Bureau of Mineral Resources, Geology & Geophysics

RECORD

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Eastern Goldfields ACORP Transect
A Proposal

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Executive Summary

This Record outlines a proposal by the Bureau of Mineral Resources, the Geological Survey of Western Australia, supported by Australian Universities and relevant Mining Companies, to undertake seismic reflection profiling across the Eastern Goldfields Province and the eastern margin of the Southern Cross Province of the Yilgarn Craton. The purpose of the profiling is to image the entire crust in areas of mineralisation, particularly the Leonora and Kalgoorlie areas of gold deposits in order to test and distinguish between conflicting models for the tectonic evolution of the Province. It will provide information not available from other geological or geophysical techniques on the shape, depth and boundary faults of the greenstone belts, and on the geometry and depth extent of thrusts and regional strike-slip shear zones in the area.

The scientific objectives for the Eastern Goldfields seismic reflection profiling are:

- To map the shape, depth and boundary faults of the greenstone belts that separate large areas of granitic rocks and define the geometry of the intrusive granites, using the seismic reflection technique. Such mapping in the third dimension is essential for a better understanding of the structural evolution of the region, and therefore on the movement of fluids responsible for mineralisation.

- To study the differences in reflection character and crustal thickness between the Eastern Goldfields and Southern Cross Provinces as a means of better understanding the similarities and differences in their tectonic evolution.

- To investigate the geometry and extent of shear zones using a combination of high resolution reflection profiling and refraction tomography. The relative importance of different types of shear zones to the pattern of mineralisation is still poorly understood. Refined seismic studies such as those of Green *et al.* (1989) (high resolution seismic) and Greenhalgh *et al.* (1989) (refraction tomography) can assist in the solution of this problem.

Two deep regional seismic reflection profiles are proposed to resolve these objectives. The first, with the highest priority, is in excess of 150 km in length and is located to the north of Kalgoorlie. The second, with lower priority, is between 150 km and 200 km in length and is located to the north-west of Leonora. It is anticipated that about 150 km to 200 km of deep reflection profiling will be funded out of the BMR core budget. A limited amount of shallow high resolution seismic reflection work is required as a means of resolving both lithological variations at depth and the fine structure of fault zones in several areas of economic importance. The high resolution work will probably attract industry sponsorship. Collaborative university or industry organised three-dimensional reflection and refraction surveys will be piggy-backed on the BMR seismic program.

Both the deep regional and shallow high resolution seismic reflection data acquisition will use explosive sources with a minimum of 96 channels of recording, and a minimum of six-fold coverage. All data processing would be carried out at the BMR. The collaborative work with universities or industry using the three-dimensional reflection recording and refraction tomography may be done by other organisations, but under the supervision of the BMR. The proposed time for the data acquisition is between April and June, 1991. Initial processing will be completed and the data released for sale within 12 months of the commencement of data acquisition, but at least two years will be required to provide reliable tectonic interpretations.

If the exploration industry provides sponsorship for the high resolution work, public release of these data would be two years after completion of the fieldwork although all participants and sponsors will have access to the data and preliminary or developing interpretations at all times.

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Introduction

The Eastern Goldfields Province of the Yilgarn Block in Western Australia (Figure 1), comprises two major terranes, a western terrane dominated by basalt and ultramafic rocks (Kalgoorlie Terrane, Figure 2), and an eastern terrane dominated by tholeiitic basalt, felsic volcanic and volcaniclastic rocks and clastic sedimentary sequences (Kurnalpi Terrane, Figure 2). The western terrane is juxtaposed against the Southern Cross Province (Figure 1), which has a distinctive magnetic signature and different geological characteristics. These three 'terranes', and the majority of the Yilgarn Block, were intruded during a massive felsic magmatic event at 2.65 to 2.68 Ma.

The nature of tectonic episodes which led to this gross geometry of the eastern Goldfields is not well constrained, despite continuing mapping and research over the past fifteen years. Models for the evolution of the Archaean crust of the Yilgarn Craton fall into two general classes:

- vertical tectonic models (Figure 3), and
- horizontal tectonic models (Figure 4).

Following enthusiasm for plate tectonic continental margin models during the 1970's, in which the greenstones where considered to represent obducted oceanic crust, several lines of evidence showed that significant parts of the greenstone belts were underlain by continental crust, and ensialic rifting models were proposed to account for generation and intrusion of the mafic and ultramafic rocks. This class of models is refered to as horizontal tectonic models (*e.g.* M.E. Barley, *et al.*, 1989) . Later explanations of the geometry in terms of 'classical' plate tectonics suggest that the western basaltic and ultramafic belt formed in a large extensional back arc basin, with the eastern terrane representing a remnant fore arc assemblage. More recently, mapping evidence has helped to define terrane boundaries more accurately, and an accretionary model, in which docking of continental fragments along largely transcurrent faults, has been proposed as an alternative model. Horizontal tectonic models allow for the generation of large volumes of granite in hinterland and back-arc regions, but predict

- a strongly layered upper crust, with
- possible remnants or layers of greenstone below granitoid layers.

A different class of model for Archaean tectonics invokes the emplacement of the vast granite batholiths as the tectonic driving force for orogeny, rather than ridge formation and subduction. Heat loss in the present-day version of this model is by conduction through the primitive crust (Campbell and Hill, 1988). The generation of basaltic and komatiitic rocks took place over large mantle plumes, and the short time interval between basalt magmatism and granite emplacement is a result of the time taken to transfer heat from the mantle plume to the crustal anatectic layer. This type of model is referred to as a vertical tectonic model. Vertical tectonic models predict that:

- granite-greenstone boundaries should be steeply dipping,
- the internal structure of the greenstone belts will be dominated by upright folding and homogeneous flattening, and
- the mid to lower crust should be fairly homogeneous.

The models predict different crustal structure, but they cannot be resolved using our present knowledge of the structure of the region. Structural evidence from throughout the Eastern Goldfields province has established a coherent three-phase deformation history:

1. Early thrust faults are well established in several areas, generally with large displacement, with north northwest-south southeast movement.
2. Upright north-south tight to open folds.

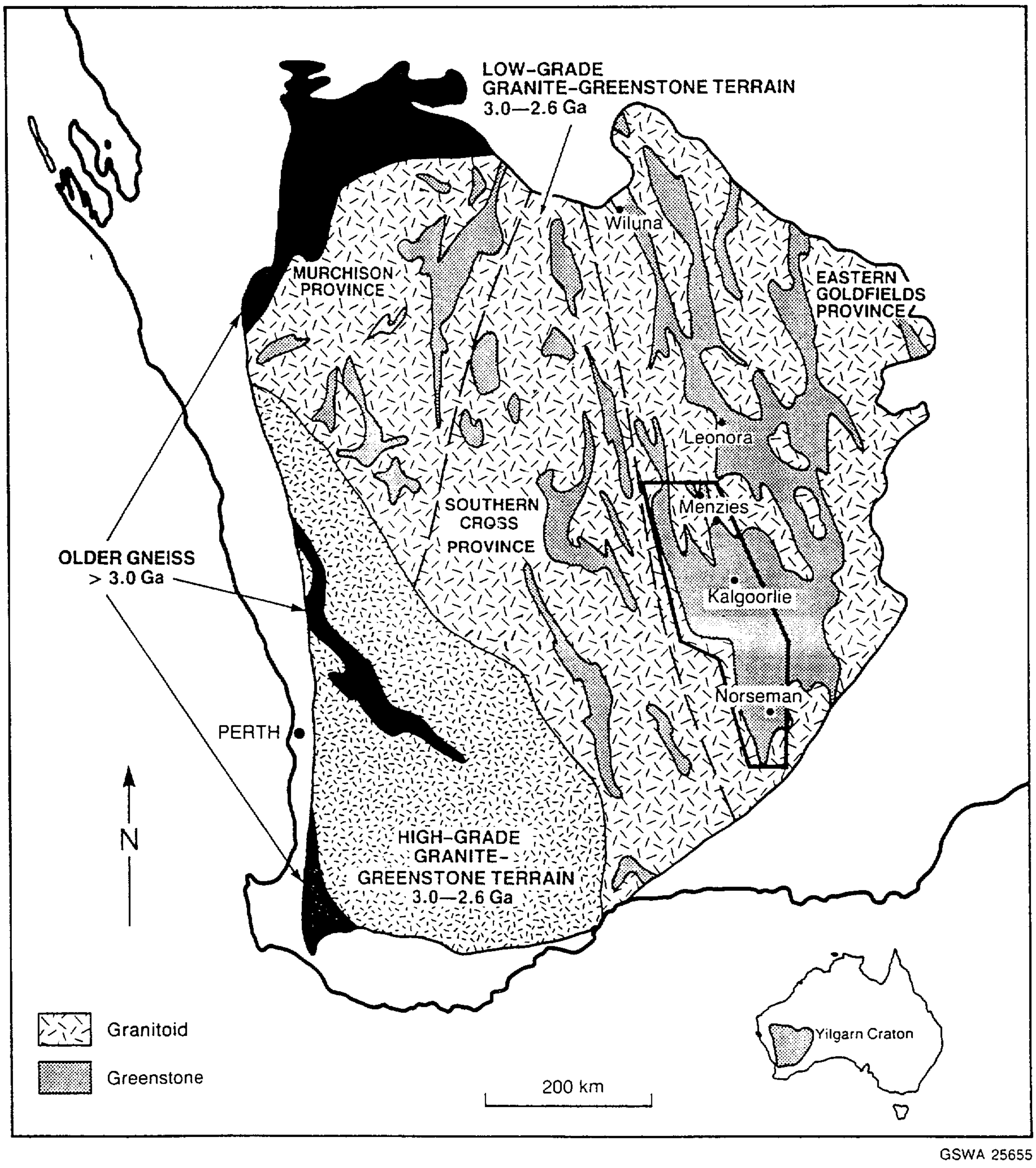


Figure 1 Geological map of the Yilgarn Craton. The region covered by the Kalgoorlie Terrane map is shown by a bold frame.

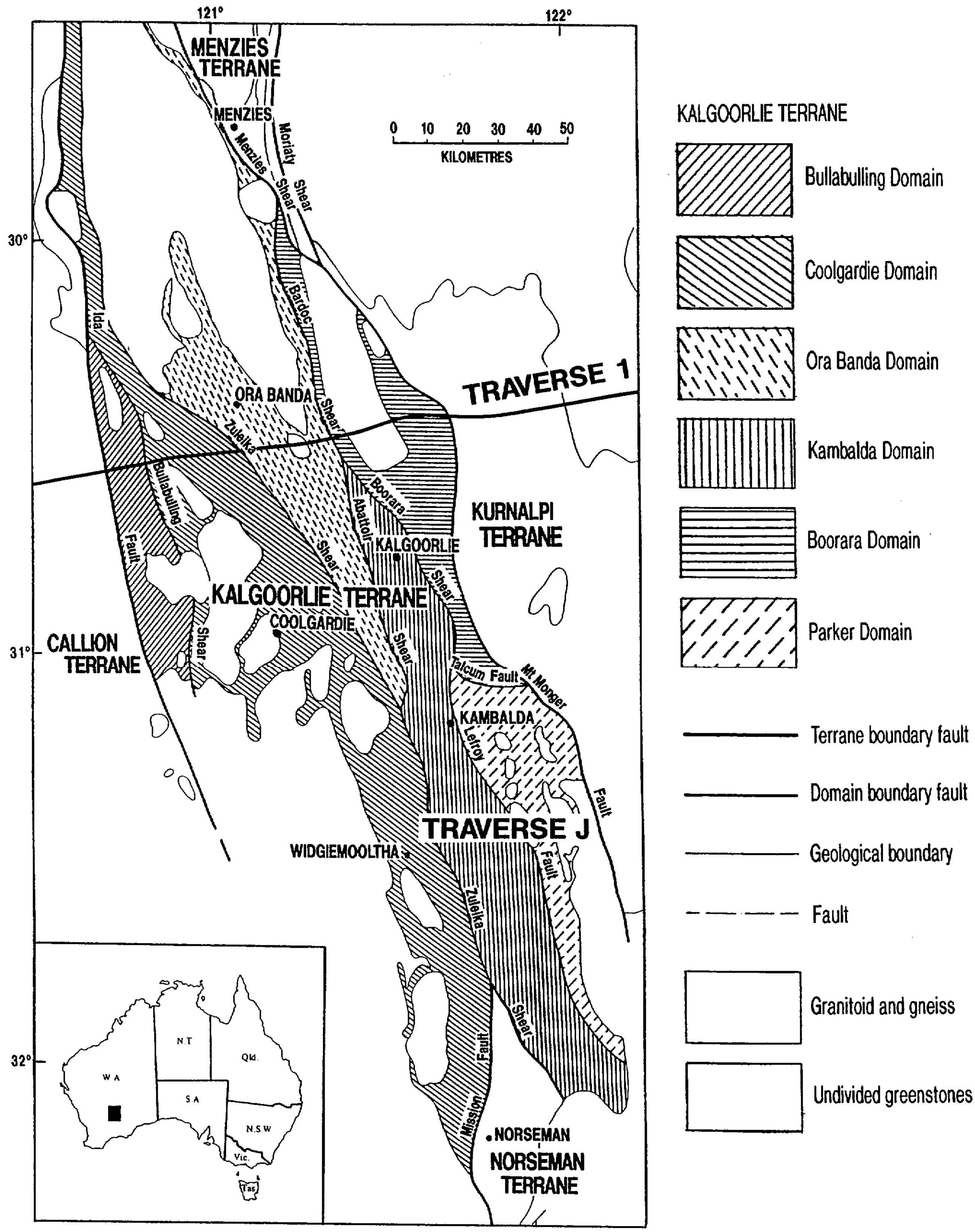


Figure 2 Major structural units of the Kalgoorlie Terrane. From Geology of the Archaean Kalgoorlie Terrane, 1:250,000. Geological Survey of Western Australia, 1990.

3. Horizontal faults and shear zones, commonly sinistral.

The three-phase deformation history is consistent with a variety of structural styles for the mid to upper crust.

- Delamination or flake models predict that steeply dipping faults at the surface are connected with shallow dipping ductile shears in the middle part of the crust.
- Fold and thrust belt models predict crustal thickening contemporaneous with tectonic shortening, resulting in a strong sub-horizontal layered or duplexed mid to lower crust.
- Extension and inversion models predict that high-grade deep-level rocks are juxtaposed against low-grade rocks at a shallow level. The crust will therefore be strongly layered at mid to upper crustal levels. Shallow dipping domal structures at granite-greenstone boundaries will be marked by reflective mylonite zones along either detachment zones or thrust faults.

There is, therefore, very little available evidence to constrain the shape of structures associated with these events in the depth dimension, but the crustal structure of the Archaean Craton is likely to be very different depending on the way the supracrustal geometry has been constructed.

Thus, vertical and horizontal tectonic models would have produced different seismic signatures of the upper crust and can therefore be tested using the seismic reflection technique. It is likely that the lower crust will be seismically similar in both cases, but deeper lithosphere structure may be markedly different.

This record details a proposal for seismic reflection profiling designed to test these crustal models. The Eastern Goldfields Seismic Survey was proposed by C. Wright, P.Williams and C. Swager in early 1989, and follows a Western Australian ACORP proposal to LITSAC to undertake profiling in the Yilgarn Block (Moss and Goleby, 1985). The proposal now forms part of a joint BMR and Geological Survey of Western Australia project to map portions of the Eastern Goldfields province as part of the National Geoscience Mapping Accord.

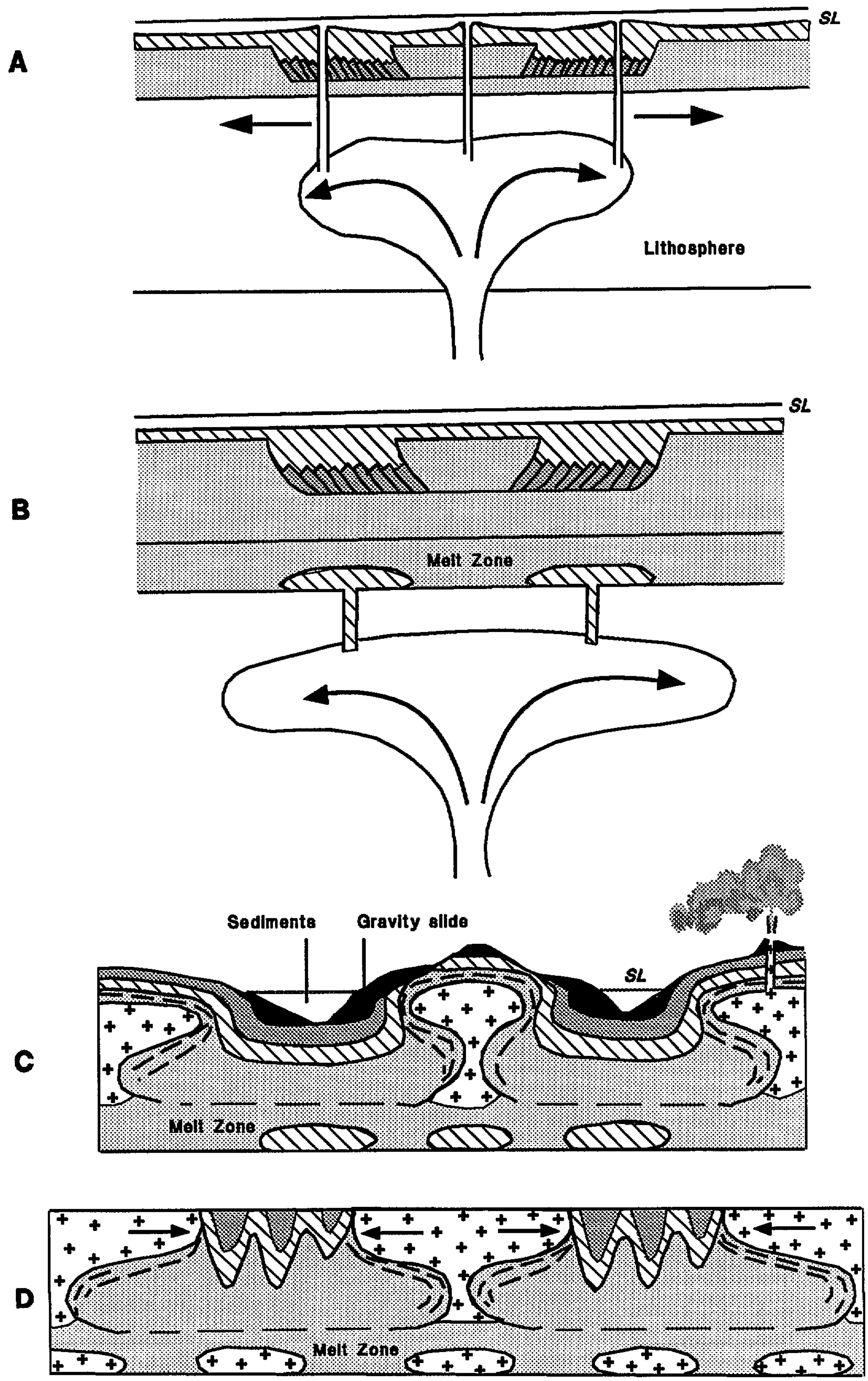
Opportunities exist for other institutions, and particularly university groups, to participate in the seismic work, and to undertake piggy-back projects. Organisations which have expressed an interest in the project include the Curtin University of Technology, the University of Western Australia, Flinders University of South Australia and the Australian National University.

Scientific Objectives

The scientific objectives for the Eastern Goldfields proposal are listed below. Detailed objectives for each profile are discussed later in the document.

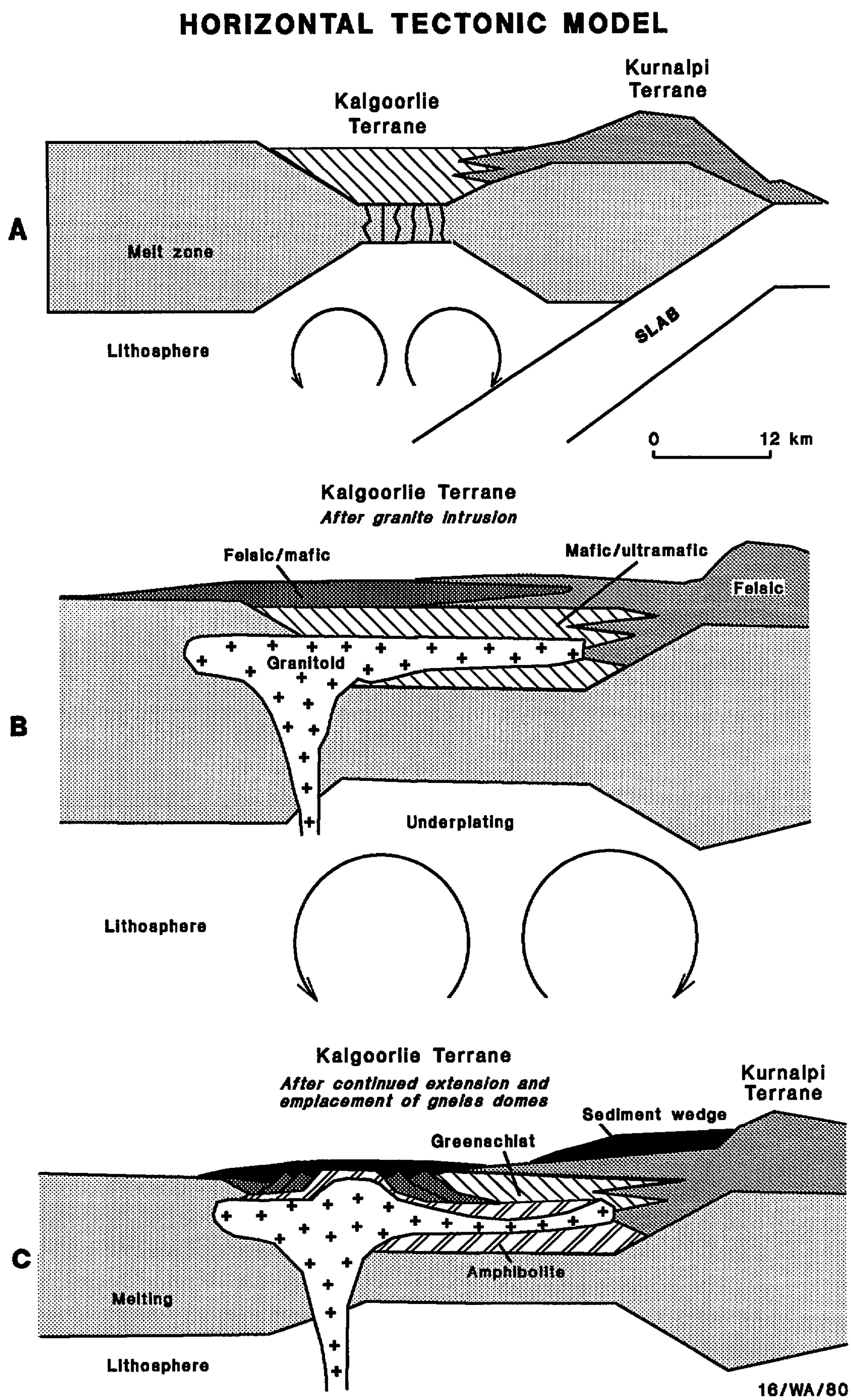
- To map the three-dimensional geometry of the greenstone belts, and in particular,
  - their shape and thickness,
  - the geometry of their boundary faults,
  - the geometry and extent of shear zones within the greenstone belts (the relationship of different types of shear zones to the pattern of mineralisation is still poorly understood),
  - the geometry of the intrusive granites within the greenstone belts;
- To investigate the structural relations of the greenstones with the adjacent areas of granitic rocks; and
- To study the differences in structure, form and crustal thickness in the Eastern

VERTICAL TECTONIC MODEL



Campbell I.H. and Hill R.(Earth and Planetary Science letters,1988) 16/WA/81

Figure 3



HORIZONTAL TECTONIC MODEL
Kurnalpi Terrane
Kalgoorlie Terrane
A
Melt zone
Lithosphere
SLAB
0
12 km
Kalgoorlie Terrane
After granite intrusion
Felsic/mafic
Mafic/ultramafic
Felsic
Granitoid
B
Underplating
Lithosphere
Kalgoorlie Terrane
After continued extension and emplacement of gneiss domes
Kurnalpi Terrane
Sediment wedge
Greenschist
C
Amphibolite
Melting
Lithosphere
16/WA/80

Figure 4

Goldfields and Southern Cross Provinces as a means of better comparing and understanding their tectonic evolution.

In summary, these objectives will assist the Eastern Goldfields Project define the three-dimensional structure of the crust beneath the Province, and particularly that of some of the major fault systems. The main zones of mineralisation in the region occur in or adjacent to the major fault systems which may have provided the plumbing systems for the mineralising fluids. These fault systems are mapped at the surface as near vertical. However, their structure at depth is not known. Old analogue data recorded by BMR in the region as part of the Geotraverse survey (Mathur *et al.*, 1977) imply that the faults may be listric. New, high quality, state-of-the art regional profiles are required to test this model, or to erect new ones.

Proposed Survey Design

The main tectonic structures within the Eastern Goldfields Province trend essentially north-south (Figure 2). The optimum orientation for seismic reflection profiles should therefore be east-west, crossing the Eastern Goldfields Province and its boundary with the Callion Terrane, Southern Cross Province (Figure 2). Two profiles are required to successfully meet all of the scientific objectives. The northern profile (about 200 to 250 km long) would cross the Leonora district, while the shorter southern profile (about 150 to 220 km long) would traverse the Kalgoorlie district. High resolution profiling would be done within the greenstone belts close to one of the mining areas to provide more detail of the near-surface structure and lithology. The technical specifications for these profiles are given in Appendix 1.

The locations of the regional lines is discussed in Appendix 2. They cross areas where recent and proposed future geological mapping will provide tight constraints on the interpretation of the seismic data. They are also areas with major mineralisation, including gold, nickel, base metals and rare metals, and thus should provide a link between the role that structure at depth played in the movement of fluids through the crust and mineralisation.

A major concern when siting the seismic lines is avoiding the numerous east-west trending mafic dykes present within the Goldfileds region. They are likely to provide strong side-swipe reflections. The proposed locations of the seismic traverses were chosen to maximize the geological structures crossed, yet be as far as possible from the dykes.

A reconnaissance visit involving initial discussions with property owners, local town councils, mining companies, local authorities and an inspection of the proposed route to gauge logistic difficulties was undertaken in April, 1990, by P.R. Williams, B.R. Goleby and C. Swager. The results from this reconnaissance are given in Appendix 2.

High resolution seismic reflection profiling is also planned as a means of resolving both lithological variations at shallow depths and the fine structure of shallow fault zones in areas of economic importance. Specific targets are listed in Appendix 3. Several companies were approached during July 1989 and indicated interest in the high resolution profiles, which will not only map specific structures but hopefully establish the method as a useful technique for mapping structures at depth in the region. This raised the potential of industry support, through AMIRA, for the high resolution work.

There is scope for cooperative organisations to undertake 'piggy-back' experiments. These include include expanding spreads, three-component recording, directional seismic recording, tomographic studies and three-dimensional reflection and refraction recording. These can be recorded during the seismic acquisition provided they do not hinder the recording of the regional lines.

Data acquisition is planned for April to June, 1991, with the high resolution work, if undertaken, extending the field season to July, 1991.

Relevance to Mineral Exploration Industry

While two episodes of deformation are responsible for the shear zones of the Leonora area, much of the gold mineralisation throughout the Kalgoorlie region appears to be associated with the later, steeply dipping strike-slip structures. It is important to determine the overall geometry of the fault systems, because if the gently dipping faults are connected to the steeper faults at shallow crustal levels, many of the apparent discepancies between observations at different places in the Province can be resolved. This has clear implications for the exploration industry.

A knowledge of the geometry of the early faults is of great importance in developing predictive metallogenic models. As the significance of the structures is established, geometric models of the upper crustal fault arrays will allow prediction of the types of structures which will be encountered during mapping. The mineralisation potential of individual structures can then be estimated according to the model.

Nickel, base metal and rare earth element prospectivity within the Yilgarn Craton have recently received less attention than gold, but this is not likely to continue in the long term. The known deposits in the area (e.g. Kambalda, Mt Weld, Windarra, Teutonic Bore) suggest that metallogenic models for these commodities are also required. Clearly, a knowledge of the shape and distribution of the greenstone belt, and its gross 'crustal-scale stratigraphy' is important when prospecting for nickel (e.g. Agnew). Similarly, understanding the nature of granite-greenstone contacts is important when evaluating ground for base metal exploration (e.g. Teutonic Bore). In all of these deposit types, therefore, a knowledge of the crustal geometry, as determined by seismic profiling, will be an invaluable exploration aid.

The Likelihood of Success - Capabilities of Deep Seismic Reflection Profiling

The seismic profiling will test the proposed tectonic models for the Eastern Goldfields by producing reflection sections along the traverses. For the method to work, the crust must contain features that have a sufficient seismic impedance contrast to produce reflections. This should be the case. Within the Eastern Goldfields Province, reflections can be expected from compositional layering, moderately-dipping shear zones, and major regional faults.

Lithologies within the greenstone belts range from ultramafic schists to granitoids, providing impedance contrasts at lithological boundaries that are sufficiently high to produce reflections. This is confirmed at deeper levels by data collected by the BMR in the Widgiemooltha area to the south of Kalgoorlie in 1969 (Mathur *et al.*, 1977).

The use of seismic reflection techniques to map major faults and shear zones was very successful in the Arunta Block, where the mapping of faults and thrust zones observed in the surface geology to lower crustal depths in excess of 30 km provided the evidence for discriminating between 'thin-skinned' and 'thick-skinned' models of tectonic evolution (Goleby *et al.*, 1989).

Geis, *et al.* (1990) provide an example of the success of the seismic reflection method in Archaean provinces overseas. They were able to erect a new structural model for the Kapuskasing suture on the basis of thin listric fault slices interpreted in their data.

Responsibilities of BMR and Participating Organisations

The BMR will coordinate the seismic work through its mapping project in the Eastern Goldfields. BMR will assume responsibility for the acquisition and processing of the regional reflection data; data interpretation will be the responsibility of the Mapping Project, and will have input from geologists from the Geological Survey of Western Australia. Other participating organisations include the Curtin University of Technology, the University of Western Australia, Flinders University of South Australia, the Australian National University and mining companies with an interest in the eastern Yilgarn Craton.

Gravity measurements will be recorded at intervals of about 500 m along the seismic traverses. These will be the responsibility of BMR.

The crust-mantle boundary is often poorly-defined in seismic reflection profiles across areas of Archaean or Proterozoic basement. However, it represents a major density discontinuity in the Earth and is therefore a major factor in controlling the effects of orogeny - a major disruption to the level of the crust-mantle boundary is unlikely to persist because isostasy will tend to be restored. Long-range seismic refraction profiles should therefore be recorded within a year of the completion of the reflection work to provide velocity control, and to define the crust-mantle boundary. If the reflection data indicate that refraction data are required, the refraction project will form the basis of a further proposal.

Geological mapping of the Eastern Goldfields area will be continued by BMR and the Geological Survey of Western Australia. These organisations will review and synthesise the existing geological, geophysical and structural information as part of the interpretation of the data from the project.

Time Scale for the Project and Release of Information

Line clearing for the regional deep seismic reflection profiling will commence in March, 1991, with the drilling and recording to begin 4-6 weeks later. It is proposed that the Kalgoorlie profile be recorded first. If it is successful the Leonora profile should be recorded during a follow up survey, preferably the following year. The high resolution profiling will be undertaken during the first field season.

Initial data processing should be completed within 12 months of the commencement of data acquisition, but at least two years will be required to provide reliable tectonic interpretations. Public release of data should occur one year after the completion of the data acquisition. However, if industry provides financial sponsorship for the high resolution work, the high resolution data will be released two years after acquisition, though all participants and sponsors will have access to the data and preliminary or developing interpretations at all times. This will be facilitated by regular 6 monthly sponsors meetings.

Recommendations

Scientific

The objectives of the Eastern Goldfields Seismic Survey require a total of approximately 300 km of regional resolution seismic data collection comprising two traverses, each of about 150 km in length. The highest priority traverse is approximately 30 km north of Kalgoorlie, and trending east-west. The lower priority traverse, near Leonora, will answer fundamental questions on the nature of the greenstones and their relation to the surrounding granitoid terranes.

Priorities

The southern line has a higher priority than the northern line, as it addresses a wider range of problems of more direct interest to the exploration industry.

Implementation

The southern line and the high resolution data should be collected between March and July, 1991, with industry funding sought to help offset the cost of the high resolution profiling.

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Appendix 1: Technical Specifications

(1) Regional Seismic Profiling

Seismic Survey Parameters

Minimum of 96 channels of recording (Possibly 120).
20 s record lengths.
2 ms sampling.
GCR 6250 bpi tape recording.
40 m geophone group interval.
6 to 12 fold recording.
320 m shot spacing (six fold) or 160 m spacing (twelve fold).

Acquisition

Geophones: 8 Hz GS-20D, minimum of 16 per group, 2.5 m between geophones.

Seismic Source

12 kg per charge per shothole.
Shot depth: at least 40 m, whenever possible.

(2) High Resolution Seismic Profiling

Seismic Survey Parameters

Minimum of 96 channels of recording (possibly 120).
2 s record lengths
0.5 ms sampling
GCR 6250 bpi tape recording
5 or 10 m geophone group interval
10 or 20 m shot interval (preferably with a minimum of 24 fold)

Acquisition

Geophones: either

High frequency (e.g. Mark Products L25E 40 Hz), single geophone per trace.

or

8 Hz GS-20D geophones.

Use of three-component geophones on an experimental basis in some locations.

Seismic Source

0.5 kg of dynamite per shot hole.

Appendix 2: Seismic Reconnaissance

A seismic reconnaissance trip was undertaken during April 1990. Participants of the reconnaissance were Peter Williams and Bruce Goleby (BMR) and Cees Swager (GSWA). The primary objectives of this initial seismic reconnaissance were to:

- determine the logistics of two proposed traverses.
- finalise the preferred line locations in relation to the scientific objectives of the proposed seismic traverse.

The Kalgoorlie Traverse

Recent mapping by the Geological Survey of Western Australia has resulted in a better understanding of the structures within the Kalgoorlie region. Figure 2 shows the structural relationships of the faults, shear zones and the terrane boundaries. The location of the Kalgoorlie Profile is shown (Figure 2).

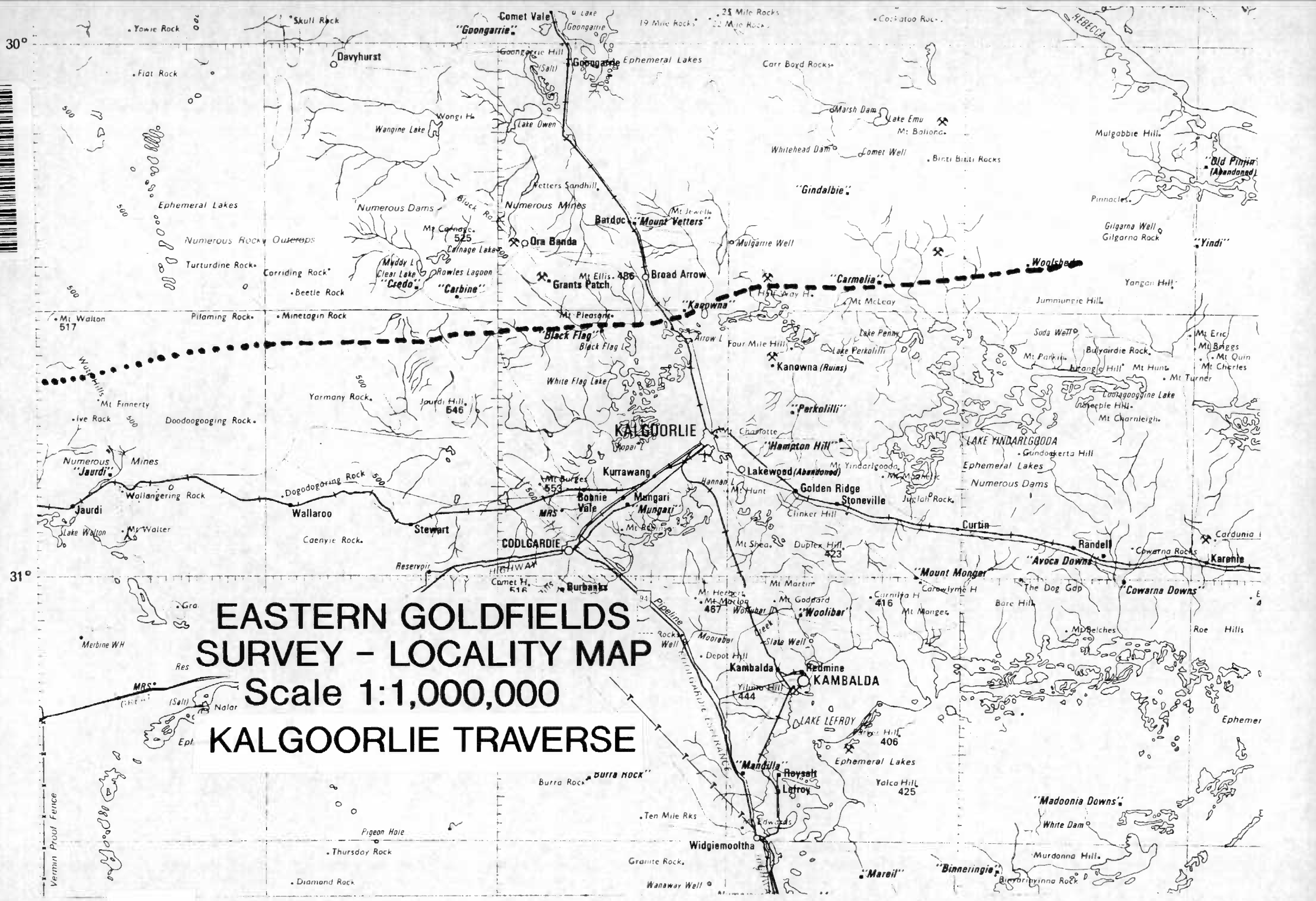
<u>Local Geology</u>

The western part of the proposed line lies to the west of the Mt Ida Fault, within the South Cross Province (Figure 2), as defined by Gee (1979). The Southern Cross Province is characterised by thick, laterally extensive BIF horizons, few and generally narrow greenstone belts, linear gneiss belts, and predominant "late" granite intrusions. The magnetic pattern of the province is dominated by the linear BIF horizons which define a NNW trending pattern. This pattern is truncated by an approximately north-south trending zone which defines the western edge of the Eastern Goldfields Province. Within the geology, this zone is also moderately well defined. The boundary corresponds to the Ida Fault (or Ida Lineament), mapped on the LEONORA, MENZIES and KALGOORLIE 1:250 000 sheets. The fault appears to be a sharp fault on the southern sheets, but on LEONORA the lineament may correspond to a 10 km wide belt of granitoid interleaved with amphibolite, silicified ultramafic rocks and banded gneiss. The lineament probably connects with the fault marking the western margin of the Agnew antiform and intrusive gneiss.

The structure therefore forms a fundamental element of the Yilgarn Craton. Its origin is unknown. It has variously been considered a continental margin to a volcanic arc (Rutland, 1973), a major a terrane boundary (Swager *et al.* 1990), a rift basin margin (Gee, 1979) or a back-arc basin margin (Barley *et al.*, 1989). There is no conclusive evidence from the geometry of the structure to strongly favour any of these alternatives. A knowledge of the three dimensional shape of structure will constrain its tectonic interpretation, and the determination of the three-dimensional geometry of this boundary is a major objective of the project.

In the LEONORA and KALGOORLIE sheets, the Ida Fault forms the locus of granite intrusions. These intrusions are undeformed and contain pegmatitic selvedges; typical of the late granites. The major province boundary may therefore be difficult to image seismically particularly if it maintains a steep dip through the crust.

The Kalgoorlie greenstone sequence is divided into two major terranes. The greenstones exposed adjacent to the Southern Cross are dominantly mafic and ultramafic rocks within a relatively well known stratigraphic sequence. This western terrane (Kalgoorlie Terrane; Figure 2) is subdivided into structural domains with coherent structural elements, separated by regional faults. East of the Kalgoorlie Terrane, interbedded felsic and mafic volcanics are overlain by clastic sedimentary sequences, and these show distinctive stratigraphic and structural features in comparison to the greenstones of the Kalgoorlie Terrane. These rocks are included in the Kurnalpi Terrane (Figure 2). The boundary between the two terranes is a wide, intense shear zone of regional extent defined as the Moriarty Shear in the north and the Mount Monger Fault in



EASTERN GOLDFIELDS
SURVEY - LOCALITY MAP
Scale 1:1,000,000
KALGOORLIE TRAVERSE
30°
31°
120°
121°
KALGOORLIE
COOLGARDIE
KAMBALDA
Kambalda
Redmine
Widgiemooltha
Comet Vale
"Goongarrie"
Goongarrie
Davyhurst
Ora Banda
Bardoc
"Mount Vetters"
Broad Arrow
Grants Patch
"Kanowna"
Kanowna (Ruins)
"Carmelia"
Woolshed
"Black Flag"
Kurrawang
Bonnie Vale
Mungari
"Mungari"
Jaurdi
"Jaurdi"
Wallaroo
Stewart
Golden Ridge
Stoneville
Curtin
Randell
Karonie
"Cowarna Downs"
"Avoca Downs"
"Mount Monger"
"Woolibar"
"Hampton Hill"
"Perkolilli"
Lakewood (Abandoned)
LAKE YINDARLGOODA
LAKE LEFROY
"Mandilla"
Lefroy
"Gindalbie"
"Yindi"
"Madoonia Downs"
"Binneringie"
"Mareil"
Burbanks
Ephemeral Lakes
Numerous Dams
Numerous Mines
Numerous Rocky Outcrops
Vermin Proof Fence

Figure 5

the south. These faults form a major boundary, equivalent to the Mount Ida Fault in tectonic importance.

The second objective of the southern line is to constrain the geometry of these internal domain boundaries. These boundaries are shear zones of significant regional extent, but of unknown depth extent. The shears tend to anastomose on a regional scale, and do not cross the major terrane boundaries. They are commonly mineralised and form a major exploration target. Examples include the Bullabulling Shear, the Zuleika Shear and the Boulder-Lefroy Fault. The regional geological pattern suggests that these may be subsidiary shears associated with the accretion of the Kalgoorlie Terrane against the Southern Cross Province. These structures are traditionally thought of as later D3 shears, and are contemporaneous with mineralisation in some areas. Thus the shape of these structures at depth is crucial in understanding their origin and also the tectonic setting of the gold mineralisation.

The geometry of these shears at depth, and the links between these shears and the major Province and domain boundaries (the Ida Fault and the Moriarty shear) form the second scientific objective of the southern line.

The third primary objective of the southern line is to determine the shape of the lower boundary of the greenstone sequences, and to compare the deep crustal structure beneath the three terranes to be crossed. If the major terrane boundaries represent accreted lithospheric fragments, then a difference in the mid- and lower crustal structure should be evident. If the Kalgoorlie Terrane represents an extensional rift basin, the crustal structures related to the rift should be evident in the seismic images beneath the three domains.

Location of Seismic Profile

The proposed seismic line crosses the Kalgoorlie Terrane at right angles, and also crosses several of the major domain boundaries within the Terrane (Figure 2). The minimum length of seismic line required to achieve these three objectives was determined to be 150 m, extending from the granitic rocks of the Southern Cross Province in an ENE direction to the Kurnalpi region (Figure 2).

Logistics and Site Reconnaissance: Kalgoorlie Traverse

General Comments:
Figure 5 shows the location of the proposed Kalgoorlie seismic profile plotted on the 1:250,000 topo maps.

Soil and Vegetation:
The terrain in the Eastern Goldfields is generally subdued, with low but steep escarpments present on laterite-capped breakaways and on the margins of granite bodies. Only one such escarpment was observed on the seismic traverse, and this presented no impediment to the seismic line. There are zones of deep weathering and potentially deep alluvial fill in major river valleys along several sections of the line. The depth of this weathering has yet to be determined but is expected to be in excess of 40 m in places. Vegetation cover is generally sparse with ample room to get a drill rig off the station track.

Access:
Road or station track access is good. However, there is no direct access from the western end of the line to Kalgoorlie; the road goes south to Coolgardie then north to Kalgoorlie and the eastern end of the line. Total travelling time from the western end of the traverse to the eastern end of the traverse is approximately 3 or more hours.

Stations:
The traverse crosses or adjoins 9 separate station leases. These and their owners are:

Lease	Owner	Phone
Crown Land	Crown	-
Credo	Tim & Megan Funston	090-242063
Mt Burges	Wolfgang Gentsch	090-242064
Carbine	Wolfgang Gentsch	090-242064
Black Flag	Mick Ferbert	090-242071
Kanowna	Peter & Jackie Carter	090-242075
Mt Vetters	Peter & Jackie Carter	090-242075
Gorden	Crown? Old Town Site	-
Hampton Hill	Burtrall Jones	090-213511

Either the owner or the manager from each of the above stations was contacted and the proposed seismic operations were discussed. In general, there was no major objection to the proposal other than that of restoration and soil erosion.

Line clearing:
Light dozing of saltbush areas and re-grading of access roads is required. Across most of the greenstone areas, tree cover is sparse and dozing activity for cable-laying access will require only minimal disruption to the tree cover.

Water:
Drinking water is not readily available along the line, but is available from outlets at Black Flag and Ora Banda from the Goldfields water supply. This water will have to be purchased. Prices range from $1.01 per tonne to $2-3 per tonne. Dam water is not suitable for drinking, but may be of use for drilling if the dams are full. At present they are mostly very low. Underground water is very salty and unreliable.

Restoration:
All station managers or owners expressed concern at potential damage to soil and vegetation. Owners in this area are used to mining companies cutting costeans and grid lines. They are also geared for financial compensation if this can be arranged.

The Leonora Traverse

Whereas the southern line is mainly concerned with the geometry of the internal structure of the greenstone belt, the northern line is aimed at determining the relationship between the South Cross Province and the northern part of the Kalgoorlie Terrane. The width of this province is considerably reduced in the LEONORA sheet, bounded on the west by the Mount Ida Fault, which is not well exposed along the seismic line, and on the east by the Mount George shear. The Wildara Shear, a poorly mapped north-south structure parallel to the Ida Fault, forms the locus of intrusion of several linear granite bodies with gneiss, amphibolite, and ultramafic screens or enclaves. It may form a major zone of tectonic disruption associated with the Southern Cross - Kalgoorlie Terrane boundary. East of the Wildara shear, the northeast Goldfields domain has a similar stratigraphy to the Kurnalpi domain, and may be tectonically equivalent.

The northern line crosses an area of largely granitic rocks between the Wildara shear and the Ida Fault. The seismic image of this domain, within the Eastern Goldfields province, will provide a comparison of the crustal structure between the dominantly granitic Southern Cross province determined from the southern line and extensive granite regions of the Eastern Goldfields province. This part of the line will also help to define the crustal layering associated with late granite intrusion, and is important in testing granite tectonics models (e.g. crustal inversion model of Campbell & Hill, 1988) for the Late Archaean.

In addition, early gneiss domes are present across the traverse line. These are either intruded by later granites or have moderately to shallowly dipping faulted boundaries with adjacent greenstones. The depth extent of the faults, and the shape of the gneiss domes has an important bearing on the nature of the earliest structures of the Eastern Goldfields province and hence provide constraints on the tectonic models for the province.

Whereas the southern line does not intersect greenstones in the Southern Cross Province, the northern line is located to intersect a major greenstone belt with parallel gneiss lenses within this belt. The Mount Elvire greenstones show complex structures on the surface (Stewart *et al.*, 1983), and the fundamental significance of the greenstone lineament is underscored by the presence of gneiss lenses and strongly foliated granite adjacent to the lineaments. The northern line is aimed at determining the depth extent and relationship of the Southern Cross lineaments to the bounding Ida Fault.

Location of Seismic Profile

The location of the Leonora Profile is shown in Figure 6. The minimum line length required to determine the scientific objectives of the northern line is 150 km. Significant advantages in terms of understanding the geometry of early domal gneisses can be obtained by extending the northern line by 50 km, but it is probable that a higher resolution survey would be required over the extension of the line, increasing the cost significantly.

Logistics and Site Reconnaissance : Leonora Traverse

Soil and Vegetation:
This line crosses granitoid terrain for much of its length. Vegetation cover fairly light.

Access:
There are well maintained tracks over the eastern 60 km.

Stations:
The traverse crosses or adjoins 5 station leases. These and their owners are:

Lease	Owner	Phone
Sturt Meadows	Lance & Norma Hurst	090-375910
Ida Valley	Jim & Prue Craig	090-365918
Perrinvale	Fred Cock	090-242048
Bulga Downs	David McQuee	?
Cashmere Downs	Phillip & Joy LeFroy	099-635836

The owner or the manager from each of the above stations except Bulga Downs, was contacted and the proposed seismic operations were discussed. In general, there was no major objection to the proposed seismic survey.

Line clearing:
The line will require only light dozing in the higher country. To the west, on Ida Valley property, there is tall and thick mulga which will require substantial dozing. Similarly, the part of the line on Perrinvale will require dozing and grading along its length.

Water:
Water along the northern line is all well or bore water, is variable in quality but often fresh enough for drinking, and is relatively abundant. There should be no major problems with water supply. Water depths are between 30 m and 100 m with flow rates ranging from 2500

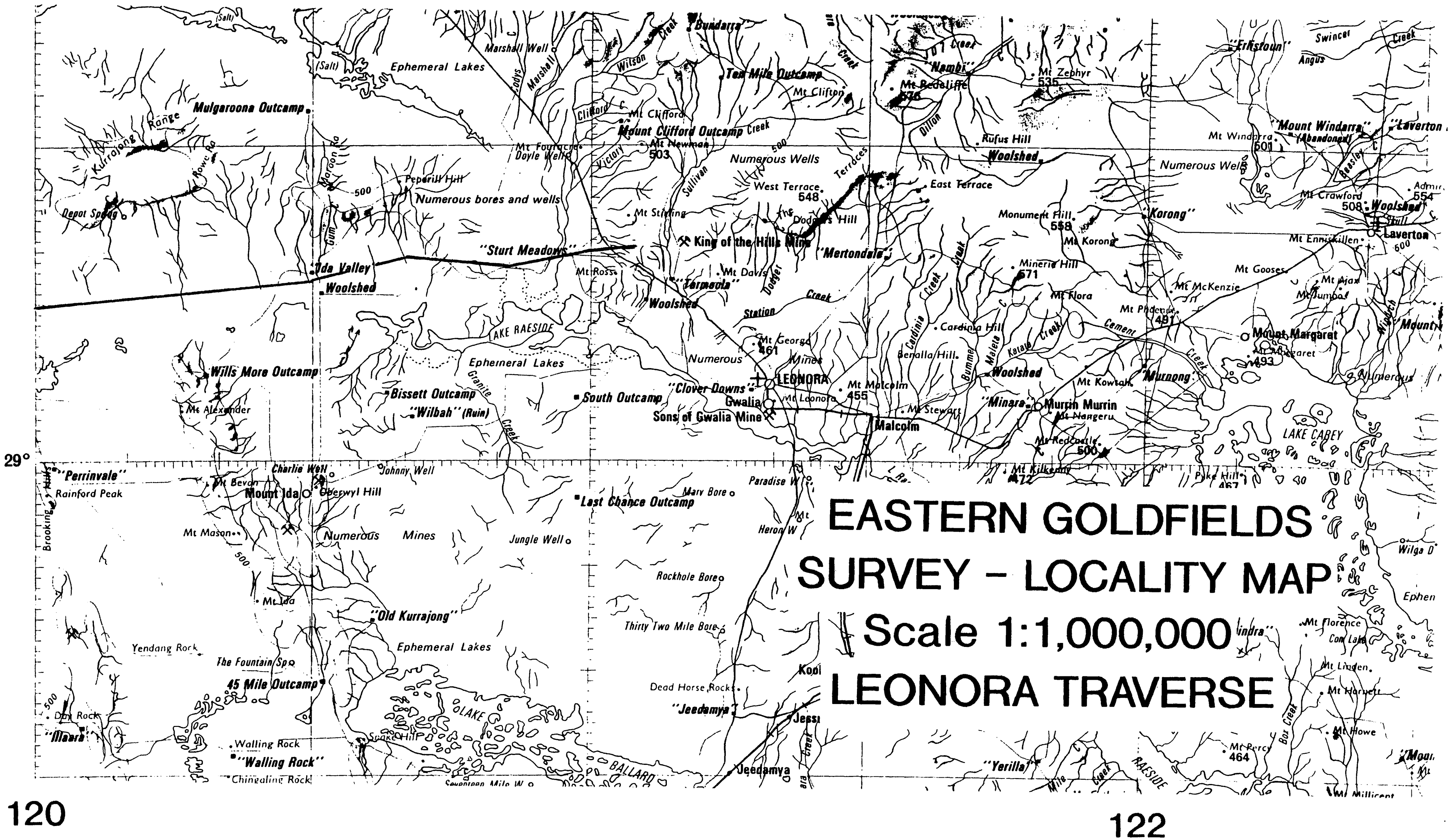

EASTERN GOLDFIELDS
SURVEY - LOCALITY MAP
Scale 1:1,000,000
LEONORA TRAVERSE
120
122
29°
Ephemeral Lakes
Mulgaroona Outcamp
Kurrajong Range
Numerous bores and wells
"Sturt Meadows"
Ida Valley
Woolshed
LAKE RAESIDE
Wills More Outcamp
Bissett Outcamp
"Wilbah" (Ruin)
South Outcamp
"Clover Downs"
LEONORA
Gwalia
Sons of Gwalia Mine
Malcolm
Mt Malcolm
455
King of the Hills Mine
"Mertondale"
Numerous Wells
West Terrace
548
East Terrace
Mount Clifford Outcamp
Mt Clifford
Mt Newman
503
Ten Mile Outcamp
Mt Clifton
"Bundarra"
Wilson Creek
Marshall Well
Mt Zephyr
535
Rufus Hill
Monument Hill
558
Minerie Hill
571
Mt Flora
"Korong"
Mt Korong
Mount Windarra
Laverton
Mt Crawford
508
Mt Enniskillen
Mt Gooses
Mt McKenzie
Mt Ajax
Mount Margaret
493
Murrin Murrin
"Minara"
"Murnong"
LAKE CAREY
Mt Redcastle
500
Mt Kilkenny
472
Paradise W
Heron W
"Perrinvale"
Rainford Peak
Mt Bevon
Charlie Well
Johnny Well
Mount Ida
Mt Mason
Numerous Mines
Mt Ida
Jungle Well
"Last Chance Outcamp"
Mary Bore
Rockhole Bore
Thirty Two Mile Bore
Dead Horse Rocks
"Jeedamya"
Jeedamya
"Old Kurrajong"
Ephemeral Lakes
Yendang Rock
The Fountain Sp
45 Mile Outcamp
Walling Rock
"Walling Rock"
Chingaling Rock
LAKE BALLARD
Snake Hill
"Yerilla"
Mt Percy
464
Mt Florence
Mt Linden
Mt Howe
Wilga
Numerous Wells
Mt Windarra
501

Figure 6

gallons/day to 3000 gallons/day.

Restoration:
Station managers or owners did not express any concern at potential damage to soil or vegetation. Some saw the line clearing operation as a means of opening up more tracks on their station. They were more concerned to damage to fences and station tracks.

Summary : Logistics

In general, the northern line is far more accessible and poses fewer logistic difficulties than the southern line. The pastoralists in the Kalgoorlie region are used to mining operations and therefore more concerned about possible damage to the soil and vegetation (including the salt bush and blue bush). Restoration of much of the seismic traverse will be required.

Seismic Parameters

Work done by the BMR in the Widgiemooltha region in 1969 (Mathur *et al.*, 1977) indicates that the method will work in the region. Results from the Arunta Block in central Australia (Goleby *et al.*, 1990) have shown that the seismic method is extremely successful in hardrock terranes. However, the interpretation of seismic reflection data in hardrock areas is more difficult than in sedimentary basins because there is a lower signal-to-noise ratio for the reflections and there is a greater variation in the irregular dips of the rock bodies being imaged.

Overseas experience of data collection in the Abitibi Greenstones (Green *et al.*, 1990) indicates that it is difficult to achieve good quality seismic images using group spacing usually considered adequate in sedimentary basin work. Because of the complexity in the Eastern Goldfields, and the similarity with the terrane imaged by the Canadian LITHOPROBE experiment, we recommend that the group spacing be decreased to about 2/3rds of that typically used in sedimentary surveys to take into account the experience gained in similar terranes overseas. The proposed seismic parameters are given in Appendix 1.

Appendix 3: High Resolution Proposals

SUITABLE SITES:

Because of the interest in the use of high resolution seismic reflection profiling in the Eastern Goldfields, considerable effort has been made to canvass opinions on the best possible sites for the profiles. In particular, the application of the method across mining or exploration leases might open the way for access to otherwise confidential industry drill hole and mapping data that would be particularly valuable in the interpretation of the seismic sections.

Approaches were made to directly to exploration companies, to university groups, and to a broad range of company and academic people through a workshop arranged by the Australian Mineral Industries Research Association (AMIRA). While people who were approached directly were asked to suggest sites where a great deal of information was already available, people who attended the workshop were asked to propose sites that fitted one of three categories:

(i) A site where the structure is known. This will be used to test whether the method works.
(ii) A site where several structural models have been suggested from the surface geology. The seismic method will be used to distinguish between the models.
(iii) A site where the surface geology gives no indication of what happens at depth. The seismic method will be used as a mapping tool at this site.

The following list summarises the proposed sites. The source of each proposal is given.

BMR/Geol. Surv. WA. Suggestions

<u>Victory/Defiance</u>: This site was chosen as one where the structure is known, and therefore provides a test of the method. It is near Kambalda, on ground held by WMC. However, WMC may not want to provide the detailed information necessary to interpret the data; this would have to be negotiated. Moore from WMC, who attended the Workshop, felt that WMC would be supportive if the information already in the public domain was sufficient, but if other information was needed, he could not guarantee what way the company would go - it could well depend on who was approached.

The target here is mineralised sub-horizontal splay faults off the Lefroy Fault.

Everyone seemed to think this was a good site.

<u>Mount Pleasant Dome</u>: This is a site where the structure is probably known, but needs to be tested. The line would look at the relationship of the greenstones to a gneissic granite that seems to have been emplaced at 4kbar and then risen with its contact aureole.

This site was agreed to by everyone.

<u>Either Ida Fault or Monger Fault</u>: These are the west and east bounding faults of the Kalgoorlie Terrane, respectively.

The Ida Fault is preferred because it is more clearly a terrane boundary. Its position at depth is unknown.

A site near the regional line could be chosen.

Industry Suggestions

<u>Lancefield</u>: Suggested by Billiton, near Leonora. This is a good site but is probably too far from

the regional line.

The object would be to map a major shear that appears to be flat lying. There are several alternative sites.

Paddington: This was suggested by several companies. It is a mine operated by Pancontinental, who were not represented at the Workshop.

It is very close to the regional line (several kilometres to the north).

There are horizontal splay faults at the mine scale but it is not known whether they continue into the regional scale. Peter Williams and Cees Swager will check on this.

Panglo: This is also a Pancontinental lease, and is less than a kilometre from the regional line. It would be selected for the same reason as Paddington.

New Celebration: Chosen for the same reason as Victory/Defiance

Coolgardie: Geopeko suggested a site across the margin of the Bailey Dome near Coolgardie. This is outside the general trend of the greenstones belt, and may not be a serious contender.

Kanowna: Suggested by Geopeko. It is south of the eastern end of the line, in an area of mineralisation which appears to coincide with the eastern edge of a younger graben filled with conglomerates. The eastern side of the graben lies along a major regional shear zone.

Sons of Gwalia: Near Leonora. Peter Williams also likes this site but it may be too far from the regional line.

Granny Smith: Suggested by Billiton. The site is near Laverton, and may be too far away from the regional line.

Murchison: Suggested by CRA as a kite flier. It is not even in the same province.

If the funding for the high resolution work is forthcoming through AMIRA, AMIRA will call all parties together to do a final site selection.

University of W.A. High Resolution Proposals

After a direct approach from BMR and the geological Survey of Western Australia, the University of Western Australia, independent of the proposals made at the workshop, suggested three suitable areas outside the Leonora area, where BMR are directly involved. These in order of geological priority would be:

1. Victory area of Kambalda Goldfields where there are major low angle thrust faults (shear zones) linked to steeply dipping shear zones including the Boulder-Lefroy Fault. These are well illustrated in Clark *et al.* (1986). Structures are hundreds of metres in length and vary in dip from 5° to 90°. Lithologies include ultramafic, mafic and felsic rocks. Some of the major shear zones are parallel to thin sulphidic sedimentary units whereas others are filled by felsic porphyries and/or lamprophyres.

2. Lancefield area of Laverton Goldfield. Here, there are flat dipping faults (shear zones) which are several kilometres in length and, collectively, tens of metres thick. Lithologies include a basal granitoid, ultramafic rocks, basalts and clastic metasedimentary rocks. A plan and cross section is given by Perriam *et al.* (1988) and Hronsky and Perriam (1988).

3. New Celebration area between Kalgoorlie and Kambalda. This is described by Cullen and Norris (1988). The main mineralised structure is the Boulder-Lefroy Fault or a splay from it. It is several kilometres long, and tens to hundreds of metres wide. It may be part of a positive flower structure. There are strong lithological contrasts and the shear zones are filled with felsic porphyries and/or lamprophyres. The main shear zone is near-vertical and extents to depths of over 500 m. A shear zone at Pernalty, to the east, may join the Boulder-Lefroy at depths, forming the flower structure.

Mining Industry High Resolution Proposals

Western Mining Corporation (WMC) has discussed with BMR, the possibility of high resolution seismic reflection work. WMC was planning to undertake high resolution seismic reflection profiling in the Kambalda area (target depths 200 - 1000 m), where they already have deep drill holes. The target area is believed to involve a relatively simple structure, where the Junction Fault and mineralisation associated with it dips to the east. The nearby Boulder-Lefroy Fault dips to the west. A 5 km line was being planned using either very high frequency Vibroseis or possibly Minisosie. The work was still very much in the planning stage. WMC has already tried high resolution seismic in the Three Springs area using a weight drop source (target depths about 150 m) with some success.