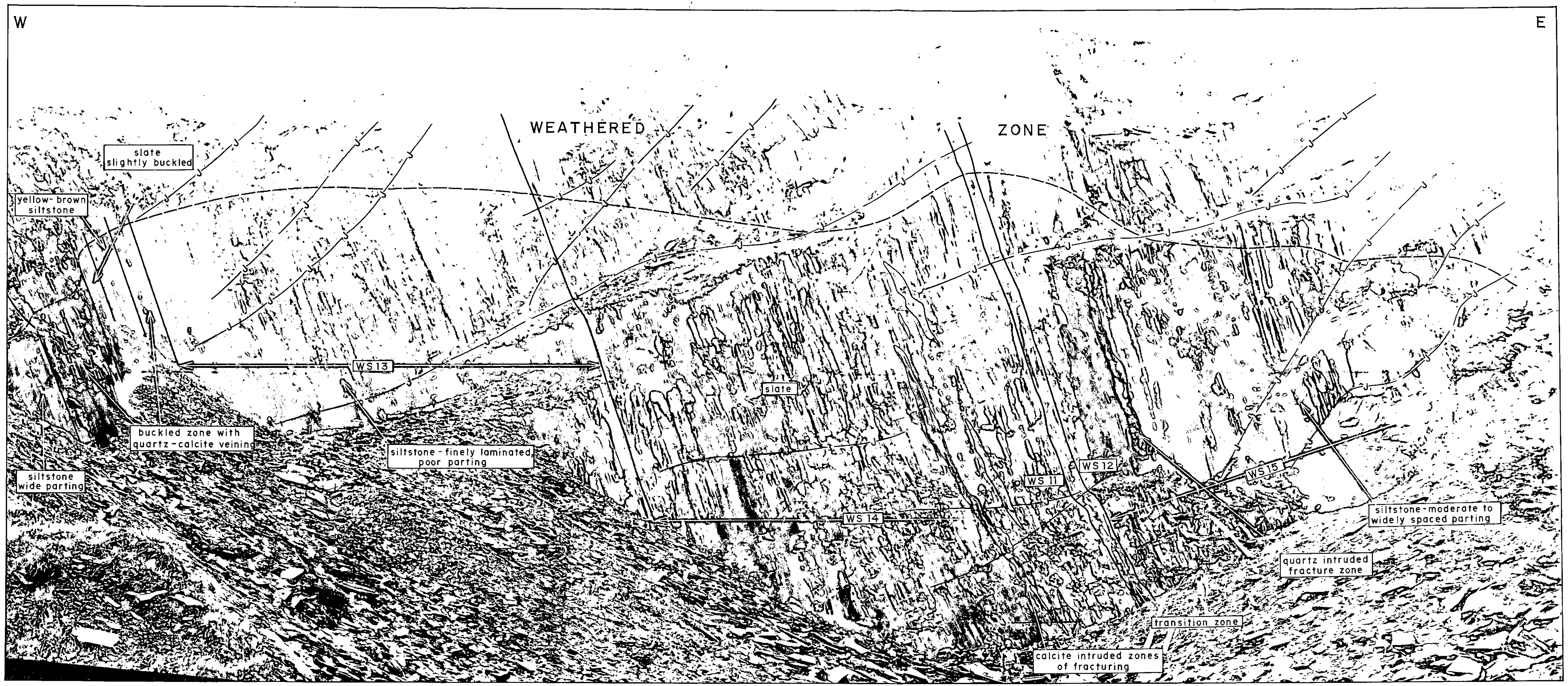
S.A. DEPARTMENT OF MINES

WILLUNGA SLATE DEPOSITS
DELABOLE–MIDDLE QUARRY

D.C. SCOTT Geologist

FIG. 5

75-1016



REFERENCE

Jointing .... —J—

Upper limit of fresh rock .... – – – – –

Selected sample .... ○ WS

Chip samples .... ←WS→

Location peg ....

Photo negative numbers 26661, 26662, 26663

metres 0 — 5 metres

Approximate Scale

S.A. DEPARTMENT OF MINES

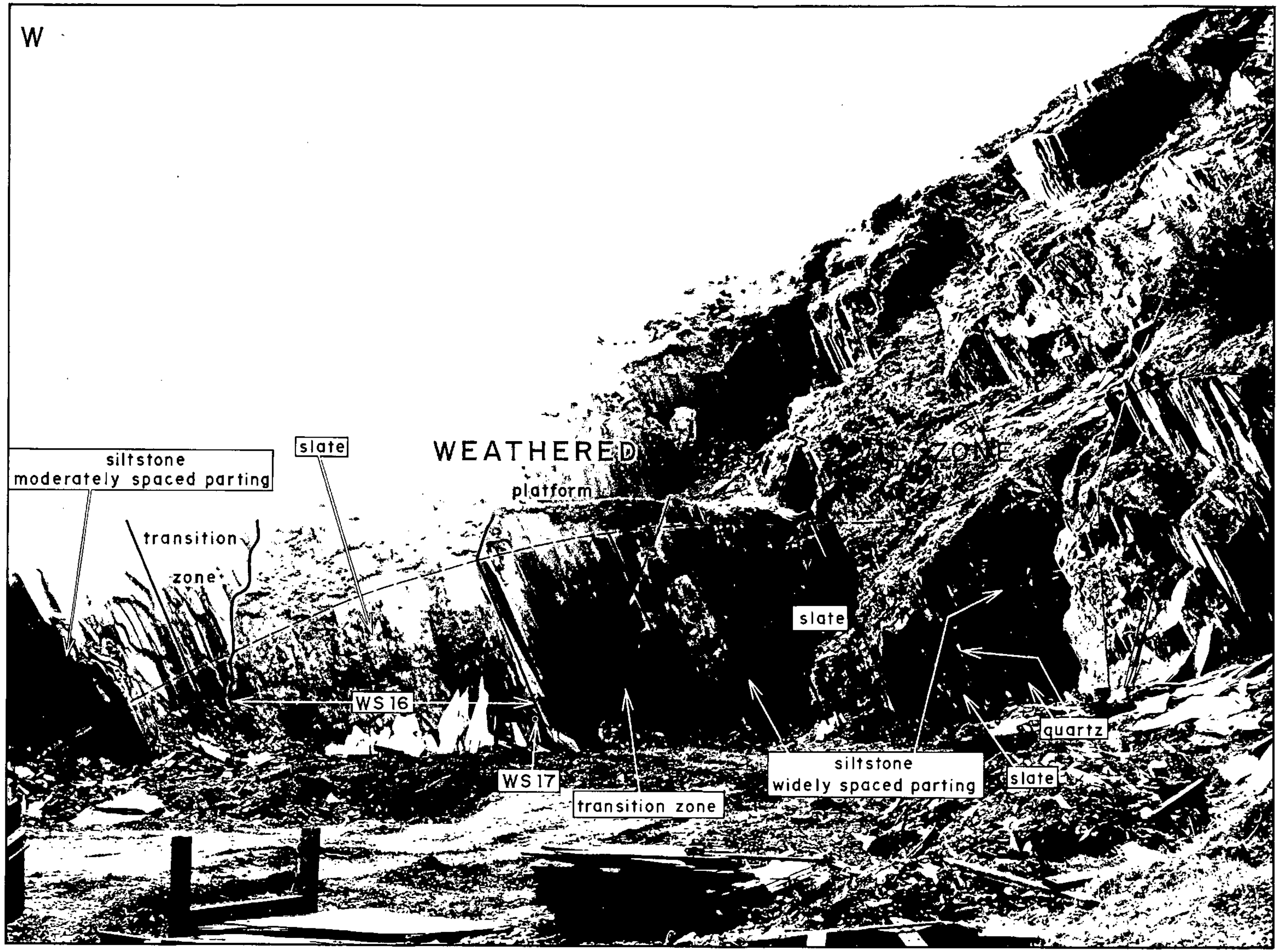
WILLUNGA SLATE DEPOSITS
BANGOR QUARRY

D.C. SCOTT Geologist

FIG. 6

75-1008

6627-III



REFERENCE

Jointing	——J——
Upper limit of fresh rock	— — — —
Selected sample	◦ WS
Chip samples	←—WS—→
Location peg	▯
Photo negative number	26655

metres 0 — 5 metres

Approximate Scale

S.A. DEPARTMENT OF MINES

WILLUNGA SLATE DEPOSITS

BASTIANS QUARRY–NORTHERN FACE

D. C. SCOTT Geologist

FIG. 7

75–1012

REFERENCE

Jointing .... —J—

Upper limit of fresh rock .... – – – –

Chip samples .... ←WS→

Location peg ....

Photo negative numbers 26659 26660

metres 0 5 metres

Approximate Scale

S.A. DEPARTMENT OF MINES

WILLUNGA SLATE DEPOSITS
MARTINS QUARRY – SOUTHERN FACE

J.G. OLLIVER Geologist

FIG. 8

75-953