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DUNTROON GEOPHYSICAL STUDY

OIL, GAS AND COAL DIVISION

by

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CONTENTS PAGE

TABLE

FIGURES

ENCLOSURES:			DWG NO.
1:		Airborne and marine contours of magnetic total intensity map.	90-387
2	(a):	Depth to top basement (east)	89-305
	(b):	Depth to top basement (west)	89-304
3	(a):	Depth to top ? Jurassic - Neocomian sequence (east)	89-303
	(b):	Depth to top ? Jurassic - Neocomian sequence (west)	89-302
4	(a):	? Jurassic - Neocomian sequence Isopach Map (east)	89-313
	(b):	? Jurassic - Neocomian sequence Isopach Map (west)	89-312
5	(a):	Depth to top Duntroon Group (east)	89-301
	(b):	Depth to top Duntroon Group (west)	89-300
6	(a):	Duntroon Group (Isopach Map) (east)	89-311
	(b):	Duntroon Group (Isopach Map) (west)	89-310
7	(a):	Depth to top Bight group (east)	89-299
	(b):	Depth to top Bight group (west)	89-298
8	(a):	Bight Group Isopach Map (east)	89-309
	(b):	Bight Group Isopach Map (west)	89-308
9	(a):	Tertiary Isopach Map (east)	89-307
	(b):	Tertiary Isopach Map (west)	89-306
10	(a):	Seismic line and shot point location map (east)	90-383
	(b):	Seismic line and shot point location map (west)	90-384

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ABSTRACT

The Duntroon Basin is located in the centre of the Southern Rift System between the Bight and the Otway Basins, west and southwest of Kangaroo Island. It is limited to the north by the Proterozoic Gawler Craton.

The formation of the basin is related to the period of continental stretching preceding the opening of the Southern Ocean, commencing in the mid-Jurassic.

Structurally the Duntroon Basin is divided into an inner half grabenal zone bounded to the north by west-northwest trending faults, and an outer zone directly connected to the continental slope. A discontinuous basement ridge, corresponding to the crests of en-échelon tilted basement blocks, forms the boundary between the outer and inner zones. The inner zone comprises a series of offset half grabens which widen toward the southeast.

A basal syn-rift sequence is confined to the half grabenal depocentres. Although undrilled to date, its age is assumed to be ? Jurassic - Neocomian. It is overlain by an Early Cretaceous sequence of fluviatile and lacustrine shales. A Late Cretaceous sequence of continental to paralic deposits rest with slight unconformity or apparent conformity on the underlying Lower Cretaceous. A Tertiary sequence of open marine carbonates and sands overlays the Cretaceous series with erosional contact. To the north, the Tertiary units rest directly on the shallow basement platform rocks of the Gawler Craton.

The Duntroon Basin is characterized by two distinct tectonic regimes: a multi-stage rifting phase related to the separation of the Australian and Antarctic plates in Early Cretaceous, and a period of fracturing and deformation in Late Cretaceous, associated with shale mass movements and basement uplift. This second tectonic phase developed above a décollement level at the base of the Duntroon Group shales (Early Cretaceous). It began in mid-Cretaceous and lasted until the Tertiary.

Of the three wells drilled in the Duntroon Basin, two tested the outer zone (Platypus 1 (TD 3368 m); Duntroon 1 (TD 3515 m)), and indicate that the section is immature down to 3000 m (in the Lower Cretaceous), and marginally mature down to TD. It is generally considered that the Lower Cretaceous contains possible source rocks and the Upper Cretaceous potential reservoirs. The Echidna 1 well was located on the basement ridge separating the outer from the inner zone, on the crest of a shale diapiric feature. The penetrated section is reduced and the Late Cretaceous sequence is missing. However, the maturation profile at this site indicates that the oil window is entirely contained in the Lower Cretaceous, and that hydrocarbon migration occurred in the section above the window. The inner zone is to date untested but extrapolation with existing wells and consideration of the tectonic and sedimentary history of this area indicate significant potential for source rocks in the ? Jurassic - Lower Cretaceous, and reservoirs and traps in the uppermost Lower Cretaceous and Upper Cretaceous.

INTRODUCTION

Of Australia's passive continental margins, the Southern Rift System is by far the longest formed by a single episode (or multiple related episodes) of extension. The rift complex includes a number of sedimentary basins and sub-basins, nominally from West to East: the Bremer, Bight, Duntroon , Otway and Sorell Basins.

The Duntroon Basin occupies the area south of the Eyre Peninsula, and west of Kangaroo Island. The basin received particular attention from explorationists (Cockshell, 1990), as it contains a thick faulted and deformed sedimentary section (up to 10 000 m thick), and lies for most part in water depths less than 200 m. The current interpretation is based on the 1983 and 1984 Getty Oil seismic surveys. This seismic grid covers an area of approximately 6000 square kilometres, and varies from detailed to semi detailed. The seismic surveys are tied with stratigraphic data at the three wells drilled in the Duntroon Basin (Platypus 1, Echidna 1, and Duntroon 1). The seismic interpretation was carried out to analyse the structural configuration and evolution of the area, in particular to clarify the roles played by the rift phases and the post rift movements in the deformation of the sedimentary cover. The study also examine the influence of these tectonic movements on the distribution of the seismostratigraphic sequences, and their relation with the hydrocarbon potential of the area.

Clarification of the tectonic history of the margin has been gradually forthcoming, over the last two decades, largely from the results of regional studies (Boeuf and Doust, 1975; Deighton et al., 1976; Fraser and Tilbury, 1979; Bein and Taylor, 1981; Cande and Mutter, 1982; Mutter et al., 1985; Nelson et al., 1986; Veevers, 1986; 1987; Hegarty et al., 1988; Powell et al., 1988; Willcox et al., 1988). The emergence of new models of extension of the lithosphere derived from the work of Wernicke and Burchfiel (1982), has considerably renewed interest in the tectonics of the Australian southern margin. Etheridge et al. (1984; 1985), Willcox et al. (1988), Willcox and Stagg (1990), Willcox (1990), used models of simple shear lithospheric extension, interpreting the tectonic structures of the southern margins in terms of transfer and detachment faults. Over the last two years a comprehensive synthesis of the geological evolution of the Duntroon - Bight Basins was undertaken by South Australian Department of Mines and Energy and the Bureau of Mineral Resources, and is published in Stagg et al., (1990).

REGIONAL SETTING

The Duntroon Basin is located on the southern margin of the Proterozoic Gawler Craton (Enclosure 1). Sediments of the Delamerian fold belt flank the craton to the east and south, and the Mesozoic breakup of the Gondwanaland may have followed ancient zones of weakness inherited from the formation of the geosyncline. Smith and Kamerling (1969) proposed that the Cygnet-Snelling fault extends to the west of Kangaroo Island to form the northern boundary of the Duntroon Basin. This fault separates the northerly Gawler Craton from the Cambrian Kanmantoo Group to the south (Thompson, 1969).

Many geodynamic models have been proposed to explain the structure and history of the southern margin of Australia. The early models generally assumed a Paleocene age for the initiation of oceanic opening, and require an important strike slip movement in the Late Jurassic and Cretaceous between the Australian and Antarctic plates (900 Km according to Harrington et al., 1973). The application of dextral (Harrington et al., 1973) or sinistral (Middleton, in Forbes et al., 1984) shear couple along the continental plates boundary resulted in the formation of pull-apart basins (including the Duntroon Basin) on the southern margins of Australia.

Re-dating of the first sea floor spreading magnetic anomaly from A22 (about 55 Ma) (Weissel and Hayes, 1972) to A34 (about 95 Ma) (Cande and Mutter, 1982) and the subsequent re-estimation of the age of continental breakup from Paleocene to mid-Cretaceous (96±4 Ma) by Veevers (1988) has introduced new constraints on the motion of the continents. Reconstructions of the East Gondwanaland (Veevers, 1987; Powell et al., 1988; Veevers and Eittreim, 1988) suggest that extension between Australia and Antarctica was oriented north-northeast - south-southwest during the Late Jurassic-Early Cretaceous continental rift phase (Fig. 1). More recently Willcox and Stagg, (1990) divided the rifting into a pre-Late Jurassic to Neocomian phase and an Early Cretaceous phase with respectively northwest and north-northeast directions of extension.

STRATIGRAPHY

The stratigraphy of the Duntroon Basin is estimated with reference to the three wells drilled in the area. Table 1 and Fig. 5 synthetise the depths and thicknesses of the formations penetrated, and their stratigraphy. A comprehensive description of the lithological and geochemical characteristics of these units is contained in Hill, (1989). The following descriptions of the units is summerised from Forbes et al., (1984); Templeton and Peattie, (1986); Hill, (1989).

The oldest penetrated sediments belong to the Early Cretaceous Duntroon Group. It comprises the Echidna, Neptune, Borda and Ceduna Formations (Fig. 5). Sediments of the Duntroon Group were penetrated in the three wells of the Duntroon Basin (Platypus 1, Echidna 1, Duntroon 1). They consist mainly of fluviatile and lacustrine shales deposits. The shales can exhibit rates of sedimentation as high as 40 cm/1000 years (Forbes et al., 1984). Thick rapidly accumulating lacustrine deposits are typical of rift sedimentary successions (Rosendahl, 1987) where they can constitute the bulk of continental rift infill (e.g. Schull 1984; Wu and Liang, 1984; Netto, 1984; Demaison, 1980; Powell, 1986).

The Bight Group (Fig. 5) comprises the Platypus Formation (upper delta plain sandstones, siltstones and coals), Wombat Sandstone member (?shoreface sands), Wigunda Formation (prodelta shales and siltstones) and the Potoroo Formation (?lower delta plain stacked distributary bar sands and shales). It is analogous with the fluvio-deltaic Sherbrook Group of the Otway Basin. The Late Cretaceous Bight Group usually disconformably overlies the Lower Cretaceous but with apparent conformity in some areas.

The three wells drilled in the Duntroon Basin encountered a very similar Tertiary section; 1219 m thick at Echidna 1, 1487 m at Platypus 1, and 1662 m at Duntroon 1. The Tertiary is represented by the sediments of the Eucla Group (comprising the Wilson Bluff Limestone; and the Nullarbor Formation; Table 1, Fig. 5) and the Pidinga Formation which consists of coarse to very coarse moderately sorted unconsolidated quartz-rich sands. The environment of deposition has been interpreted as paralic (Forbes et al., (1984).

The Wilson Bluff Limestone consists of soft marl with limestone beds grading to argillaceous lime siltstones and dolomitic limestones. The overlying Nullarbor Limestone forms the major part of the Tertiary section. It is composed of a series of dolomitic limestones and grainstones containing skeletal fragments of bryozoa and echinoderm, and dark cherts. The environment of deposition is shallow marine - wave dominated.

SEISMOSTRATIGRAPHIC PRINCIPLES

The seismic sequence analysis is based on the recognition and identification of regional unconformities used for stratigraphic correlations. The division of the sedimentary pile in units separated by unconformities may vary according to different authors.

The terminology used by Exxon (Vail et al., 1977) defines the seismic sequence boundaries as unconformities related to relative fall of sea level resulting in an abrupt basinward shift in the site of sediment accumulation. The unconformities are characterised by sub-aerial exposure of the underlying sequence and two types are recognised. Type I is associated with sub-aerial erosion with stream rejunevation, onlap of overlying strata, downward shift in coastal onlaps and basinward shift of facies. Type II is marked by sub-aerial exposure and downward shift in coastal onlap landward of the depositional shore line break, but lacks both sub-aerial erosion and basinward shift in facies. A type II boundary is interpreted to form when the rate of subsidence at the depositional shoreline break exceeds the rate of sea level fall.

More recently, Galloway (1989) proposed a division of the sedimentary section of marine basin margins based on the identification of flooding surfaces. These boundaries separate genetic sequences and record the depositional hiatus occurring over much of the transgressed upper slope and continental shelf during the maximum marine flooding.

There has been active debate on the relation between the relative sea level variations and basin subsidence (or uplift), sedimentation rates, and eustatic sea level changes. The world wide synchroneity of the Exxon's variation in coastal onlaps (usually referred as sea level changes) has been questioned, and although sequence boundaries are commonly accepted as chronostratigraphic markers within a basin, they may be localised results of the combined effects of subsidence, sedimentation rate and eustatic variation (Hubbard 1985, 1988).

Despite controversy over the choice of the dividing seismostratigraphic boundaries and their possible synchroneity and significance to eustatic sea level, seismic unconformities are widely used for regional correlations within a basin. However, seismostratigraphic analysis is greatly hampered when sediments are deposited in continental area deprived of direct connection with a marine continental margin. Seismic unconformities in a continental basin reflect tectonic style, changes in sedimentation rates or in source of clastic deposits, rather than sea level changes. Such tectonically induced unconformities would not have chronostratigraphic significance.

Seismic facies analysis aims to provide geological models for depositional environments from seismic data. Analysis of the geometry and terminations of the reflections provides the basis for defining seismic sequences, however several other features of the seismic data are also considered: reflection configuration, continuity, amplitude, frequency, interval velocity, the external shape of the sequence, and the areal distribution of the facies. These features can be used to indicate stratigraphic information, such as bedding pattern, bed spacing thickness and continuity, fluid content, depositional process, gross depositional environment, and ultimately lithology type.

Stratigraphic interpretation of seismic data remains ambiguous owing primarily to the multiple geological configurations that may produce similar seismic images and the relatively weak documentation relating seismic facies and sedimentary facies.

CHOICE AND RELIABILITY OF THE HORIZONS MAPPED

Open marine conditions in the Duntroon Basin are not recorded before the Tertiary, with most of the Mesozoic sediments being deposited in continental or paralic environments. This severely limits seismic sequence and seismic facies investigations, as continental sediments usually present a limited range of seismic features and have poor reflection continuity. Unconformities within the Mesozoic series result primarily from tectonic effects combined with changes in sedimentation rates, sources and distribution.

Four main horizons were chosen for seismo-sequence mapping, on the basis of their structural and stratigraphic significance.

- the top of the basement
- the top of a basal syn-rift unit (?Jurassic - Neocomian sequence)
- the top of the Duntroon Group (near top Early Cretaceous sequence).
- the top of the Bight Group (top Late Cretaceous sequence).

The seafloor was also mapped to provide the upper surface for the Tertiary sequence.

Basement

The top of the basement is usually well defined in the inner parts of the basin, and in the shallow basement area corresponding to the Gawler Craton. Oceanward, the basement is down-faulted to the continental slope, and the association of greater sediment thickness and deterioration in seismic quality decrease the level of confidence in mapping in the southern outer zone of the basin.

Top ? Jurassic - Neocomian

The top ? Jurassic - Neocomian horizon is discontinuous and has been recognised in three isolated depocentres within the inner parts of the Duntroon Basin. The horizon has yet to be intersected by drilling, and the correlations between the Jurassic depocentres are based on similarity of seismic character and structural relationship with the overlying sequences and the basement surface.

Top Duntroon Group

This horizon is correlated with the top of the Duntroon Group at the Platypus 1 and Duntroon 1 wells, and marks approximately the breakup between the Australian and Antarctic plates. The existence of a tentative breakup unconformity is best illustrated in the north west termination of the inner zone of the Duntroon Basin. The determination of a breakup unconformity in the rest of the basin is somewhat vague and complicated by the superposition of an intense fracturing pattern related to mass sliding of the Duntroon Group shales on a décollement surface and associated anticlinal features. The breakup of the Antarctic and Australian plates is commonly considered to have occurred between 110 and 90 Ma (Cande and Mutter, 1982). Veevers (1988) refined these values and estimated the breakup age at 96 ± 4 Ma.

This horizon also marks the onset of the mass shale movements on a ? Neocomian décollement surface, and associated faulting. This intense fracturing decreases the data quality in the anticlinal crestal area, and lowers the level of confidence in mapping the horizon across the anticlines. Correlation of this horizon across many faults, coupled with possible large variations in thickness and depositional environments in the Cretaceous series, is fair to poor.

Locally, at the crest of some anticlinal features this horizon coincides with the base of the Tertiary, where the Upper Cretaceous is missing.

Top Bight Group

In contrast with the top Duntroon Group horizon, this horizon offers very good reliability, generally coinciding with the base of the Tertiary. The base of the Tertiary is an erosional surface corresponding to an abrupt decrease in tectonic activity. This prominent horizon was considered by early workers as the breakup unconformity, and although the age of the separation of the continents has been revised, no satisfactory explanation has been found to account for the vigour of the event at the base of the Tertiary. This period marks also a major change in depositional environment from continental in the Cretaceous to open marine in the Tertiary.

This horizon coincides locally with the base of the Tertiary carbonates where the thin sandstones of the Pidinga Formation were eroded or not deposited.

VELOCITY FUNCTION AND TIME/DEPTH CONVERSION

Two way time values for each horizon derived from interpreted seismic sections were converted to depths using a single velocity function. This function (Fig. 2) was derived from well velocity data (Platypus 1, Echidna 1 and Duntroon 1) for the uppermost 2400 m of the sedimentary section, and averaged VRMS velocities derived from processing of the 1984 seismic data for the deeper section.

The velocity data from the wells are very similar, indicating that depth conversion for at least the upper part of the section should be reasonably accurate. However reliability is likely to decrease in the lower part of the section. The use of a single function over such a vast area covering a variety of geological terrains will result in an averaging effect masking possible lateral changes. This limits the confidence of the absolute depths obtained, but the relative values should reliably portray the configuration of the basin.

SEISMOSTRATIGRAPHIC SEQUENCES

Basement

Smith and Kamerling (1969) proposed that the basement west of Kangaroo Island comprises two types of rocks of different velocity characteristics. They interpreted this difference as representing the boundary between the Proterozoic Gawler Craton to the north and the Cambrian Kanmantoo Group to the south. This boundary would also correspond to the northern bounding faults of the Duntroon Basin which separate a sparsely faulted highly diffracting basement in the north, from a rifted basement to the south, which frequently displays apparently organised low frequency reflections. The Mesozoic Duntroon Basin is thus inferred to be underlain by Cambrian metasediments of the Kanmantoo Group, (Smith and Kamerling, 1969; Forbes et al., 1984).

? Jurassic - Neocomian sequence

The deposition of the first recognised sedimentary sequence appears to have been structurally controlled by northwest and southeast faults isolating deposition in three half grabenal depocentres separated by the crests of faulted basement blocks (Enclosures 3 and 4). The earliest sediments occupy wedge shaped bodies and blanket minor basement reliefs within the depocentres (Fig. 3).

The sequence is characterized by high amplitude reflections of moderate continuity presenting a constant direction of downlaps towards the south. Occasional channels and thick alluvial fans are apparent along the fault scarps (Fig. 3&4). They thin basinward to form sub-parallel piles of more continuous reflections. This suggest that clastic materials were supplied by erosion of the basement highs, and transported on a relatively short distance within the basin. At the time of deposition, the depocentres were relatively isolated and enclosed, however, the unit is remarkably consistent in seismic character from one depocentre to another, suggesting that conditions of deposition were similar throughout the area. Although no syn-rift wedge was detected in the outer zone of the basin, the decreasing quality of the seismic in this area and the limited coverage do not preclude the presence of such a unit. zone.

By comparison with the top of a similar sequence in the Eyre Sub-basin sampled by the Jerboa 1 well (Bein and Taylor, 1981), the basal syn-rift sequence of the Duntroon Basin may consist of non-marine fluvial to lacustrine sediments. Powis and Partridge (1980) proposed a Jurassic age (Callovian to lowermost Berriasian) for the sedimentary section penetrated immediately before encountering the Archaean basement. The re-dating of the samples by Morgan (1990) indicates that the deposits could be of Neocomian age. In any case, only the very top of the syn-rift sequence was penetrated at the Jerboa 1 site, as the well is located on the apex of a tilted basement block. The deeper levels remain undated, hence the timing of onset of rifting remains conjectural.

Additional support for a Jurassic age of at least part of this unit comes from the occurrence of Jurassic sedimentation in the Polda Trough. Three wells penetrated a Jurassic section: Gemini 1, Mercury 1, and Columbia 1. The section comprises non-marine fluviatile sands, commonly coarse to very coarse, poorly consolidated, often poorly sorted and feldspathic, with occasional siltstones, clays and coals interbeds. The sequence is Oxfordian-Kimmeridgian in age. The presence of Bajocian tholeiitic basalt on Kangaroo Island (Milnes et al., 1982) also supports a Jurassic age for the commencement of the rifting. Furthermore, it suggests that the early syn-rift unit in the Duntroon may include volcanoclastics.

A Jurassic age for the earliest syn-rift deposits may be a conservative estimate, and older sediments could be present as suggested by Forbes et al. (1984). The reworking of Triassic palynomorphs within the Cretaceous series intersected in Potoroo 1 suggests local Triassic sediments.

Conversely, the seismic characteristics of the sequence indicate apparent similarities of depositional environment with the proximal alluvial fan deposits of the Neocomian Pretty Hill Sandstone of the Otway Basin (Gravestock et al., 1986). This suggests, along with the recent re-dating of Morgan (1990), that the basal syn-rift sequence of the Duntroon Basin may be partly or entirely Neocomian. Within the exploration framework both hypotheses lack tangible evidence, but they could have far reaching implications for the generation of hydrocarbons.

Duntroon Group

In contrast with the restricted area of deposition of the ? Jurassic - Neocomian sequence in basement depressions, the Early Cretaceous sediments were deposited over the whole Duntroon Basin. Although considered a syn-rift sequence, it should be noted that the Lower Cretaceous does not have the common characteristics of a syn-extensional unit (wedge shaped body and overall fan configuration). The sequence shows an increase in reflection continuity, and in further contrast with the underlying sequence, is the absence of major fan development along the basin margins. This can be explained by a balance between the sedimentation and tectonic subsidence rates, eliminating the basin edges effect, during the Early Cretaceous.

The Early Cretaceous sequence overlies the basement ridges separating the Jurassic depocentres and covers the ? Jurassic - Neocomian strata with only a slight unconformity. The sequence appears as a relatively monotonous pile of moderately continuous reflections of medium frequency. These fluviatile sediments, display a general lack of definition in terms of cyclic sedimentation. The absence of a regional unconformity within the section prevents the division of the sequence into sub units. Facies analysis is considerably hampered by the heavy faulting and deformation by shale mass movement which occurred in the Late Cretaceous. It is important to note that although minor movements may have occurred in the Early Cretaceous, the deposition of the Early Cretaceous sequence generally predates faulting and anticlinal growth. Their facies distribution was originally governed solely by depositional environment and independent of subsequent tectonics. However, Late Cretaceous tectonism redistributed the Early Cretaceous shales and variations in thickness of the Early Cretaceous sequence result mainly from variation in subsidence rates within the basin and blanketing the palaeorelief inherited from the ? Jurassic - Neocomian topography, and later shale movements.

A decrease in Early Cretaceous rock competence with depth is indicated by the flattening with depth of the Late Cretaceous faults, and their sole-ing out near the base of the Lower Cretaceous. However, the transition is gradual and without any apparent sharp contrast in acoustic impedance. Chaotic configuration in the core of the anticlines is interpreted as a loss of bedding organization in the shaly material. Additional loss of seismic information could be due to decreased dip of the fault planes with depth and the consequent increase in dip of the bedding surfaces.

Overall, the lack of variation in seismic character of the sequence is consistent with the rapidly accumulating shaly and silty lacustrine deposits of the Duntroon Group. However differences in subsidence rates could have induced variations in depositional environments and sedimentation rates causing the undercompaction of the lacustrine deposits. Further south and west, towards the continental slope, it is probable that the lacustrine-fluvial conditions of deposition graded to more transitional environments, in response to marine ingressions.
The top Duntroon Group horizon marks the possible breakup of the Australian and Antarctic plates and indicates a change from predominantly lacustrine-fluvial facies, in the Early Cretaceous, to regressive deltaic sedimentation in the Late Cretaceous.

Bight Group

The Late Cretaceous sequence, as defined from the base Platypus Formation to the top Potoroo Formation, thickens westward (from 757 m in the Duntroon 1 well location to 1657 m in the Platypus 1 well). This variation of thickness reflects the westward increase in total overall fault throw in the outer growth fault belt.

The Platypus Formation corresponds to a regressive cycle (Hill, 1989), and displays occasional seaward downlaps. The formation is locally overlain with a slight angular unconformity by a transgressive cycle which can be correlated (at the Duntroon 1 well) with the Wombat Member (clean sands) and the Wigunda Formation (prodelta siltstones, shales and carbonaceous mudstones). However the boundary between the Platypus Formation and the overlying units does not appear to correlate landward with a clear erosional surface. The Wigunda Formation is in turn conformably overlain by the Potoroo Formation. The Wigunda/ Potoroo interface is clearly diachronous (Hill, 1989), and gets younger from the west (Bight Basin) to the east (Duntroon Basin). The contact between the Potoroo Formation and the overlying Tertiary section corresponds to a prominent erosional event, followed by the first truly marine incursion in the Duntroon Basin.

Forbes et al. (1984) suggested a correlation of the top Platypus Formation with a mid-Cenomanian global fall in sea level (of Vail et al. 1977), and a rise in sea level corresponding to the deposition of the Wigunda Formation ending with the regressive cycle of the Potoroo Formation sandstones. The major unconformity at the base of the Tertiary could correspond to the end of the megacycle ZC-4 of Haq et al. (1987) (eustatic curve, published in Bally (1987).

The depositional history of the Late Cretaceous Bight Group is governed by several factors:

- mass movements of the underlying shales of the Duntroon Group.
- related gravity movements due to the presence at the base of the Early Cretaceous sequence of a ductile zone with local topographic gradient towards the newly created Southern Ocean.
- regional uplift of the basement in the central ridge area and to a lesser extend in the outer zone of the basin.

These factors controlled the formation of three major structures: the Echidna-Koala and Cockatoo anticlinal features in the inner part of the basin, and a growth fault belt in the outer part of the Basin (Figs. 7,9 and 12). The onset of this tectonic phase is documented by the geometrical relationship between the Early and Late Cretaceous reflectors (Fig.6).

The growth of the diapiric-cored anticlines and the variations in uplift along their axis determined the location of the depocentres and probably commanded the distribution of the depositional facies of the Upper Cretaceous.

The central part of the Echidna-Koala structure corresponds to a zone of total erosion or non-deposition of the Late Cretaceous sequence (Fig.16). This area seems to have acted as an effective sedimentary barrier, during at least part of the Late Cretaceous (Platypus Formation), between the flanking northern and southern synclinal depocentres. Sediments entered the southern syncline on both sides of the structures and from the eastward end of the basin. In cross section the anticlinal feature appears asymmetrical with a southern flank subsiding significantly more rapidly than the northern one (Figs. 3,8). Progressive growth of the anticlinal structure in Late Cretaceous generated intra-formational unconformities within the thick stacks of prograding beds in the southern syncline (Fig.8), whilst the northern syncline accommodated a thinner pile of parallel strata conformably overlying the Duntroon Group. As the anticlinal axis of the Echidna-Koala structure plunges to the east, the structure is progressively "overridden" eastward by Late Cretaceous sediments (owing perhaps to high deltaic sedimentary input from the north). In this area, crestal faults delineate an extensional apical graben where the Upper Cretaceous is preserved.

Facies distributions and variations in thicknesses of the Late Cretaceous formations also occur in the outer zone of the Duntroon Basin as a result of sliding and rotation along listric faults. This is illustrated by the difference in thickness of the Platypus Formation from 49 m at the Duntroon well on the top of a rotated Early Cretaceous block, to 402 m at the Platypus 1 well site (Figs. 13,14).

Tertiary

The Tertiary can be divided into two main seismiostratigraphic sequences on the basis of differences in acoustic character. The lower sequence consists of a relatively thin (0 - 200 m) section resting unconformably on the Upper Cretaceous (at Platypus 1 and Duntroon 1 wells) or on the Lower Cretaceous (Echidna 1). It correlates directly with the Pidinga Formation.

The basal unconformity seems related to an abrupt reduction in the rate of growth or up-lift in the anticlinal area and rotation along the growth faults in the outer zone. The measured angle of unconformity between the horizontal Tertiary and the underlying rotated Early Cretaceous reaches 20 degrees at Echidna 1. Cande and Mutter (1982) suggested that the Early Tertiary unconformity might also be related to a sea level change.

The base of the second sequence is marked by a prominent horizon over the entire Duntroon Basin. This event corresponds to the first open marine ingression into the Duntroon Basin. The sequence contains a complex architecture of stacked progrades. It correlates with the Wilson Bluff and Nullarbor Limestone and conformably overlies the lower sequence (Pidinga Formation). Typically the isopachs of the Tertiary (enclosure 9 a&b) show a gentle increase in thickness towards the shelf edge, characteristic of the built up of prograding wedges.

The first fully marine incursion in the Duntroon Basin occurred about 45 Ma after the start of oceanic spreading between Australia and Antarctica. The absence of a decisive marine transgression during the Cretaceous could be explained by high continental sedimentation input limiting the marine incursions, as Deighton et al. (1976) suggested in the Otway Basin. The marine transgression would appear consistent with the decrease in the rate of detrital supply recorded in the Tertiary as well as the slowing in fault and diapiric growth. However vertical movements, although with limited amplitudes, persisted along the main growth faults through the Tertiary (Fig. 8). The shift from detrital to carbonate sedimentation and the increasing marine influence in the Tertiary is also interpreted to reflect the widening gap between the Australian and Antarctic plates, and the expanding southern Ocean (Deighton et al., 1976; Willcox et al., 1988).

TECTONIC HISTORY

Rift Phase

The overall aspect of the Duntroon Basin is an extensional continental margin bounded to the north by west-northwest to almost east-west faults. On cross section the basin presents an inner half grabenal zone separated by a basement high from an outer zone connected to the continental slope. This high is discontinuous and represents by the crests of en échelon tilted basement blocks forming west-northwest to northeast trending ridges. These ridges plunge to the west and southwest. The inner zone widens to the east and comprises three main offset depocentres (enclosure 2 a&b; Fig. 11). The seismic grid does not cover the outer part of the basement ridge separating the basin in its southeastern sector, but an outer faulted zone is also very likely to be present in that area.

The northern bounding faults separate a crystalline basement associated with the Proterozoic Gawler Craton from the Mesozoic-Cenozoic to the south with throws of up to 8000 m. Throws decrease to the east and, as the faults progressively coalesce and die out in that direction, the basement forms a gently rising ramp towards Kangaroo Island. No major bounding fracture affecting the basement was detected on east-west seismic sections, indicating that there is continuity of the Cambrian Kanmantoo Group, from Kangaroo Island to beneath the basement of the Duntroon Basin. However, in the eastern end of the basin, west of Kangaroo Island, the west-northwest - east-southeast trending faults appear to curve to a more north-northwest - south-southeast direction, and merge into a complex fractured zone interpreted as an accommodation or transfer zone (Cockshell, 1990).

The rifting history of the Duntroon Basin can be divided into two distinct episodes of extension and collapse, accompanied by two different sedimentary cycles. The first cycle is a typical syn-rift infill by sediments of estimated ? Jurassic - Neocomian age of half grabenal depocentres located in the inner part of the basin (Fig. 3,4,8,9). These depocentres are delineated by faults oriented along the west-northwest and east-southeast directions (enclosure 3 a&b). The two sets of faults are contemporaneous and appear to have an horizontal component of extension.

The basement faults within the inner basin are sealed at the top of the ? Jurassic - Neocomian syn-rift sequence, whereas the north bounding faults of the basin remained active and extended during the second cycle of extension beginning in the Early Cretaceous. This new episode of extension terminated whith the commencement of spreading between the continental plates at 96 +/- 4 Ma (Veevers, 1988). During this second rifting pulse the

? Jurassic - Neocomian depocentres were down-faulted and became part of an expanded Early Cretaceous Basin. The extension of the ? Jurassic - Neocomian faults to the east resulted in the broadening of the inner zone in the eastern sector of the basin.

The second rifting cycle is accompanied by sagging of the southern edge of the basin towards the continental slope, allowing the thick accumulations of Early Cretaceous sediments.

A general review of the structural history of the Southern Rift System (Stagg et al., 1990; Willcox, 1990; Willcox and Stagg, 1990) also points strongly to the existence of two distinct episodes of extension preceding the final breakup in Cenomanian time. The first extensional event is inferred to be pre-Valanginian, and lasted till the top of the Neocomian. The Neocomian surface (top of the ? Jurassic - Neocomian sequence) is interpreted by the above authors as a potential breakup unconformity, marking the possible first injection of oceanic material in the thinned continental crust in the area of the magnetic quiet zone. The second extensional phase, post-Neocomian to Cenomanian, terminated when massive oceanic spreading occurred, allowing the recording of the fist magnetic anomalies used from the determination of the age of continental breakup. The two extensional cycles affected the entire Southern Rift System, and are interpreted to have developed in almost orthogonal stress fields. The early Jurassic - Neocomian extensional faults trending northeast, whilst the Early Cretaceous faults were oriented west-northwest. However in the Duntroon Basin, the ? Jurassic - Neocomian depocentres are delineated by west-northwest and northeast faults and the two sets appear contemporaneous and present an horizontal component of extension.

The onset of rifting is not precisely dated, no well having penetrated the entire syn-rift sequence, but a Mid-Jurassic age of about 160 Ma is usually applied in the computation of the geohistory plots (Mutter et al., 1985; Hegarty et al., 1988). These models do not appear to reflect the two extensional pulses recorded in the sedimentary infill of the Duntroon Basin.

The mid-Cretaceous surface marks the possible breakup of the Australian and Antarctic plates, and the onset of oceanic spreading at 94 ± 4 Ma (Veevers, 1988).

Post Rift Phase

In the Duntroon Basin, the continental breakup usually did not take the form of an unconformity, but is typically related to an abrupt slowing in the rate of subsidence (Mutter et al., 1985; Hegarty et al., 1988). This drop is interpreted to represent the passage from fault controlled extensional subsidence to slower thermal subsidence. However, fault controlled subsidence continued after that time along the north bounding faults.

The most dramatic effect of these post rift movements is the uplift, in the Late Cretaceous, of the central basement ridge separating the outer and the inner zones of the basin, particularly in the Echidna area. Seismic interpretation suggests that the ridge was already structurally high in ?Jurassic - Neocomian time by the significant thinning of the corresponding series on the basement. Reactivation and rotation on the northern bounding fault of the basin in Late Cretaceous resulted in the increased tilting of the basement in the inner zone, and the consequent uplift of the basement ridge. However the uplift of the ridge was not accompanied by a reactivation of its southern bounding fault sealed in Early Cretaceous. The ridge seems to have acted as a hinge zone between a fast subsiding inner zone and a slow subsiding or relatively uplifted outer zone. The overall result of this large scale tilt is a general shift in depocentres from the outer zone (Early Cretaceous) to the inner zone (Late Cretaceous) where the increased tilt of the basement allowed accumulation of thick Late Cretaceous deposits. The outer zone received reduced thicknesses of Upper Cretaceous whilst the uplifted central ridge became locally a zone of non deposition or erosion during the Late Cretaceous (Fig. 7) as in the Echidna area (Fig. 16). Seismic interpretation does not provide conclusive evidence to assess the respective roles played by erosion or non deposition. The strong angular unconformity at the base of the Tertiary in the Echidna 1 well suggest both an important uplift and erosion, but part of it can be attributed to independent rotational associated with mass sliding of the Cretaceous sedimentary cover (see below). A significant part of the missing Late Cretaceous section between the inner zone to the ridge can be attributed to paleotopographic thinning. Forbes et al. (1984) attempted to estimate the thickness of the missing Late Cretaceous section, assuming continuous deposition in Late Cretaceous and a paleotopographic thinning of 60% from Platypus 1 to Echidna 1.

Their estimate was approximately 885 m of uplift and erosion at Echidna 1 in Late Cretaceous, whilst similar calculation from Duntroon 1 to Echidna 1 would also indicate about 1000 m of uplift.

The origin of these movements remain unexplained, since by Late Cretaceous time the continental plates were separated by several hundreds of kilometres, and extensional management would have been restricted to the oceanic spreading axis. Alternatively the apparent Late Cretaceous extensional movements can be interpreted as a response to continuing high sedimentation rates rather than lithospheric stretching. Similar interpretations have been made in the Gippsland Basin (Hegarty et al., 1986; Rahmanian et al. in press) in the Otway (Williamson et al. 1987) and in other parts of the world such as the North Sea (Sclater and Christie, 1980). In this hypothesis, the sedimentary overloading of the inner zone in Late Cretaceous would have induced the overall tilt of the basin and the uplift of the central ridge and, to a lesser extent, of the outer zone.

Mass sliding and shale diapiric movements

a) <u>Structures related to mass sliding and shale diapiric movements</u>

The prominent features of the inner part of the Duntroon Basin are complex domal structures with marked anticlinal dips (Figs. 4,8,9,12). Two sets of faults (one hading seaward the other hading landward) typically cause collapse of the structural crest. The doming affects both the Early and Late Cretaceous sequences, and the crestal faults occasionally extend through the Tertiary levels, rarely reaching the sea floor. These features trend west-northwest, parallel to the basin axis, varying from 80 km long and 40 km wide for the Koala-Echidna structure, to about 30 km by 12 km for the Cockatoo structure (Fig. 12). The outer zone is occupied by a growth fault belt developed in the Late Cretaceous, and sealed at the base Tertiary level. These structures present striking similarity in aspect with salt and shale diapiric features observed in other part of the world (Larberg, (1983); Skeryane and Kolodny, (1983); Whittle and Short, (1978), in: Lowell, (1985); Bol and Van Hoorn, (1978), in: Lowell (1985). These structures in the Duntroon Basin are interpreted as resulting from the mobilization of incompetent overpressured shales of the Duntroon Group. The Koala structure is developed above a deep basement faulted and tilted block. The fault is sealed by ? Jurassic - Neocomian deposits, and does not show any sign of reactivation in Late Cretaceous time. However, the origin of the structure could be partly explained by an hinge effect of the basement block during the general tilting of the Basin in Late

Cretaceous. In this hypothesis, the arched and fractured Mesozoic cover would have passively deformed. Variations in competency could explain the difference in response to the arching: the Late Cretaceous sequence being competently arched and fractured, the faults dying in the ductile shales of the Duntroon Group Early Cretaceous wilst the ? Jurassic - Neocomian sequence was incompetently warped. The flanking of the anticlinal features affecting the Cretaceous series are observed to flatten with depth and die out in a décollement level located immediately at the base of the Early Cretaceous sequence, and the ? Jurassic -Neocomian sequence in unaffected by faulting. Although this hypothesis may partially explain the nucleation of the Echidna -Koala structure, it should be noted that the Cockatoo structure developed independently of any basement block (Fig.12), and that its origin cannot be attributed to a passive hinge effect. It should be also noted that these structures are not related to a Late Cretaceous reactivation of a deep seated basement fault, and therefore cannot be directly interpreted as the result of transpressional strike-slip movements (flower structures).

Southward dipping growth faults characterised the outer parts of the Duntroon Basin. These faults also flatten with depth and die out in a décollement level located in the deepest part of the Early Cretaceous series. This décollement level is interpreted to be continuous from the inner to the outer zones of the basin. The downward movement along the concave faults causing rotation of the down-thrown Early Cretaceous layers and rollover structures.

The Echidna-Koala structure comprises a "symmetrical" compartment containing both south and north dipping faults (respectively synthetic and antithetic faults), and an "asymmetrical" compartment containing only synthetic faults (down throw to the south) (Fig. 8,10,12). The flanking faults strike essentially parallel to the anticline axis and (Enclosure 5 a&b). Crestal faults, with either southward or northward dip, are usually steeper and tend to be less continuous. They can present very large vertical displacements. Similar compartments can be delineated in the Cockatoo-outer growth zone structure. The change from asymmetrical to symmetrical seems to occur somewhat abruptly, although no fractures (transfer or accommodation zone) are observable on the seismic sections (Fig. 12). Compartments with only south dipping faults are observed in the outer parts of the basin where the ductile sliding level at the base of the Duntroon offers a topographic gradient toward the continental slope. Conversely, in the inner zone, being isolated from the continental slope by a basement high, the décollement level does not present a topographic gradient toward the oceanic basin and the anticlinal features are affected by both sets of faults. The limits of the compartments are usually found to be controlled by changes in trend and arrangement of the underlying basement ridges separating the inner to outer zones (Fig. 11 and 12). As these en échelon ridges plunge and disappear to the southwest, the décollement level progressively dips to the south, whilst the north dipping faults, present in more inner parts of the basin, disappear.

b) <u>Origin of the overpressures</u>

Salt or shale tectonics are a common occurrence in sedimentary basins, when loading of relatively dense clastic deposits over highly ductile substrata initiates the flow of mobile material away from the depocentres. The best studied examples are found in the oil producing provinces of the Gulf of Mexico and the Niger Delta (Bruce, 1983; Evamy et al., 1978,; Larberg, 1983; Skeryane and Kolodny, 1983; Weber, 1971). The structures typical of shale or salt tectonics are diapirs or growth ridges, growth faults and withdrawal synclines.

The causes of formation pressures greater than hydrostatic influencing the mobilization and migration of incompetent material has been attributed to load pressure, due to rapid increase in overburden, without fluid escape. In general the resulting shale tectonics has been closely associated with deltaic regressive cycles (Bol and Van Hoorn, 1978; Bruce, 1983; Evamy et al., 1978; Larberg, 1983; Weber, 1971).

Hydrocarbon phase change can also induce higher than normal formation pressures. On the North West Shelf of Australia, all the oil and gas fields are located within or immediately adjacent to overpressured shales (Horstman, 1988). A study of 90 wells in that area has shown that overpressuring can be related to hydrocarbon generation when the first occurrence of overpressuring is below the top of the oil window and is coincident with the top of the source rock, or when the overpressuring coincides with the top of the oil window (Horstman, 1988). When the first occurrence of overpressure is above the oil window in a thermally immature section, the abnormal pressures are more likely to be related to undercompaction of the shales, caused by inability of contained water to escape because shale permeability seals formed early. In 31 wells, the top of the overpressured section was found in an interval with thermal maturity greater than Ro 0.5%, and it is suggested that the overpressuring is caused by hydrocarbon generation (Horstman, 1988). Unravelling the relation between the Early Cretaceous overpressured levels of the Duntroon Basin and the top of the oil window would certainly provide an interesting approach to the assessment of the exploration risks in the Duntroon Basin.

c) Age of the mass sliding and shale diapiric movements

The shale diapirism divides the sedimentary infill of the Duntroon Basin into pre-, syn- and post-withdrawal series. Withdrawal of the ductile shales towards diapiric ridges causes the subsidence of withdrawal synclines, which accommodate the sedimentary input. Pre-withdrawal strata are arched and affected by crestal faulting. Syn-withdrawal series are characterized by expansion along the withdrawal fault flanking the dome, thinning towards the raising diapiric ridge, and an overall fan configuration. Thus the first interval which expands towards the growth faults documents initial lateral withdrawal and initiation of the diapiric growth.

The pre-withdrawal series include the ? Jurassic - Neocomian and Early Cretaceous sequences. As the ductile material is provided by shales of the Duntroon Group located above the décollement level at the base of the sequence, only the upper part of the Lower Cretaceous is competently arched and fractured (fig.9).

Subsidence of the withdrawal synclines, along the flanks of the diapiric anticlines, does not appear to have occurred significantly before the mid-Cretaceous times (Fig.6). The first series to illustrate expansion in the withdrawal syncline belongs to the Late Cretaceous and can be correlated with the Platypus Formation. The onset of anticlinal arching is most clearly outlined in a central zone located along the southern flank of the Echidna-Koala structure, by onlaps of reflections of the Platypus Formation on the Duntroon Group (Figs. 6 and 7).

The Tertiary is clearly post- withdrawal as illustrated by its basal unconformity (Figs. 4,9,8).

The initiation of the growth fault belt in the outer zone of the basin is estimated by analogy with the Koala structure at mid-Cretaceous. By this time, the formation of the growth faults would have benefited from a topographic gradient of the ductile substratum (sliding plane) toward the newly created Southern Ocean. However, early syn-deposisional growth within the Duntroon Group is not excluded in that area.

The main impediment to the detailed analysis of the history of growth of the anticlinal features of the Duntroon Basin remains the lack of stratigraphic control. The well spacing in producing oil fields in area of growth faulting and associated rollover anticlines (e.g. in the Niger Delta) can be as close as 500 m. Comparison with the well spacing in the Duntroon Basin illustrates this difficulty.

PETROLEUM ASPECTS

Hydrocarbon potential in the Duntroon Basin is assessed with reference to the three wells drilled in the basin. Drilled samples from the Cretaceous section were picked for geochemical analysis and the results are summarised from AMDEL (1984); Forbes et al., (1984); Templeton and Peattie, (1986), and Hill, (1989).

The evaluation of the petroleum potential of the basin based on existing well data is restrictive due primarily to the particular location of the wells. Of the three wells, two tested the outer growth belt (Duntroon 1 and Platypus 1), with very close results. The third well (Echidna 1) was located along the basement ridge separating the outer zone from the inner part of the basin, on the crest of an anticlinal feature (Echidna - Koala). It penetrated a reduced section and showed a thermal maturity profile which differs greatly from that of the outer growth belt. The inner basin has not been drilled and the evaluation of its potential derives from extrapolation from the three existing wells and considerations on the tectonic and sedimentary history of this particular area. The Tertiary section lies in inadequate depths for hydrocarbon generation to have occurred, and the lack of effective seal downgrades the trap potential of the sandy units (Hill, 1989).

Outer growth fault zone

a) Platypus 1 well

Structure

The Platypus 1 well was drilled in 1972. It targeted a wide rollover structure defined on Shell 1970 seismic data (Fig. 13), and was plugged and abandoned at TD 3881 m, in shales of the Ceduna Formation. The Platypus structure is located along the major fault limiting the outer growth fault belt from the central basement ridge. The structure originated in response to the sliding and rotation of the Early Cretaceous sediments on the shallow dipping fault plane at the time of deposition of the Platypus Formation (mid-Cretaceous). The rollover provides dip closure to the north at the mid-Cretaceous level (base of the Platypus Formation). Dip closure to the south and laterally, along the rollover axis, appear to be limited. The sedimentary section penetrated contained adequate reservoirs in the Platypus Formation (334 m thick) and the Wombat Sandstone (103 m thick) and seal (Wigunda Formation, 665 m thick).

Maturity

Vitrinite analysis results indicate that the section is immature down to 3047 m, VR < 0.5% (resinite rich). The top of the oil window for resinite poor, woody herbaceous OM (VR = 0.7%) occurs at 3764 m, in the Early Cretaceous Duntroon Group. Potential yield (S1 + S2) in the shales of the Platypus Formation indicate moderate to good source rock below 3014 m, with the coals exhibiting excellent source potential. The shales of the Duntroon Group rate as good source rocks (TOC > 1.5%), and the hydrogen index values for coals indicate also good source potential. Geochemical analysis did not indicate the migration of hydrocarbons through the section. Van Krevelen plots in conjunction with organic petrological data demonstrate that most of the organic matter in the Cretaceous sediments is of terrigenous origin (type III, woody herbaceous), usually considered to be gas prone, although coals of the Platypus and Ceduna Formations have liquid generating capacity with likely products being light paraffinic oil and wet gas.

The absence of hydrocarbon accumulation in Platypus 1 could result from:

- inadequate closure
- insufficient volumes of hydrocarbons generated in the mature parts of the Ceduna Formation and deeper levels of the Duntroon Group.
- restricted vertical migration of the hydrocarbons generated at depth (below 3000 m) due to intraformational seals within the Duntroon Group.

b) Duntroon 1 Well

Structure

The Duntroon well was located on the Numbat prospect, with its primary objective as the Platypus Formation (Fig. 14). The well was plugged and abandoned at 3515 m. The Numbat prospect is interpreted as a mid-Cretaceous structure generated by mass sliding on a ductile shaly substratum. The structure is limited to the south by a growth fault which was active in mid-

Cretaceous time and affected the top of the Ceduna Formation (near top Early Cretaceous). The deposition of the Platypus Formation appears to be controlled by the growth of this fault, whilst sealing of the fault would have occurred during deposition of the Wigunda Formation. Closure along the east-west axis corresponds to simple dipping of the mid-Cretaceous surface, and does not seem fault related.

However, earlier sliding on the basal plane may have occurred during the Early Cretaceous at site of the Numbat prospect, with associated growth faults active during the deposition of the lower Duntroon Group (Neptune and Echidna Formations). If these faults were sealed by shales of the lower Duntroon Group (Fig. 14), migration of hydrocarbons towards shallower levels, in the Upper Cretaceous would be hampered.

The Platypus Formation is relatively thin (49 m between 2541 to 2590 m, (Hill, 1989) due to uplift and subsequent erosion. The deposition of the formation is here interpreted as synchronous of the structuring of the Numbat prospect (Fig. 14). There is no evidence for hydrocarbon migration in the penetrated Cretaceous section.

Maturity

Vitrinite reflectance data indicate that the section is immature to 3000 m, and marginally mature for oil from 3000 to 3515 m (TD) in the Neptune Formation (0.58% to 0.67% VR). The non coaly mudstones and siltstones throughout the entire section have insignificant potential (max potential 3.9 kg/tonne). Coals were found in the Duntroon Group and in the Cenomanian Platypus Formation. The Cenomanian coals are mostly gas prone and show minor potential to source waxy condensate; potentials average 143 kg/tonne. The Aptian-Albian Borda Formation coals are generally more oil prone, with potential yields averaging 145 kg/tonne.

The absence of hydrocarbon accumulation in Duntroon 1 could be speculatively attributed to:

- lack of significant quantities of coals in the deep levels of the Lower Cretaceous.
- insufficient thermal maturity for generation of hydrocarbon in these levels.
- inadequate vertical migration to the reservoirs of the Upper Cretaceous.

The shaly nature of the Duntroon Group could furthermore present an obstacle to vertical migration of hydrocarbons. Conversely, lateral migration could have occurred within the Early Cretaceous formations, from the outer zone to more inner parts of the Duntroon Basin. This could account for the traces of hydrocarbons which migrated through the Cretaceous section at the Echidna 1 well.

c) <u>Conclusion</u>

Assuming that the maturity profile at the Platypus 1 and Duntroon 1 wells is representative of the outer zone, the main factors affecting the hydrocarbon potential of this area are therefore the immaturity of the section down to depths averaging 3000 m, and the volumetric importance of source rocks in the deepest (unpenetrated) levels of the Duntroon Group.

Structuring is essentially related to growth faulting commencing in the mid-Cretaceous, and if migration along these faults occurred, the Late Cretaceous section contains possible reservoir sands (sands form 45% of the Platypus Formation, 58% of the Potoroo Formation, in the Platypus 1 well). The zone of maximum oil generation in Platypus 1 was estimated to be at 4420 m by Forbes et al. (1984). The potential of the outer zone relies on important vertical migration of fluids from the deepest parts of the Duntroon Group to fill Late Cretaceous reservoirs. Vertical migration of hydrocarbons from considerable depths (down to 4000 m) over several kilometers (2 to 3 km) have been reported in the Gippsland Basin (Burns et al., 1984; James, 1983; Rahmanian et al., in press).

Syn-depositional faulting in the lower Duntroon Group shales could prevent vertical migration of the hydrocarbons to the Upper Cretaceous reservoirs.

Alternatively, lateral migration of hydrocarbons from the deep mature levels of the outer zone (in the Duntroon Group) to the ridge separating the outer zone from the inner zone could also be considered. Fluorescence in the Early Cretaceous Borda Formation at Echidna 1 (see further) may have originated from the outer zone, and migrated to the Echidna site through lateral pathways within the Lower Cretaceous section.

Central basement high

a) <u>Echidna well</u>

Structure

The Echidna 1 well was drilled in 1972 on a structure defined by Shell lines. As shown in Fig.16, the Echidna well tested a rotated shale mass on the apex of the large basement ridge separating the outer zone from the inner zone. The important rotation of the Early Cretaceous sequence associated with the shale tectonics and the dense faulting decrease the quality of the seismic records and the degree of confidence in the closure of the structure.

The Echidna structure resulted from a combination of:

- the ? Jurassic-Early Cretaceous rift extensional period.
- the Late Cretaceous post rift uplift of the central ridge.
- the mid-Late Cretaceous mass sliding and shale movements.

The sedimentary section is characterized by the absence of the Upper Cretaceous and incomplete preservation of the Duntroon Group, directly below the base Tertiary unconformity.

Maturity

The oil window is relatively narrow (Hill, 1989) and located entirely within the Borda Formation. The top window for resinite-rich (VR = 0.45%) is at 1402 m, for resinite-poor (VR = 0.7%) at 2042 m, and bottom window (VR = 1.35%) at 2316 m. Elemental analysis and organic petrological investigation tend to confirm the woody-herbaceous origin of the organic matter in the Duntroon Group.

Interestingly, production index values (S1/ S2 + S3) in the interval 1310 to 2042 m indicate the migration of hydrocarbons in the section immediately above the oil generation window (for resinite-poor). This suggests that had a valid seal such as the Wigunda Formation been present, hydrocarbons may have been trapped. However the volume of hydrocarbons cannot be estimated. Analysis of the distribution of the Late Cretaceous formations, especially the Wigunda Formation which acts as a seal (Hill, 1989), is essential for assessing the hydrocarbon potential of the central ridge.

Inner half grabenal zone and other play concepts

The maturation profile for the inner half graben is difficult to predict from data from the outer zone, due to a vastly different structural setting. The existence of deep seated tilted basement blocks in the inner zone of the basin precludes a direct extrapolation of the thermal history (paleo- heat flow and temperatures) from the outer zone.

Source rocks

The basal sequence of the basin has not intersected by drilling. If we assume that these sediments are at least partly Jurassic in age, then analogies with the closest time-equivalent deposits of the Polda Basin, some 250 km north of the Duntroon Basin, can be made. Geochemical analysis carried out on samples of the Mercury-1 well (over a depth range of 310 to 810 m) (Mc Kirdy, 1984) indicate that the Jurassic (Polda Formation) has good non-reservoir source potential with a mean TOC value of 2.56%. The Rock-Eval analysis confirms the good source potential with genetic potential (S1 + S2) ranging from 2.97 to 22.42 kg/tonne. However, in the Polda Basin, the three wells drilled to date have not entered the oil window, with vitrinite reflectance values not exceeding 0.38%. Since the ? Jurassic can be buried to depths of 9000 m in the Duntroon Basin, and if the TOC values are similar to those of the Polda Basin, significant volumes of hydrocarbon may have been generated during the Mesozoic and Cenozoic.

The maturation profile for the Early Cretaceous section is also unknown and might differ significantly from its time equivalent in the outer zone, owing in particular to the increased thickness of the Bight Group in the withdrawal synclines. Sediments of the Duntroon Group are deeply buried, especially in the southeast sector of the basin where the added thicknesses of the Upper Cretaceous and Cenozoic reach up to 3500 to 3800 m, giving a total sediments thickness in excess of 10000 m. Assuming that organic maturity sufficient for hydrocarbon generation is achieved in sediments of the Duntroon Group, as extrapolated in the outer zone, the potential of the inner zone relies also on the ability for hydrocarbons to migrate through the shales of the upper Duntroon Group. An analogous situation occurs in the Campos Basin (offshore Brazil) where the hydrocarbon accumulations are found in syn-growth faulting deposited turbidites lying above carbonate and salt layers. There, the hydrocarbons were generated by lacustrine shales located below the salt layers, and migrated a relatively long distance through faults and fractures to the turbiditic reservoirs (Moraes, 1989).

Structures

Structures at the Neocomian level are usually related to warping and normal faulting above the apices of deep basement blocks, and are found in the deepest parts of the inner zone.

Structures in the Cretaceous section of the inner zone are related to the development of the anticlinal features. As previously discussed, the onset of diapirism is estimated as mid-Cretaceous. As a consequence of the doming-arching of the series, the faulting of the competent part of the Cretaceous sedimentary section occurs along the axis of the anticlinal features. Typically these crestal faults have an average length of 5 km with highly variable vertical throws. The importance of these fractures is twofold. They may have created pathways for the migration of hydrocarbon generated in the Duntroon Group lacustrine deposits, and may have produced the combination of structural/stratigraphic traps and seals within the Late Cretaceous as indicated in Fig. 15. The presence of Late Cretaceous sediments within the apical graben delineated by the crestal faults is significant when compared to Echidna 1 where the absence of Late Cretaceous reservoir and seal prevented the possible entrapment of migrating hydrocarbons.

Multiple pinchouts within the Upper Cretaceous and the uppermost Lower Cretaceous during the down-warp of the southern withdrawal syncline of the Koala structure produce possible stratigraphic traps on the southern flank of the anticlinal feature (Fig. 6).

Conclusion

In conclusion, the inner zone is characterised by the presence of potential ? Jurassic - Neocomian source rocks, thick lacustrine Early Cretaceous potential sources, and relatively thick Late Cretaceous reservoirs and seals. Late Cretaceous deformation, related to mass sliding and shale movements, resulted in a dense fracturing of the Upper Cretaceous. This faulting could create structural/stratigraphic traps, although the high density od fault may downgrade the hydrocarbon potential of the crestal portion of the anticlinal structures. Additional stratigraphic traps are possible on the flanks of the anticline features.

The maturation profile of the inner zone is likely to differ from the outer zone, owing particularly to Late Cretaceous post-rift movements which resulted in increased subsidence in the inner zone and relative uplift of the outer zone.

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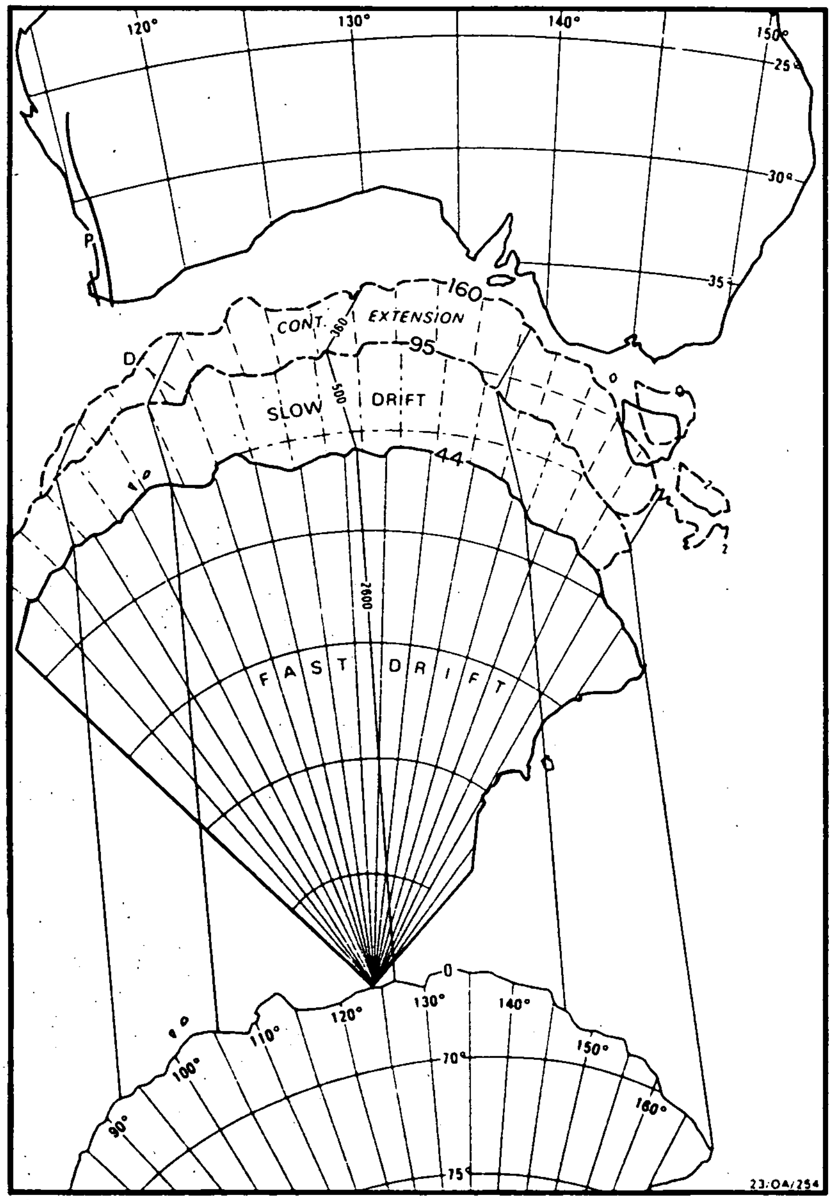
TABLE 1

BIGHT/DUNTROON BASINS: FORMATION TOPS: DATUM KB (m)
(after Hill, 1989)

WELL	APOLLO 1	DUNTROON 1	ECHIDNA 1	JERBOA 1	MALLABIE 1	PLATYPUS 1	POTOROO 1
YEAR	1975	1986	1972	1980	1969	1972	1975
SEA LEVEL DATUM	9	27	30	10	60	30	9
SEABED	75	171	169	761	-	188	261
ROCK UNIT							
EUCLA GROUP							
NULLARBOR LST.							
WILSON BLUFF		1 424	1 002	1 075	33	1 421	
PIDINGA/HAMPTON*	380*	1 631	1 209	1 103*	141	1 628	940*
BIGHT GROUP							
POTOROO FM.	ABS	1 833	ABS	ABS	ABS	1 691	990
WIGUNDA FM.	ABS	2 155	ABS	ABS	ABS	2 206	1 570
WOMBAT SANDSTONE MEMBER	ABS	2 468	ABS	ABS	ABS	2 871	ABS
PLATYPUS FM.	ABS	2 541	ABS	[1148]	ABS	2 974	[1 776]
DUNTROON GROUP							
CEDUNA FM.	ABS	2 590		[1224]	ABS	3 376	[2 420]
BORDA FM.	ABS	2 983	1 304	ABS		NP	ABS
NEPTUNE FM.	ABS	NP	3 016	[1635]		NP	[2 690]
ECHIDNA FM.	ABS	NP	3 595	ABS		NP	
MADURA FM	394				169		
LOONGANA FM.	547			2 099	260		2 734
UNNAMED PERMIAN	633	NP	NP	ABS	335	NP	ABS
PRECAMBRIAN-ARCHAEAN	858	NP	NP	2 509	437	NP	2 812
TD	892	3 515.6	3 823	2 537.5	1 496	3 881	2 923

[ ] denotes 'equivalent'
NP not penetrated
* Hampton Sandstone



After Veevers and Eittreim (1988)

Reconstruction of the separation of the Australian and Antarctic plates:

- 160 Ma initial position
- 96 Ma end of continental extension
- 44 Ma end of slow drift phase

Figure 1

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas	C.D.O.	DATE 1·10·90
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN E. Calabio	SCALE	
AUSTRALIAN AND ANTARCTIC PLATES RECONSTRUCTION AT RIFTING AND AFTER RIFTING STAGES	DATE 27/4/90	PLAN NUMBER S 21616	
	CHECKED		

5060

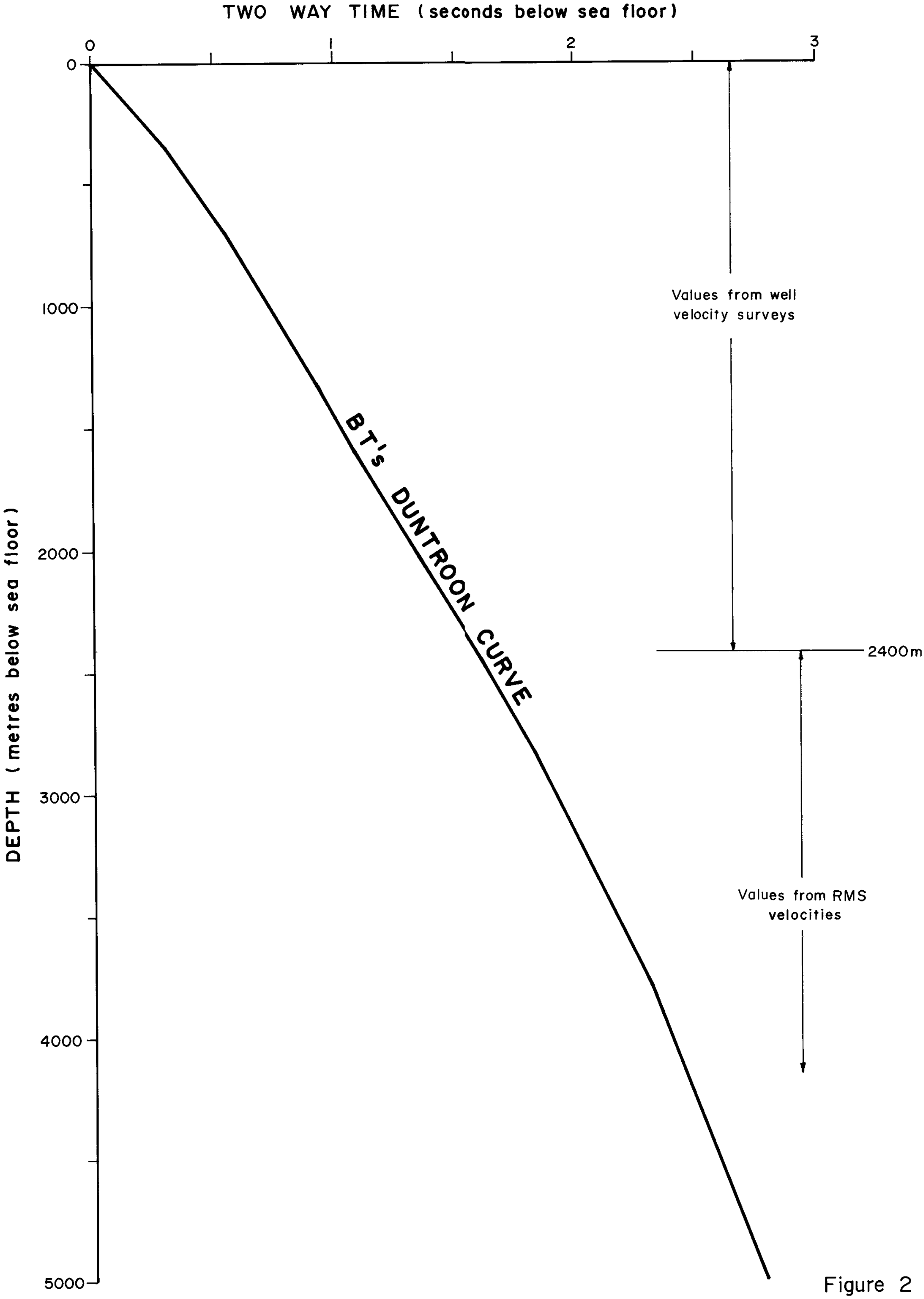


Figure 2

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas	C.D.O. DATE 1.10.90
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN E. Calabio	SCALE graph
TIME DEPTH CURVE	DATE 26/4/90	PLAN NUMBER
	CHECKED	S21617

5060

Figure 3

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

DUNTROON BASIN GEOPHYSICAL STUDY
SEISMIC LINE 83-70

COMPILED B. Thomas	C.D.O. DATE
DRAWN E. Calabio	SCALE As shown
DATE April '90	PLAN NUMBER
CHECKED	90-369

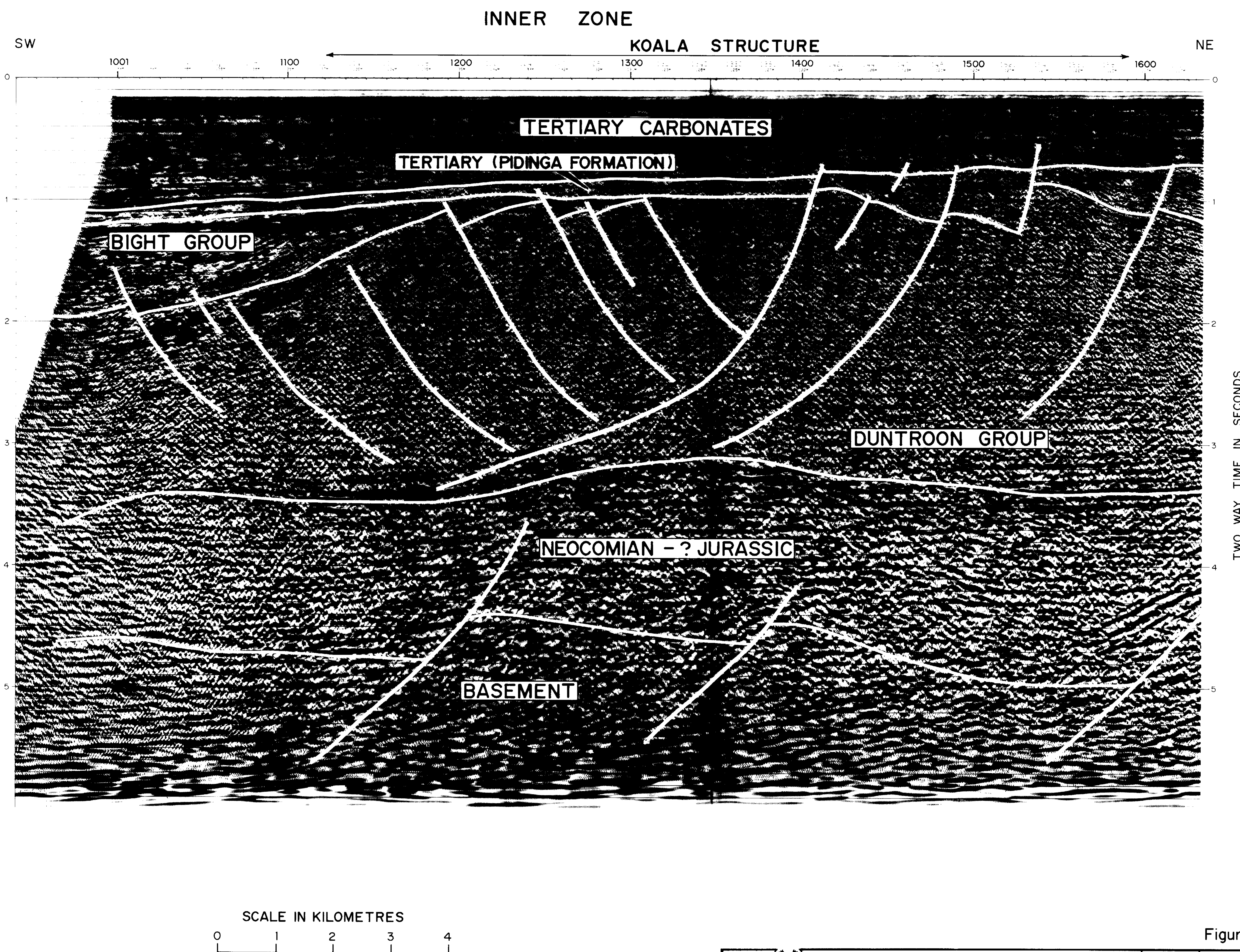
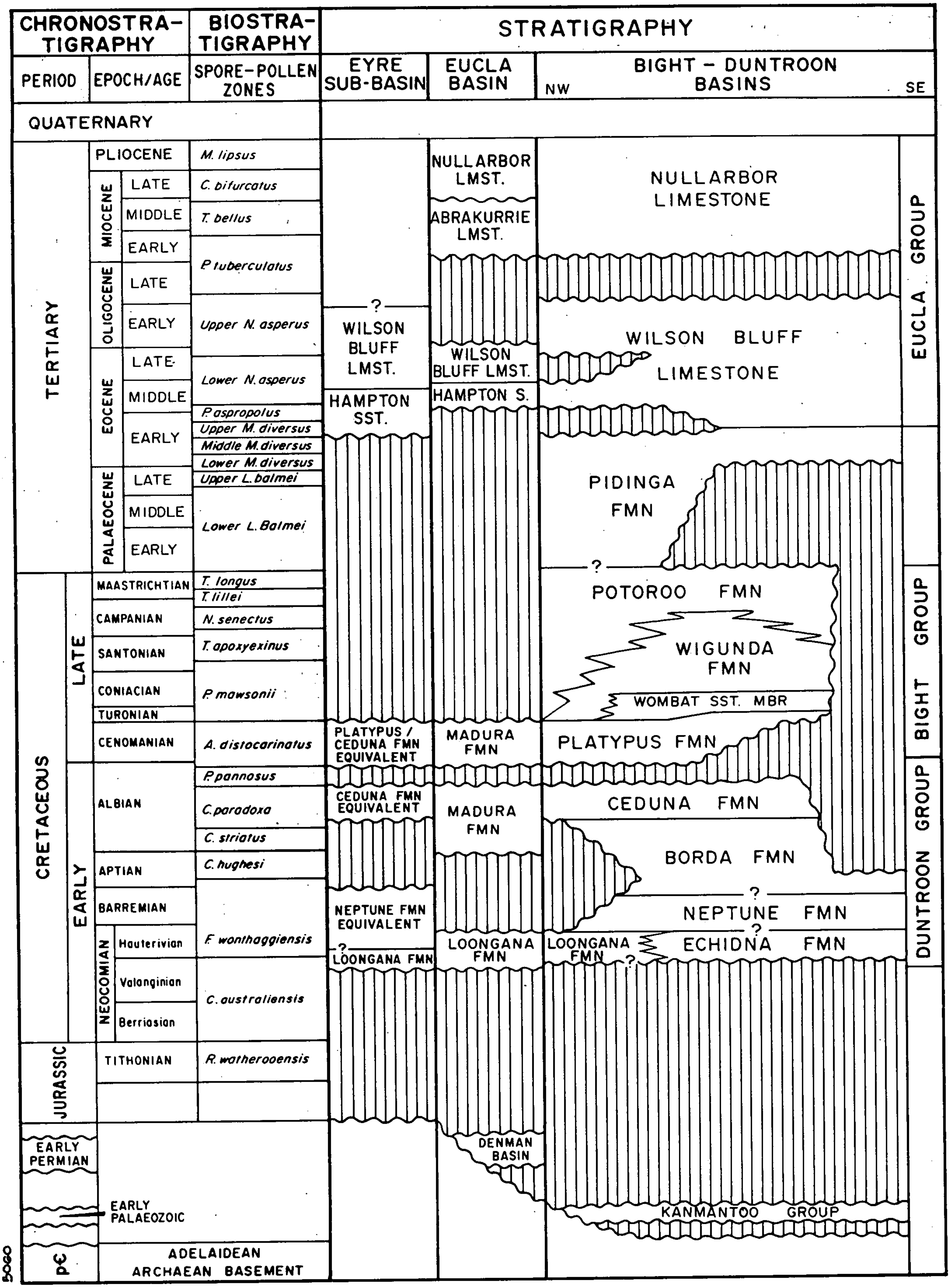


Figure 4

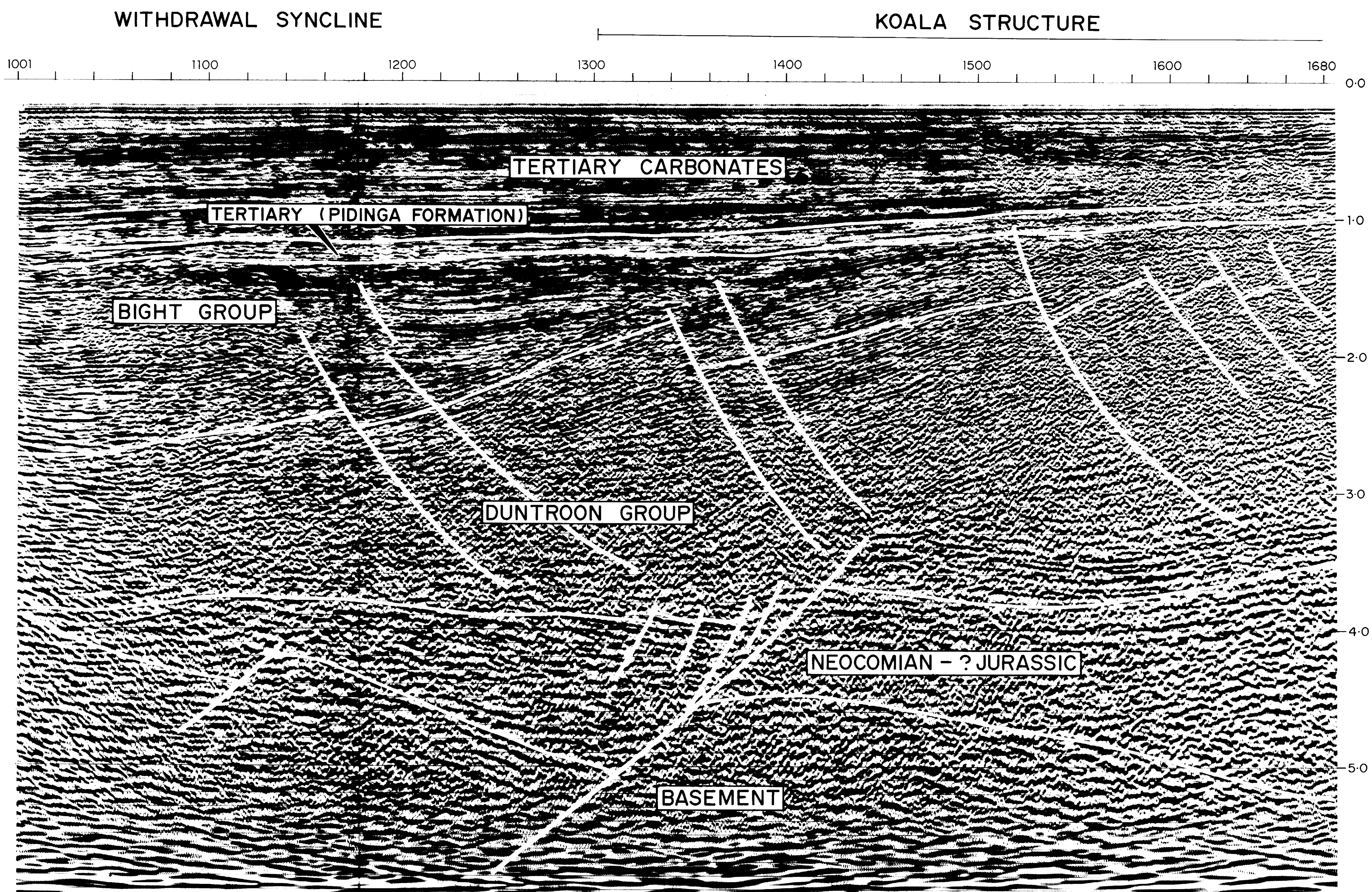
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas	C.D.O. DATE
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN A.F.	SCALE As shown
SEISMIC LINE 84-16	DATE May 1990	PLAN NUMBER
	CHECKED	90-370

STRATIGRAPHY OF EUCLA, BIGHT – DUNTROON BASINS – SOUTH AUSTRALIA



SADME Figure 5 S 21701

8.1.10.90



SCALE IN KILOMETRES

0 1 2 3 4

Figure 6

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

DUNTROON BASIN GEOPHYSICAL STUDY

SEISMIC LINE 84-17

COMPILED B. Thomas	C.D.O.	DATE
DRAWN A.F.	SCALE As shown	
DATE May 1990	PLAN NUMBER	
CHECKED	90-371	

5060

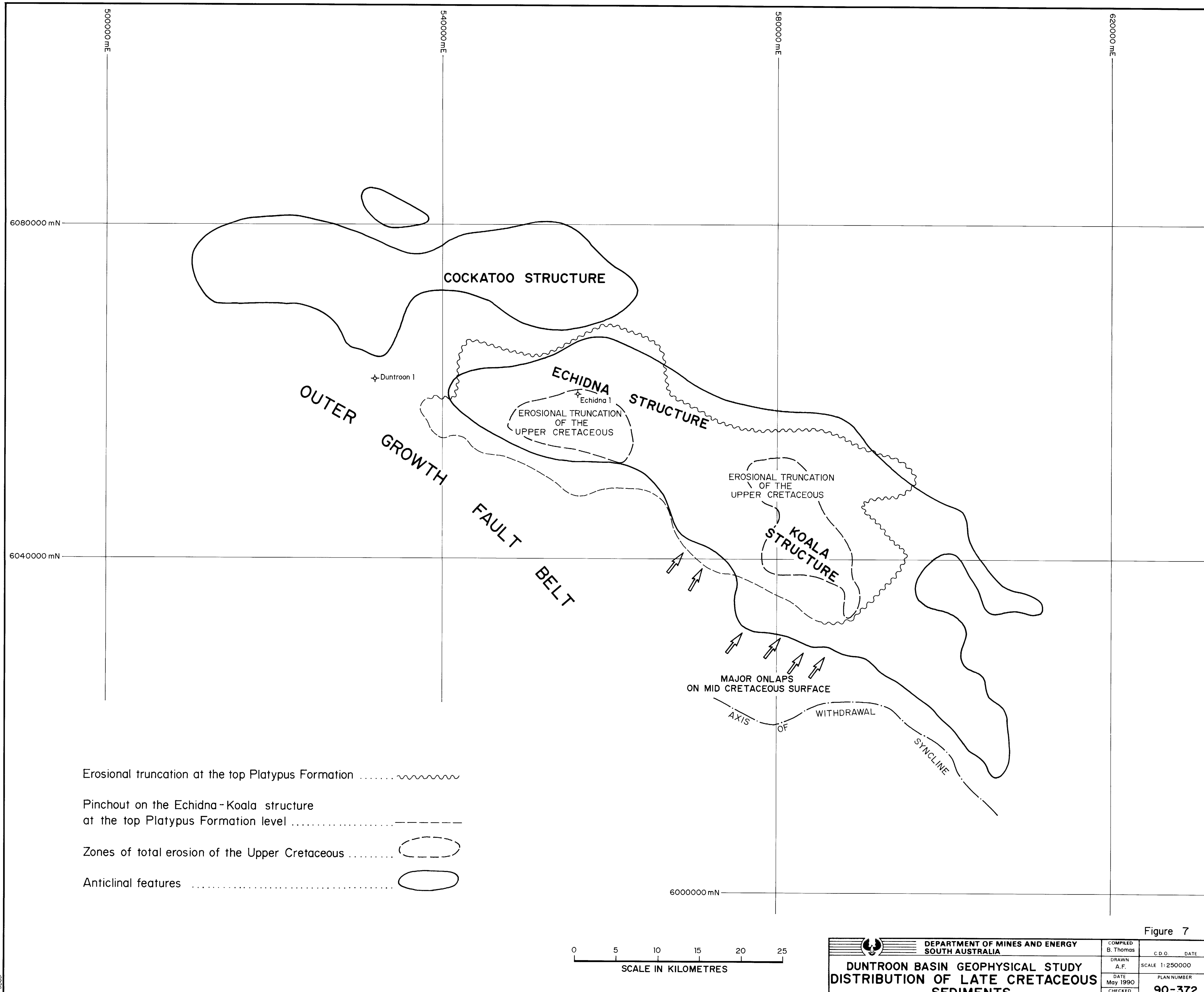

500000 mE
540000 mE
580000 mE
620000 mE
6080000 mN
6040000 mN
6000000 mN
COCKATOO STRUCTURE
Duntroon 1
ECHIDNA STRUCTURE
Echidna 1
EROSIONAL TRUNCATION OF THE UPPER CRETACEOUS
OUTER GROWTH FAULT BELT
EROSIONAL TRUNCATION OF THE UPPER CRETACEOUS
KOALA STRUCTURE
MAJOR ONLAPS ON MID CRETACEOUS SURFACE
AXIS OF WITHDRAWAL SYNCLINE
Erosional truncation at the top Platypus Formation
Pinchout on the Echidna-Koala structure at the top Platypus Formation level
Zones of total erosion of the Upper Cretaceous
Anticlinal features
0 5 10 15 20 25
SCALE IN KILOMETRES
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA
DUNTROON BASIN GEOPHYSICAL STUDY
DISTRIBUTION OF LATE CRETACEOUS SEDIMENTS
COMPILED B. Thomas
DRAWN A.F.
DATE May 1990
CHECKED
C.D.O. DATE
SCALE 1:250000
PLAN NUMBER
90-372

Figure 7

Figure 8

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

DUNTROON BASIN GEOPHYSICAL STUDY
SEISMIC LINE 83-64

COMPILED	B. Thomas	C.D.O.	DATE
DRAWN	E. Calabio	SCALE	As shown
DATE	May '90	PLAN NUMBER	
CHECKED		90-373	

Figure 9

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED D. Cockshell	E.B.T pw WDR C.D.O 2·10·90 DATE
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN E. Calabio	SCALE As shown
SEISMIC LINE 84-27	DATE Mar. '90	PLAN NUMBER
	CHECKED	90-192

4858

LINE 83-18

Figure 10

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED C.D.Cockshell	E.B.T. per WDR 2·10·90 C.D.O. DATE
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN L.W.	SCALE
SEISMIC LINE 83-18	DATE March 1990	PLAN NUMBER 90-191
	CHECKED	

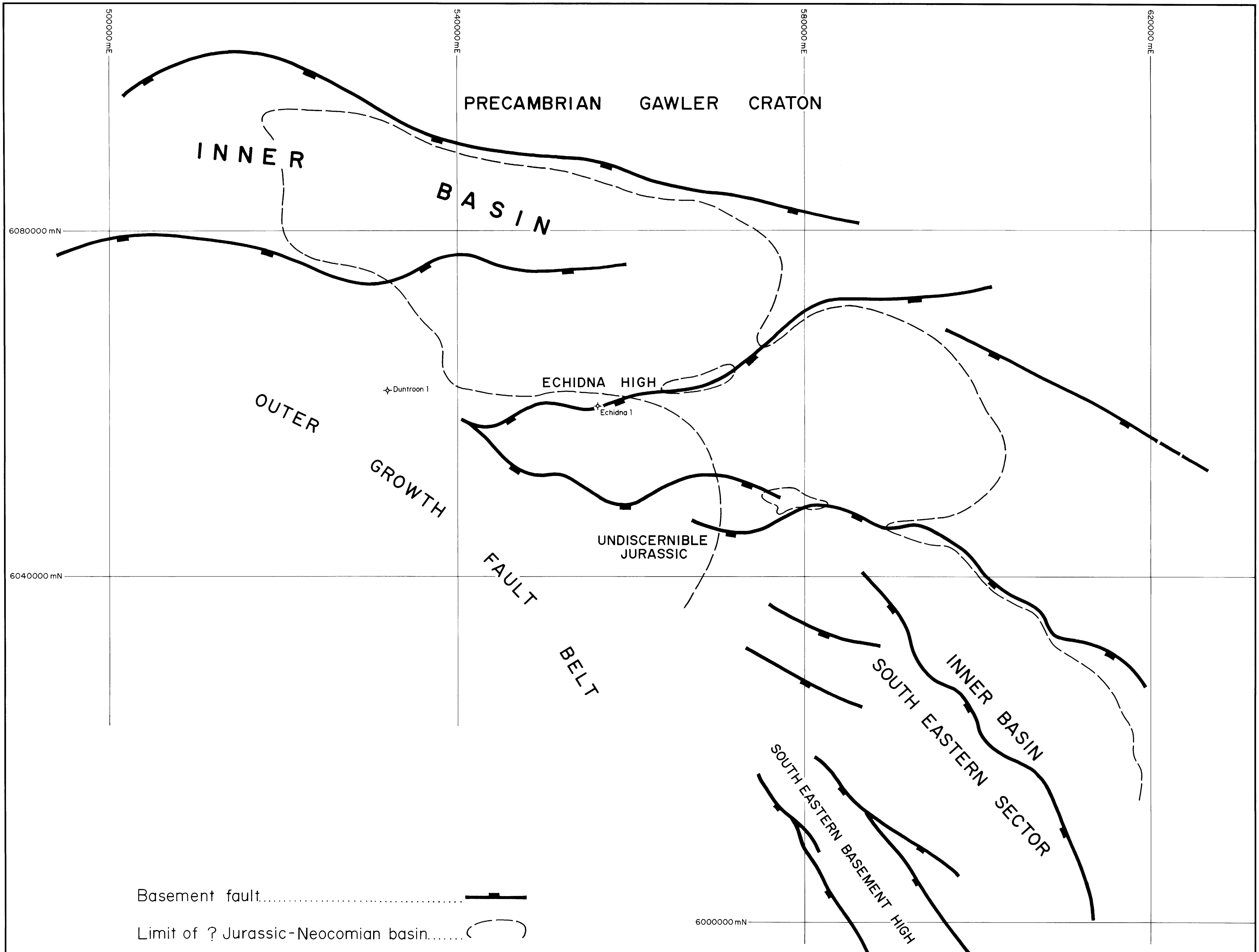


Figure 11

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas	CDO DATE
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN A.F.	SCALE 1:250000
STRUCTURAL ELEMENTS – BASEMENT	DATE May 1990 CHECKED	PLAN NUMBER 90-374

5060

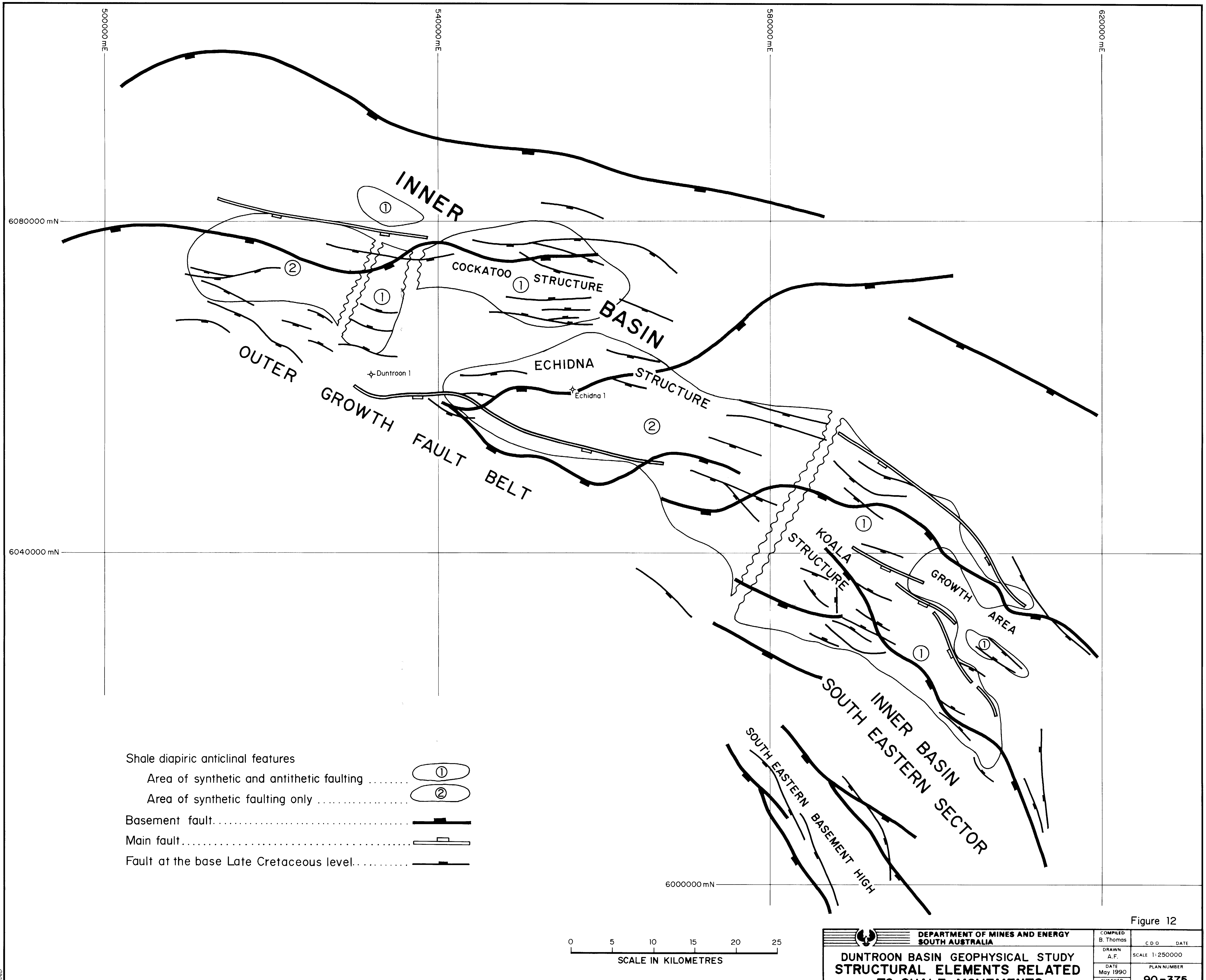
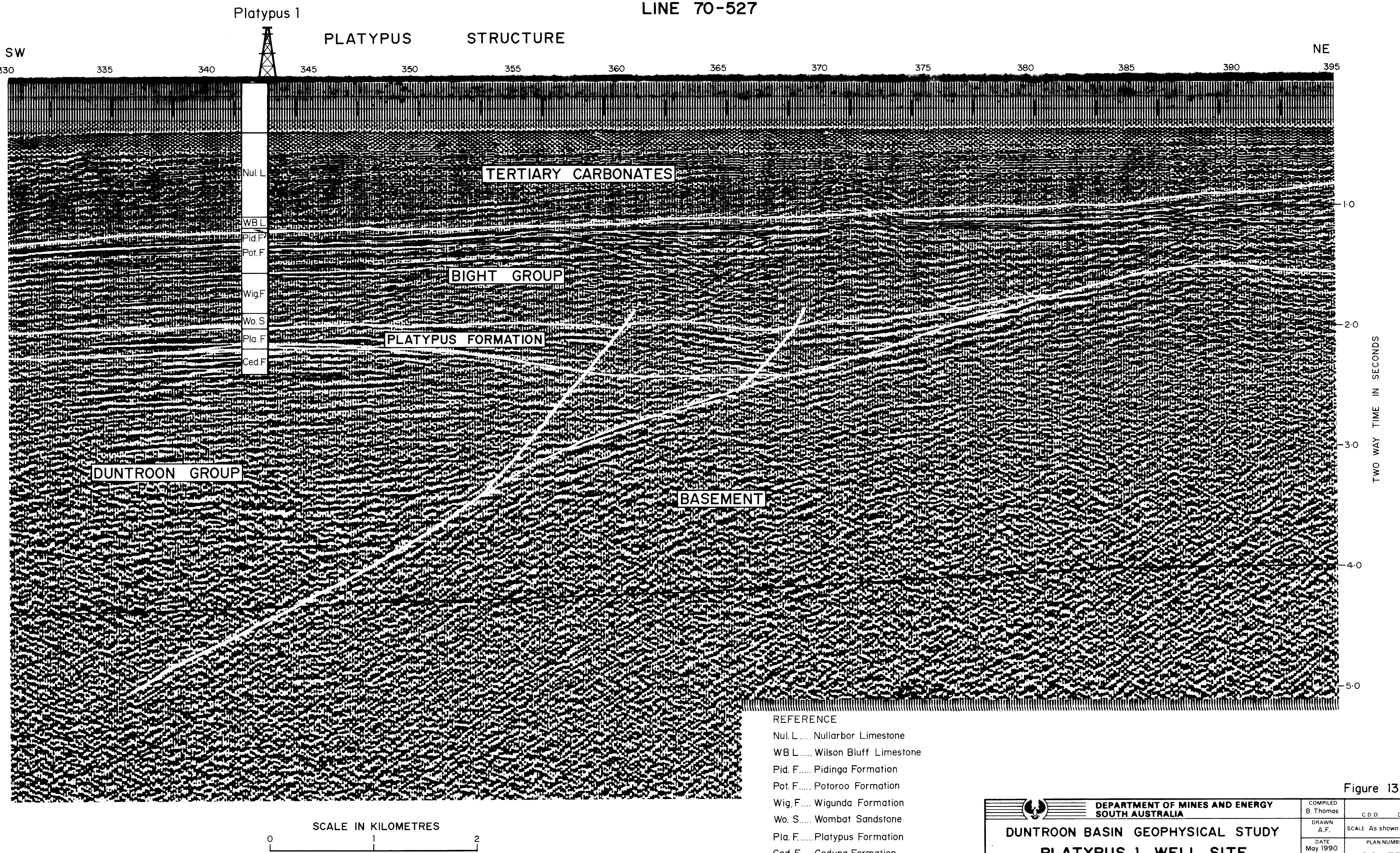

500000 mE
540000 mE
580000 mE
620000 mE
6080000 mN
6040000 mN
6000000 mN
INNER BASIN
OUTER GROWTH FAULT BELT
COCKATOO STRUCTURE
ECHIDNA STRUCTURE
Duntroon 1
Echidna 1
KOALA STRUCTURE
GROWTH AREA
INNER BASIN SOUTH EASTERN SECTOR
SOUTH EASTERN BASEMENT HIGH
Shale diapiric anticlinal features
Area of synthetic and antithetic faulting .... ①
Area of synthetic faulting only .... ②
Basement fault..
Main fault...
Fault at the base Late Cretaceous level..........
0 5 10 15 20 25
SCALE IN KILOMETRES
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA
DUNTROON BASIN GEOPHYSICAL STUDY
STRUCTURAL ELEMENTS RELATED TO SHALE MOVEMENTS
COMPILED B. Thomas
DRAWN A.F.
DATE May 1990
CHECKED
CDO DATE
SCALE 1:250000
PLAN NUMBER 90-375

Figure 12



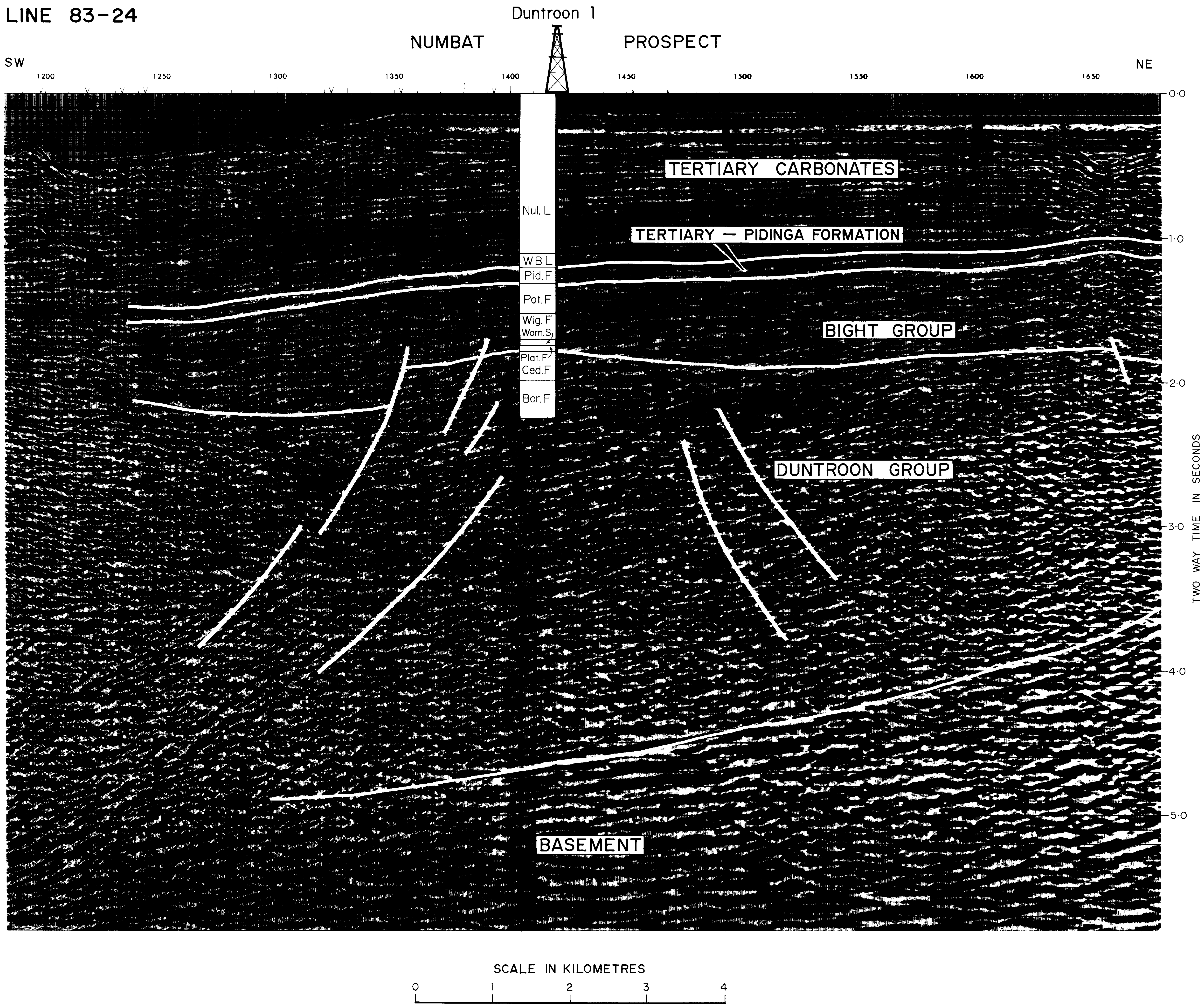
REFERENCE

Nul. L ..... Nullarbor Limestone
WB L ..... Wilson Bluff Limestone
Pid. F ..... Pidinga Formation
Pot. F ..... Potoroo Formation
Wig. F ..... Wigunda Formation
Wo. S ..... Wombat Sandstone
Pla. F ..... Platypus Formation
Ced. F ..... Ceduna Formation

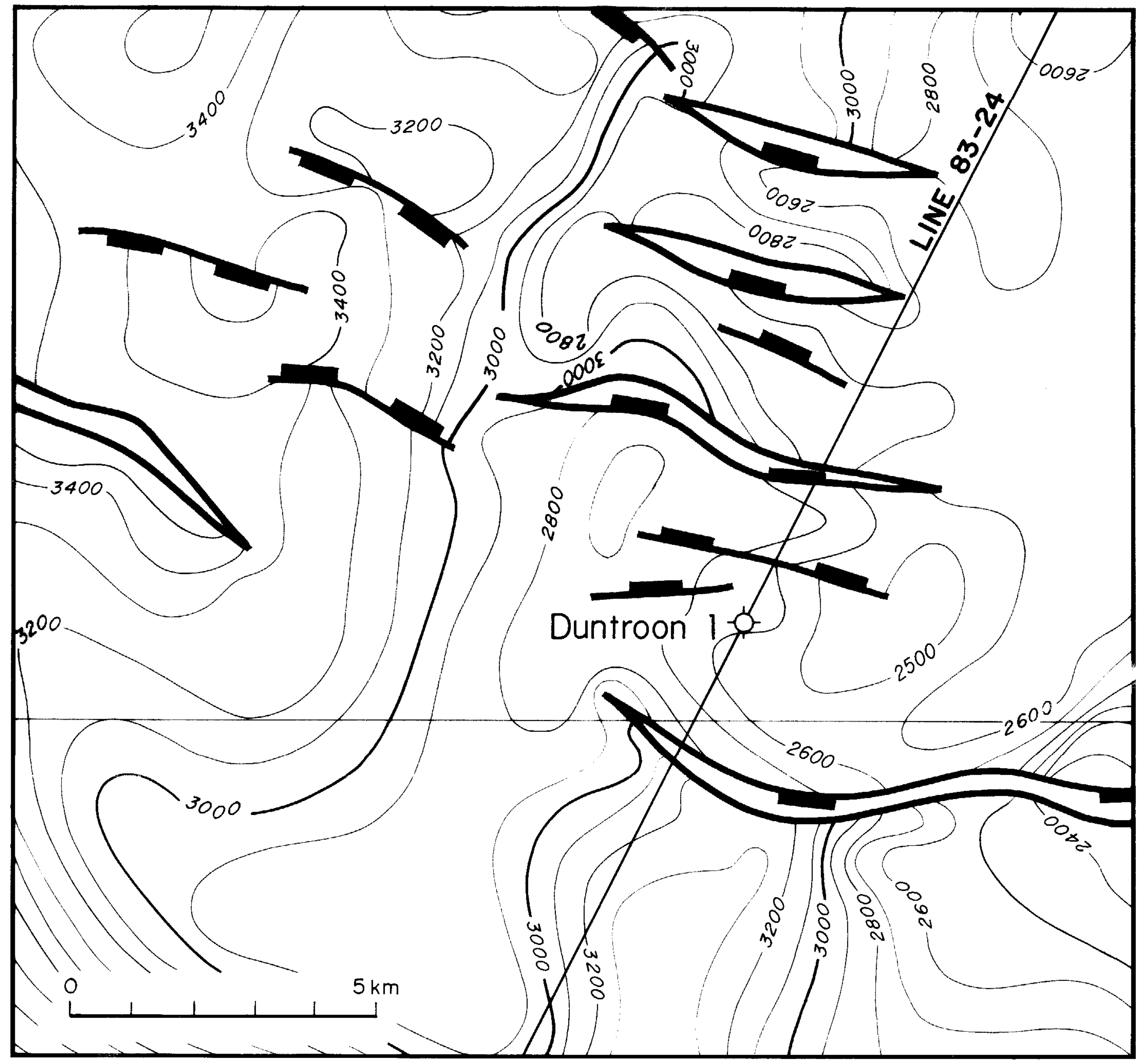
Figure 13

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas	C.D.O. DATE
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN A.F.	SCALE As shown
PLATYPUS 1 WELL SITE	DATE May 1990	PLAN NUMBER
	CHECKED	90-376

5060



DEPTH TO DUNTROON GROUP

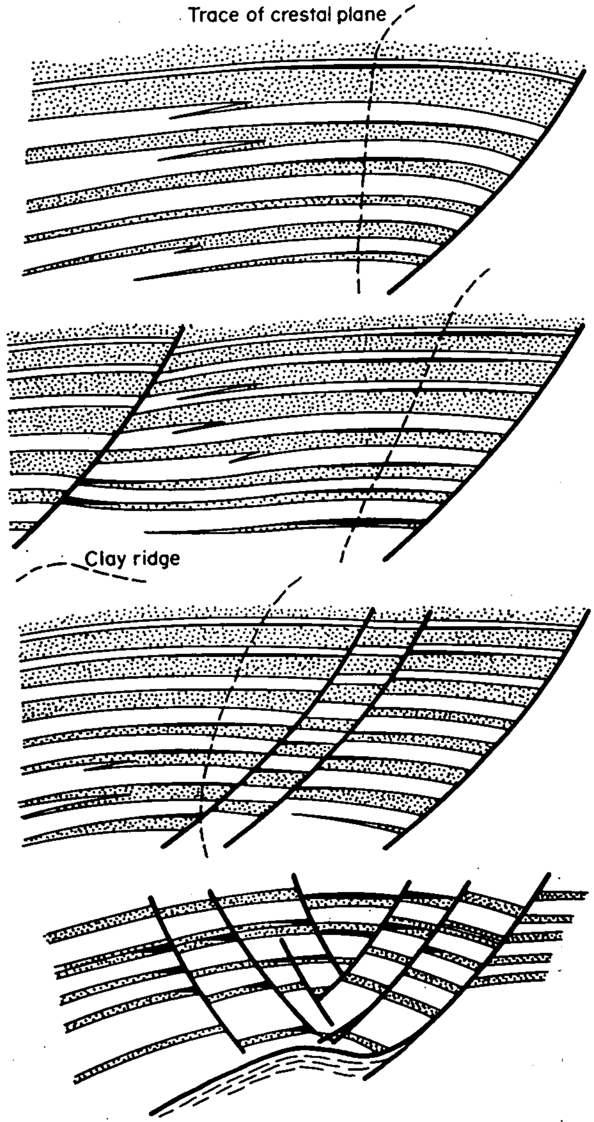


REFERENCE

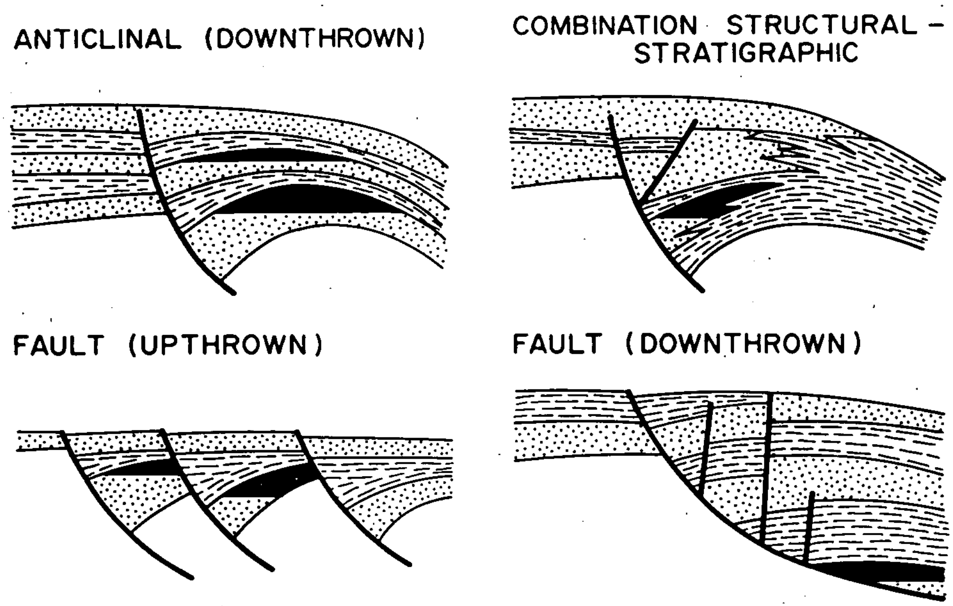
- Nul. L ..... Nullarbor Limestone
- W B L ..... Wilson Bluff Limestone
- Pid. F ..... Pidinga Formation
- Pot. F ..... Potoroo Formation
- Wig. F ..... Wigunda Formation
- Wom. S .. Wombat Sandstone
- Plat. F ..... Platypus Formation
- Ced. F ..... Ceduna Formation
- Bor. F ..... Borda Formation

Figure 14

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas	CDO DATE
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN A.F.	SCALE As shown
DUNTROON 1 WELL SITE	DATE May 1990	PLAN NUMBER 90-377
	CHECKED	



A. In the Niger Delta (after Evamy et al., 1978)



B. In the Texas Gulf (after Larberg, 1983)

Figure 15. Principal types of hydrocarbon traps associated with growth faults.

Department of Mines and Energy-South Australia

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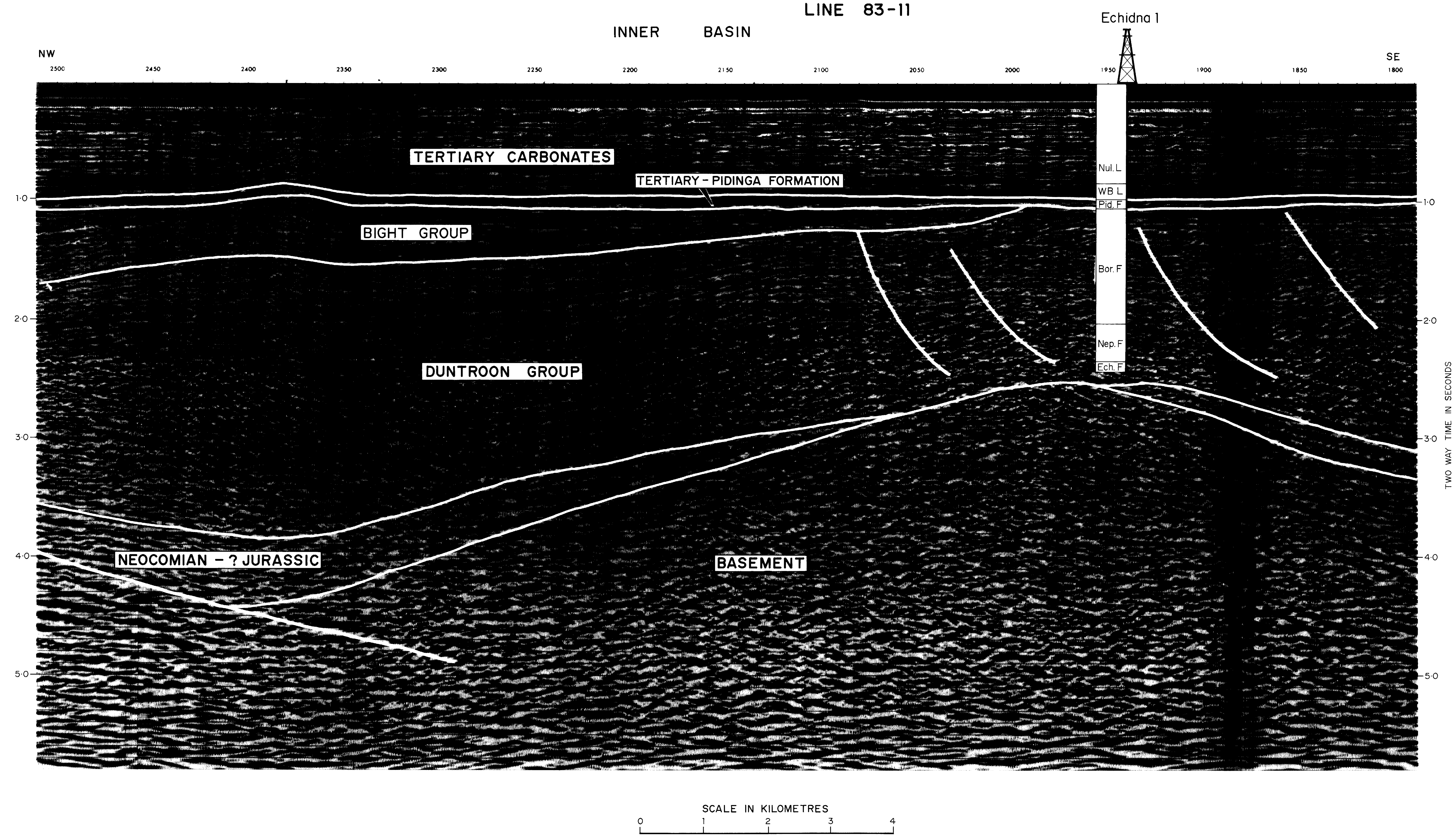
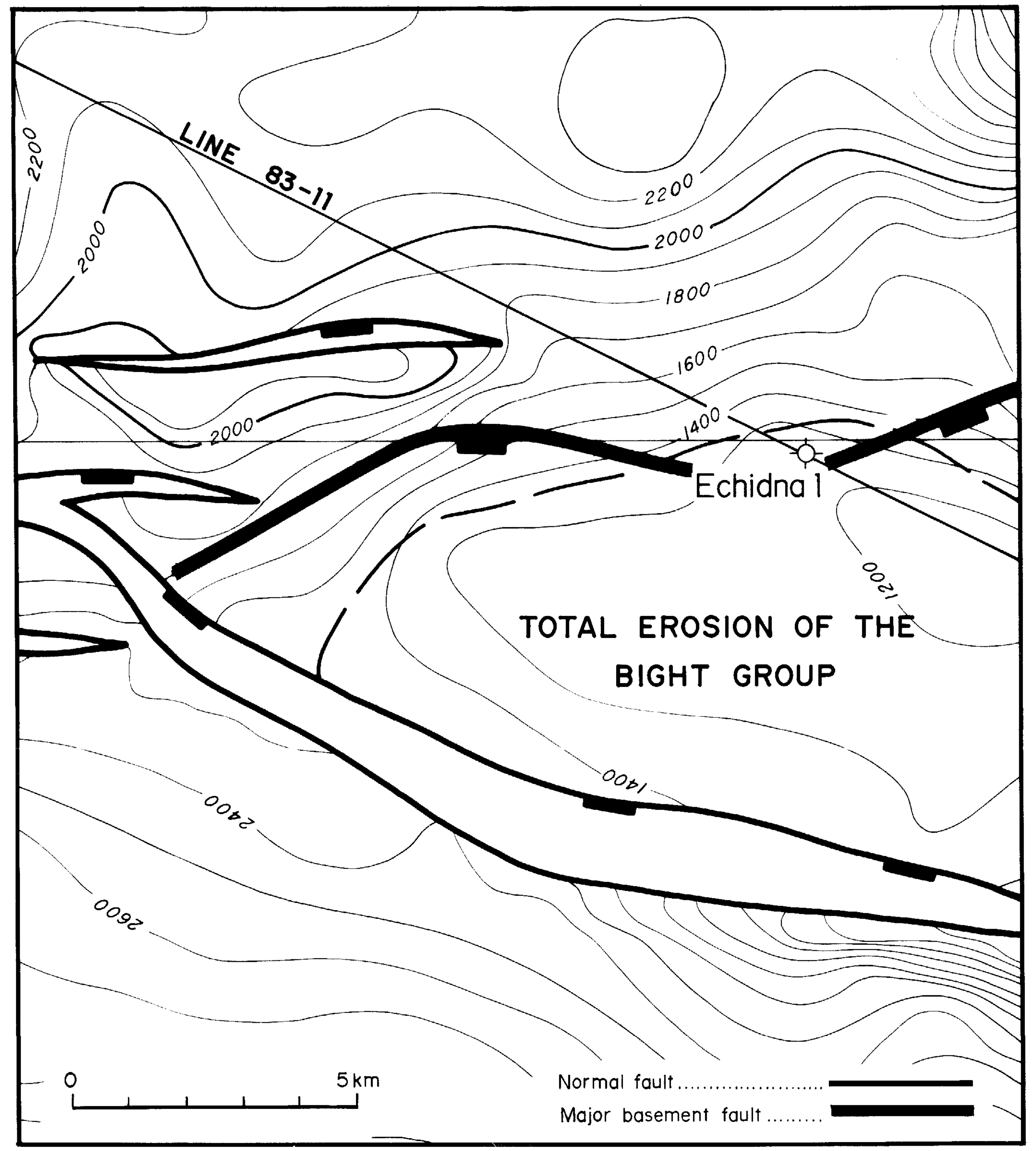
5060

1·10·90



DEPTH TO DUNTROON GROUP

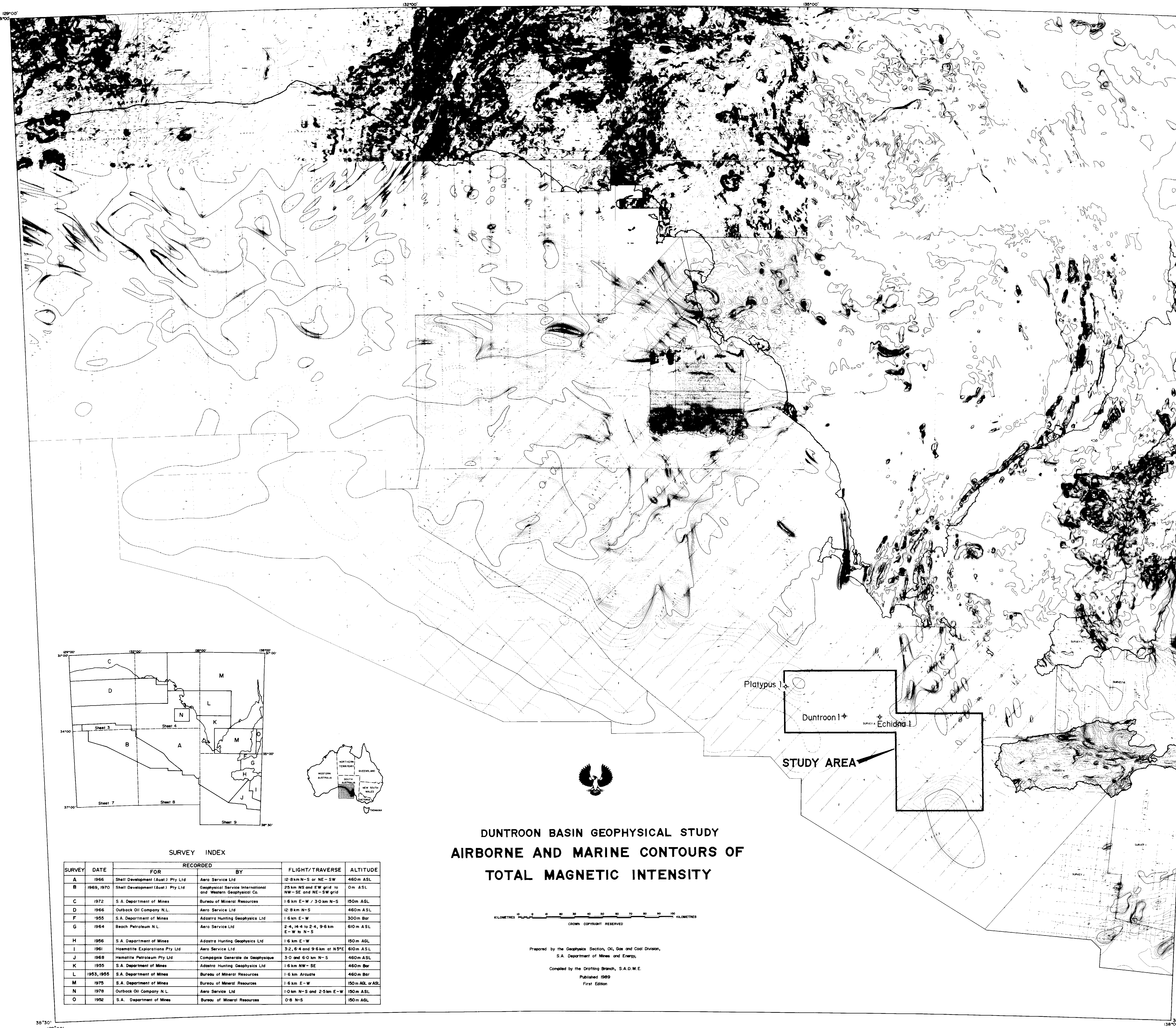


REFERENCE

Nul. L ..... Nullarbor Limestone
WB L ..... Wilson Bluff Limestone
Pid. F ..... Pidinga Formation
Bor. F ..... Borda Formation
Nep. F ..... Neptune Formation
Ech. F ..... Echidna Formation

Figure 16

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas	C.D.O.	DATE
DUNTROON BASIN GEOPHYSICAL STUDY	DRAWN A.F.	SCALE As shown	
ECHIDNA 1 WELL SITE	DATE May 1990	PLAN NUMBER 90-378	
	CHECKED		



DUNTROON BASIN GEOPHYSICAL STUDY

AIRBORNE AND MARINE CONTOURS OF TOTAL MAGNETIC INTENSITY

SURVEY INDEX

SURVEY	DATE	RECORDED FOR	RECORDED BY	FLIGHT/TRAVERSE	ALTITUDE
A	1966	Shell Development (Aust.) Pty Ltd	Aero Service Ltd	12·8km N-S or NE-SW	460m ASL
B	1969, 1970	Shell Development (Aust.) Pty Ltd	Geophysical Service International and Western Geophysical Co.	25km NS and EW grid to NW-SE and NE-SW grid	0m ASL
C	1972	S.A. Department of Mines	Bureau of Mineral Resources	1·6km E-W / 3·0km N-S	150m AGL
D	1966	Outback Oil Company N.L.	Aero Service Ltd	12·8km N-S	460m ASL
F	1955	S.A. Department of Mines	Adastra Hunting Geophysics Ltd	1·6km E-W	300m Bar
G	1964	Beach Petroleum N.L.	Aero Service Ltd	2·4, 14·4 to 2·4, 9·6km E-W to N-S	610m ASL
H	1956	S.A. Department of Mines	Adastra Hunting Geophysics Ltd	1·6km E-W	150m AGL
I	1961	Haematite Explorations Pty Ltd	Aero Service Ltd	3·2, 6·4 and 9·6km at N5°E	610m ASL
J	1968	Hematite Petroleum Pty Ltd	Compagnie Generale de Geophysique	3·0 and 6·0km N-S	460m ASL
K	1955	S.A. Department of Mines	Adastra Hunting Geophysics Ltd	1·6km NW-SE	460m Bar
L	1953, 1955	S.A. Department of Mines	Bureau of Mineral Resources	1·6km Arcuate	460m Bar
M	1975	S.A. Department of Mines	Bureau of Mineral Resources	1·6km E-W	150m AGL or ASL
N	1978	Outback Oil Company N.L.	Aero Service Ltd	1·0km N-S and 2·5km E-W	150m ASL
O	1952	S.A. Department of Mines	Bureau of Mineral Resources	0·8 N-S	150m AGL

KILOMETRES 10 0 10 20 30 40 50 60 70 80 90 100 KILOMETRES

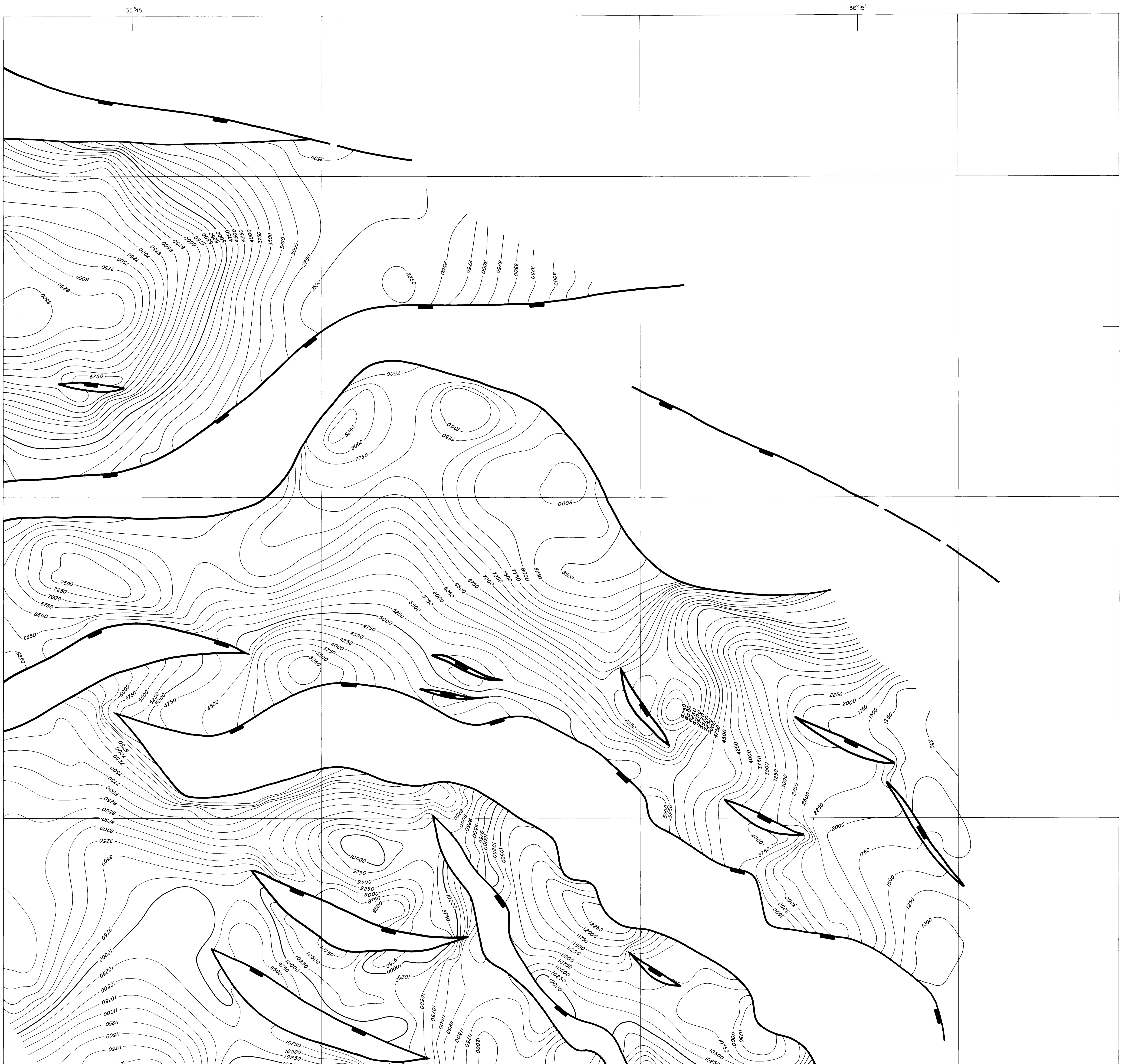
Prepared by the Geophysics Section, Oil, Gas and Coal Division,
S.A. Department of Mines and Energy,

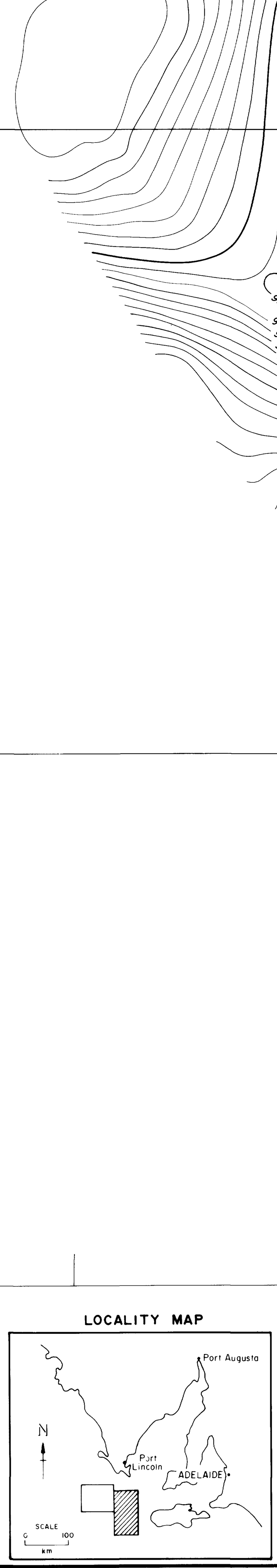
Compiled by the Drafting Branch, S.A.D.M.E.

Published 1989
First Edition

Encl. 1

90-387





SCALE

km 2 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

Note: Contour values are in metres below sea level (Datum: AHD)

Enclosure 2a

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

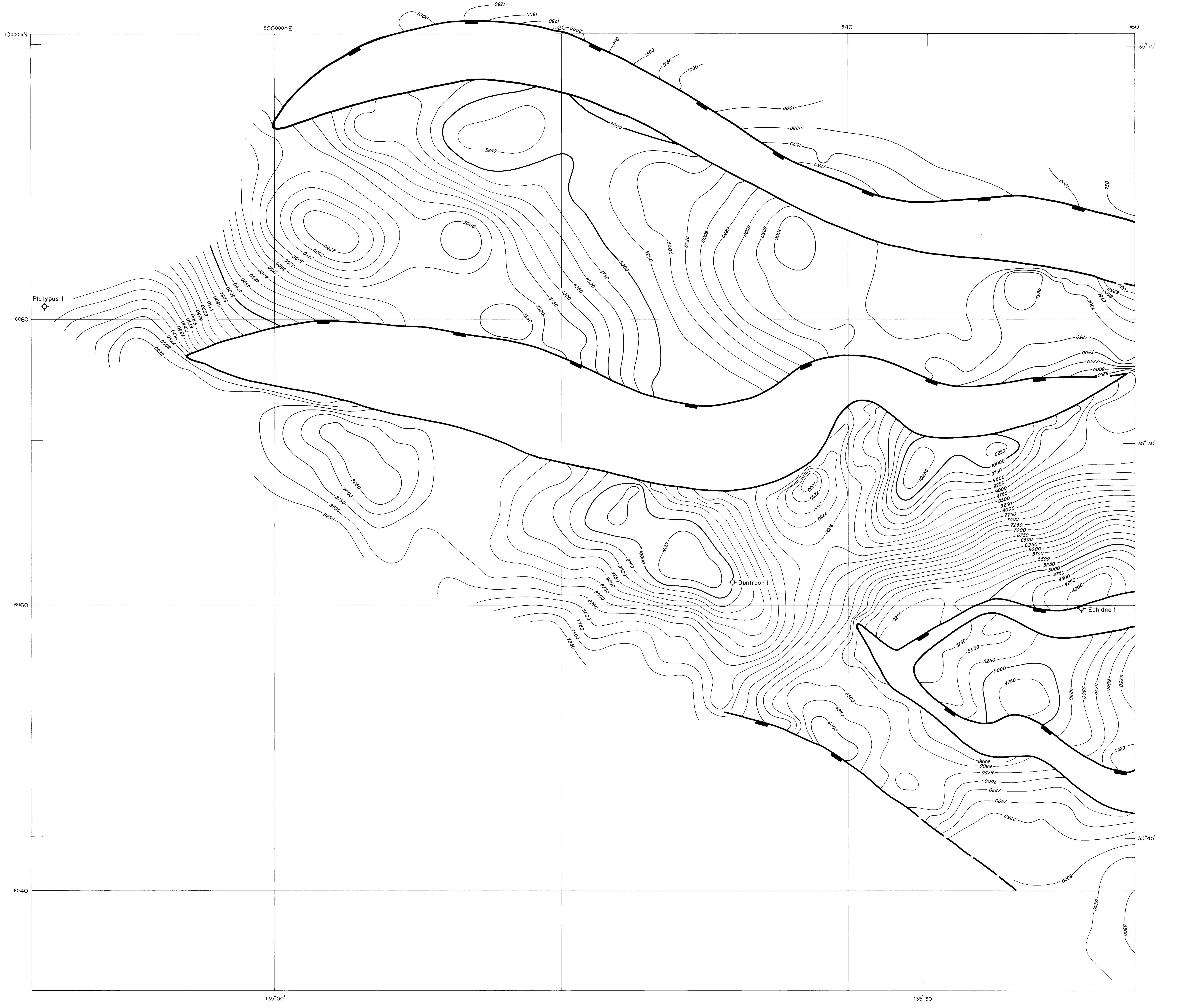
DUNTROON BASIN GEOPHYSICAL STUDY

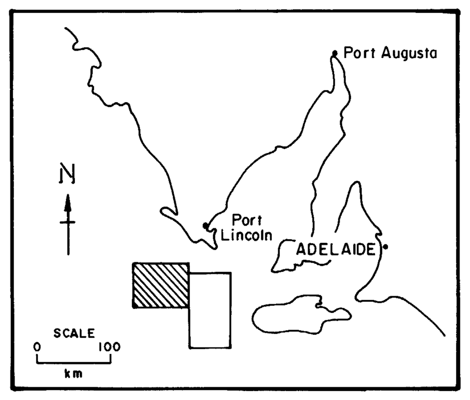
DEPTH TO BASEMENT

EASTERN SHEET

COMPILED	B. Thomas
DRAWN	E. Calabio
DATE	July '1989
CHECKED	
CDO	DATE 1·10·90
SCALE	1:100 000
PLAN NUMBER	89-305

4858





SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

Note: Contour values are in meters below sea level (Datum: AHD)

Enclosure 2b

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

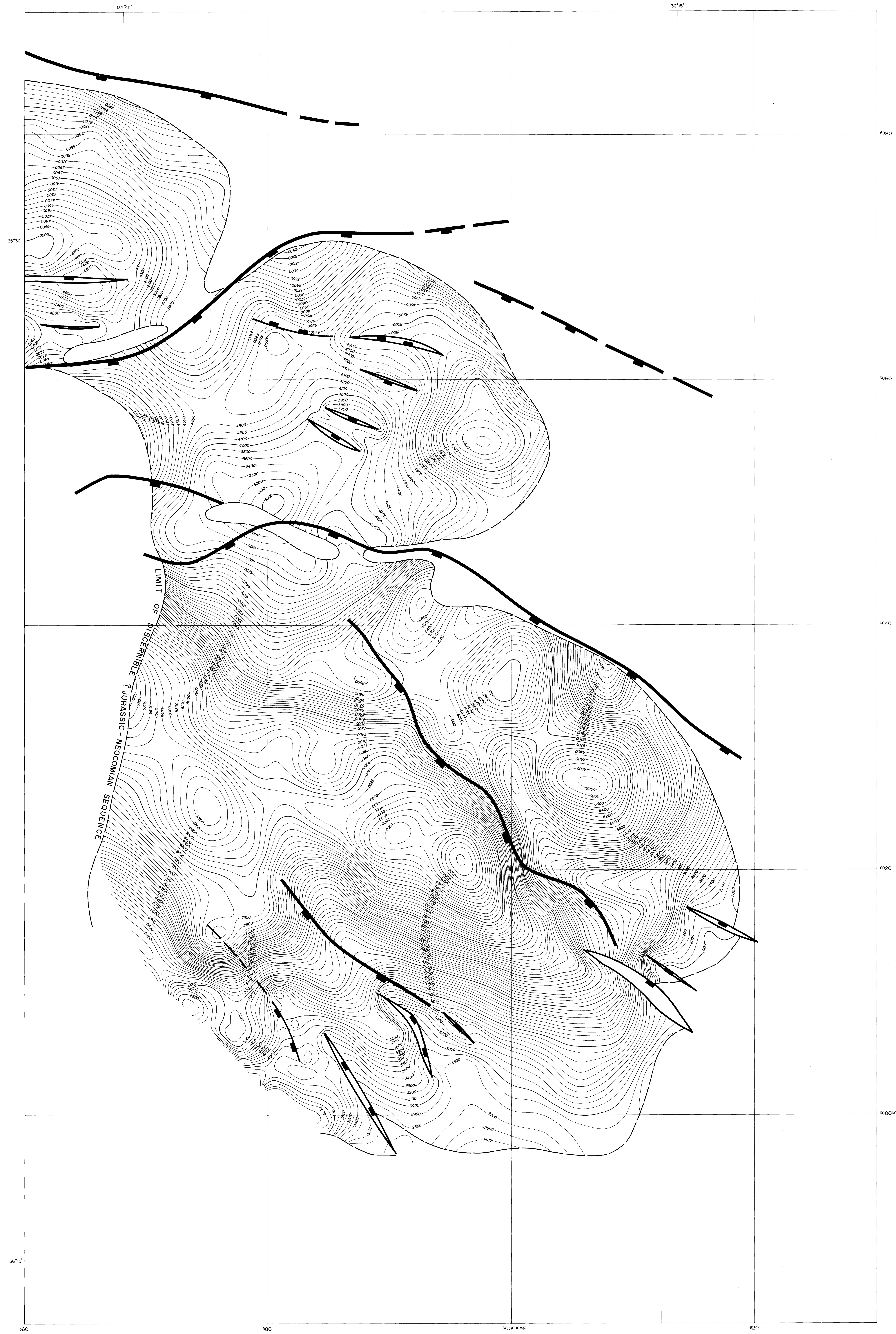
DUNTROON BASIN GEOPHYSICAL STUDY

DEPTH TO BASEMENT

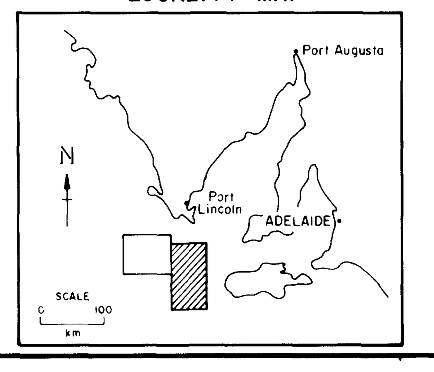
WESTERN SHEET

COMPILED B. Thomas
DRAWN E. Calabio
DATE July '1989
CHECKED
C.D.O. DATE
SCALE 1:100 000
PLAN NUMBER
89-304

4856



LOCALITY MAP



SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

Note: Contour values are in metres below sea level (Datum: AHD)

See 'Western Sheet' for legend.

Enclosure 3a

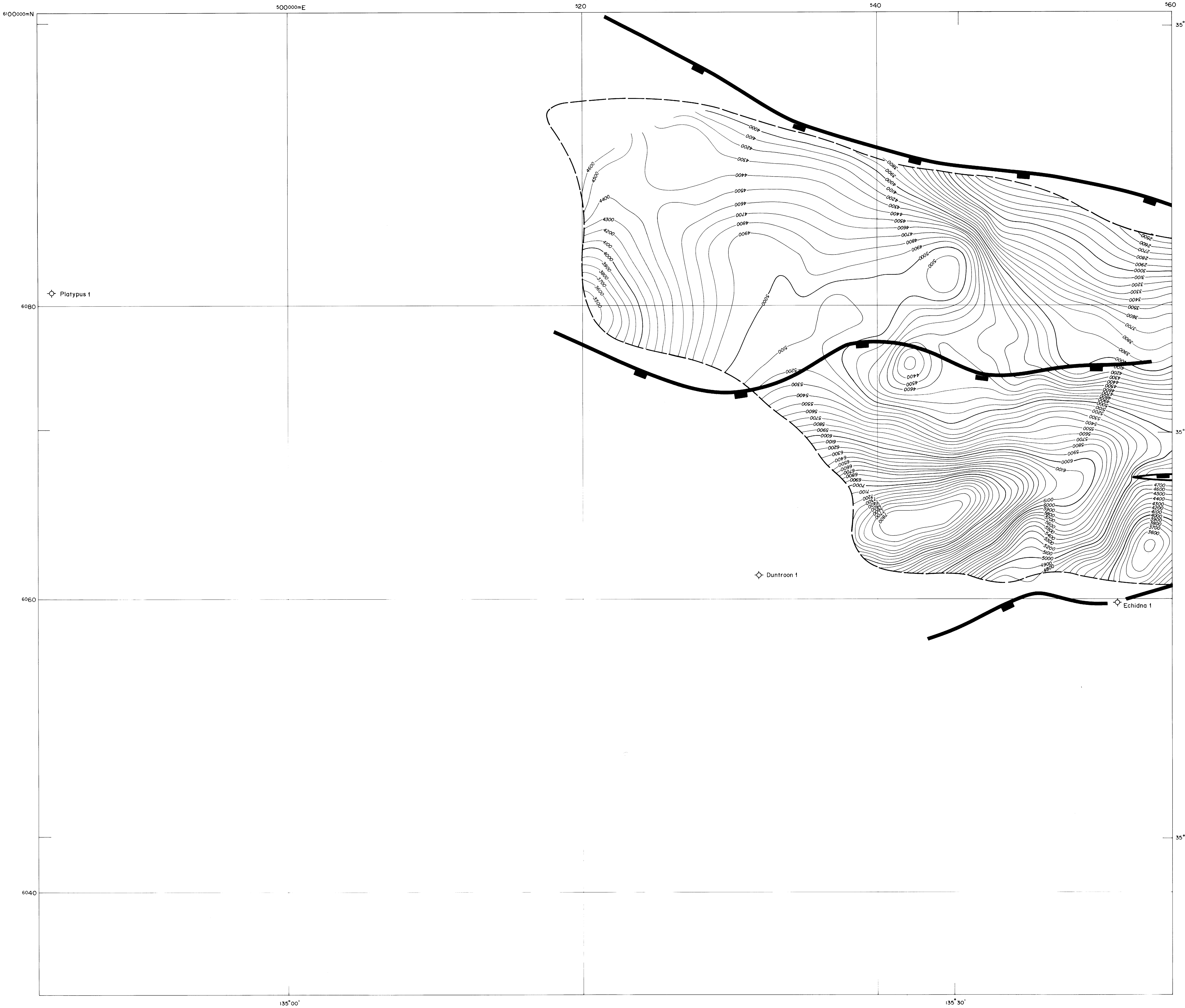
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

DUNTROON BASIN GEOPHYSICAL STUDY

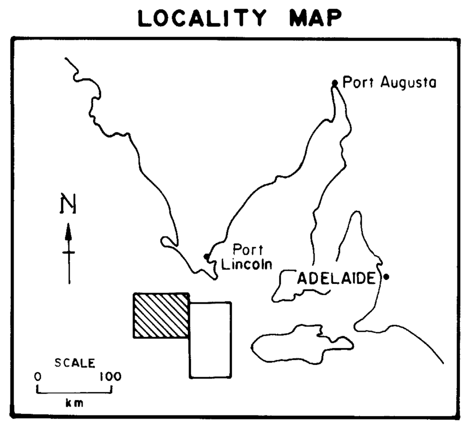
DEPTH TO TOP
? JURASSIC - NEOCOMIAN SEQUENCE

EASTERN SHEET

COMPILED	B. Thomas
DRAWN	E. Calabio
DATE	July '1989
CHECKED	
CDO	DATE 1·10·90
SCALE	1:100 000
PLAN NUMBER	89-303



LOCALITY MAP



SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

LEGEND

Normal Fault..............

Major Basement Fault ......

Note: Contour values in meters below sea level (Datum: AHD)

Enclosure 3b

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

COMPILED B. Thomas
DRAWN E. Calabio
DATE July 1989
CHECKED
C.D.O. DATE
SCALE 1:100 000
PLAN NUMBER
89-302

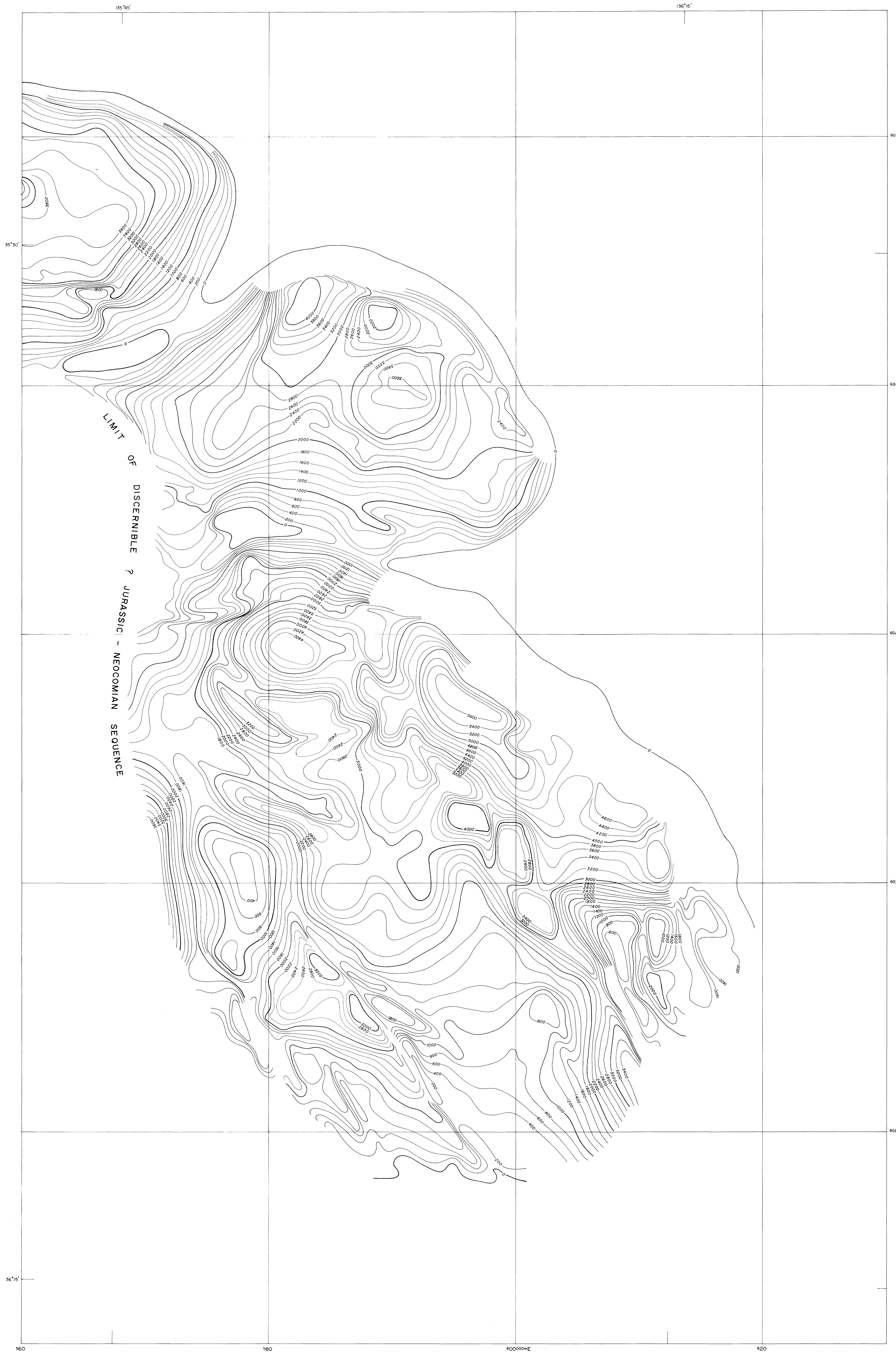
DUNTROON BASIN GEOPHYSICAL STUDY

DEPTH TO TOP

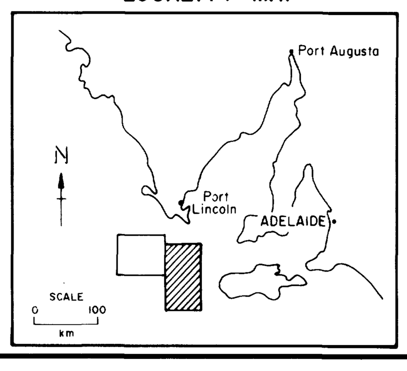
? JURASSIC - NEOCOMIAN SEQUENCE

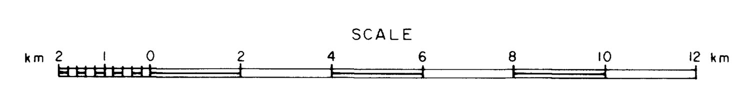
WESTERN SHEET

4856



LOCALITY MAP





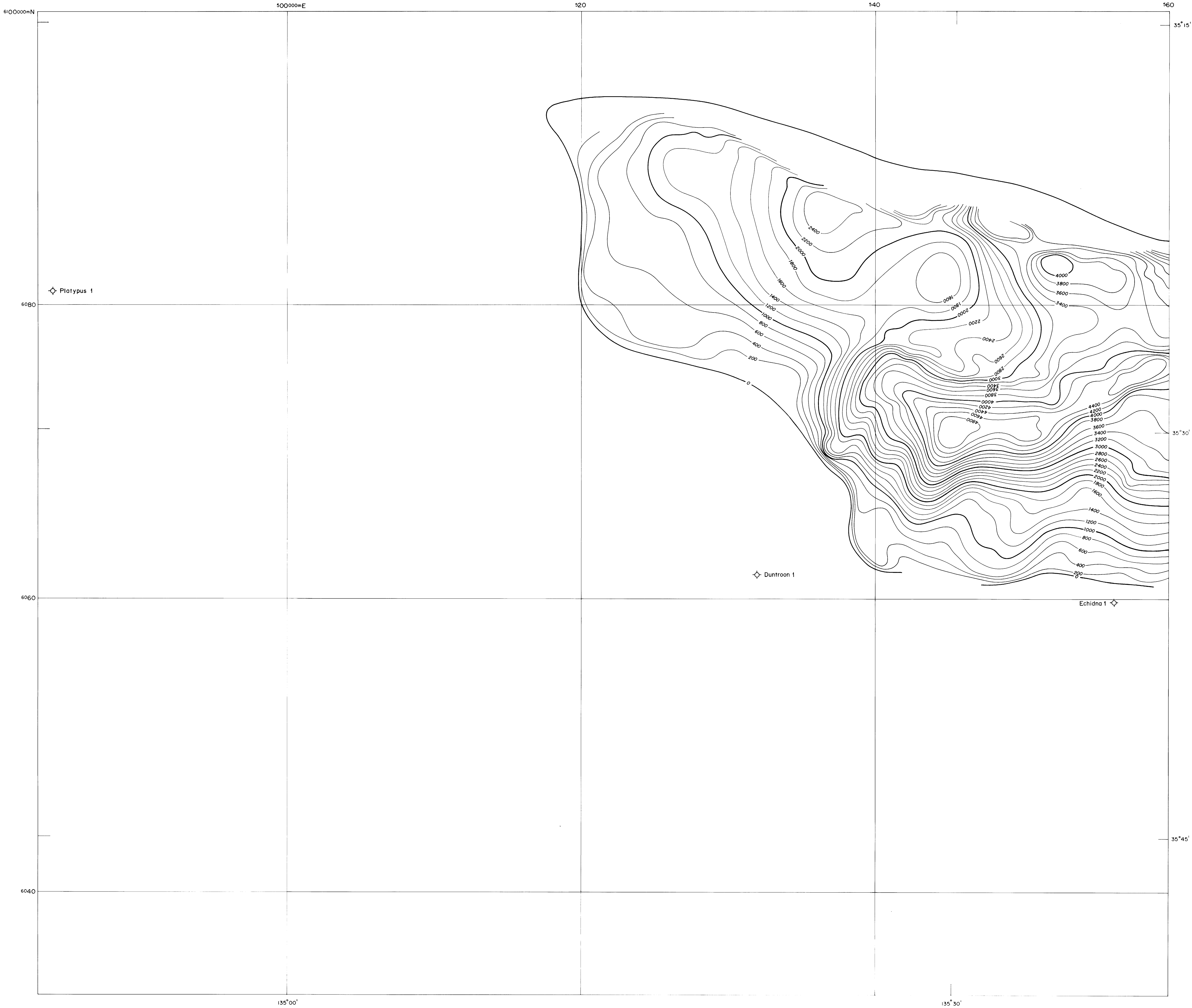
Australian Map Grid Zone 53

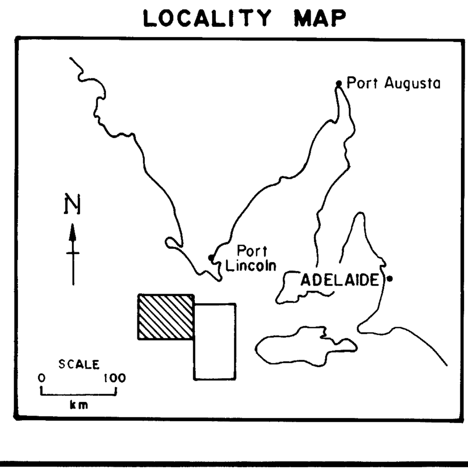
Note: Isopach values are in metres.

Enclosure 4a

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE July '1989
DUNTROON BASIN GEOPHYSICAL STUDY	CHECKED
? JURASSIC - NEOCOMIAN SEQUENCE	CDO 1-10-90 DATE
ISOPACH MAP	SCALE 1:100 000
EASTERN SHEET	PLAN NUMBER 89-313

4658





SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

Note : Isopach values are in metres.

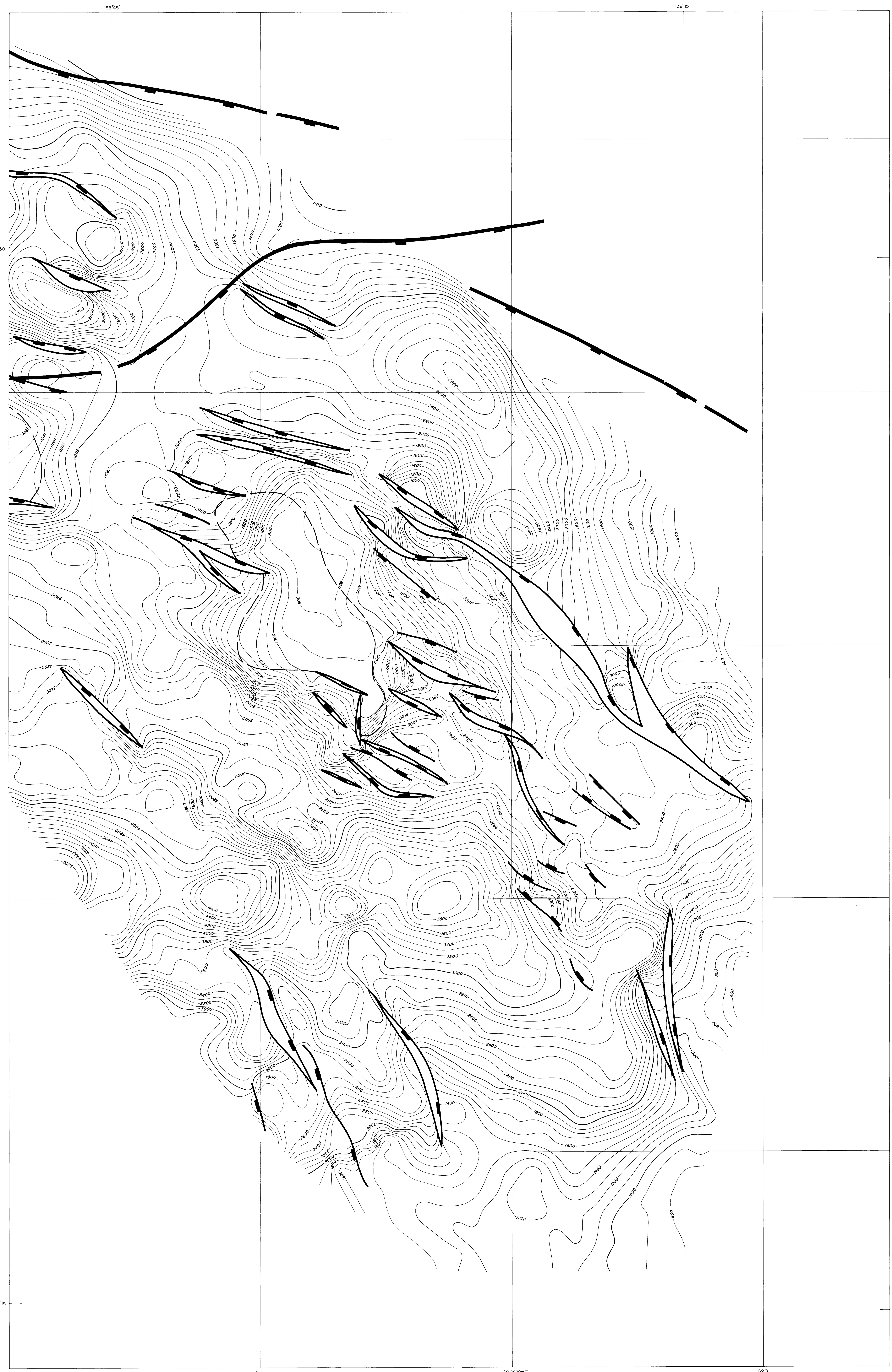
Enclosure 4b

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

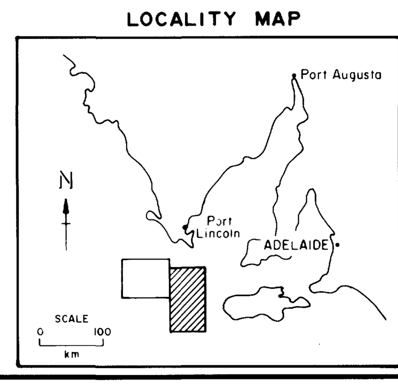
DUNTROON BASIN GEOPHYSICAL STUDY
? JURASSIC – NEOCOMIAN SEQUENCE
ISOPACH MAP
WESTERN SHEET

COMPILED	B. Thomas
DRAWN	E. Calabio
DATE	July '1989
CHECKED	
CDO DATE	
SCALE	1:100 000
PLAN NUMBER	89-312

4856



LOCALITY MAP



SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

Note: Contour values are in metres below sea level (Datum: AHD)
See 'Western Sheet' for legend.

Enclosure 5a

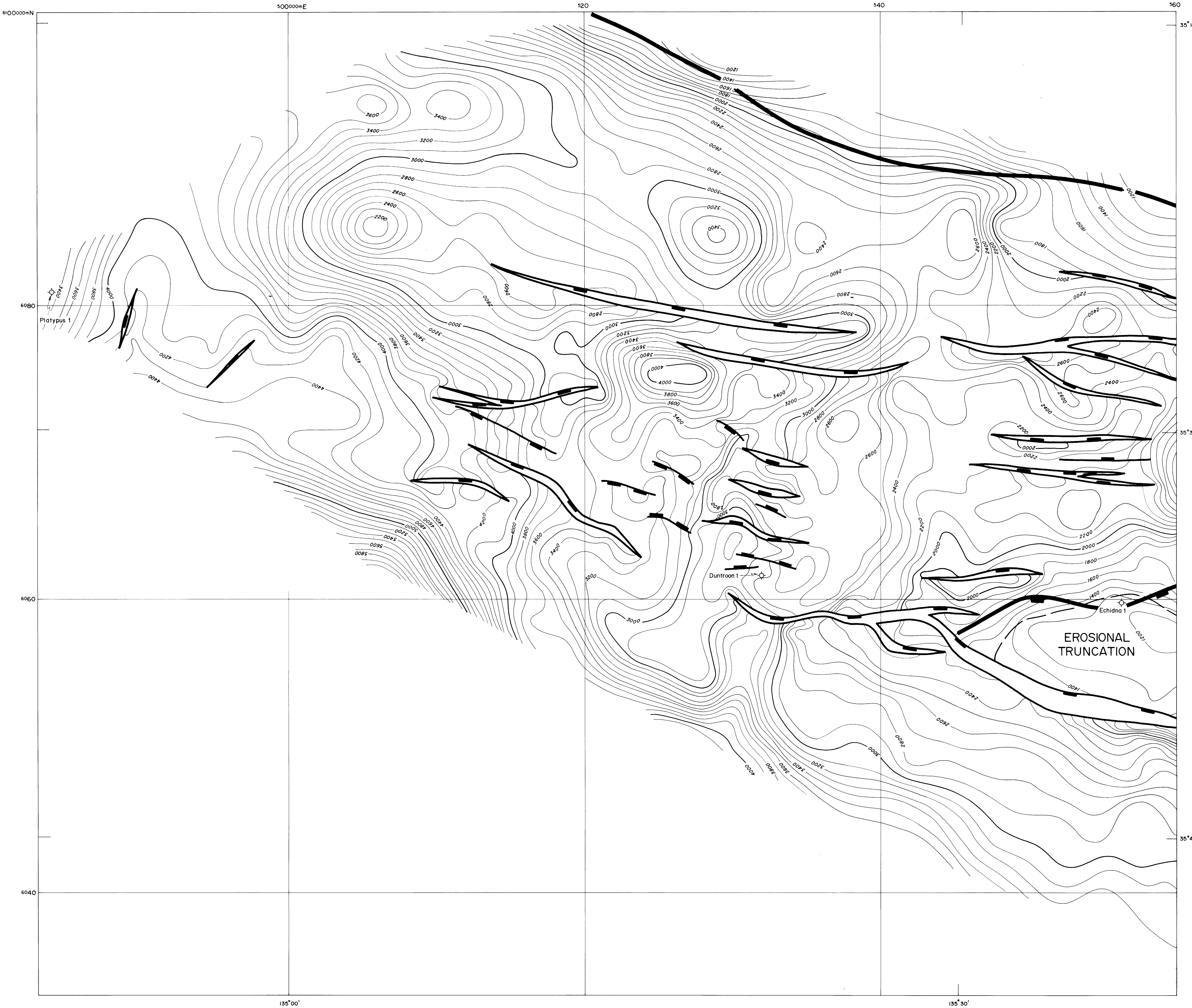
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

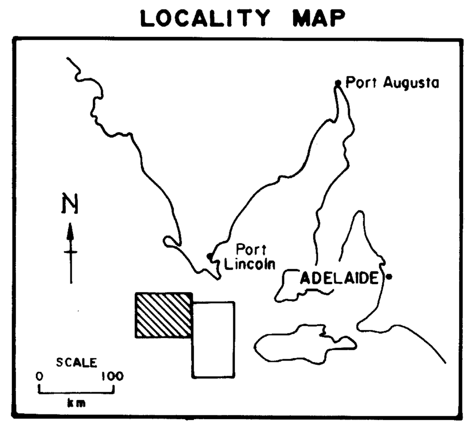
DUNTROON BASIN GEOPHYSICAL STUDY

DEPTH TO TOP DUNTROON GROUP

EASTERN SHEET

COMPILED	B. Thomas
DRAWN	E. Calabio
DATE	July '1989
CHECKED	
CDO	DATE 1·10·90
SCALE	1:100 000
PLAN NUMBER	89-301





SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

LEGEND

Normal Fault ....

Major Basement Fault ......

Note: Contour values in metres below sea level (Datum: AHD)

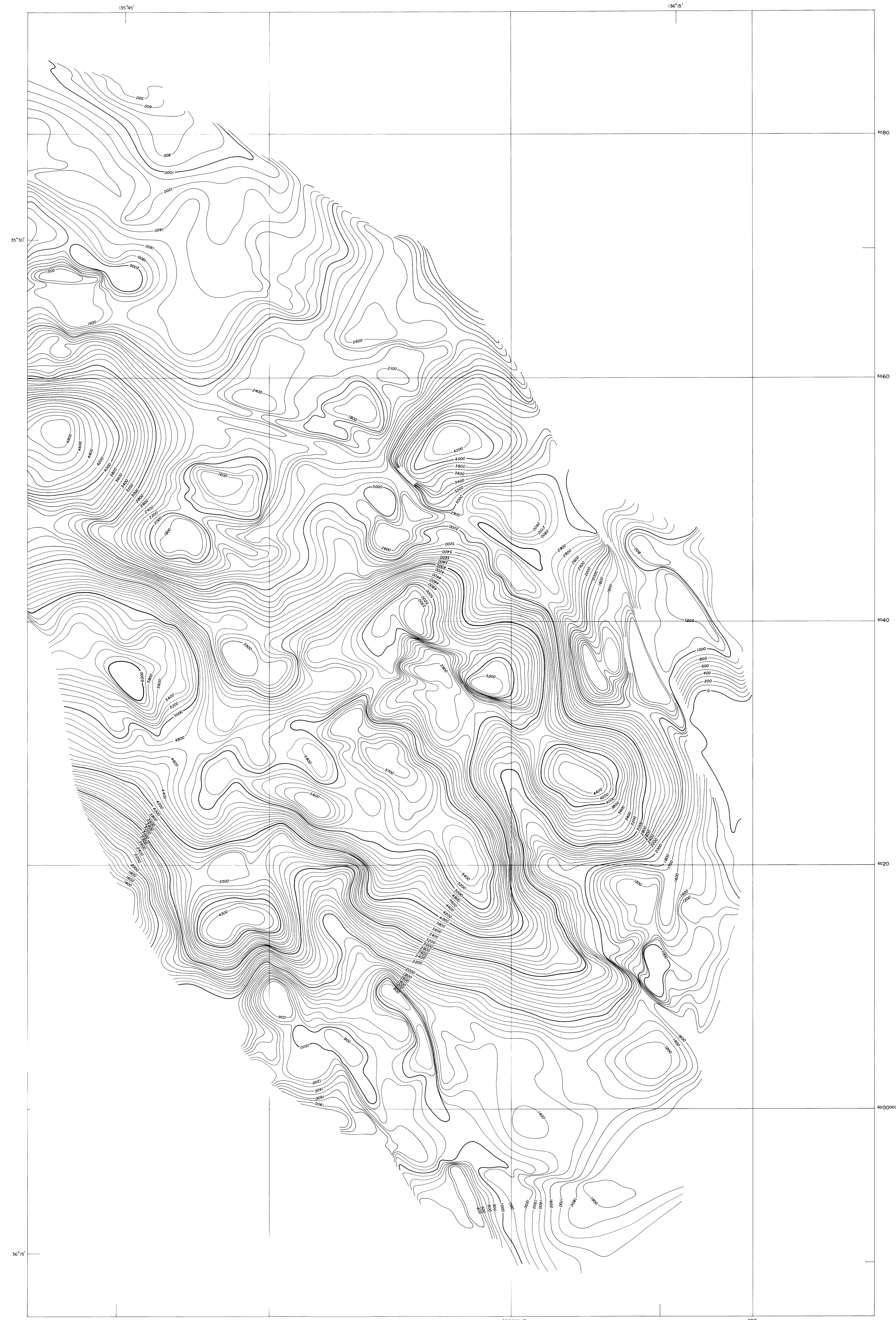
Enclosure 5b

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

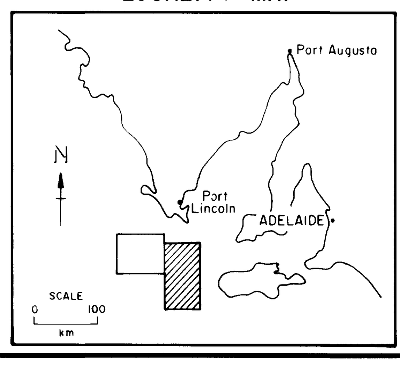
DUNTROON BASIN GEOPHYSICAL STUDY
DEPTH TO TOP
DUNTROON GROUP
WESTERN SHEET

COMPILED	B. Thomas
DRAWN	E. Calabio
DATE	July '1989
CHECKED	
C.D.O.	DATE 1·10·90
SCALE	1:100 000
PLAN NUMBER	89-300

4856



LOCALITY MAP



SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

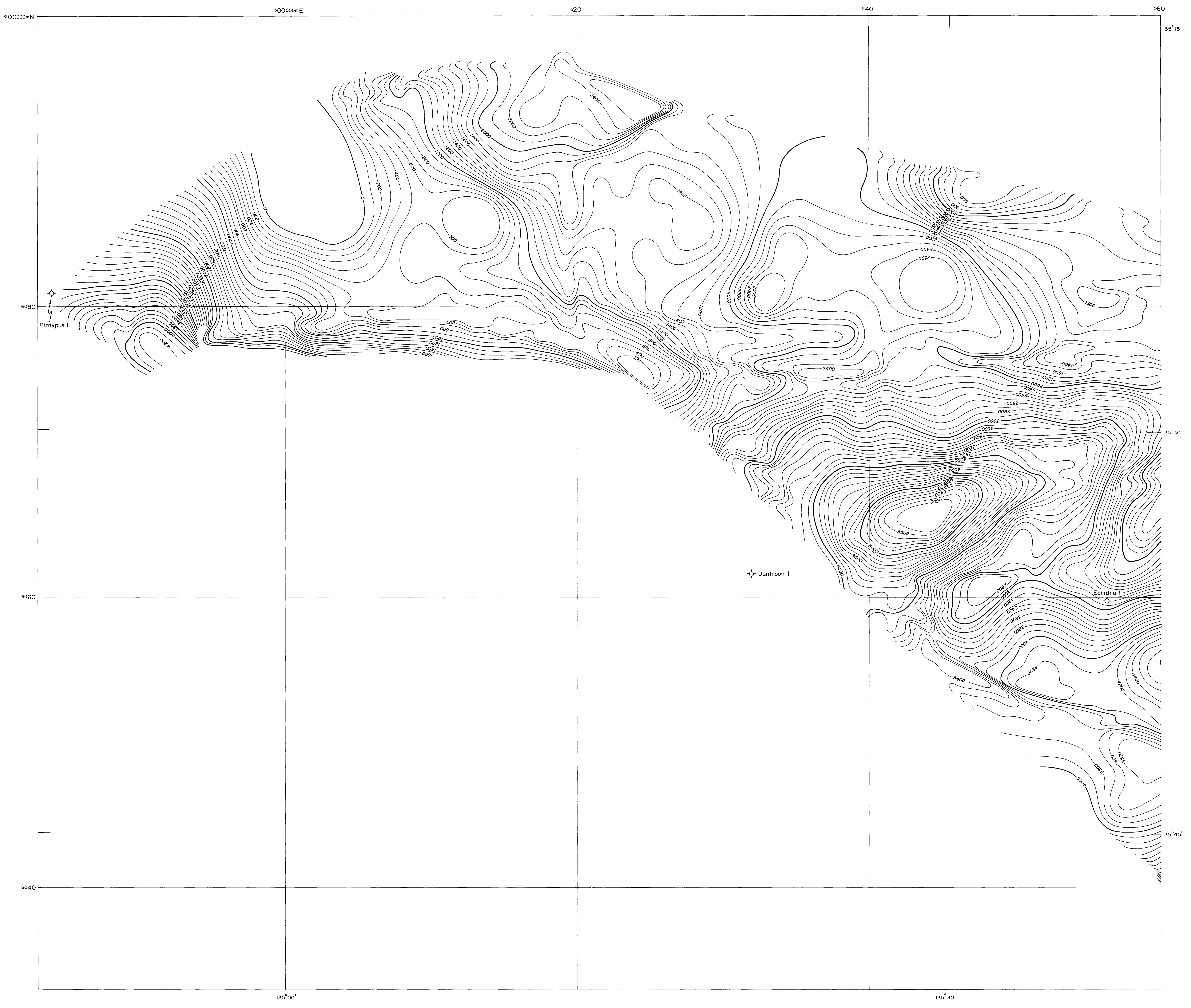
Note : Isopach values are in metres.

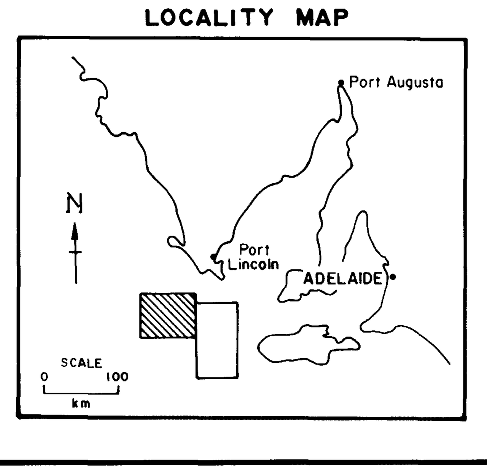
Enclosure 6a

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

DUNTROON BASIN GEOPHYSICAL STUDY
DUNTROON GROUP
ISOPACH MAP
EASTERN SHEET

COMPILED B. Thomas
DRAWN E. Calabio
DATE July '1989
CHECKED
1·10·90
CDO DATE
SCALE 1:100 000
PLAN NUMBER
89-311





SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

Note: Isopach values are in metres.

Enclosure 6b

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

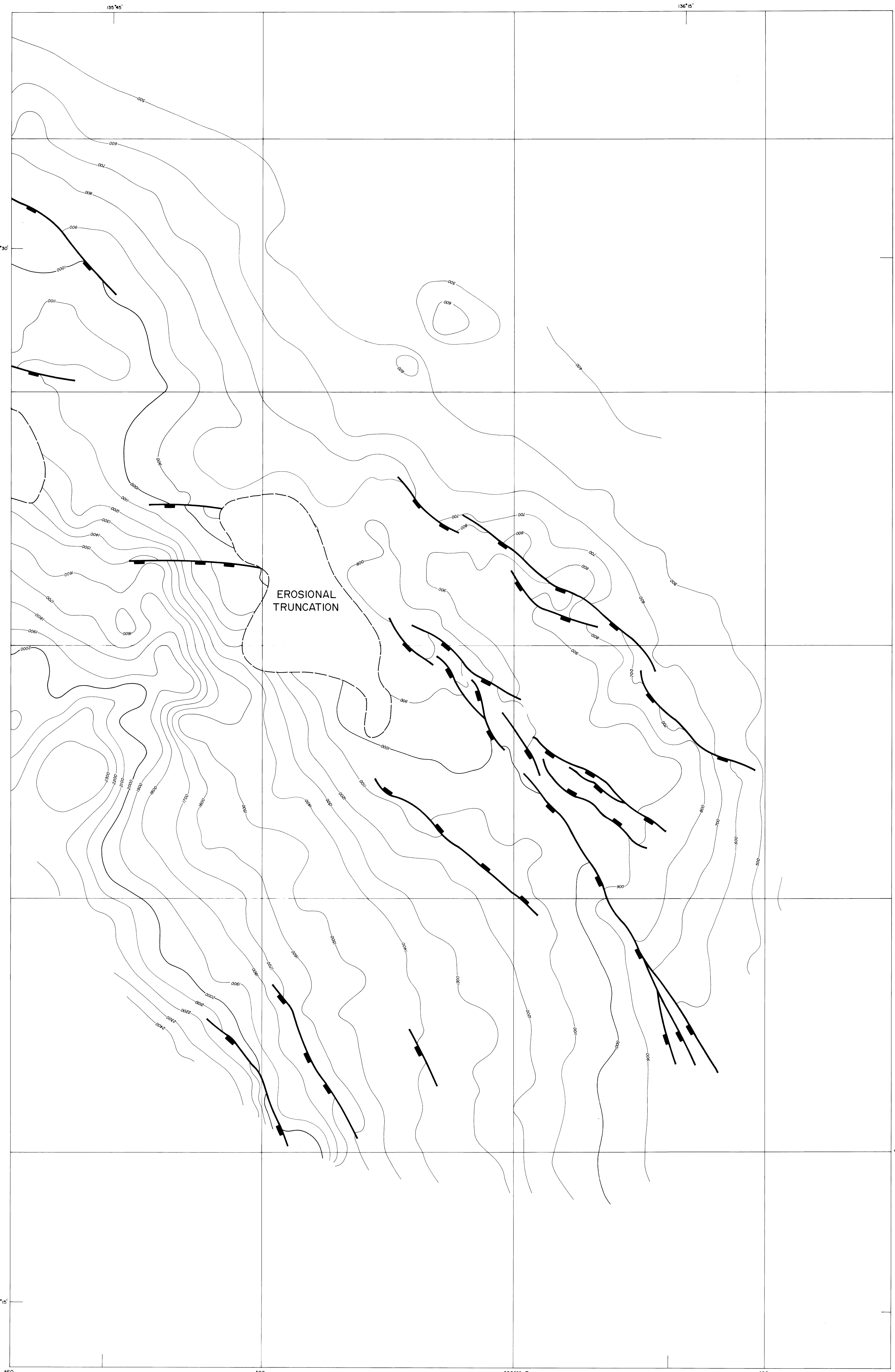
COMPILED	B. Thomas
DRAWN	E. Calabio
DATE	July '1989
CHECKED	
CDO	DATE
SCALE	1:100 000
PLAN NUMBER	89-310

DUNTROON BASIN GEOPHYSICAL STUDY

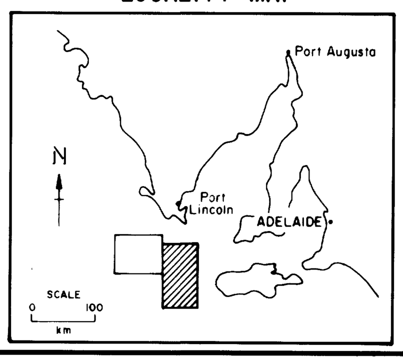
DUNTROON GROUP ISOPACH MAP

WESTERN SHEET

4856



LOCALITY MAP



SCALE

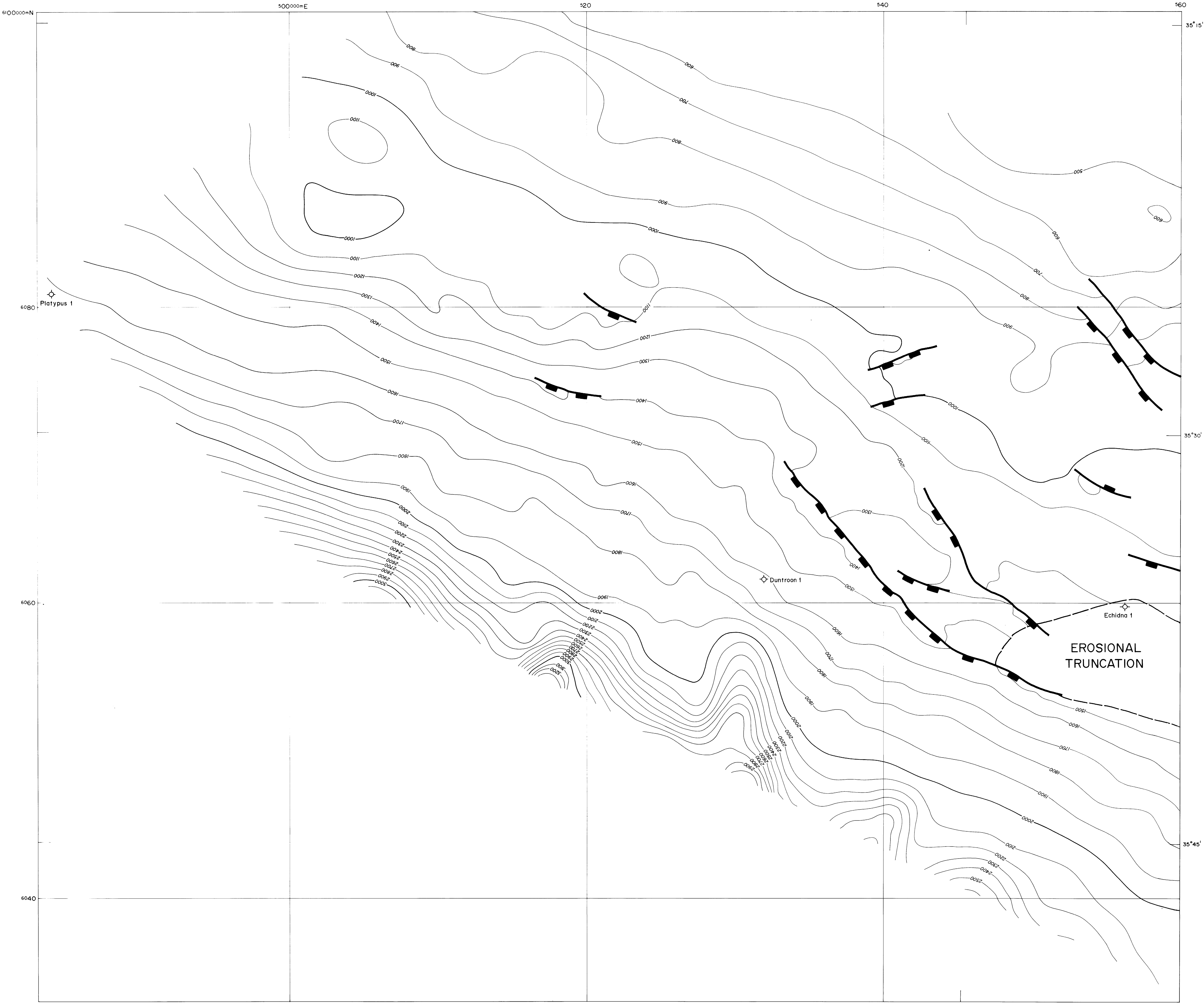
km 2 1 0 2 4 6 8 10 12 km

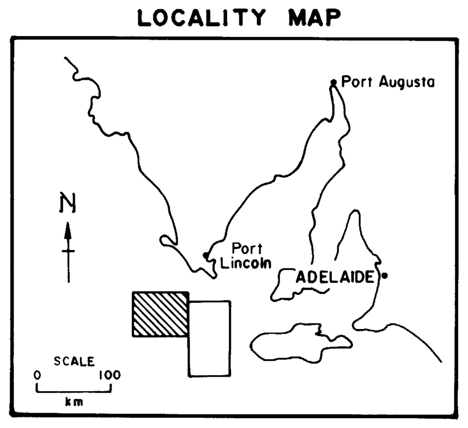
Australian Map Grid Zone 53

Note: Contour values in metres below sea level (Datum: AHD).

Enclosure 7a

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE July '1989
DUNTROON BASIN GEOPHYSICAL STUDY	CHECKED
DEPTH TO TOP BIGHT GROUP	C.D.O. DATE 2.10.90
EASTERN SHEET	SCALE 1:100 000
	PLAN NUMBER 89-299





SCALE

km 2 1 0 2 4 6 8 10 12 km

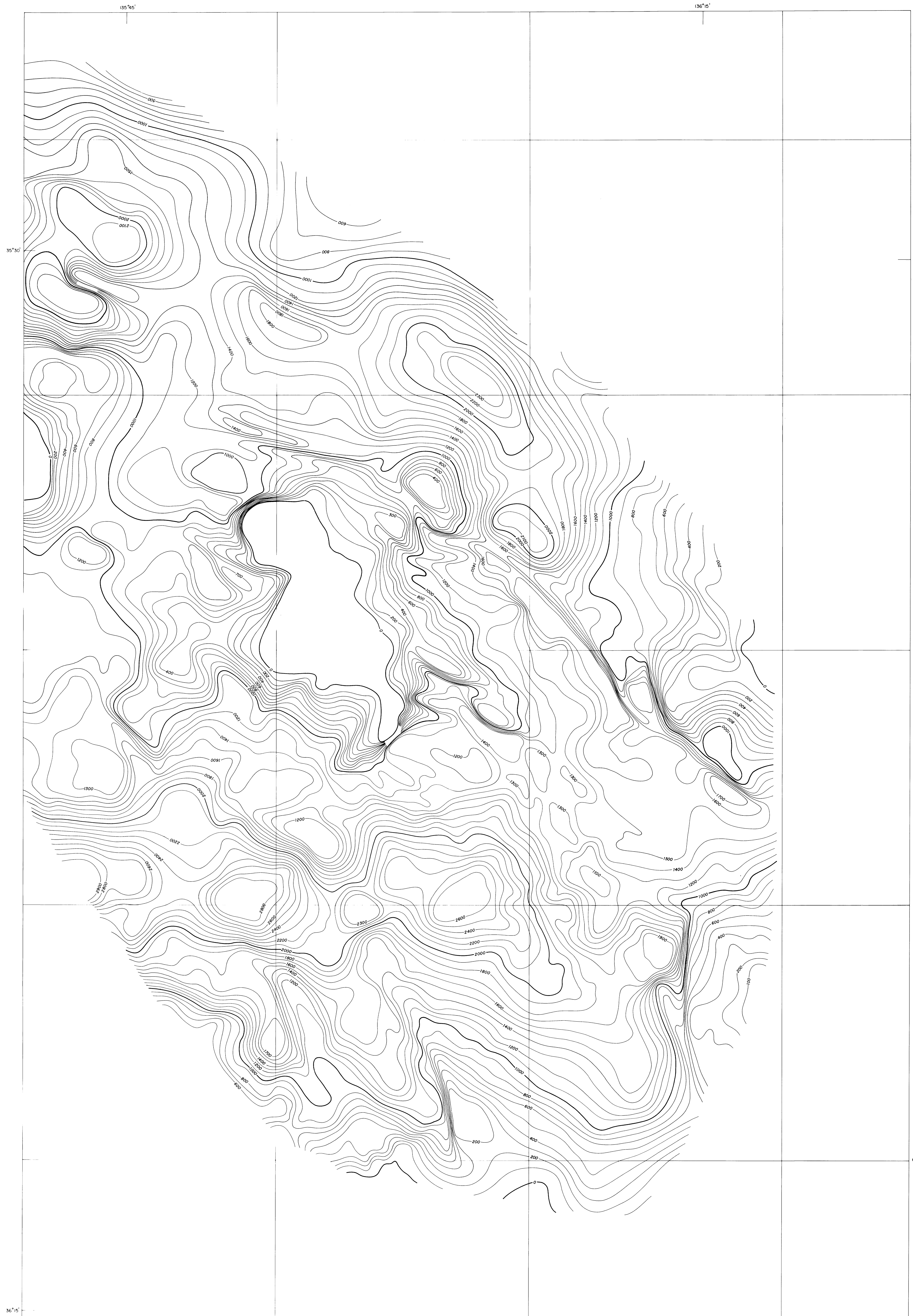
Australian Map Grid Zone 53

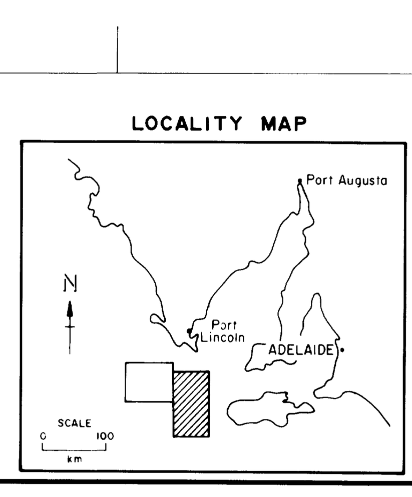
Note : Contour values in metres below sea level (Datum : AHD).

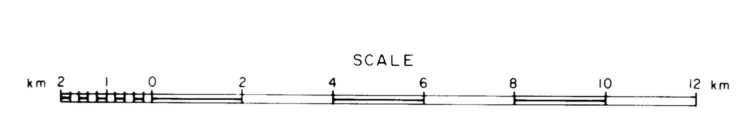
Enclosure 7b

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE July '1989
DUNTROON BASIN GEOPHYSICAL STUDY	CHECKED
DEPTH TO TOP BIGHT GROUP	E.B.T per WDR 2/10/90 C.D.O. DATE
WESTERN SHEET	SCALE 1:100 000
	PLAN NUMBER 89-298

4856





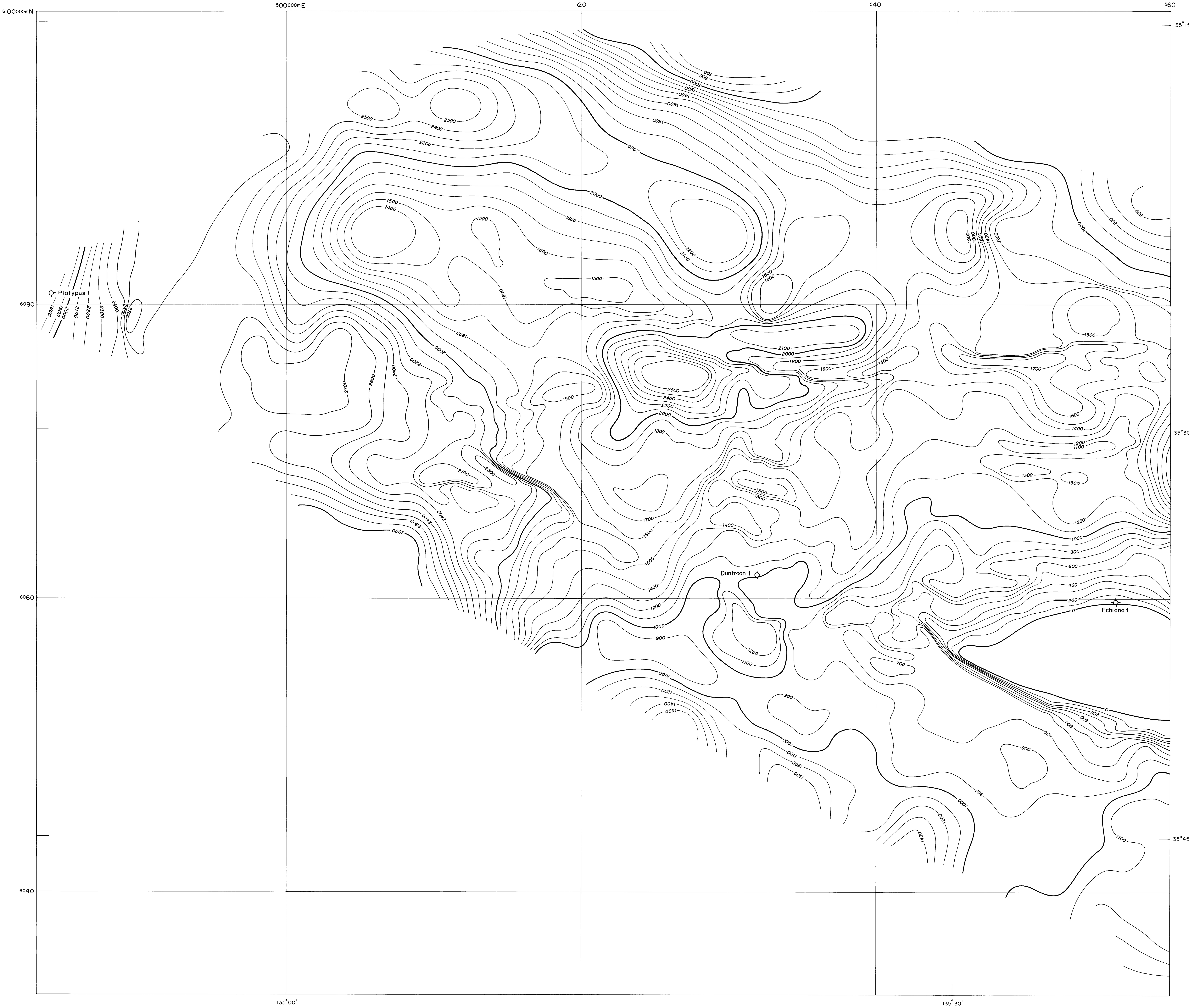


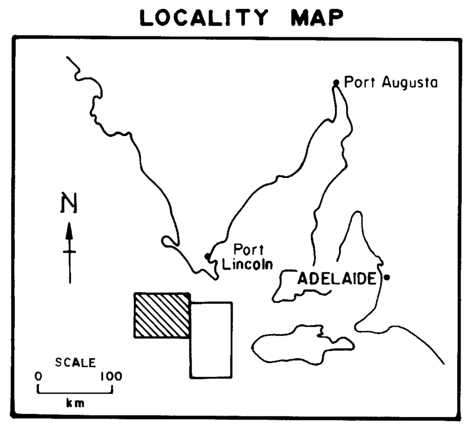
Australian Map Grid Zone 53

Note : Isopach values are in metres.

Enclosure 8a

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE July '1989
	CHECKED
DUNTROON BASIN GEOPHYSICAL STUDY	1·10·90 CDO DATE
BIGHT GROUP ISOPACH MAP EASTERN SHEET	SCALE 1:100 000
	PLAN NUMBER 89-309





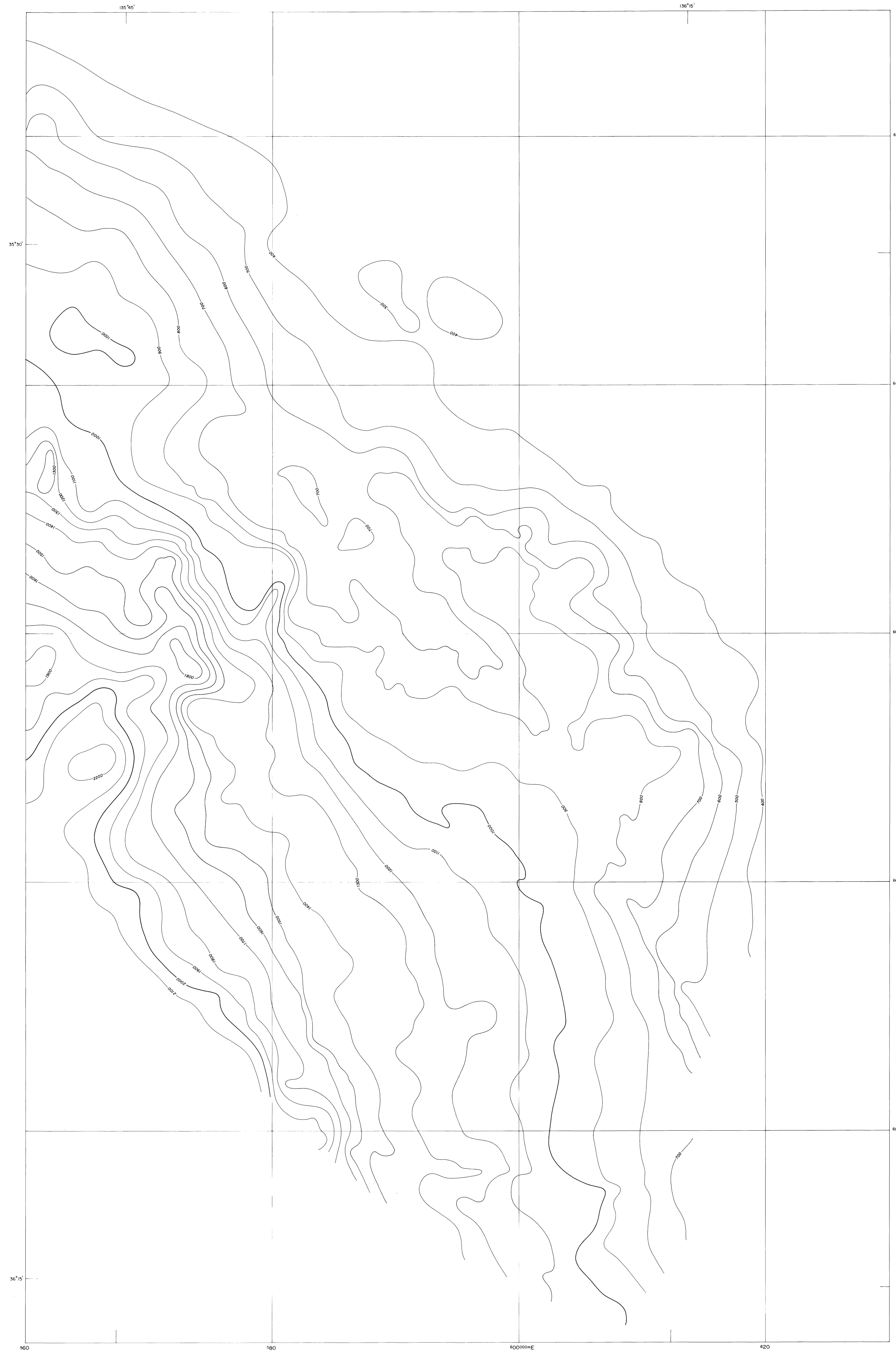
Australian Map Grid Zone 53

Note : Isopach values are in metres

Enclosure 8b

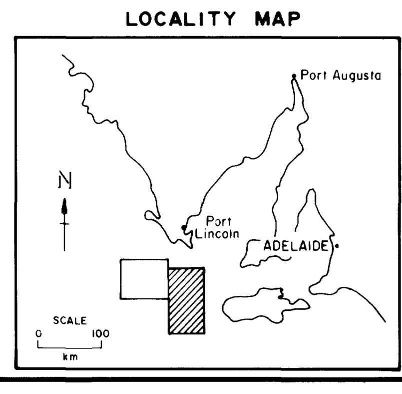
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE July '1989
DUNTROON BASIN GEOPHYSICAL STUDY	CHECKED
BIGHT GROUP	CDO DATE
ISOPACH MAP	SCALE 1:100 000
WESTERN SHEET	PLAN NUMBER 89-308

4856



Note : Isopach values are in metres

LOCALITY MAP



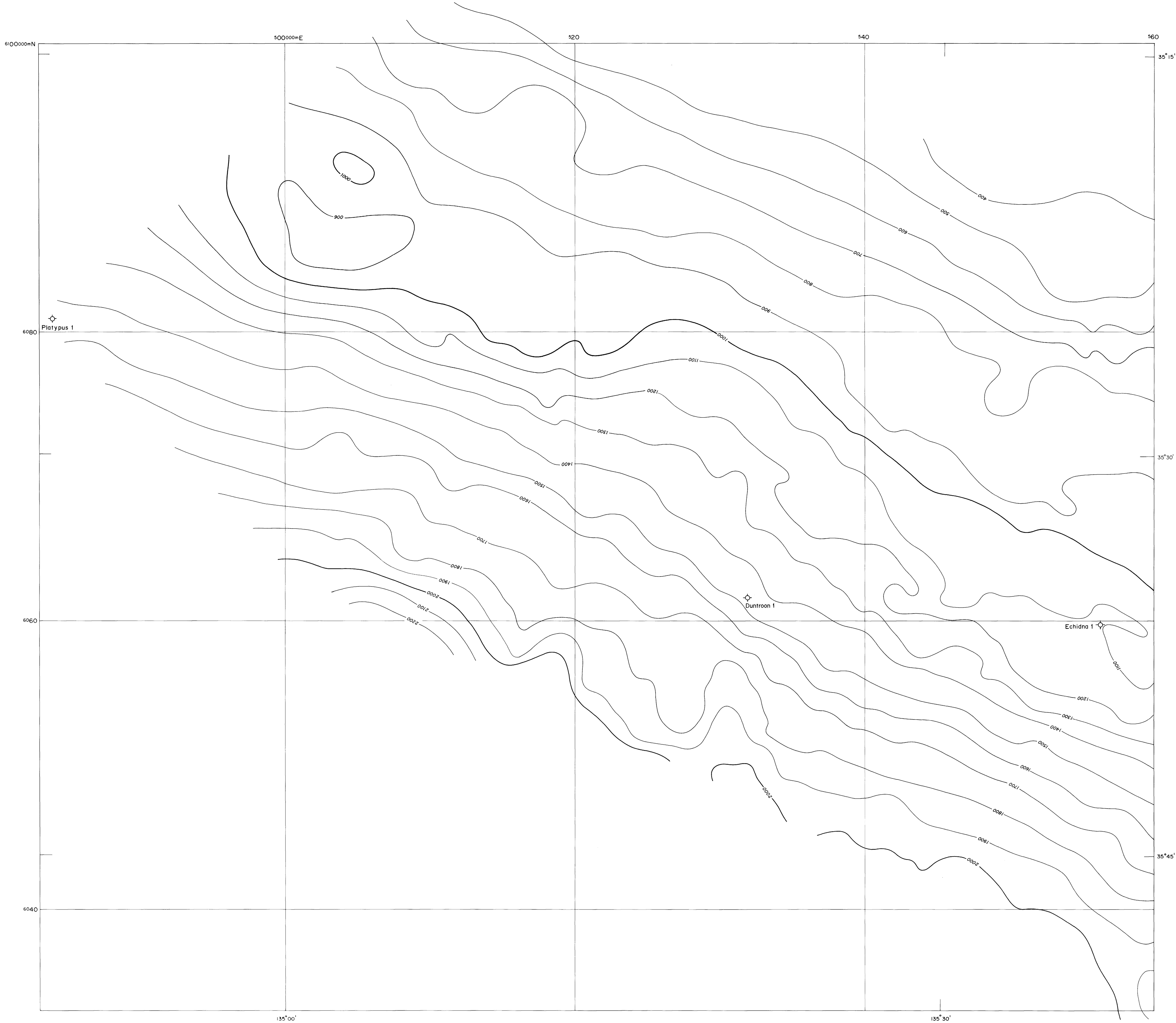
SCALE

km 2 1 0 2 4 6 8 10 12 km

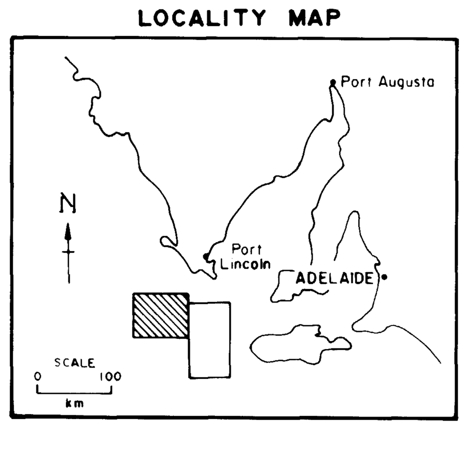
Australian Map Grid Zone 53

Enclosure 9a

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE July '1989
DUNTROON BASIN GEOPHYSICAL STUDY	CHECKED
TERTIARY ISOPACH MAP	BF 1·10·90 CDO DATE
EASTERN SHEET	SCALE 1:100 000
	PLAN NUMBER **89-307**



LOCALITY MAP



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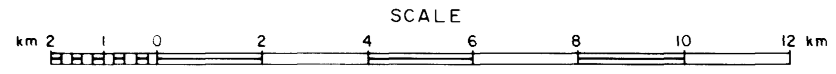


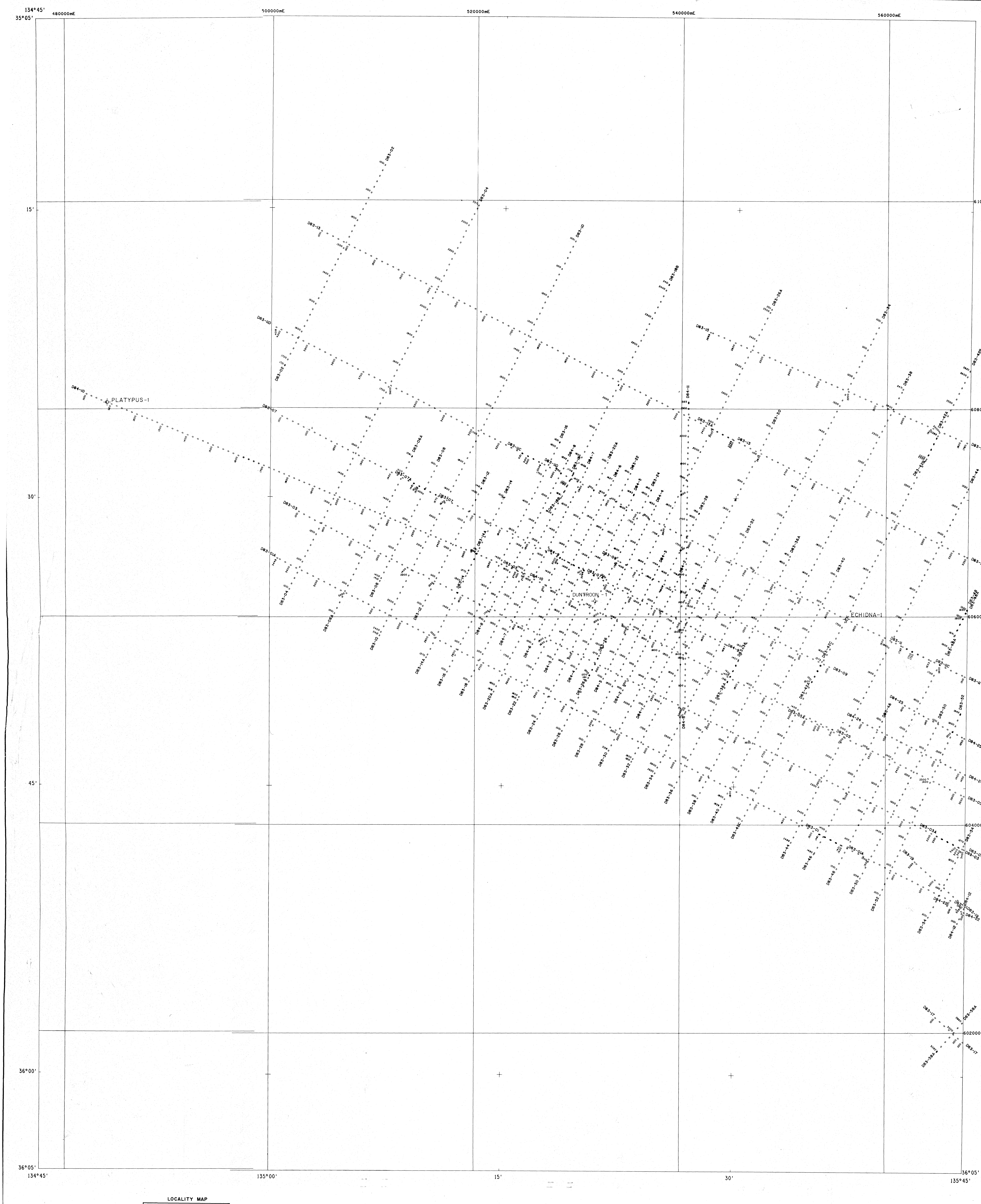
Australian Map Grid Zone 53

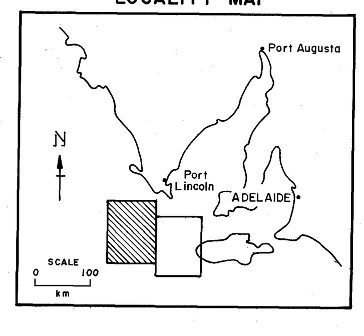
Note : Isopach values are in metres

Enclosure 9b

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE July '1989
DUNTROON BASIN GEOPHYSICAL STUDY	CHECKED
	C D O DATE
TERTIARY ISOPACH MAP	SCALE 1:100 000
WESTERN SHEET	PLAN NUMBER 89-306

4856





SCALE

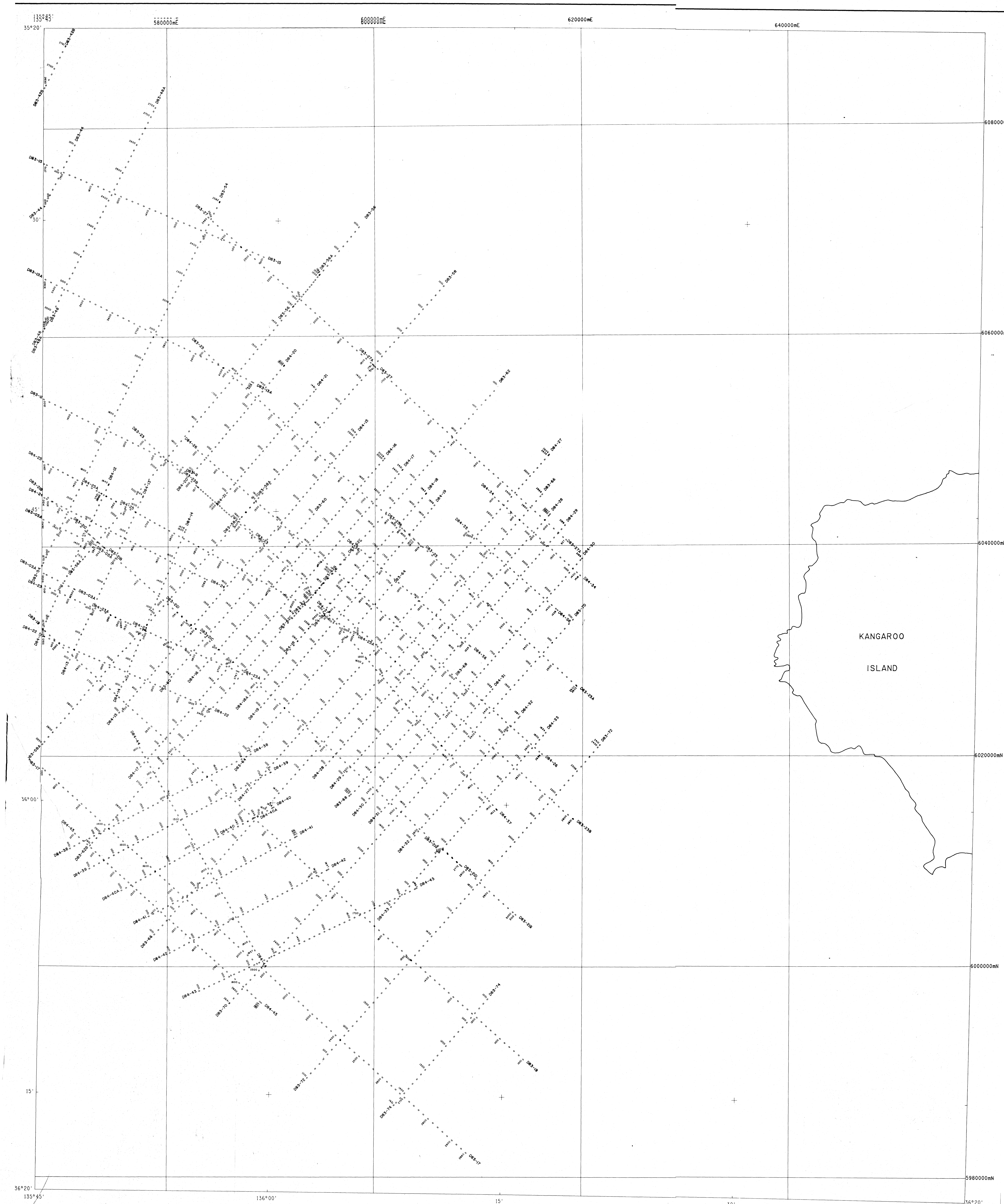
km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

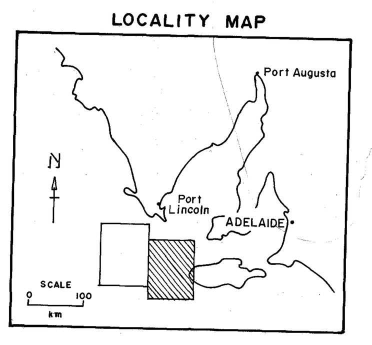
Seismic line number and shot point location.................... D83-40

Enclosure 10 a

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE June '1990
DUNTROON BASIN GEOPHYSICAL STUDY	CHECKED
SEISMIC LINE AND	C.D.O. 1·10·90 DATE
SHOT POINT LOCATION	SCALE 1:100 000
WESTERN SHEET	PLAN NUMBER 90-383



LOCALITY MAP



SCALE

km 2 1 0 2 4 6 8 10 12 km

Australian Map Grid Zone 53

Seismic line number and shot point location.................. D83-40 1829 18000

Enclosure 10b

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED B. Thomas
	DRAWN E. Calabio
	DATE June '1990
DUNTROON BASIN GEOPHYSICAL STUDY	CHECKED
SEISMIC LINE AND SHOT POINT LOCATION EASTERN SHEET	C.D.O. DATE 1·10·90
	SCALE 1:100 000
	PLAN NUMBER 90-384