GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

RECORD 1992/4

THE GEOLOGY AND MINERAL RESOURCES OF THE PROPOSED KENNEDY RANGE NATIONAL PARK

by

K. M. FERGUSON, A. RYALL, AND R. M. HOCKING

DEPARTMENT OF MINES
WESTERN AUSTRALIA

PROPOSED KENNEDY RANGE NATIONAL PARK

The Resolution of Conflict Policy of the Western Australian Government requires that the resource potential of proposed National Parks is assessed, and the assessment made available for public scrutiny.

This publication has been prepared by the Geological Survey of Western Australia to assist the mining and exploration industries, and the general public, in their evaluation of the mineral, petroleum, and groundwater potential of the proposed Kennedy Range National Park.

Public comments on the findings of this resource assessment are encouraged. They should be addressed to:

The Director
Geological Survey of Western Australia
Department of Minerals and Energy
100 Plain Street
EAST PERTH 6004

The closing date for submissions is 26 August 1992.

Corrigendum: Subsequent to the printing of the report, additional petroleum permits were granted in the Kennedy Range area. Updated versions of Figure 1 (p. 3) and Figure 5 (p. 14) are included in the pocket at the back of the report.

Geological Survey of Western Australia

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K. M. Ferguson, A. Ryall,(1) and R. M. Hocking

(1) Petroleum Division

Perth 1992

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The geology and mineral resources of the proposed Kennedy Range National Park

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Abstract

This report describes the geology, stratigraphy and economic resources of the proposed Kennedy Range National Park, and assesses its mineral and petroleum potential.

The proposed park, located about 150 km east of Carnarvon, Western Australia, is based on the EPA System 9 Red Book recommendation of an A Class National Park over the Range (EPA System 9, Recommendation 9.5). The core of this area has been returned to Vacant Crown Land by the acquisition of pastoral leases.

The proposed park, which lies entirely within the Merlinleigh Sub-basin of the Carnarvon Basin, is relatively unexplored for petroleum, with the existing low density of seismic and drillhole information resulting from activity in the late 1960s and the early 1980s. Potential source and reservoir rocks are present within the Early Permian succession and may also exist in older sequences. Potentially favourable anticlinal trap structures have formed on the western limb of the Kennedy Range syncline adjacent to the faulted margin of the sub-basin.

The history of mineral exploration in the region has focused on uranium and base-metal potential in the Devonian - Lower Carboniferous succession, and on diamond potential related to the faulting at the sub-basin margin. Results of uranium and base-metal exploration have been poor and potential exists only where the target units are close to the surface, 15 to 20 km east of the proposed park. Diamond results have also been negative, despite the presence of Kimberlite-like bodies northwest of the park area.

KEYWORDS: national parks, geology, mineral resources, mineral exploration

Introduction

General

The purpose of this report is to describe the geology, stratigraphy and economic resources of the proposed Kennedy Range National Park (KRNP) and to assess its mineral and petroleum potential.

The KRNP (Figs 1 and 2) is based on the EPA System 9 Red Book recommendation of an A Class National Park over the Range (EPA System 9, Recommendation 9.5). The core of this area has been returned to Vacant Crown Land by the acquisition of pastoral leases. Following section 6.2.1 of the State Conservation Strategy for WA, which relates to the protection of native species and ecosystems, an expanded area is now proposed to become a National Park.

Sources

This report was compiled from Geological Survey of Western Australia (GSWA) and Petroleum Division sources within the Western Australian Department of Mines.

The principal sources for the geology section are GSWA Bulletin 133, Geology of the Carnarvon Basin, WA, by Hocking et al. (1987), and the 1:250 000 map sheet and explanatory notes, KENNEDY RANGE* (Hocking et al.,1985). The sections on mineral resources and exploration history include information from industry reports held at the Department of Mines, and from previous compilations such as Harrison (1985) and Carter (1981).

Location and access

The KRNP lies within the area bounded by latitudes 24°10'S and 25°00'S, and longitudes 114°50'E and 115°20'E. It is located about 150 km east of

* Sheet names are printed in capitals to avoid confusion with identical place names

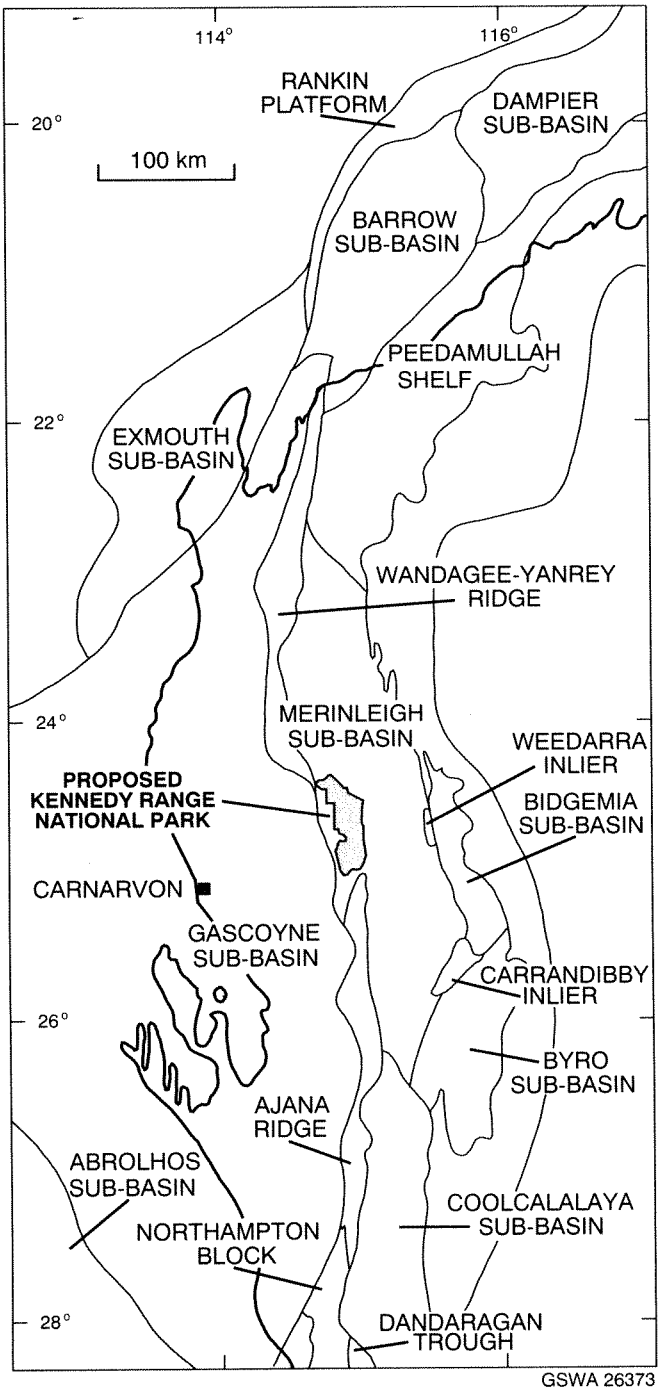


Figure 1. Locality map showing sub-basin boundaries

Carnarvon and 800 km north of Perth in the Gascoyne region of the northwest of Western Australia (Figs 1 and 2). The park is covered by MARDATHUNA, BINTHALYA, MOUNT SANDIMAN and LYONS RIVER 1:100 000 map sheet areas, and the eastern part of the KENNEDY RANGE 1:250 000 sheet. The Park has an area of 2250 km^2 and covers the bulk of the Kennedy Range plateau.

Climate

The proposed park has a Mediterranean climate. Rainfall is confined mostly to winter with an annual average of about 200 mm: potential annual evaporation is about 2400 mm. Average daily maximum and minimum temperatures are about 32°C and 22°C in January, and 22°C and 11°C in July.

Geomorphology

The dominant feature in the area is the partially incised, elevated plateau which forms the Kennedy Range. The range is an isolated remnant of the Victoria Plateau (which extends south into the Perth Basin) and consists of sandstones, wackes and siltstones of the Permian Kennedy Group. In the Oligocene, these were extensively silicified and lateritized under humid climatic conditions to form a duricrust. Unconsolidated sand associated with laterite subsequently formed an extensive dunefield, on the southwest-dipping face of the plateau, during two major arid phases (40 000 - 70 000 BP, and 16 000 - 25 000 BP).

The eastern, northern, and southern edges of the plateau form prominent cliffs which adjoin etch plains, alluvial plains, and mixed dune and playa terrain marginal to the Lyons, Gascoyne, and Minilya drainage systems. In the west, the range is extensively dissected and gradually steps down to a broad sandplain and dunefield underlain by siltstones, shales and radiolarite of the Cretaceous Winning Group.

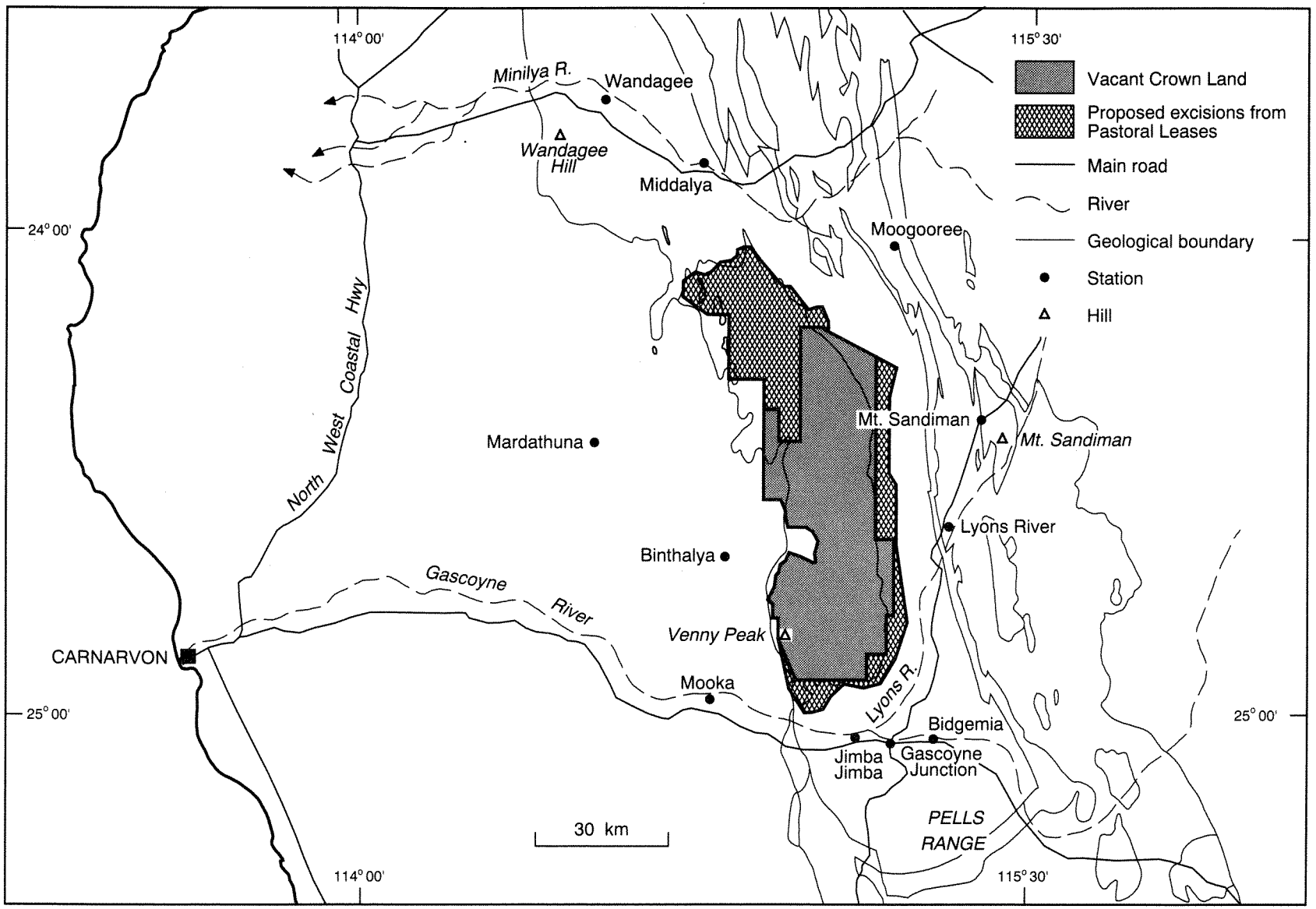


Figure 2. Infrastructure

Previous investigations

The earliest reported geological investigations of the Kennedy Range area are those of Gregory (1861), Huddleston (1883), and Maitland (1901). Sporadic studies and visits continued through the early 1900s, and in 1948 the Bureau of Mineral Resources (BMR) commenced a systematic mapping program of the entire Carnarvon Basin. This culminated in a three-part Bulletin (Condon, 1965, 1967, 1968). The first KENNEDY RANGE 1:250 000 geological map with explanatory notes was also published (Condon, 1962). The GSWA commenced a re-evaluation of the Carnarvon Basin in 1975. From this arose a second edition of the KENNEDY RANGE map sheet (Hocking et al., 1985) and a Bulletin on the whole basin (Hocking et al., 1987).

Interest in the hydrocarbon potential of the Carnarvon Basin began in the 1920s. Oil Search Limited began investigations in 1929 but relinquished tenements in 1934 without drilling a well (Condit, 1935). West Australian Petroleum Pty Ltd (WAPET) began exploration in the basin in 1951 and discovered oil in their first well, Rough Range 1. On KENNEDY RANGE, WAPET drilled Merlinleigh Core Holes 1 to 5 and Kennedy Range 1, to test Permo-Carboniferous sediments in an anticlinal structure. These holes all lie within the KRNP. Two shallow holes, Moogooree 1 and 2, were drilled in 1972 by Hartogen Exploration Pty Ltd a few kilometres from the northeast boundary of the KRNP.

In the early 1980s, Esso took out tenements over the range and conducted limited seismic exploration. The company drilled two petroleum exploration wells; at the south end of Kennedy Range, and to the northwest in the Burna Hills. Their work is summarized in Percival and Cooney (1985).

Mineral exploration in the basin,and on KENNEDY RANGE, has expanded since the mid-1960s. Electrolytic Zinc Company Ltd (EZ) and Cyanamid Australia Pty Ltd conducted regional reconnaissance for phosphate deposits from 1965 to 1967. Base-metal exploration in Devonian - Carboniferous shelf sediments has been underway since the early 1970s and has involved a number of companies. Uranium exploration in Devonian and Permian units was undertaken in the 1970s with Uranerz Australia Pty Ltd and Afmeco the most active. Diamond explorers, principally CRA, Amax, and BHP, were involved from the late 1970s and through the 1980s in exploration which followed CRA's

discovery of kimberlite-like alkali-picrites in the Wandagee area on WINNING POOL. These activities are summarized for the basin in Hocking et al. (1987) and by Harrison (1985).

Geology

Regional setting

The proposed KRNP lies entirely within the Merlinleigh Sub-basin of the Carnarvon Basin (Figs 1 and 3). The Carnarvon Basin extends 1000 km along the west and northwest coastline of Western Australia, is up to 300 km wide, and contains sediments ranging from Silurian to Quaternary age. Onshore, these range up to 7 km in thickness and, offshore, up to 15 km.

The Merlinleigh Sub-basin is one of several depocentres in the Carnarvon Basin which were active primarily in the Palaeozoic, between 250 and 450 million years ago. The sub-basin contains up to 3000 m of Permian sediments which are underlain by Devonian and Carboniferous sediments in the north, and overlain throughout by a thin cover of Cretaceous or Tertiary sediments. It is bounded to the west by a major fault system, and onlaps basement to the east. The Kennedy Range itself overlies a major syncline in the axis of the basin. The west side of the range contains several anticlines which developed in response to movement of the faults at the western boundary.

Stratigraphy

The Palaeozoic stratigraphy in the Merlinleigh Sub-basin is shown in Figure 4, and descriptions of the more significant units (from oldest to youngest are given below.

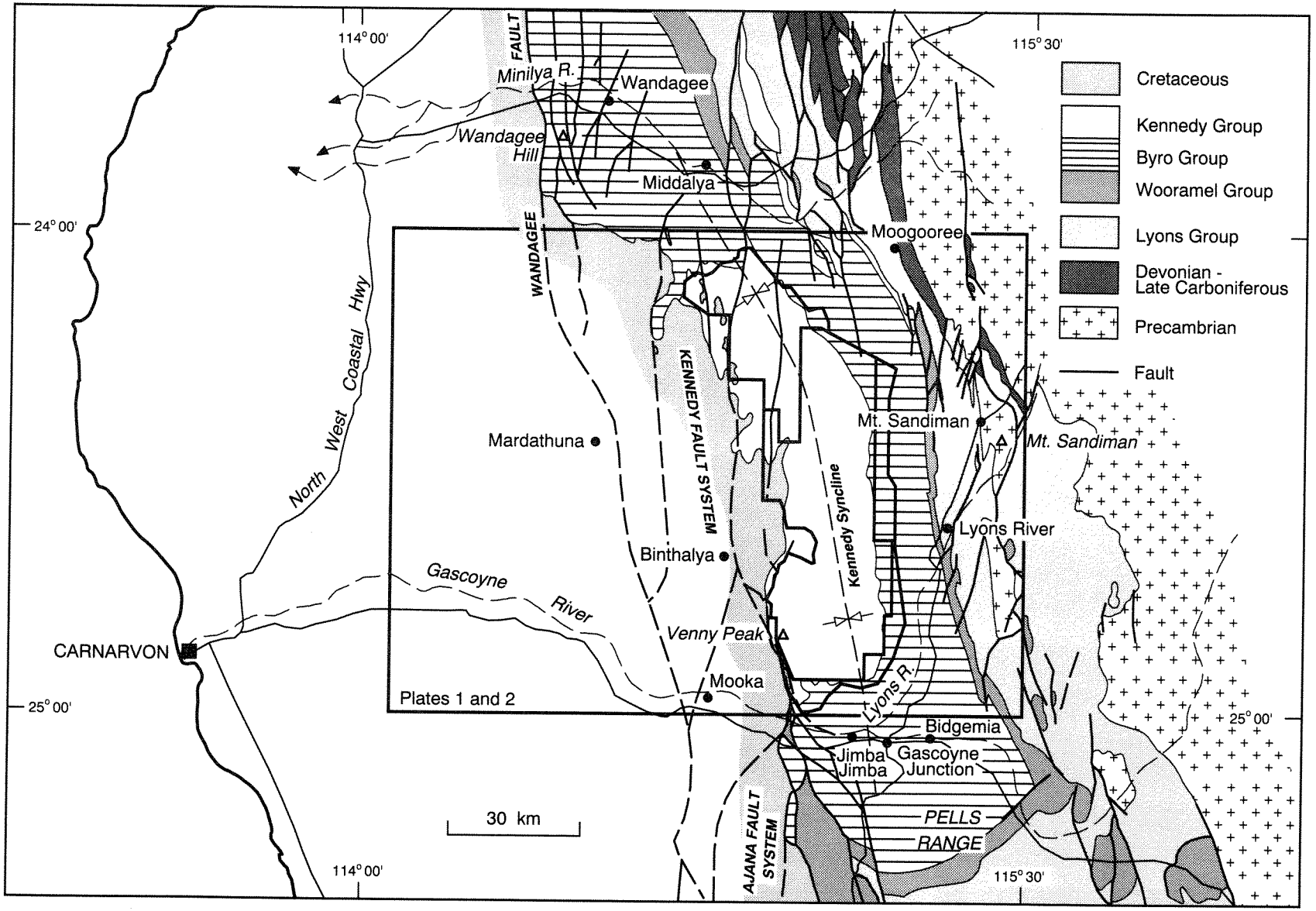


Figure 3. Regional geology

Devonian and Lower Carboniferous

Devonian and Lower Carboniferous sediments are exposed along the eastern margin of the Merlinleigh Sub-basin, about 20 km east of the KRNP, between Mount Sandiman and Williambury Stations. They are progressively truncated by the Upper Carboniferous Lyons Group and thus are probably present only under the northern half of the KRNP.

The Devonian and Lower Carboniferous sequence is about 2000 m thick and consists of basal sandstone overlain by alternating carbonate and clastic units, each 300 - 500 m thick. The calcareous units (Gneudna Formation and Moogooree Limestone) have potential as hydrocarbon source rocks, and for base-metal mineralization. The thickest sandstone, the Munabia Sandstone, is also a possible hydrocarbon reservoir.

Upper Carboniferous and Permian

There are about 4 km of Upper Carboniferous and Permian sedimentary rocks in the Kennedy Range area. They rest unconformably on Devonian and Lower Carboniferous rocks northeast of the range, and on Precambrian basement to the east, where they probably underlie the range.

The lower two kilometres of the sequence, the Lyons Group, is a product of the continental glaciation of the Gondwana supercontinent in the Late Carboniferous and Early Permian. It is a mixed sequence of sandstone, siltstone, conglomerate, and limestone, and was deposited in glacially influenced marine, fluvial, and lacustrine environments. Interglacial deposits are also present as deposition spanned several glacial episodes. Giant-boulder beds containing boulders up to 4 m in diameter, striated glacial pavements, and glacial outwash deltas are present in outcrop east of Kennedy Range. A very fossiliferous limestone, the Callytharra Formation, caps the group. This unit developed in the slightly warmer oceanic waters which followed the period of glaciation.

The upper two kilometres of the Upper Carboniferous - Permian sequence consist of the Wooramel, Byro and Kennedy Groups: the Kennedy Range itself is composed of the latter two. Deposition of all three groups was very rapid.

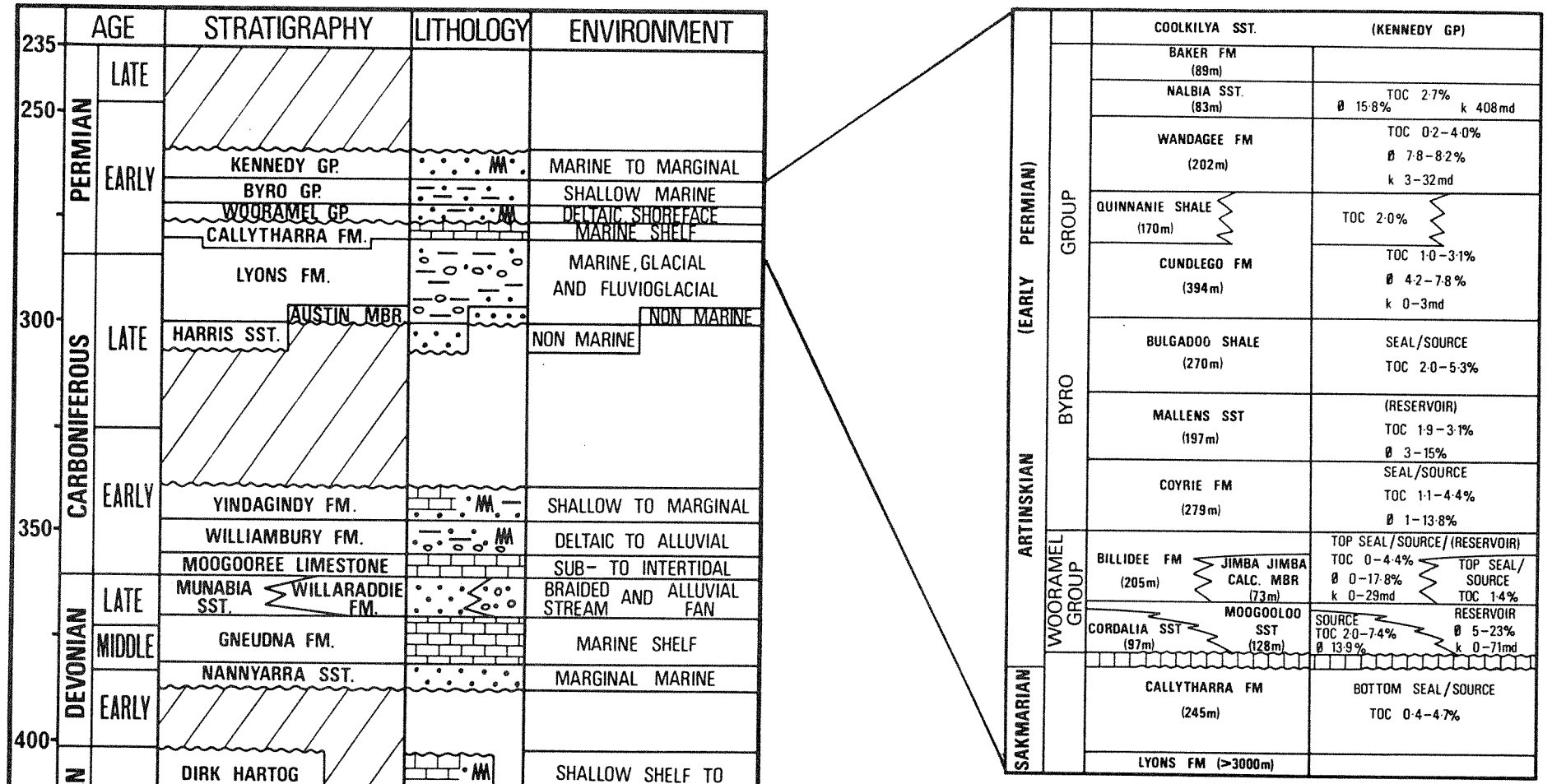


Figure 4. Stratigraphy - Merlinleigh Sub-basin (after Percival and Cooney, 1985)

The Wooramel Group is a complex, fluviodeltaic, sandy sequence up to 300 m thick, which was deposited when sediment trapped under the ice sheet in the basin hinterland was released during melting and flushed into the basin. The Byro and Kennedy Groups consist of alternating silty and sandy units, each 100 to 300 m thick, which were deposited on a storm-swept marine shelf. The shelf was subject to periodic rapid subsidence and sediment influx, an evironment which produced the cyclic nature of the groups.

Cretaceous

Cretaceous sediments, which thicken to the west, are exposed in thin cappings along the western margin of the KRNP. These were deposited during a prolonged period of high eustatic sea level after the separation of the Australian and Indian plates. Early sandstone and fine siliclastics were replaced by silicic and then calcareous pelagic units as transgression proceeded; the sea level rose and oceanic circulation patterns changed.

Units of theWinning group are exposed along the western margin of the Kennedy Range. The Birdrong Sandstone was deposited during the the early phase of the transgression. It is a widely distributed, shallow-marine sand, weakly lithified and about 30 m thick. This is conformably overlain by the Muderong Shale which developed in a low-energy, offshore setting and consists of bentonitic shale, claystone, and siltstone with some bioturbated silty, green sand. It rarely exceeds 15 m thickness and is overlain by the Windalia Radiolarite, a radiolarian siltstone and chert which formed on a marine shelf with minimum terrigenous influx. Deep weathering of onshore areas may have provided the dissolved silica necessary for the growth of radiolarian blooms.

Cainozoic

The Merlinleigh Sandstone is the only named Tertiary unit known in the vicinity of the KRNP. It underlies much of the high sandplain on the Kennedy Range plateau and is a fine- to coarse-grained sandstone (with lesser siltstone and conglomerate) of mixed fluviatile and marine origin. It is generally less than 10 m thick, and developed during a widespread but brief Eocene transgression which reworked much of the siliclastic detritus onshore.

Ferruginous and siliceous duricrust, including laterite and silcrete, formed over much of the area in a humid climatic regime during the Oligocene. It is now preserved as a capping to the Kennedy Range plateau, and is dissected at the margins. Quaternary sandplain and dune sands were developed over this capping in two arid phases and are present over most of the Kennedy Range plateau.

Structure

As mentioned previously, the KRNP lies totally within the Merlinleigh Sub-basin of the Carnarvon Basin. The Merlinleigh Sub-basin is a west-dipping half graben onlapping Precambrian rocks to the east.

The western margin of the sub-basin is a series of northerly trending en echelon faults (downthrown to the east) which links the fault systems defining the eastern margins of the Wandagee Ridge in the north with the Ajana Ridge to the south. The development of this block faulting in the Triassic - Jurassic was associated with the separation of the Australian and Indian plates. Only steep, normal faults are present, but these may reflect an underlying dextral transcurrent regime.

The Kennedy Range is at the core of a large northerly trending syncline, over the deepest part of the Merlinleigh Sub-basin. Three small anticlines, the Merlinleigh, Watermelon, and Birdrong Anticlines, occur in the western limb of the syncline close to the Kennedy Fault system and are related to the en echelon faulting. The Winning Group is displaced down to the west over the Kennedy Fault system indicating minor post-Cretaceous reverse movement. The duricrust level is also downfaulted to the west, possibly indicating that movement has continued to the present.

Mineral resources

Hydrocarbons

Petroleum

Sealot Pty Ltd (guaranteed by Pan Pacific Petroleum) currently hold title to explore for petroleum over parts of the proposed park (EP 347 and EP 348 awarded 27 February 1990; Figure 5).

It was first suggested in the 1930s that this area had hydrocarbon potential when 'oily matter' was noted in the slurry from water wells being drilled on the Mia Mia Station. In 1985, when the last round of active hydrocarbon exploration ceased, Esso described the Merlinleigh Sub-basin as 'enigmatic', having hydrocarbon shows and evidence of source and reservoir potential but still being at the frontier stage of exploration. Sealot Pty Ltd has indicated a preference for a less traditional approach to exploration, one which has been used in other areas of Australia and the USA to focus future exploration on lower risk areas.

Previous exploration

Three main phases of exploration have occurred over KENNEDY RANGE (Fig. 5). The first was in the late 1950s and 1960s when the BMR surface-mapped the area and WAPET undertook geological and geophysical surveys (Table 1). The information gained lead to the drilling of several stratigraphic and petroleum wells (Table 2). Of these wells, Kennedy Range 1 in the proposed park area recorded numerous gas shows.

In the early 1970s Hartogen drilled three shallow stratigraphic wells, and BHP drilled seven coreholes for coal. As there were no hydrocarbon shows during this phase, exploration ceased.

The last major exploration program was undertaken by Esso, whose original target was oil shale. After determining that the Merlinleigh Sub-basin was more prospective for liquid hydrocarbons, the company recorded 2188 km of

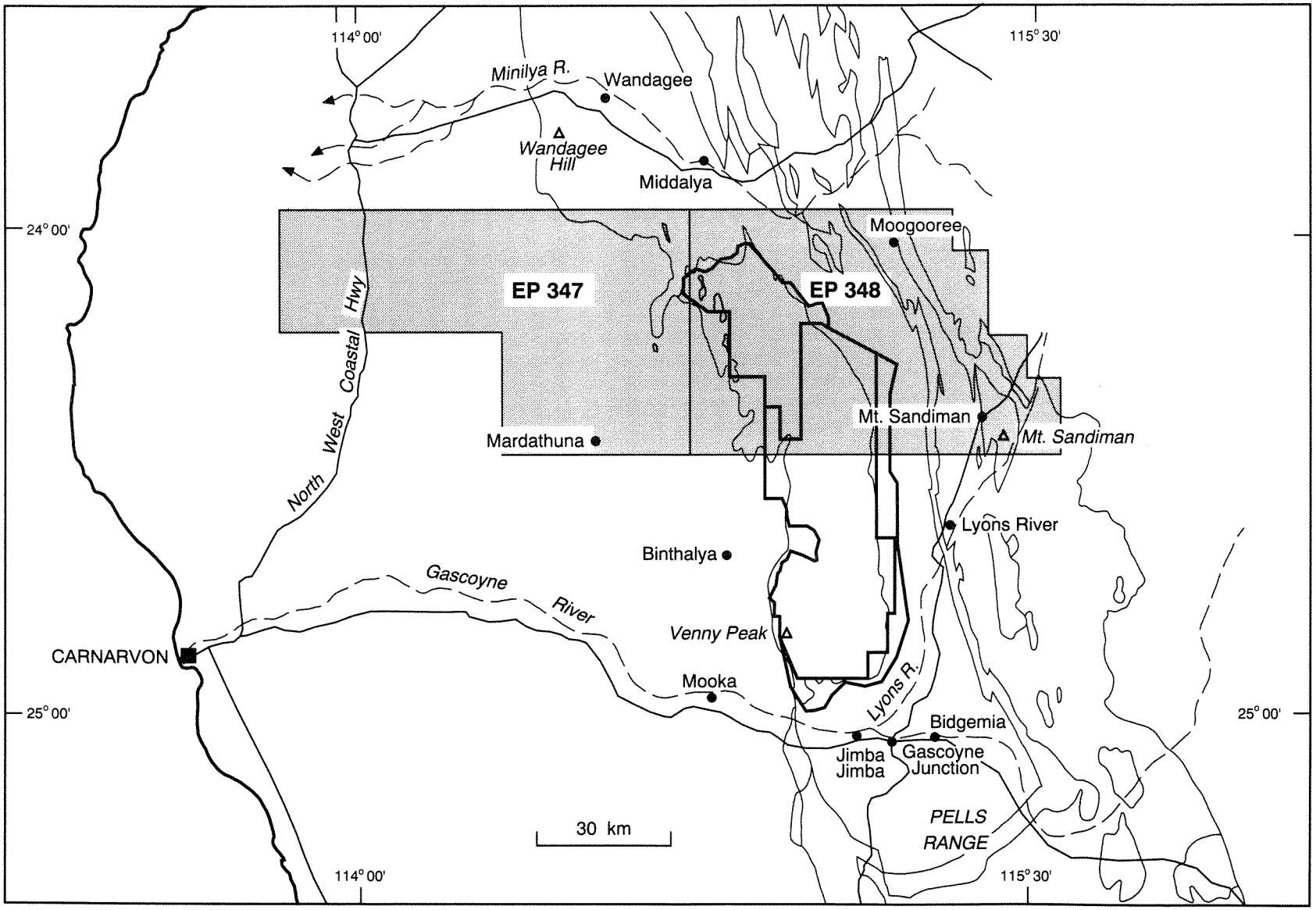


Figure 5. Present petroleum tenements

Table 1. Geophysical surveys: Kennedy Range area

Operator	*Survey*	*Year*
BMR	Carnarvon Basin airborne magnetics, radiometric survey	1956
PE-28-H	Carnarvon Basin airborne magnetics, radiometric survey	1957
WAPET	Quail Anticline seismic survey	1963
PE-28-H	Kennedy seismic survey	1965
Esso Australia	K 82 A seismic survey and extension seismic survey	1982
EP-189	K 82 B seismic survey and gravity survey	1982
	K83 A seismic survey	1983

Table 2. Exploration drilling: Merlinleigh Sub-basin

Operator	*Well*	*Classification*	*Year*	*Total depth (m)*
BMR	BMR 6 Muderong	Strat.	1958	305
BMR	BMR 7 Muderong	Strat.	1958	609
WAPET	Wandagee 1	NFW	1962	1 073
WAPET	Wandagee 2	Strat.	1962	309
WAPET	Wandagee 3	Strat.	1962	223
WAPET	Quail 1	NFW	1963	3 580
WAPET	Merlinleigh 1	Strat.	1966	305
WAPET	Merlinleigh 2	Strat.	1966	306
WAPET	Merlinleigh 3	Strat.	1966	166
WAPET	Merlinleigh 4	Strat.	1966	136
WAPET	Merlinleigh 5	Strat.	1966	175
WAPET	Kennedy Range 1	NFW	1966	2 227
Hartogen	Moogooree 1	Strat.	1972	129
Hartogen	Moogooree 2	Strat.	1972	193
Hartogen	Bidgemia 1	Strat.	1972	212
Esso	Burna 1	NFW	1984	768
Esso	Gascoyne 1	NFW	1984	527

Note: NFW new-field wildcat; Strat. stratigraphic

seismic data, and drilled 11 shallow stratigraphic holes and two exploration wells between 1981 and 1985.

Since that time, Sealot met its permit commitment for year 1 of EPs 347 and 348 by performing a soil-gas survey in 1990.

Future exploration

The future commitments for these permits are given in Table 3. Vacant acreage over the proposed park is available for application under the State's quarterly release policy.

Prospectivity

Data set: Plate 1 plots the location of most of the existing petroleum data for the area in and around the proposed park.

The KENNEDY RANGE 1:250 000 geological map gives an interpretation of the pre-Cretaceous subcrop and basic structural configuration, based on the surface mapping and various geological field reports from the exploration companies.

In addition to the stratigraphic holes and petroleum new-field wildcats, seismic shot-holes were used for gaining stratigraphic information. They were used to determine pre-Cretaceous geology in areas where this cover is thinnest, and to assess the presence of primary source and reservoir sequences.

Table 3. Petroleum work commitments: Kennedy Range area

Year ending	*EP347*	*EP348*
26.02.92 (Yr 2)	Geochemical survey	Geochemical survey
26.02.93	100 km seismic	100 km seismic
26.02.94	1 well	1 well
26.02.95	1 well or 100 km seismic	1 well or 100 km seismic

Modern seismic data are available only from Esso's exploration of 1981 to 1985, shown on Plate 1. Previous WAPET surveys had sparse grids, with limited coverage and poor-quality records. Esso's lines are of better quality in that about half the records are described as being of fair to good quality. However, only two lines are located on the Kennedy plateau. The data have been tied by Esso to petroleum wells and outcrop data, and four moderately strong reflectors have been mapped. With the relatively few control points, however, interpretations contain significant extrapolations, and confidence levels are at best moderate. Future acquisition of seismic data is constrained by limited access to the plateau.

Sealot's geochemical data points follow roads and tracks in the main, again with extremely limited coverage of the plateau.

Play Analysis: Table 4 summarizes the major plays in the Merlinleigh Sub-basin which have recognized potential.

Previous operators in the immediate vicinity of the proposed park have targeted the Early Permian section as having the highest potential. Within the Wooramel Group, the Moogooloo Sandstone has reservoir potential (subject to diagenetic degradation, particularly with depth) and is surrounded by units with indications of source potential, particularly the underlying Cordalia Sandstone and Callytharra Formation. These source rocks are currently oil-mature within

Table 4. Petroleum plays: Merlinleigh Sub-basin

Play	*Reservoir*	*Source*
Early Permian Byro Group	Mallens Sandstone	Bulgadoo Shale, Coyrie Siltstone
Early Permian Wooramel Group	Moogooloo Sandstone	Cordalia Sandstone, Callytharra Formation
Early Carboniferous	Williambury Formation	Moogooree Limestone
Silurian	Tumblagooda Sandstone	Dirk Hartog Formation, (Permian) Byro Group

the syncline, and are also mature at shallower depths on the western limb owing to earlier greater depth of burial. Modelling suggests that this oil maturity may have been reached as early as the latest Permian. Siltstone interbedding within the lower Billidee Formation forms the lowermost seal over the Moogooloo Sandstone, with a regional seal above this in the shale and siltstone of the Coyrie Formation.

On the basis of current data, the western limb of the syncline offers most potential for structural trap formation, associated with en echelon faulting in the Wandagee,Kennedy and Ajana faults. Mapping of the top Wooramel Group (top of the primary play sequence) demonstrates fault-associated closures (folding or drape) west of the proposed park area (designated A on Plate 2). Similar closures may exist along faults located within the park area. Although the lack of a suitable seismic-data grid precludes mapping of such closures at depth, several anticlines have a surface expression (Plate 2). The time of formation of these traps is important because it is hypothesized that oil generation may have begun less than 10 Ma after deposition. At this stage, there are insufficient data to realistically evaluate stratigraphic traps.

Some potential within the pre-Permian is envisaged where these rocks are shallow enough to have preserved porosity and permeability, particularly along the above fault trend where the formation is thin. Source and maturity are the primary risks.

The synclinal area under Kennedy Range remains largely unknown because of sand cover and difficulties in obtaining good-quality seismic data. However, surface geology on Middalya and Williambury Stations, immediately north of the range, indicates that there is potential for fault traps which could juxtapose source and reservoir. There is also potential for stratigraphic traps in local deltaic developments in the Wooramel Group (Billidee Formation especially) and possibly in the Coolkilya Sandstone of the Kennedy Group.

Coal

Sizeable delta-plain and coastal-swamp deposits occur in the Wooramel Group (Fig. 6). In the Kennedy Range area BHP intersected a thin coal seam

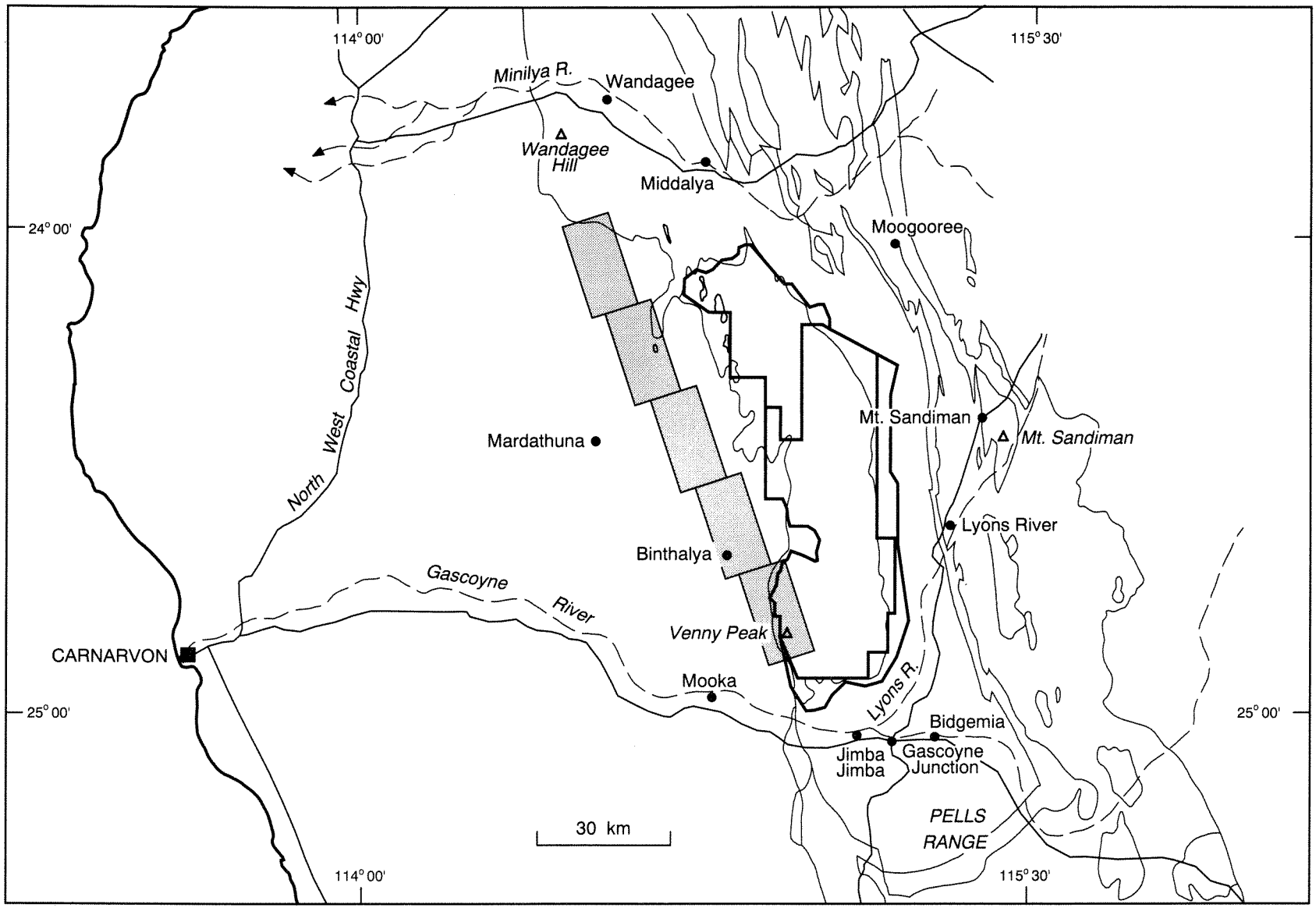


Figure 6. Coal exploration from 1970

(< 1 m) in the Billidee Formation. Farther north in the Wandagee area this parabituminous coal occurs at a depth of 170 m. Carbonaceous material is also present in the Moogooloo Sandstone at greater depth. The Wooramel Group is at uneconomic depths (> 1 km) beneath the range itself, except near Merlinleigh and Moogooree.

Base metals

Exploration for base metals in the vicinity of the KRNP has been in progress since the early 1970s (Figs 7 and 8).

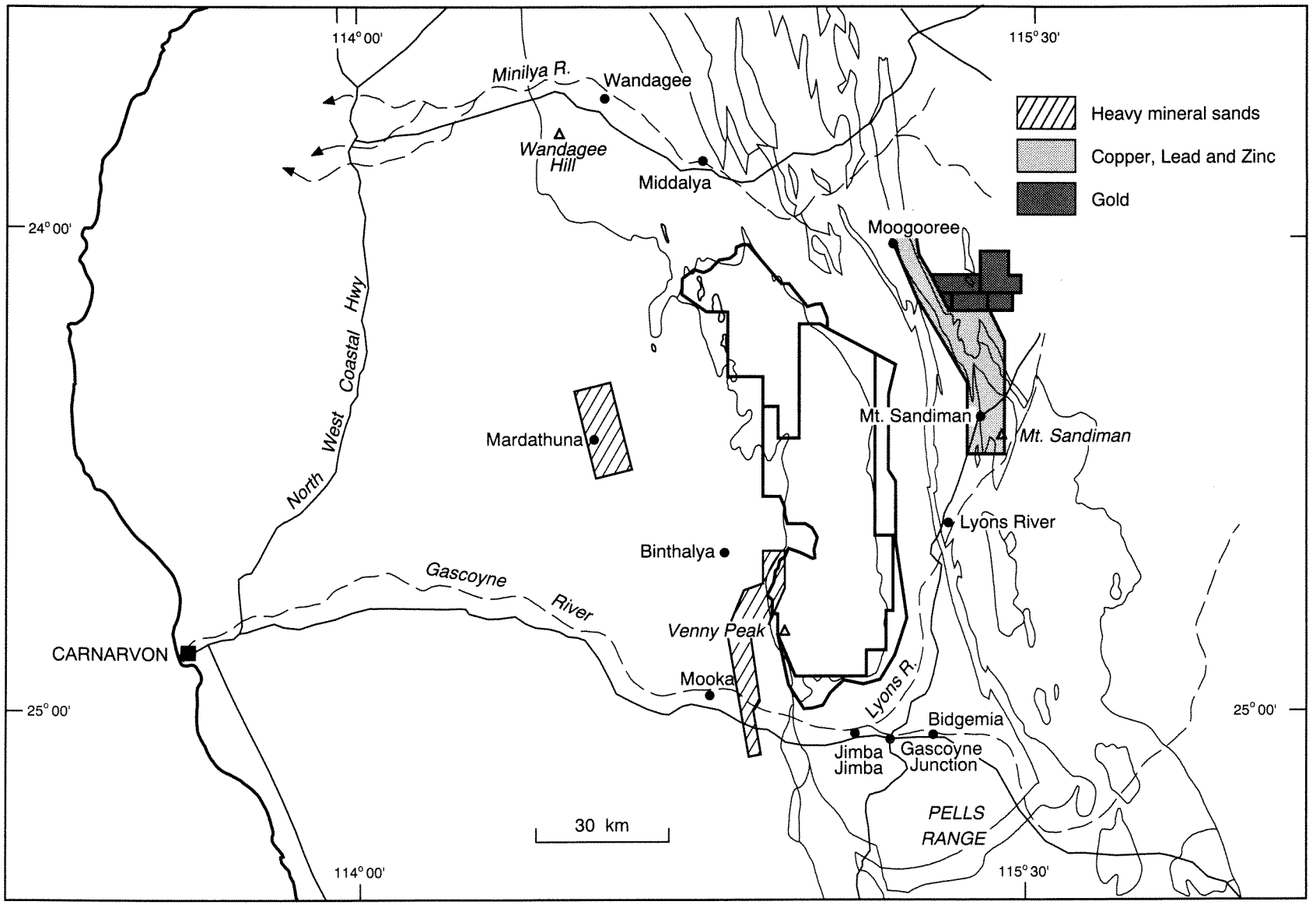
Exploration has concentrated on two main target types: the Mississippi Valley (Pb - Zn mineralization in carbonate-rich sediments), and the stratiform (Pb - Zn or Cu - Pb (- Ag) in carbonaceous shales).

The Mississippi Valley type requires the movement of metal-rich brines through the sedimentary pile, via a 'plumbing-system' such as that provided by fault zones. These brines then encounter carbonate sequences displaying palaeokarstic weathering, or reef/fore-reef breccia environments, unconformably overlain by suitable trap rocks. Epigenetic sulfide mineralization occurs in these karst or reef zones and is often associated with dolomitization or silicification of the host carbonate.

In the stratiform type, similar mobile brines deposit their metallic content on contact with black-shale facies sediments during sedimentation or soon afterwards.

Prospective units for the Mississippi Valley type are the Devonian Gneudna Formation, the Carboniferous Moogooree Limestone and the Lower Permian Callytharra Formation. For the black-shale (stratiform) type the shales of the Permian Byro Group, particularly the Bulgadoo Shale, are prospective. Outcrops of all these units lie in a north-northwest trending zone to the east of the KRNP and have undergone exploration by several companies.

Both the Gneudna Formation and the Moogooree Limestone are unconformably overlain in this area by the Carboniferous - Permian Lyons



GSWA 26379

Figure 7. Present mineral tenements

Group which consists of suitable trap rock. Veins carrying barite, galena and sphalerite cut both Precambrian basement and basal Lyons Group sediments south of Mount Sandiman homestead. This indicates that metalliferous brines were circulating in the sediments from Late Carboniferous times.

Between 1970 and 1972, Aquitaine concentrated on the Moogooree Limestone in the immediate area of Moogooree homestead. Here the limestone is dolomitized and shows favourable reefs and breccias. Rock sampling followed by two diamond drillholes gave assays of up to 2.2% Zn and 1400 ppm Pb. Geological mapping and auger drilling were carried out but there was no follow up. Inco did further work in this area in 1978 - 1980. Their geological mapping showed a palaeokarst overlain by Permian sediments. IP surveys indicated potential sulfide conductors. Attempts to drill prospective zones were frustrated by problems with cavities in the rock. Up to 1% Pb was found in the Gneudna Formation but was of limited extent.

In 1988 EZ Ltd and Aberfoyle Resources again took up this area, with more extensive coverage, as they considered the potential of the Moogooree Limestone and the Gneudna Formation to be still untested. Extensive soil and rock-chip sampling failed to extend the known mineralization, and reinterpretation of Inco's IP results suggested that anomalies did not relate to sulfides. All of the zone where the Devonian - Carboniferous sediments are exposed adjacent to Precambrian basement is presently under tenement to Dominion Mining.

In 1983 Amoco took up ground in the area of Mount Sandiman where poorly sorted sandstones of the Lyons Group overlie the basement. Soil and stream-sediment sampling gave poor results for Cu, Pb, Zn, and Ba.

Reconnaissance exploration by Inco over the Callytharra Formation, which outcrops closer to the KRNP, indicated low potential. This may be due to the relatively poor trap-rock characteristics of the overlying Moogooloo Sandstone, or because the main mineralizing event preceeded the deposition of the Callytharra Formation.

There may be some potential for black-shale-hosted Cu, Pb, Zn mineralization in the Permian Bulgadoo Shale which outcrops less than 10 km

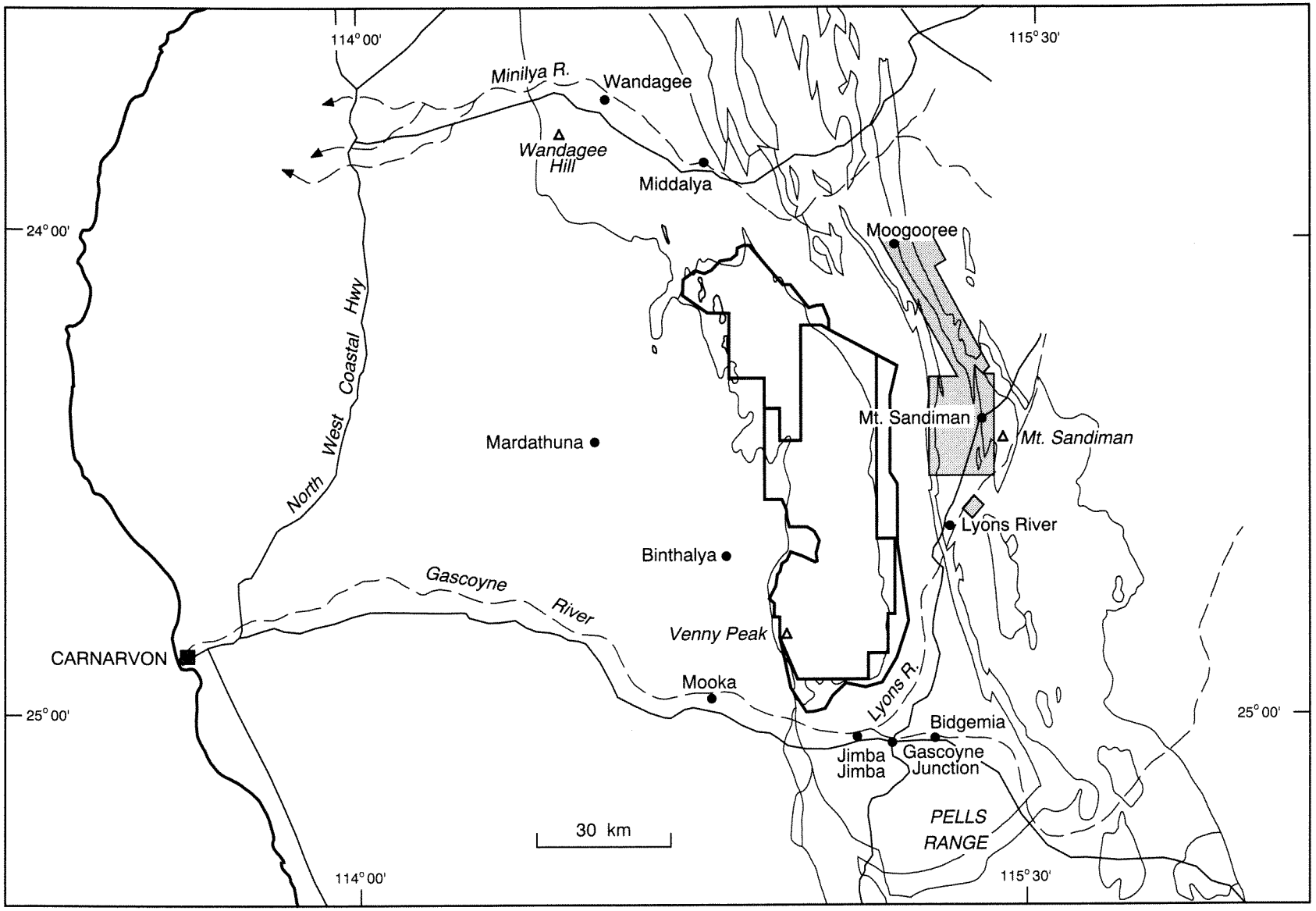


Figure 8. Pb/Zn/Cu exploration from 1970

east of the KRNP. This does not seem to have been tested except in regional reconnaissance.

In summary, if potential for base-metal mineralization exists in the Devonian to Permian part of the sequence in this area, then it is greatest in the basal Devonian - Carboniferous carbonate units. These outcrop at least 19 km from the eastern boundary of the KRNP and would only be present at considerable depth (2 - 3 km) beneath the proposed park.

Harrison (1985) suggests some potential may exist in shale and siltstone sequences of the Cretaceous Winning Group for base-metal mineralization based on analogies with presently forming mineral deposits in brine pools of the Red Sea. These have been tested without success by Inco in the Giralia Anticline, well to the northwest of the KRNP. The lower part of the Winning Group outcrops extensively immediately west of the KRNP, but only a small area is contained within the proposed park.

Uranium

Exploration for uranium (Fig. 9) in the vicinity of the KRNP was carried out between 1973 and 1980 over the Precambrian Gascoyne Province granitoids and metamorphic rocks, and the marginal sediments of the Merlinleigh Sub-basin. The main target type was roll-front deposits associated with redox fronts in sandstone - shale sequences marginal to basement containing numerous 'hot' granitoids.

Between 1973 and 1974, Uranerz Australia Pty Ltd carried out airborne reconnaissance over Archaean/Proterozoic basement and Devonian and Permian units in the Mount Sandiman area. Follow-up ground work focused on the siltstones and calcarenites in the Devonian Gneudna Formation and Carboniferous Lyons Group greywackes but no anomalies were found. Farther north, in the area of Moogooree homestead, Uranerz carried out comprehensive airborne and ground exploration (1972 to 1976) over basement and Devonian sediments. Several carnotite and tyuyamunite zones were located within 3 m of the surface in 'marl' zones of the Gneudna Formation. Minor anomalies were also encountered in the Nannyarra and Munabia Sandstones.

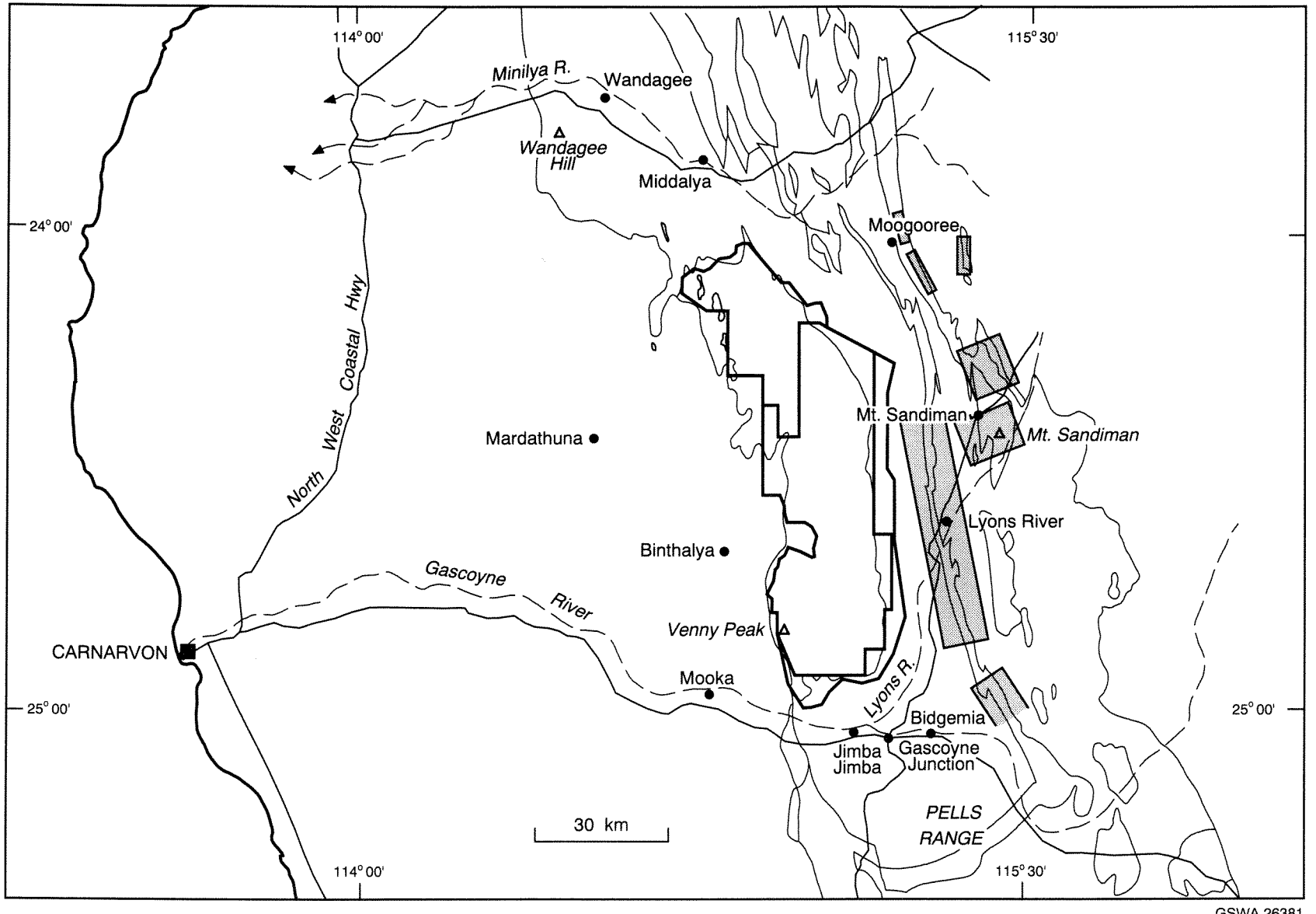


Figure 9. Uranium exploration from 1970

In 1976, Samedan briefly examined a postulated palaeochannel in Lyons Group sediments in the Lyons River - Davis Creek area. Afmeco were active between 1976 and 1980 concentrating on the basal Permian Moogooloo Sandstone in an area extending south from Miller Bore (Mount Sandiman) to their discoveries in the Pells Range area on WOORAMEL. The mineralization in Pells Range shows some similarities with the peneconcordant target type in that the uranium occurs in strongly carbonaceous silty shales. The highest value drillhole intersection (from 84 holes) was 2619 ppm U over 0.3 m. Exploration to the north in the same unit, which extended onto the area of the KRNP near South End Bore, was unsuccessful with no anomalies located. It was concluded that the sedimentary facies in this area were unfavourable.

Nord Resources followed up this work in 1978 - 79 with no further success.

Diamonds

The Carnarvon Basin was the focus of a search for kimberlites in the mid-1970s (Fig. 10). This culminated in the discovery, by CRA Exploration Pty Ltd in 1978, of alkali-picrite dykes, sills, and pipes in the Wandagee area on WINNING POOL.

Sixteen separate dykes, sills, and pipes are located in a cluster just east of the Wandagee Fault, on the eastern margin of the Merlinleigh Sub-basin. Emplacement may have been due to tensional crustal fracturing during the separation of the Australian and Indian plates, and probably occurred in the Jurassic. The pipes have been eroded to a deeper level than the AK 1 pipe at Argyle.

This discovery triggered exploration on KENNEDY RANGE along the trend of the controlling fault zone to the south. Stockdale Prospecting Ltd discovered a further six prospective bodies. In the total of 22 bodies only three small diamonds were found.

In the late 1970s and early 1980s, CRA, Cultus Pacific/Metramar/York Resources, Siberia Nickel, and Amax/Seltrust all carried out regional reconnaissance, with little success, northwest and west of the KRNP. Both Amax

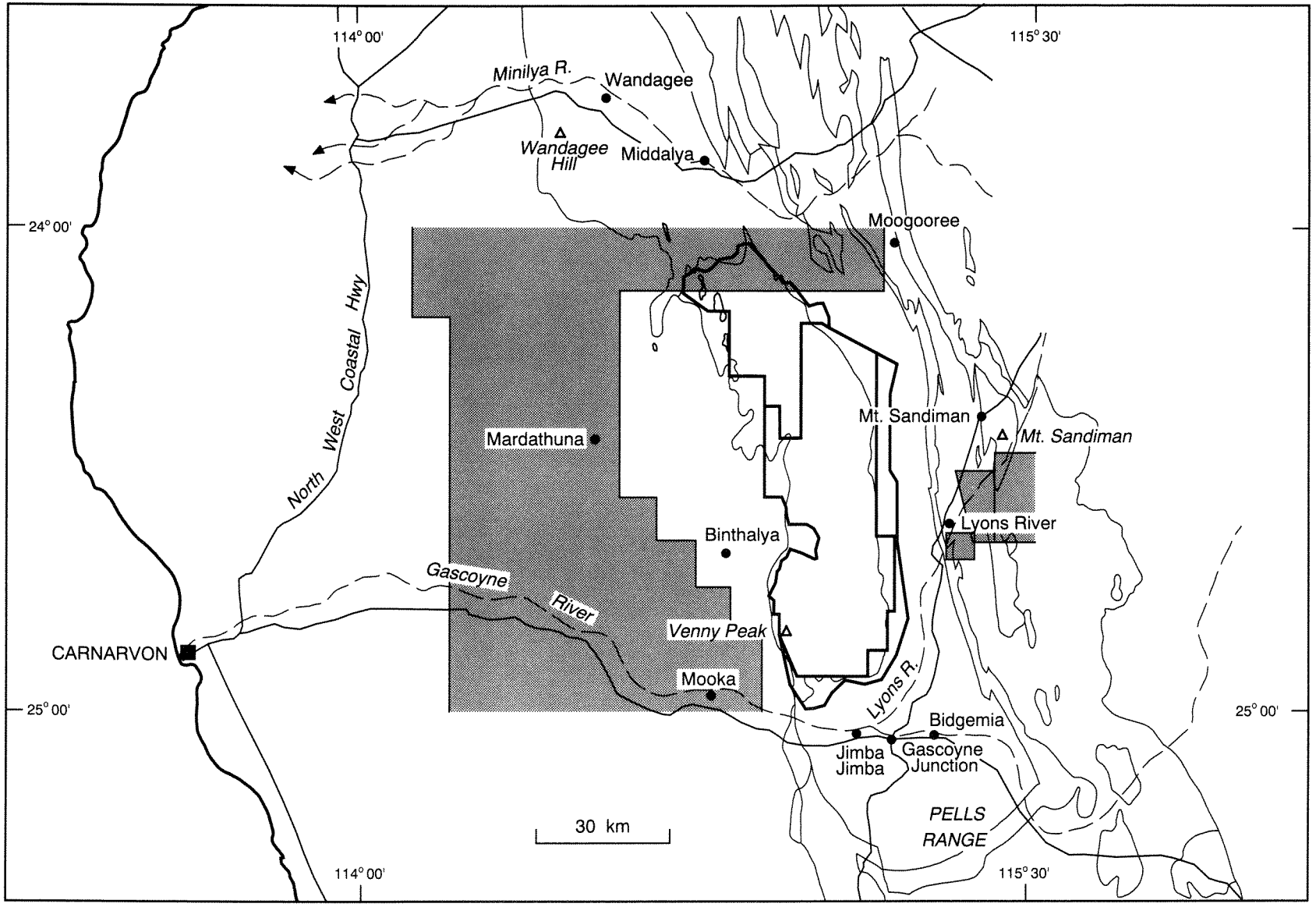


Figure 10. Diamond exploration from 1970

and the Cultus group tested aeromagnetic anomalies on the margin of the KRNP but did not locate kimberlitic material.

In 1984 - 85, BHP Minerals explored for diamonds in the glacigene sandstone, siltstone, and tillite of the Lyons Group which overlies Precambrian basement in the Lyons River - Davis Creek area. Some chromites and one small diamond were located in material that was believed to be considerably reworked and from a source some distance to the north.

Gold and platinum

There is little history of gold or platinum exploration in this area. Recent interest seems to have been confined to the Precambrian basement rocks over 18 km east of the KRNP (Fig. 7).

Phosphate

Regional reconnaissance was carried out in the 1960s by EZ Ltd in the Permian Bulgadoo Shale, and by Cyanamid Australia Pty Ltd in the upper part of the Cretaceous sequence. Exploration, which centred on the Gascoyne Junction area, was unsuccessful.

Heavy-mineral sands

The conjunction of marine strandlines and drainage systems originating in granite/gneiss basement has encouraged several companies to explore for heavy-mineral sands (Fig. 7) in the coastal regions of the Carnarvon Basin. Few explorers, however, have considered palaeostrandlines as opposed to recent systems.

Harrison (1985) considered potential heavy-mineral assemblages in relation to provenance. He concluded that the most favourable potential was in the south where dilution of the heavy minerals by garnets, kyanites, staurolites, or epidotes from the Morrissey Metamorphic Belt, or by magnetite and titanomagnetite from the Hamersley Basin, would be minimal.

In 1976 - 77, Inco examined Quaternary sands in the vicinity of a proto-Murchison rivermouth identified by Landsat imagery. Although possible coastal notches were identified, heavy-mineral contents were found to be low.

In 1989 - 90, Metana tested Cainozoic sands in three widely spaced areas in the basin. Remote sensing, airphoto interpretation, and grab sampling defined prospective palaeostructures. Heavy minerals found in these areas were diluted by iron oxides and windblown sand.

The Birdrong Sandstone, originally deposited in a coastal environment, has some potential although heavy-mineral sand bodies have not been noted in outcrop.

Lapidary stone

Two forms of lapidary stone are found within the Kennedy Range area in the Cretaceous Windalia Radiolarite.

'Mookaite' (informal name derived from Mooka Station) is an opalized form of the radiolarite coloured in tones of red and yellow. Currently utilized deposits at Mooka Station lie outside the KRNP.

'Peanut Wood' is silicified wood with common *Teredo* borings infilled with white radiolarite. This stone is found in scattered small localities.

A tenement application covering the southwest corner of the KRNP was withdrawn in 1989 owing to the low commercial potential of these semi-precious gemstones. They are primarily of amateur interest.

Water

Within the Merlinleigh Sub-basin, supply and quality of water from the Palaeozoic sediments is highly variable. The Moogooloo and Munabia Sandstones generally provide good-quality water at shallow to moderate depths.

In the Kennedy Range, depending on site conditions, small supplies of groundwater can be obtained from unconfined aquifers in the Permian formations within 100 m of the surface. Within the Binthalya Formation, Mungadan Sandstone and Coolkilya Sandstone, which are present towards the top of the range, are local aquifers which produce small supplies. This water occurs in local and perched flow systems which are the source of some of the springs which occur on the western side of the range. However, many of these springs are located along the Kennedy Fault System and probably discharge, at least in part, from the main flow system in the area. Others, e.g. Maslen and Kurrajong Springs, originate from perched watertables (A. D. Allen, *in* Hocking et al., 1978). Fresh groundwater is restricted to intake areas near outcrops of sandstone; elsewhere, water is brackish to saline. The lack of pastoral exploitation of the top of the range indicates a scarcity of adequate groundwater, even of a poorer quality suitable for sheep. Only a few bores are present (near Moogooree) and these present salinity problems.

Conclusions

The mineral resource (other than hydrocarbons) potential of the area proposed for the Kennedy Range National Park is low. A significant history of mineral exploration in the general area, aimed mainly at base metals, uranium, and diamonds, has resulted in no significant discoveries. Few tenements have encroached on the park area in the past. Only one existing exploration licence slightly overlaps (in the southwest corner) the KRNP boundary.

Base-metal potential lies principally in the Devonian - Carboniferous carbonate units which outcrop at least 18 km east of the KRNP and which (if present) are at great depth beneath the KRNP. Similar considerations apply to uranium potential in roll-front or penecontemporaneous target types near the basin margin. Diamond potential in the area has been downgraded owing to poor results from exploration which followed CRA's earlier discovery of

kimberlite-like bodies in the Wandagee area. The area of the Kennedy Fault System would have most potential for diamonds within the KRNP, but all exploration to date has indicated that the associated alkali-picrite intrusives only rarely contain diamonds. Gold and platinum potential is restricted to Precambrian basement.

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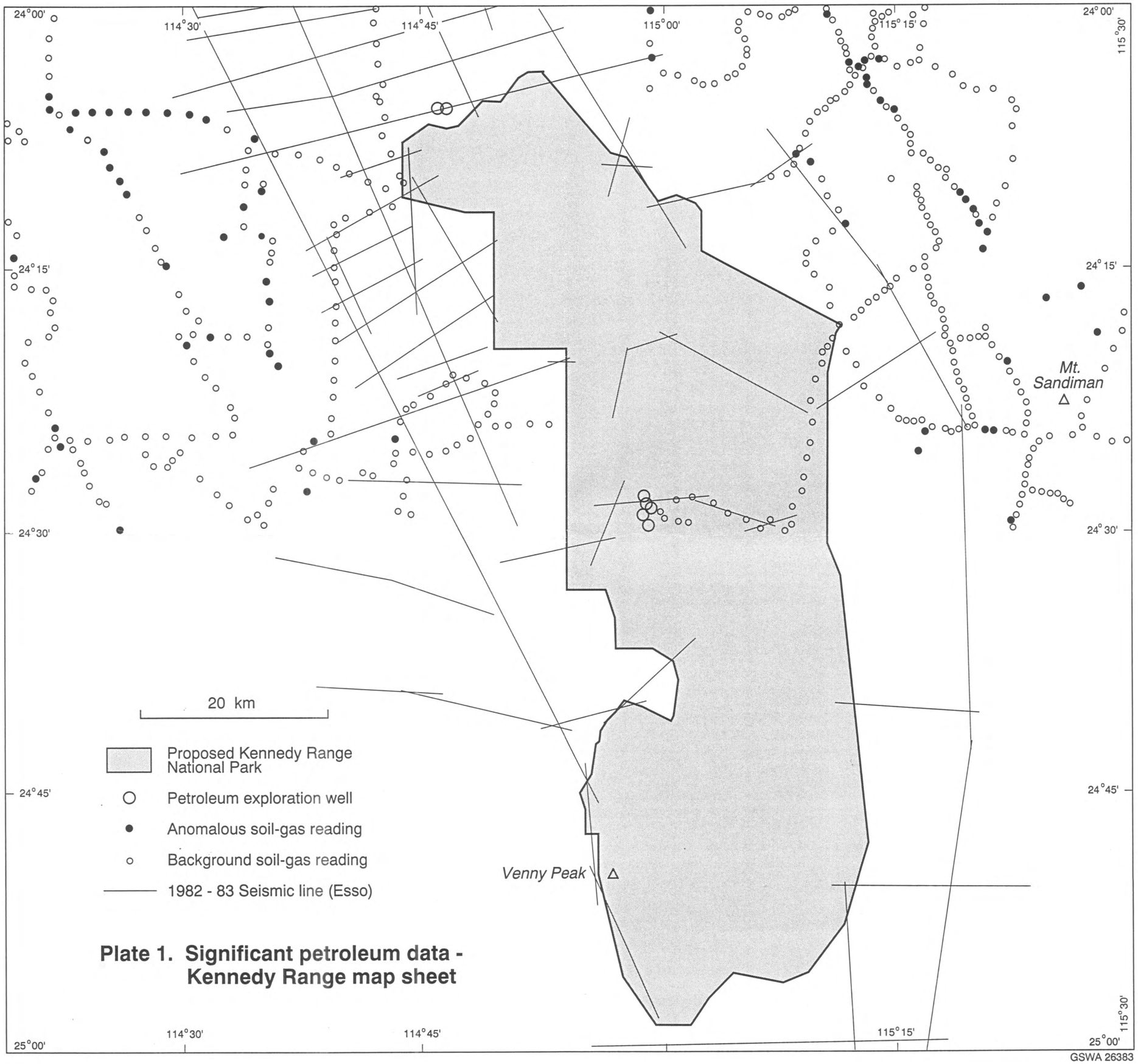

Plate 1. Significant petroleum data - Kennedy Range map sheet

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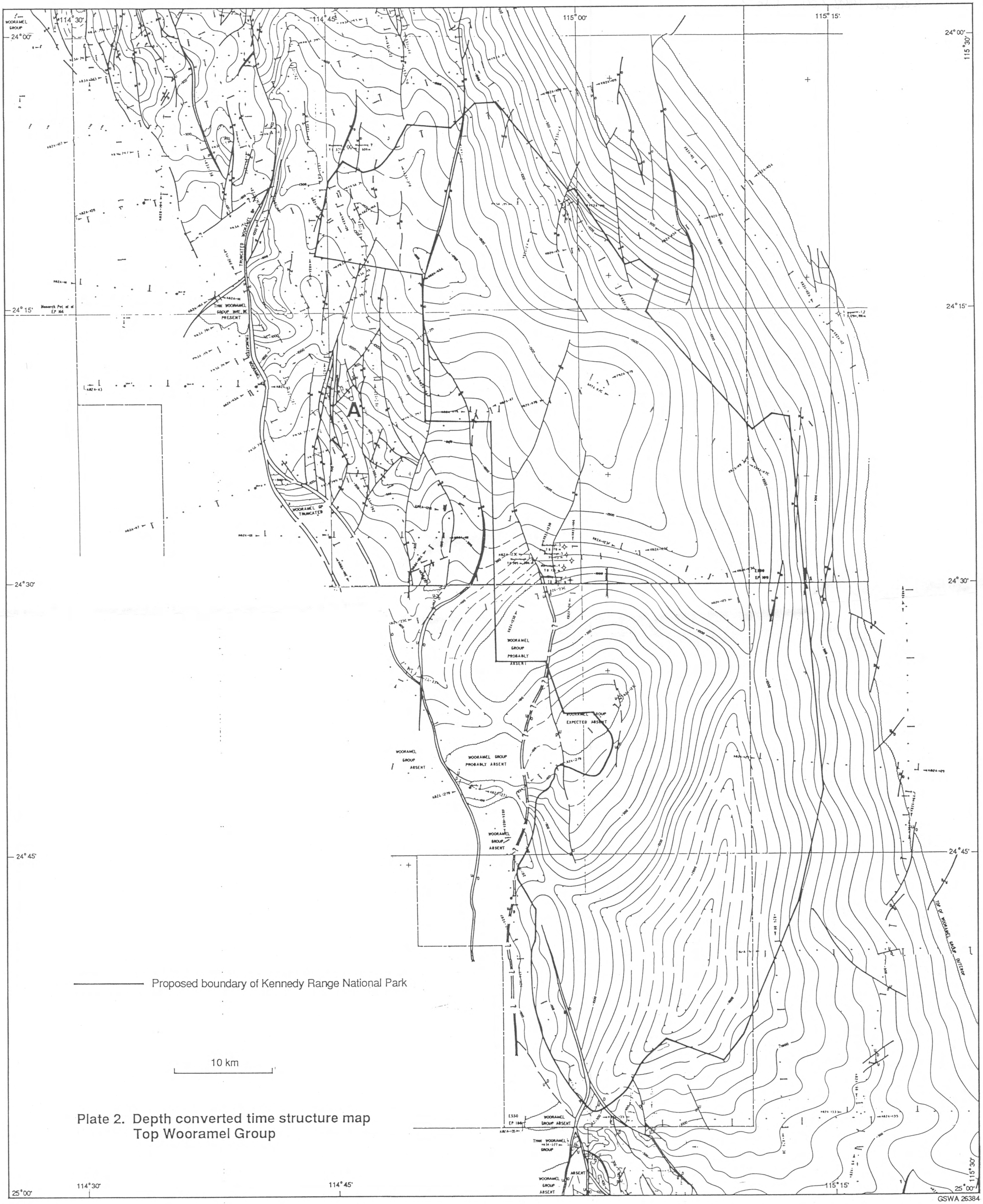

Plate 2. Depth converted time structure map
Top Wooramel Group

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