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DEPARTMENT OF MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record No. 1973/53 + Figures.

THE GALILEE BASIN

by

R.R. Vine+

+Principal Executive Officer, Department of Minerals and Energy; formerly Superivising Geologist, Bureau of Mineral Resources; published by permission of the Director, BMR.

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SUMMARY

The Galilee Basin extends over approximately 190 000 km^2 west of the Anakie Inlier. It formed by periodic downwarping during late Carboniferous, Permian and Triassic times and received thick, predominantly terrestrial sediments.

Isopachs demonstrate the development of a trough close to the eastern margin in Upper Carboniferous and early Permian times. In mid-Lower Permian time downwarping of the trough ceased, but two sub-basins formed by downwarping associated with movements of the Hulton - Rand Structure and Cork Fault. Most of the later Lower Permian is represented by a basin-wide unconformity but deposition resumed late in Lower Permian times and continued through the Upper Permian; sediments are predominantly coal measures but there were brief marine incursions in the southeast on the Springsure Shelf. Upper Permian sedimentation was widespread and the basin reached its maximum area at this time although Triassic sedimentation locally extended beyond the Upper Permian margins.

During the Lower Triassic two troughs developed, one near the eastern margin and the other to the west of the Cork Fault. Mountainous country to the north provided a thick wedge of sand close to the margin. Rapid downwarping of the easterly trough in Upper Triassic times, partly to the east of the present Moolayember Formation outcrops, was possibly a precursor to the earth movements which finally ended development of the Galilee Basin.

An oil and gas show in Lake Galilee No. 1 well is important in showing that hydrocarbons have been generated in the Galilee Basin.

INTRODUCTION

This brief report on the Galilee Basin was prepared for the petroleum volume of "Economic Geology of Australia and Papua New Guinea", to be published by the Australian Institute of Mining and Metallurgy. Space limitation dictated the selection of material in the report, and the version finally submitted for publication is a slight abridgement of that presented here. The eight figures were planned for reduction to very small size so that all may appear on two pages. This necessitates elimination of much detail, such as well names. The original drafts of the illustrations at 1:1 000 000 scale are presented here as an aid to more detailed study and later amendment.

HISTORY OF EXPLORATION

Early geological studies in the Galilee Basin were mainly in connexion with a hydrological investigation of the Great Artesian Basin (Whitehouse, 1954). Subsequently, systematic surface mapping and subsurface studies of the whole area were carried out by the Bureau of Mineral Resources and the Geological Survey of Queensland; geological maps of 1:250 000 scale with accompanying Explanatory Notes for the whole area of the basin have either been published by the Bureau or are in press.

Exploration specifically for petroleum has been predominantly by geophysical surveys supplemented by drilling. The geophysical programs have covered practically the whole of the basin. They have generally been conventional, with a progression in individual areas from aeromagnetic or gravity work to reconnaissance seismic investigations followed by detailed seismic surveys to select drill sites. Unfortunately, for large parts of the basin, reconnaissance seismic surveys provided little useful data from below the "P" reflector at the top of the Permian sequence, but this can probably be rectified by use of more modern multiple-coverage techniques. Approximately 50 wells have been drilled in the Galilee Basin, but less than half and as prime objective the Galilee Basin sequence. References for all except the most recent geophysical surveys and wells are given in the Explanatory Notes accompanying the geological maps.

DEFINITION AND RELATIONSHIPS

Whitehouse (1954) named the Galilee Basin in passing, using the name on his Figure 34 with no more explanation than that it applied to a Permian and early Mesozoic basin. However (p. 15), he referred to the development of a meridional depression west of the Drummond Ranges. Present-day usage of the term is essentially for such a depression west of the Anakie Inlier, although it is now known that Permian and Triassic sediments are more extensive than Whitehouse postulated, and that sedimentation started earlier than he realized. The Galilee Basin can now be defined as the basin formed by periodic downwarping of a large area (about 190 000 km^2) west of the Anakie Inlier during late Carboniferous, Permian, and Triassic times and filled by sediments. The Bowen and Galilee Basins can be regarded as complimentary downwarps on either side of the Anakie Inlier, and merging with each other over the Springsure Shelf.

Much of the basin is now concealed beneath sediments of the Jurassic-Cretaceous Eromanga Basin; outcrops of Galilee Basin rocks are confined to a belt along the eastern margin, but even in that belt there are extensive areas covered by Cainozoic deposits.

Galilee Basin sediments rest on a variety of older rocks including thin Carboniferous sediments of the Drummond Basin on the northeast margin, Devonian sediments of the Adavale Basin in the south and a possible northern continuation of unknown extent (Vine, 1972), and a complex of older Palaeozoic and Precambrian crystalline rocks. The distribution of basement rock types is, as yet, poorly known.

STRUCTURE

Structure contours of the top of the Permian section illustrate the present shape of the Galilee Basin (Fig. 1). The horizon is generally easily recognizable on both well logs and seismic sections owing to the presence of late Upper Permian coal seams which form good seismic reflectors. Locally, where there are no Upper Permian coal seams, the horizon is an unconformity between older Permian sediments and overlying Mesozoic rocks.

The prominent features of the regional structure are the major basement ridges: the Pleasant Creek Arch, and the Canaway, Barcaldine, Beryl, and Elderslie Ridges; most have flanking faults. Where they extend below the basin sediments, the basement ridges are expressed by large elongate anticlines indicating subsequent differential uplift.

There are three main depressions. Two, adjacent to the Cork and Canaway Faults, are largely the result of post-Triassic movements of the faults. The third, in the northeast, is not evident in the overlying Jurassic section, so it reflects Triassic downwarping. The regional slope to the southwest of the whole Permian surface conforms to that of the flanking basement and is the result of downwarping during development of the Jurassic-Cretaceous Eromanga Basin.

STRATIGRAPHY

Upper Carboniferous and Permian

Upper Permian sediments on the Springsure Shelf are transitional from those of the Denison Trough of the Bowen Basin; some contain marine faunas. Elsewhere in the Galilee Basin marine faunas are lacking and well preserved macrofloras are rare in the pre-Triassic rocks. Dating is, therefore, almost entirely palynological, generally in terms of the five palynological stages of Evans (1969). He regarded the oldest, Stage 1, as Upper Carboniferous; Stages 2, 3, and 4 are Lower Permian, and Stage 5 is Late Lower Permian and Upper Permian by correlation with the marine sequence in the Bowen Basin. Dating of outcropping units is summarized in Table 1.

Little of the Upper Carboniferous and Permian sequence can be reliably correlated lithologically apart from the named formations on the Springsure Shelf. There are also marked similarities in the sections penetrated in the wells close to the Hulton-Rand Structure. The most widespread lithological unit is an argillaceous interval of late Stage 2 to Stage 3 age in the northern half of the basin. On wireline logs this unit is recognizable by low resistivity, a flat self-potential curve along the shale base line, generally high gamma-radiation, and commonly a gamma-ray peak at the base; the interval 3440 to 3960 feet (1048 to 1207 m) in Thunderbolt No. 1 is fairly typical. The unit commonly includes varved shale and probably includes all except the basal sandstone of the outcropping glacigene Boonderoo Beds. Allen (1973) used the name "Marchmont Formation", without definition, for this unit.

Table 1 Outcropping Units

Palynological Stage	Age	Northeast of Hughenden	East of Lake Buchanan	Alpha area	Springsure Shelf
5	Late Lower to Upper Permian	Betts Creek Beds	Betts Creek Beds	Unnamed coal measures Colinlea Sandstone	Undivided Blackwater Group Black Alley Shale Peawaddy Formation Colinlea Sandstone
4	Lower Permian	Not present	Not present	Not present	Not present
3	Lower Permian	Not present	Not present	Not present	Reids Dome Beds
2	Lower Permian	Boonderoo Beds (late Stage 2)	Not present	mapped as Joe Joe Formation	Not present
1	Upper Carboniferous	Not identified	Unnamed clastics	Joe Joe Formation	Joe Joe Formation

For the rest of the sequence various alternative correlations can be made, and marked lithological changes are characteristic. This is clearly evident by detailed correlation of wells in close proximity. The intervals selected for isopaching (Figs 2-5) are based upon gross lithological similarities and identification depends heavily upon palynological dating.

The lowest interval, the Upper Carboniferous sequence, extends from the basal unconformity up to a change from a prominent sandstone into an overlying argillaceous unit, both commonly about 50 m thick. The interval corresponds closely with palynological Stage 1, and the occurrence of Stages 1 and 2 microfloras are used to identify the appropriate lithological pair to determine the boundary where there are alternative correlations.

In the southeast of the basin, the Upper Carboniferous sequence includes the outcropping Joe Joe Formation. Mollan et al. (1969) described this formation as comprising a lower conglomeratic part with lithic sandstone and an upper fine-grained part with varved lutites; the formation is regarded as glacially-derived (Crowell & Frakes, 1971), Elsewhere the interval is dominated by sandstone, with interbedded shale and siltstone; conglomerate is locally abundant. There is a complete range of sandstone types, from labile (both lithic and feldspathic) to quartzose, from very fine to coarse-grained, and from tight to porous and permeable. Some shale beds are dark and carbonaceous, others are varicoloured and tuffaceous.

The isopachs (Fig. 2) show clearly the development of a deep trough close to the eastern margin of the basin, a more gentle westerly shelving, and the formation of a subsidiary downwarp south of the Barcaldine Ridge. Probably the Drummond Basin was being folded and its rocks uplifted at this time, with the Galilee Basin trough developing along the front of the mountain range. Relief to the west may not have been great, although there was obviously appreciable movement on the Hulton-Rand and Tara Structures and on the Warrego Fault. The Barcaldine Ridge was mainly upstanding. It was a time of glaciation, but glaciers may have been confined to the "Drummond Mountains".

The early Permian sandstone-shale sequence corresponds to most of Stage 2. It overlies conformably the Upper Carboniferous interval, and extends up to the base of the "Marchmont Formation". Lithologically the sequence is similar to the Upper Carboniferous one, except that conglomerate is rare, shale is a little more common, and interbedding tends to be thinner.

The isopachs (Fig. 3) show that altough a trough continued to deepen close to the eastern margin, the southern end migrated to the west, and downwarping south of the Barcaldine Ridge became restricted to a smaller area. A small sub-basin developed in the extreme south. A noticeable feature is the development of a lobe of the main trough extending towards the Hulton-Rand Structure. The Barcaldine Ridge remained. Evidently tectonism in the Drummond area continued: high relief was maintained there, and detritus dumped fairly rapidly in the adjacent trough. There is no evidence of glaciation.

Mid-Lower Permian sedimentation of late State 2 and Stage 3 age is represented by the "Marchmont Formation" and overlying coal measures together with most of the Boonderoo Beds in outcrop in the north, and the thin section of Reids Dome Beds on the Springsure Shelf. The Reids Dome Beds can best be regarded as a minor extension of the thick section deposited in the Denison Trough of the Bowen Basin to the east. Varved lutites in the "Marchmont Formation" have been reported from several wells; they also occur in the glacially-derived Boonderoo Beds. The top of the interval is a basin-wide unconformity evidenced by the complete absence of any Stage 4 microfloras in the Galilee Basin.

The main developments evident from the isopachs (Fig. 4) are the disappearance of the marginal trough in the east and the initiation of two separate centres of downwarping on the downthrown sides of the Hulton-Rand Structure and the Cork Fault, in which two sub-basins were formed. For the first time sedimentation extended on to the upthrown side of the Hulton-Rand Structure, and similarly transgressed onto the upthrown side of the Cork Fault. This extension and the widespread occurrence of fine-grained sediments of the "Marchmont Formation" and of the overlying coal measures indicate that relief in the whole region was fairly low, sedimentation being concentrated in, but not confined to, the downthrown areas adjacent to the major faults. The highest areas were glaciated. On the east flank of the eastern sub-basin, Stage 2 sediments of the "Marchmont Formation" are overlain directly by Stage 5 coal measures. This probably reflects erosion near the basin margin during Stage 4 time.

The youngest Permian sequence, principally the Colinlea Sandstone and Upper Permian coal measures, extends from the basin-wide Lower Permian unconformity to the base of the Rewan Formation and corresponds to Stage 5. These sediments can be devided into defined formations on the Springsure Shelf, but the only division recognizable north of latitude 24°S is the basal unit, the Colinlea Sandstone, and this cannot be mapped north of latitude 23°S. Elsewhere Stage 5 sediments are predominantly coal measures. In late Lower Permian and Upper Permian times deposition was more extensive than at any earlier stage, but the sediments are not very thick. Downwarping was greatest in three areas: near the eastern margin, on the downthrown side of the Cork Fault, andwest of the Pleasant Creek Arch (Fig. 5). On the Springsure Shelf the total sequence thickens towards the outcrop belt, where the rate of downwarping was sufficiently great to allow brief marine incursions. The Barcaldine Ridge was still a positive feature. The widespread occurrence of coal measures indicates that relief was subdued.

Triassic

The main Triassic nomenclature of the Galilee Basin corresponds with that of the Bowen Basin because in each there is a basically similar lithological sequence. In each basin there is a lower argillaceous unit (Rewan Formation), a middle arenaceous unit (Clematis Sandstone), and an upper argillaceous unit (Moolayember Formation). There are, however, significant differences in detail between the units of the two basins and the Galilee Basin nomenclature is due for review.

In the Galilee Basin, the Rewan Formation consists of interbedded sandstone, mudstone, and siltstone. The sandstone is predominantly labile and generally has an abundant clay or silt matrix and poor permeability. The lutites are varicoloured, mainly in shades of red, green, and grey.

At the top of the Rewan Formation in the Galilee Basin, and possibly a facies variant of the uppermost part of the formation, are the Dunda Beds. They are predominantly sandstone, with interbedded subordinate lutites. The sandstone ranges from quartzose to labile, and generally has a much greater porosity and permeability than that of the Rewan Formation.

The overlying Clematis Sandstone is mainly quartzose. It is characteristically cross-stratified, with high-angle planar cross-beds. Interbedded lutites are minor. The Clematis Sandstone has the greatest porosity and permeability of the Triassic sequence and forms one of the major aquifers of the Great Artesian (hydrological) Basin.

Cross-bedding azimuths indicate that the Dunda Beds and Clematis Sandstone were deposited by two separate stream systems, the first originating in the west, and the second in the east. They may be partly contemporaneous units.

The Moolayember Formation is conformable on the Clematis Sandstone. It is lithologically comparable to the Rewan Formation, but appears to contain a greater proportion of red lutites, particularly in the northern part of the Basin.

The Warang Sandstone is a thick unit in the north of the basin, forming most of the outcrops in the White Mountains northeast of Hughenden. Characteristically it has an abundant kaolin matrix, possibly from in situ weathering of feldspar, and large-scale trough cross-stratification. It is interpreted as a marginal facies of the complete Triassic sequence farther south.

At the start of the Triassic the area of sedimentation shrank considerably (Fig. 6). Rewan deposition was mainly restricted to three areas of downwarping: a trough on the downthrown side of the Cork Fault, a re-established trough near the northeast margin of the Basin, and a sub-basin to the southeast of the Barcaldine Ridge, into which a minor marine incursion is recorded by the occurrence of abundant microplankton in one sample from Jericho No. 1.

Isopachs of the combined Triassic sandstone units (Fig. 7) are interpreted as indicating mountainous country to the north shedding a large amount of detritus onto a flanking piedmont extending into two main valleys along the established troughs to southwest and southeast. The thickest section is almost entirely Warang Sandstone. The Barcaldine Ridge was still a positive feature, but downwarping in the sub-basin to the south continued and became more extensive. Sandstone in this southern sub-basin is principally Clematis Sandstone..

Isopachs of the Moolayember Formation (Fig. 8) document a major tectonic change. The formation generally thickens eastward towards the present outcrop area and a deep trough which developed in the northeast may have extended southeastwards to the east of the present outcrops. The downwarping which produced this trough may have been a precursor of the widespread late Triassic earth movements and local uplift which brought to an end development of both the Bowen and Galilee Basins.

PETROLEUM

The best hydrocarbon show reported from the Galilee Basin was in Lake Galilee No. 1, where, from a drillstem test of the interval 8679 to 8752 feet (2645 to 2668 m), 10 feet (3 m) of oil was recovered and gas flowed to the surface at a rate too small to measure. The oil is 44.6^{o} API gravity. The reservoir is in the lower half of the Upper Carboniferous sequence in a thick sandstone section in which quartz grains have silica overgrowths. Analysis of the drillstem test data established that the reservoir is tight. Lake Galilee No. 1 was drilled as a deep stratigraphic well, but testing a seismically-defined closed anticline. Vertical closure of the anticline was estimated at 38 m, and the area of closure about 25 km^2.

Several other minor oil and gas shows were encountered, including gas reaching the surface for a short time during air drilling at a depth of 9675 feet (2949 m) in Koburra No. 1. Most of the shows are in the northern half of the basin.

The main significance of the hydrocarbon shows is in demonstrating that oil and gas have been generated in the Galilee Basin. All the shows have been associated either with coal seams or tight sediments, or were in porous beds which have produced low-salinity water on test. The presence of fresh or brackish water may indicate flushing by meteroic water, so possibly one of the main problems for future exploration will be to determine the environmental control on the distribution of beds with good porosity but shielded from flushing.

Encouraging features of the Galilee Basin are:

1. the long continued growth of anticlines over basement ridges, involving movements of the flanking faults during sedimentation;
2. the abundance of carbonaceous matter in large parts of the whole sequence. A major complicating factor in considering possible migration paths is the southwest tilt imposed during development of the Jurassic-Cretaceous Eromanga Basin.

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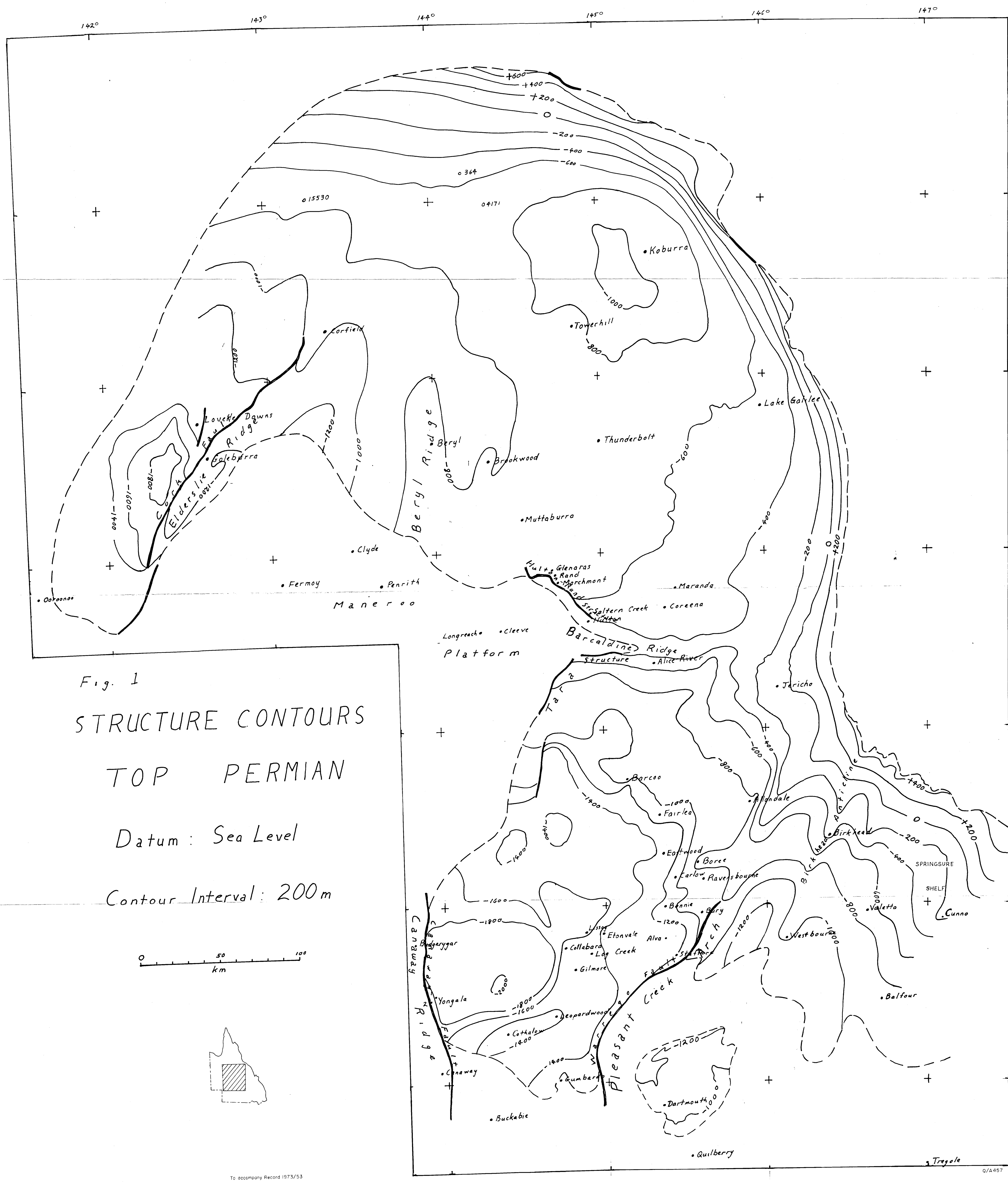

Fig. 1

STRUCTURE CONTOURS

TOP PERMIAN

Datum : Sea Level

Contour Interval : 200 m

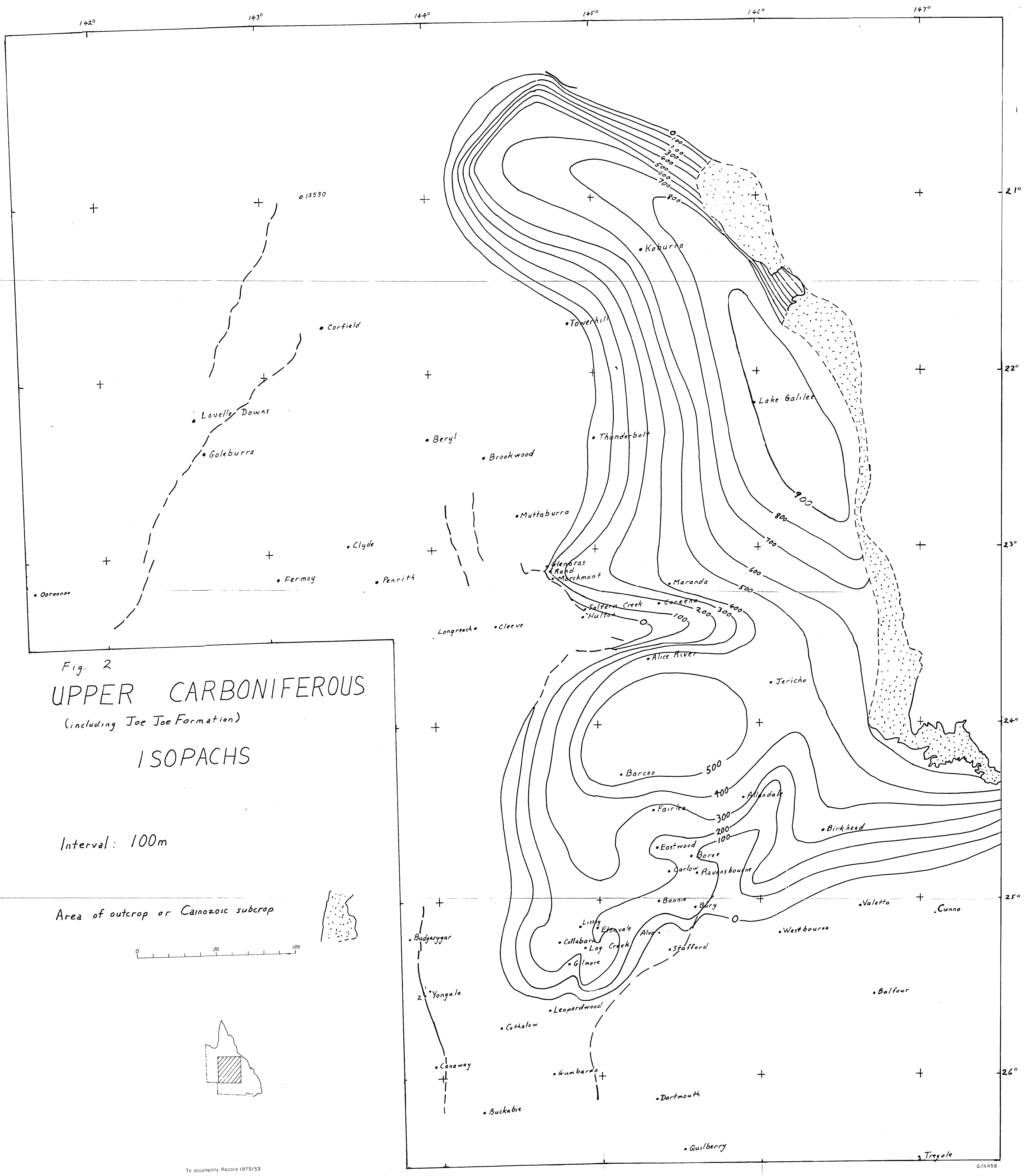

Fig. 2

UPPER CARBONIFEROUS

(including Joe Joe Formation)

ISOPACHS

Interval: 100m

Area of outcrop or Cainozoic subcrop

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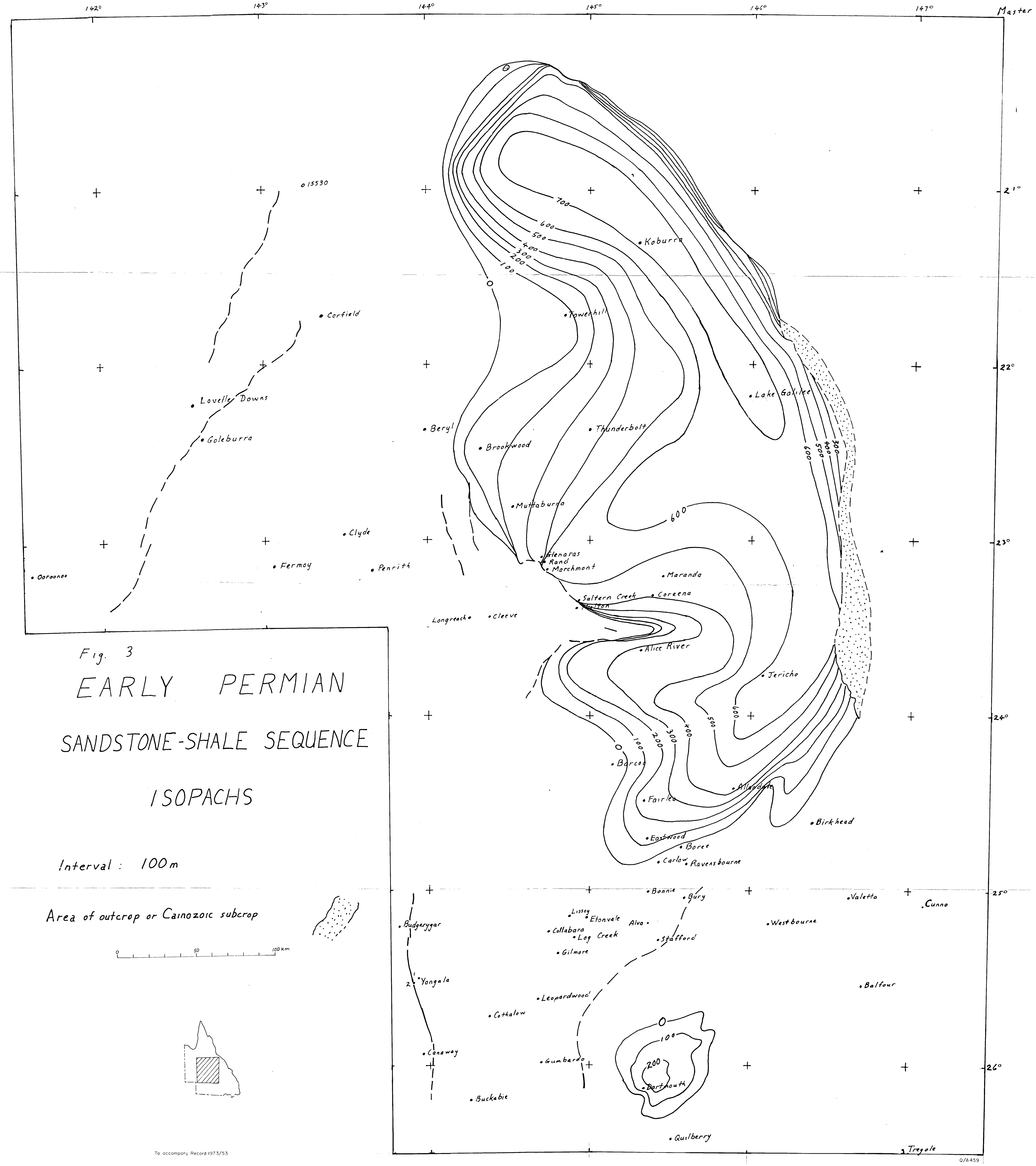

Fig. 3

EARLY PERMIAN

SANDSTONE-SHALE SEQUENCE

ISOPACHS

Interval : 100m

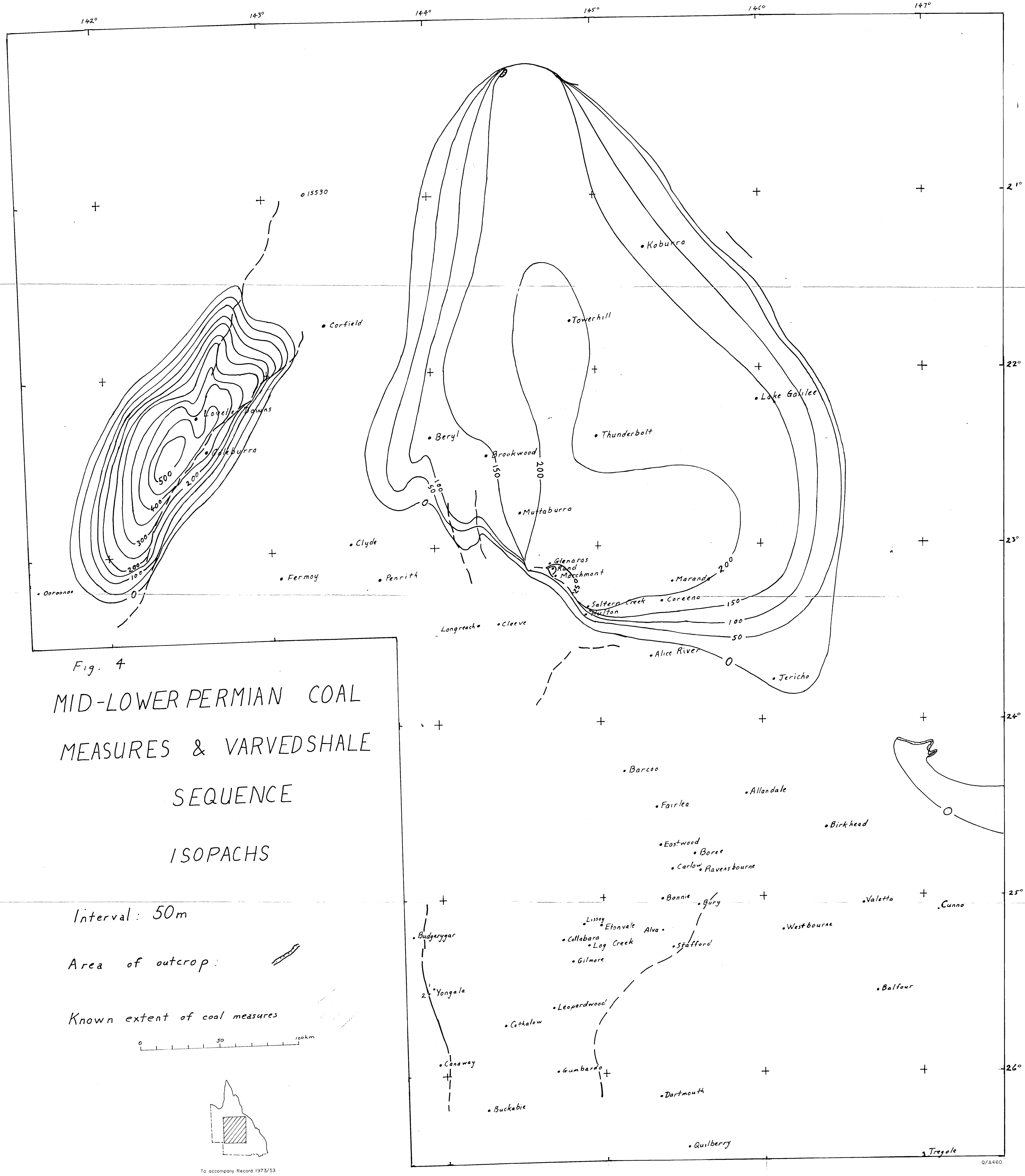

Fig. 4

MID-LOWER PERMIAN COAL MEASURES & VARVED SHALE SEQUENCE

ISOPACHS

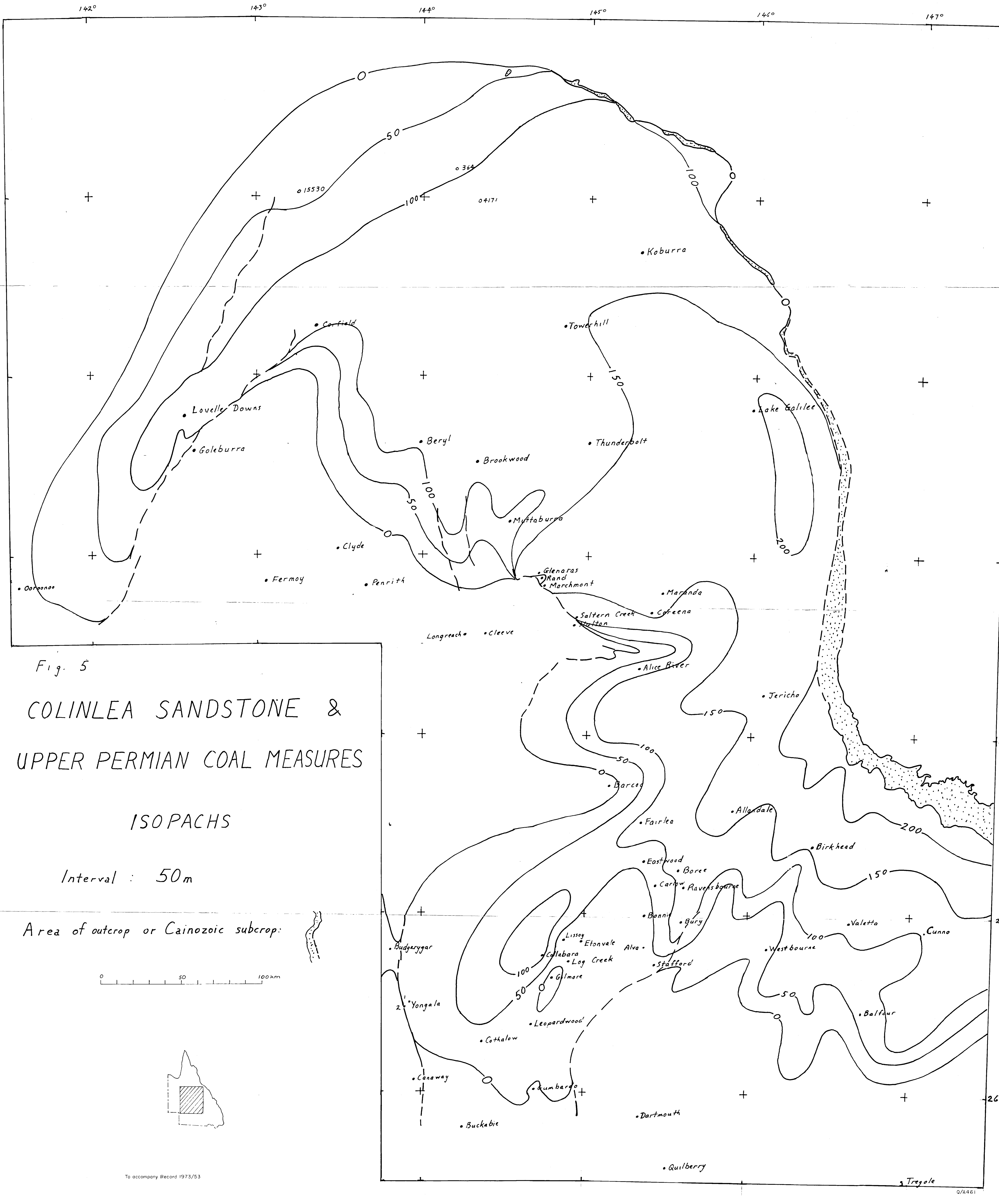

Fig. 5

COLINLEA SANDSTONE & UPPER PERMIAN COAL MEASURES

ISOPACHS

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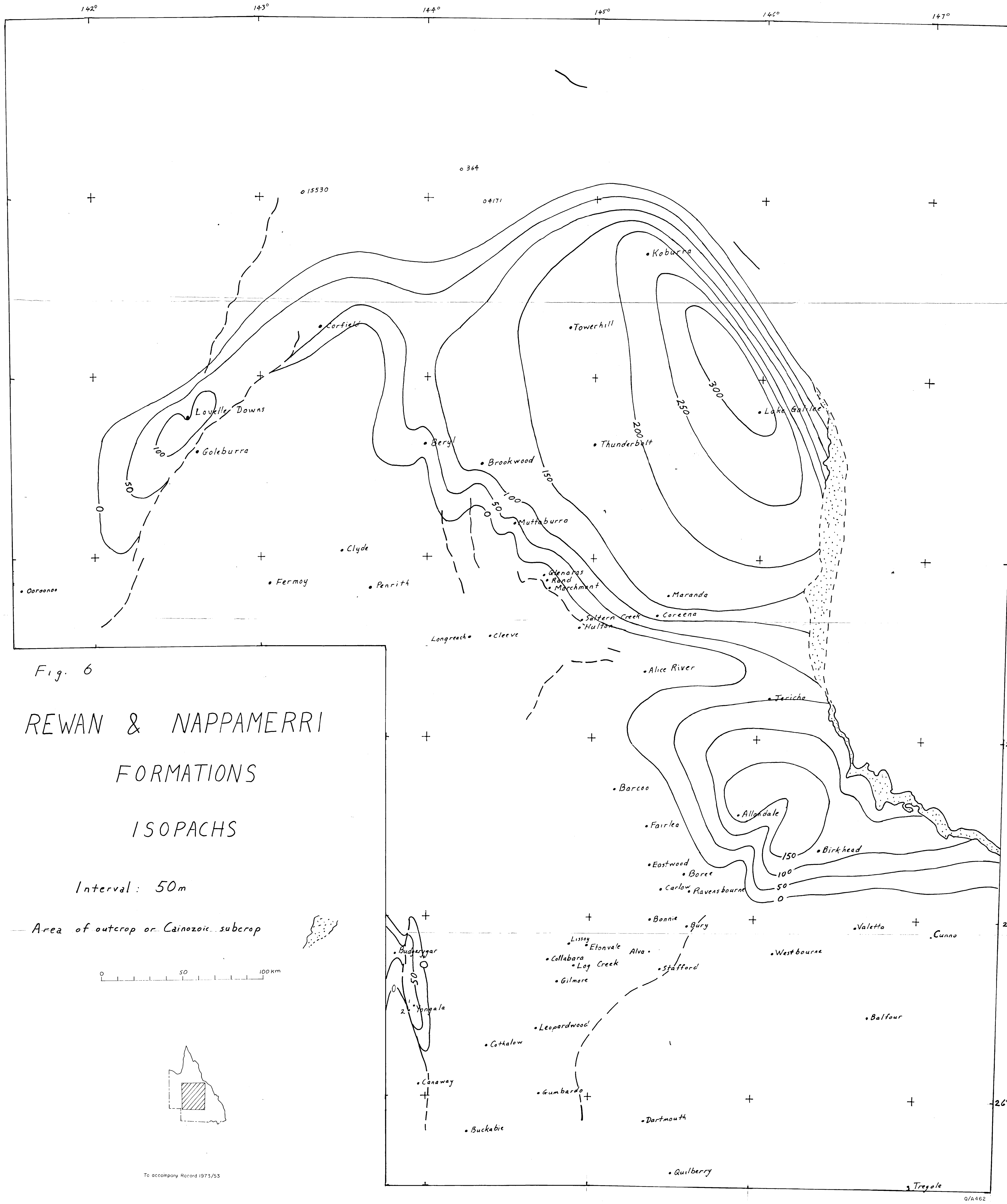
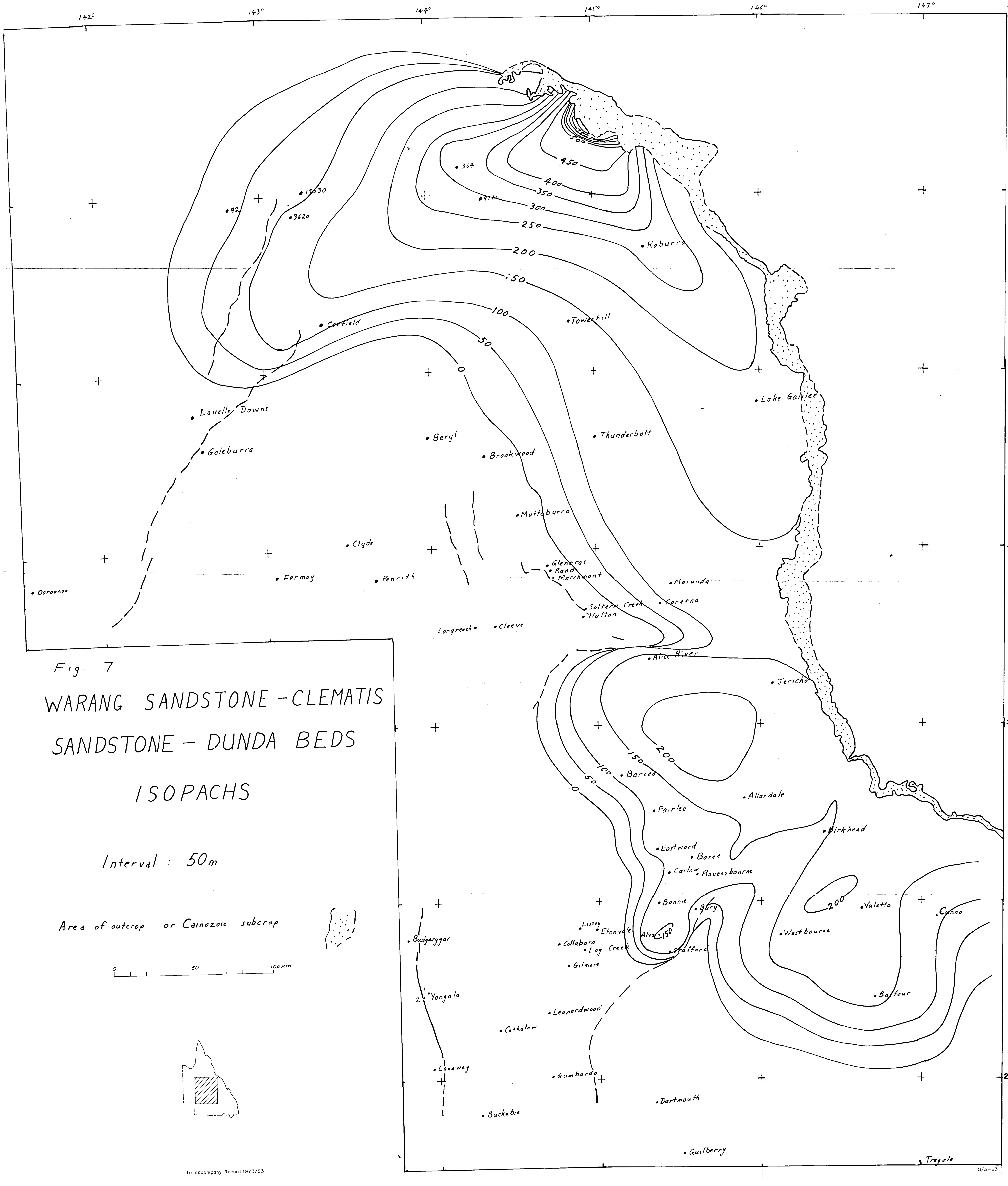


Fig. 6

REWAN & NAPPAMERRI FORMATIONS ISOPACHS



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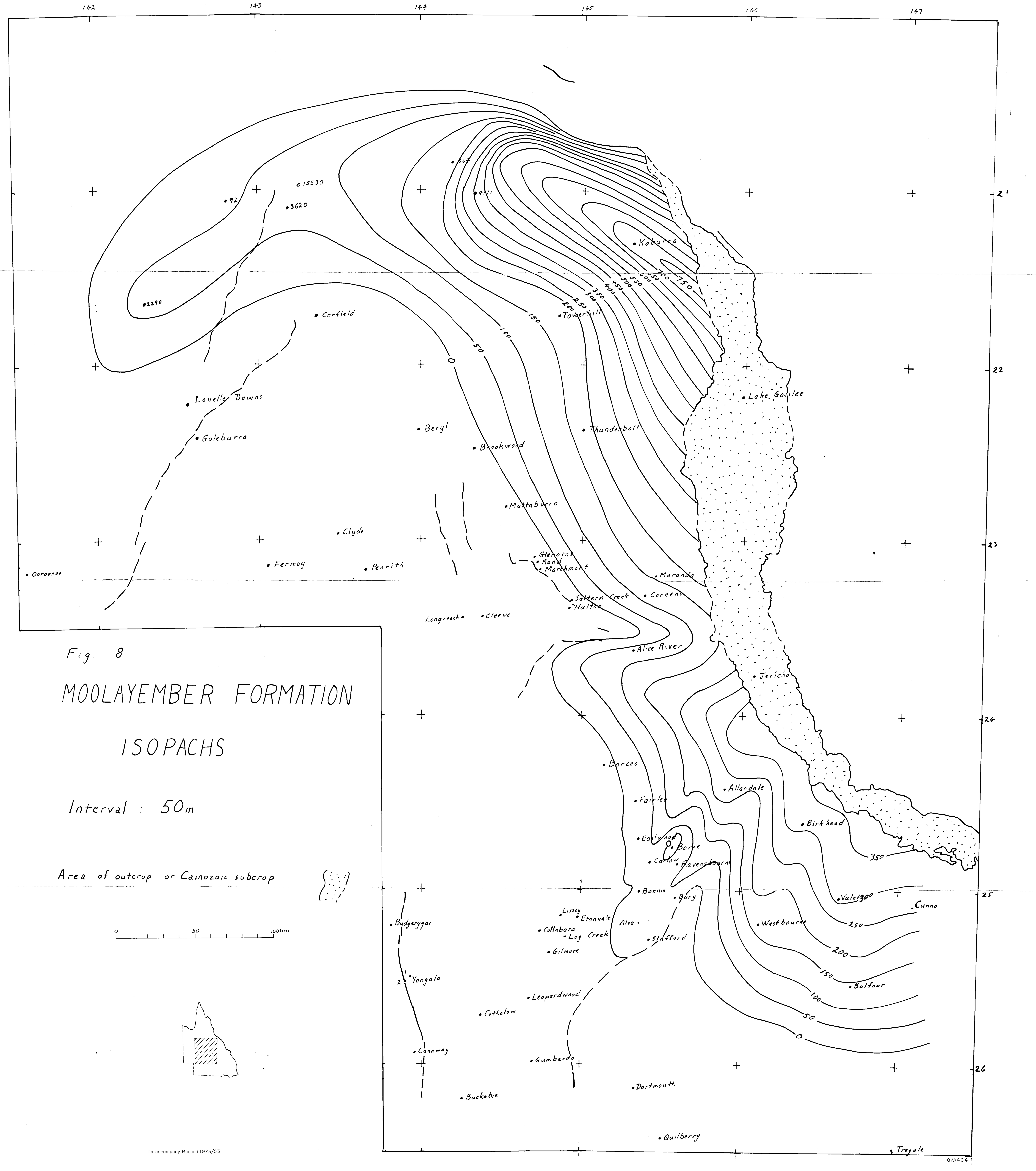

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