A new investigation of some Australian continental scale gravity lineaments

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Abstract: An investigation of the crustal lineament framework was undertaken in northwestern Australia, an important mineral and hydrocarbon province. The Australian continental scale lineament framework was examined so that northwestern Australia could be understood in terms of the larger regional picture.

E.S. Hills identified a number of mega morphological lineaments using a "Great Relief Model" of Australia. His morphological lineaments often coincided with deeper gravity lineaments interpreted by both Australian lineament researcher, E.S.T. O'Driscoll, and the author. O'Driscoll used a number of data sets including a diffused gravity image of Australia to interpret a network of continental scale lineaments.

Continental scale gravity lineaments can be verified by their response in the rock record. Examples are given along the west-northwest trending G3 lineament and the north-northeast trending G5. In northwestern Australia, the G3 and G5 are coincident with the King Leopold and Halls Creek Mobile Zones respectively. These mobile zones have undergone a reactivation history from the Early Proterozoic/Archean through to the Late Palaeozoic/Mesozoic. An influence of the G3 on the faulting pattern of the Arunta Block in Central Australia and the Sydney Basin region of eastern Australia can be observed. The G5 can be traced offshore in a north-northeast direction through the Arafura Basin where it is coincident with the ancient, reactivated Lyndoch Bank Fault System. The east-northeast trending Malita Graben terminates against the western edge of the G5 and swings into a parallel north-northeast orientation becoming the Calder Graben. The regional tectonics of northwestern Australia, both onshore and offshore, relate closely to the distribution of gravity lineaments in this region.

A spatial distribution relationship exists between the continental scale lineaments and major petroleum and mineral discoveries in Australia. Lineament intersections are of particular importance where it appears that the required geological conditions for economic deposits are most favourable. The same relationship can be observed in northwestern Australia, particularly between lineament intersections and major petroleum, base metal and diamond occurrences. The significant economic discoveries of the Challis and Jabiru oilfields occur at the intersection of the northwest trending G11 with the north-south orientated NS1 lineament. Onshore, the NS1 lineament is coincident with the only significant Canning Basin oil discoveries together with the Ellendale and Noonkanbah diamondiferous lamproites. At a local scale, a sinistral flexure termed by O'Driscoll a "Tethyan Twist", is often interpreted as economic discoveries where a west-northwest lineament intersects the host rock or mineral deposit.

INTRODUCTION

This paper is an overview of several components of the Ph.D. thesis currently being undertaken by the author at the University of Melbourne in Australia. It examines important aspects of crustal lineaments in northwestern Australia, an important mineral and hydrocarbon province.

In the early part of the study, the overall Australian continental scale lineament framework was examined so that northwestern Australia could be understood in terms of the larger regional picture. One of the aims of the thesis was to determine whether continental scale lineaments could be identified on a variety of data sets; such as gravity etc. Several Australian authors have already identified and examined continental lineaments and their surface and deeper responses in the crust. Authors such as Hills (1953, 1956a, 1956b, 1959), O'Driscoll (1980, 1981, 1982, 1985, 1986, 1989a, 1989b), Katz (1974, 1976), Schiebner (1974), Campbell (1989), Campbell and O'Driscoll (1989), Cozens (1986) and Heidecker (1989). An attempt was made to verify the existence of the lineaments by documenting the geological expression along their length.

This work presents as a "new investigation" or reinterpretation of some continental scale gravity lineaments. The majority of lineaments discussed in this paper have been previously published in the extensive works of Australian lineament researcher, Dr. Tim O'Driscoll. A reinterpretation and documentation of geological evidence and associations is presented here.

This paper occasionally refers to the gravity lineaments as corridors. A corridor is a term adopted from the works of O'Driscoll to describe a mega-lineament. In this classification scheme, it represents a lineament at least 50 km in width and in excess of 200 km in length.

HISTORICAL ASPECTS OF AUSTRALIAN LINEAMENT RESEARCH

Professor Edwin Sherbon Hills of the University of Melbourne, was a pioneering Australian geologist who examined the morphotectonic features of Australia and constructed a "Great Relief Model of Australia"; a scaled topographic model of the Australian continent approximately 8 metres in diameter. He was commissioned to build this by the Australian Government for defence purposes and it took 14 years to complete, from 1942 and 1954. The model provided a basis for much of his well documented research on lineaments and morphotectonics (Hills 1956a, 1956b, 1959).

Figure 1 is a photograph of the model with a few of his morphotectonic lineaments indicated with arrows. Figure 2 is a photograph of the northern Australia segment of the model with a several major mineral deposits annotated. Hills observed that major mineral accumulations were located along morphological lineaments and more specifically, at the lineament intersections (Hills, 1953). He described lineaments as "zones of yielding" in the earth's basement and suggested that they acted as preferential pathways for ore bearing fluids in the earth's crust.

Another pioneering Australian researcher in lineament tectonics is Dr. Tim O'Driscoll who has published extensively on the subject since 1968. O'Driscoll documented a network of ten prominent continental scale gravity lineaments and a number of geological lineaments. Figure 3 is a diffused Bouger gravity image of Australia which he constructed before modern image processing techniques became available. It is still one of the most useful images for interpreting these lineaments. O'Driscoll's lineament tectonics modelling was fundamental in the discovery of the world class Cu-Au-U deposit, Olympic Dam in South Australia in 1975 by Western Mining Corporation (Fig. 1).

Figure 4 is a diagrammatic representation of the major morphotectonic lineaments of northwestern Australia interpreted by Hills (1956a, 1956b) and the major gravity corridors of the region interpreted by both O'Driscoll (1982) and the author. There is a remarkable correlation between the deep seated basement features reflected in the gravity, and the younger morphological features observed in the topography. This suggests that even the most recent surficial geological processes are influenced by the reactivation of ancient, deep seated, weakness zones.

GEOLOGICAL EVIDENCE FOR CONTINENTAL SCALE GRAVITY LINEAMENTS

Continental scale gravity lineaments can be verified by the response in the rock record. Observable structural and geological evidence suggests that the geologic and tectonic history of terrain within a corridor, differs from that on either side of the corridor. Examples are given along two continental scale gravity lineaments, the G3 and the G5 (see diffused gravity image for locations, Fig. 3).

The G3 Gravity Lineament

The G3 lineament can be traced on gravity images from Derby in northwestern Australia, through the Arunta Block in Central Australia and across to Sydney on the east coast. Figure 5 is an ingredient map of Proterozoic granitic rocks from the western Kimberley region. In this area, the G3 coincides with the Proterozoic King Leopold Mobile Zone. Figure 6 is an ingredient map of the distribution of Proterozoic metamorphic and igneous rocks of the western and southern region of the Kimberley. Corridor G5, which aligns with the Halls Creek Mobile Zone in this region, has also been annotated. There is a strong correlation between the distribution of Proterozoic igneous and metamorphic lithologies and the gravity corridors. Research carried out by White and Muir (1989), suggest that the two mobile zones have operated as an orthogonal coupled system during alternating periods of extension and compression since the Early Proterozoic/Archean. A deep seismic line situated near Derby and transversing the G3, was shot and interpreted by the Australian Geological Survey Organization (see Fig. 5 for locality). A major feature in the G3, the Pinnacle Fault, has been interpreted to extend to at least the Moho (B. Drummond *pers. comm.,* 1991).

To the southeast, the G3 corridor intersects the Proterozoic Arunta Block in Central Australia. The Arunta Block is an intersection zone of at least three continental scale gravity lineaments, the G2, G3 and G6 (Fig. 7). It has undergone a complex

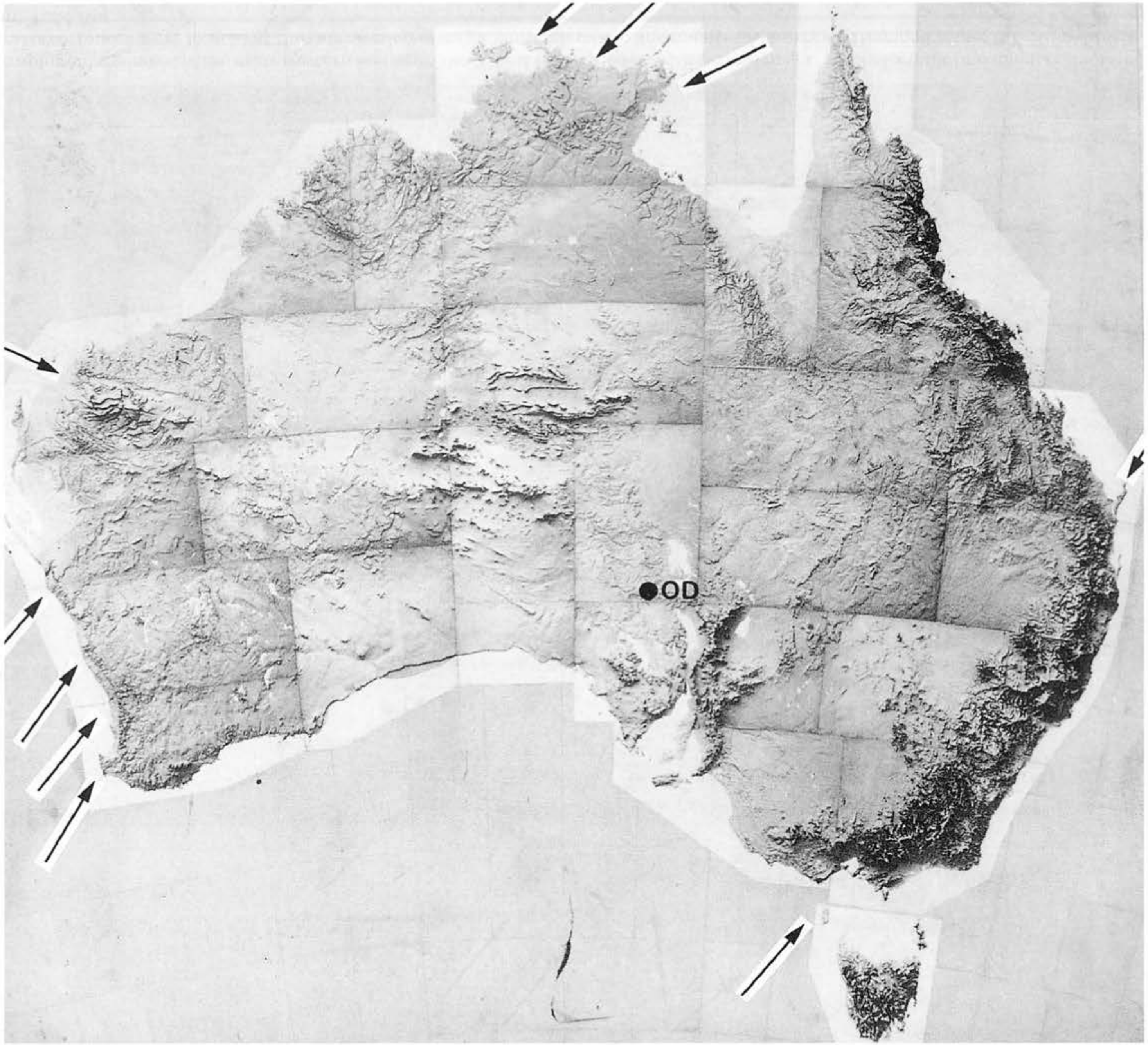

Figure 1. Photograph of the "Great Relief Model" of Australia constructed by Professor Edwin Sherbon Hills with several of the mega morphotectonic lineaments indicated with arrows. **OD** = Olympic Dam Cu-Au-U deposit in South Australia.

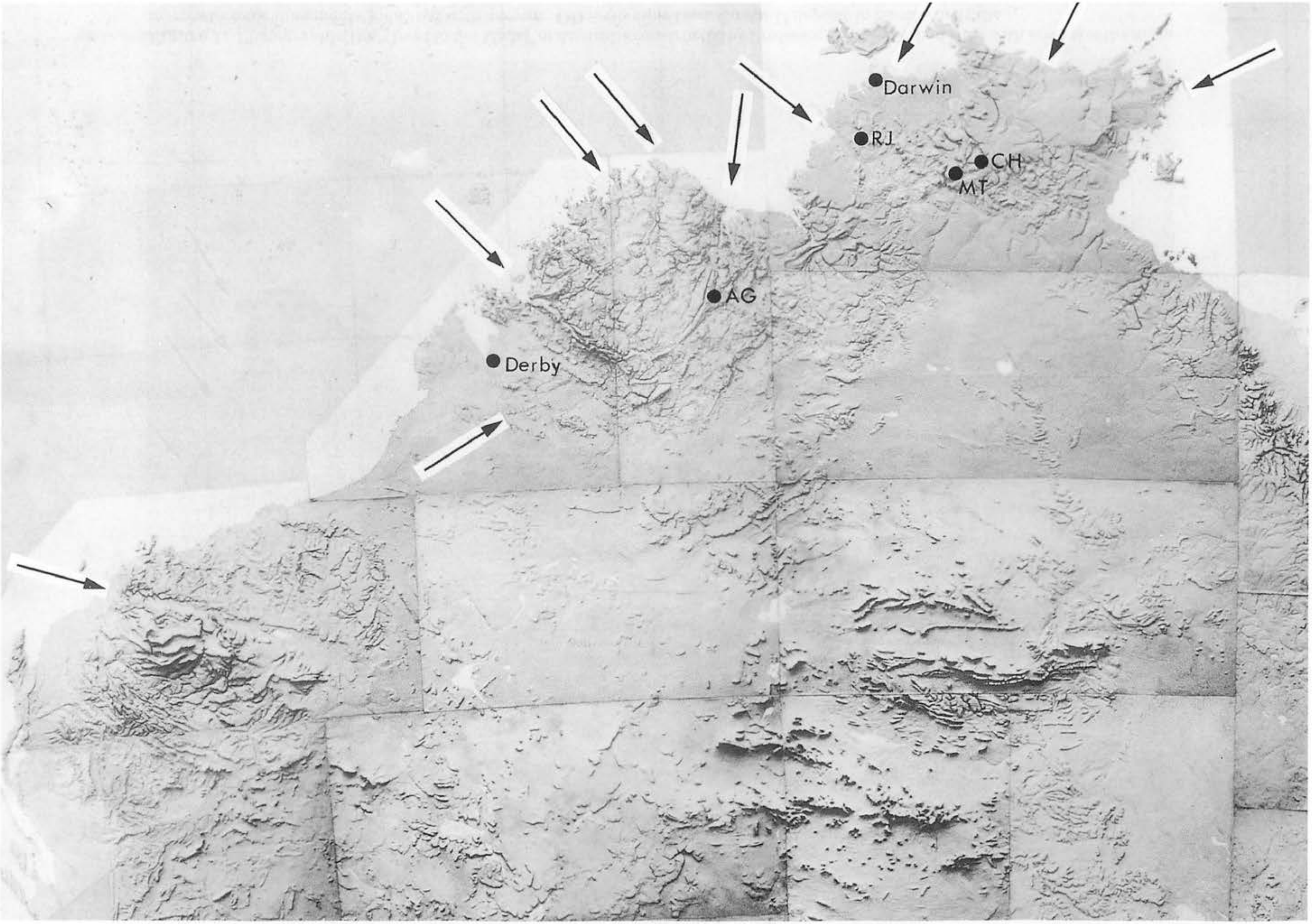

Figure 2. Photographic enlargement of the northwestern section of the "Great Relief Model" with several mega morphotectonic lineaments annotated. Hills noted that many major mineral occurrences were located at the intersection of mega morphotectonic lineaments. **AG**=Argyle Diamond Mine; **RJ**=Rum Jungle U; **C**=Coronation Hill Au; **MT**=Mount Todd Au.

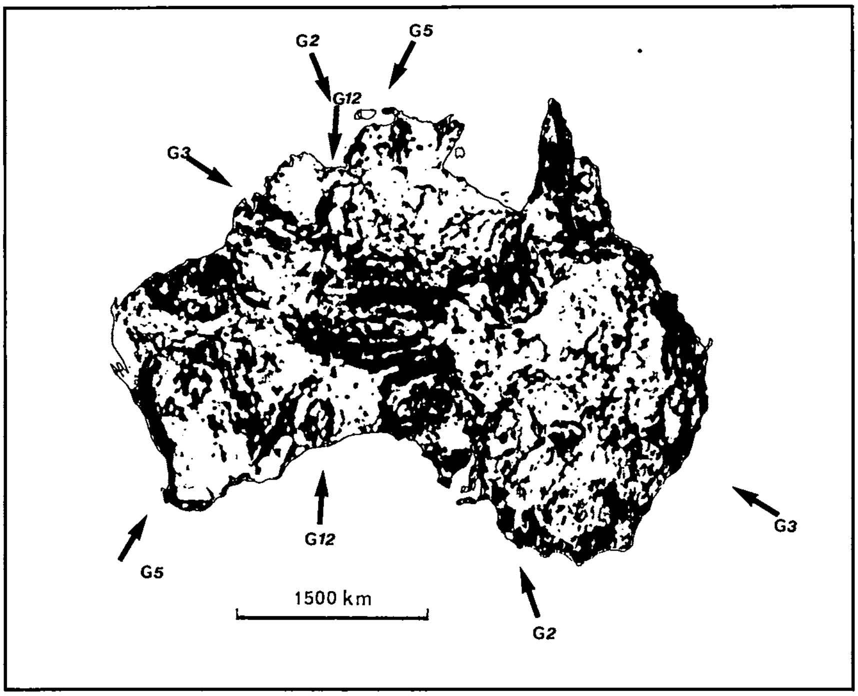

Figure 3. Diffused Bouger gravity map of Australia (O'Driscoll 1986). Several major gravity lineaments are annotated with guiding arrows. The lineaments are best observed at a low angle.

tectonic history from the Proterozoic through to the Carboniferous. The regional tectonics have been well documented by Shaw *et al., (1984)*. The area is a major continental lineament intersection zone and the generalized faulting pattern clearly shows the influence of the three corridors. A north-northeast trend in the G6 corridor can be seen to swing into a west-northwest orientation parallel to and within the G3 corridor. A strong north-northwest influence on the faulting is observed within the G2. The "Weldon Tectonic Zone" is subparallel to and lies within the G2 corridor. Research carried out by Shaw *et al., (1984),* suggests that the zone forms a major deep crustal boundary with significantly greater uplift and erosion to the west relative to the east.

On the east coast of Australia, the G3 corridor can be traced on the gravity data to intersect the coast between Sydney and Newcastle (Fig. 8). It subdivides the Palaeozoic New England Fold Belt to the north from the Palaeozoic Lachlan Fold Belt in the south and is coincident with the Permo-Triassic depocentre of the Sydney Basin. In this region, the G3 is coincident with a paleogeographically mapped nearshore marine to lacustrine environment from the Devonian through to the Triassic (Cooke, 1988). The generalized faulting pattern of the area appears to reflect the influence of the lineament with the dominant north south orientation swinging into a west-northwest trend within the G3 corridor (Fig. 8).

The G5 Gravity Lineament

The G5 gravity lineament trends in a north-northeast orientation and can be interpreted on both gravity and magnetic data sets to extend from Perth in the southwest through to Darwin in the north. Further offshore it can be traced using Seasat, magnetic and bathymetric data sets across to Irian Jaya. In northwestern Australia, it coincides with the Halls Creek Mobile Zone and, as mentioned previously, has had a reactivation history from the Proterozoic through to at least the Palaeozoic.

Figure 9 is an ingredient map of the distribution of the Proterozoic granitic rocks in the region and Figure 10, the distribution of Mid Proterozoic clastic sediments. There appears to be an influence of the G5 lineament on both the intrusive and depositional history of the area. This is a relationship commonly seen. Lineaments appear to act as energy release zones and therefore regions of high heat flow. They are coincident with sites of preferential igneous and metamorphic activity along with increased tectonic activity.

The onshore Bonaparte Basin and eastern Kimberley region, both in northwestern Australia, provide good examples of the influence of major lineaments on the regional faulting pattern. Figure 11 demonstrates the influence of the G5 corridor on the north-northeast trend of major faulting. This diagram highlights the influence of the northwest trending G11 corridor and the intersection zone shows an interesting intersection pattern. Northwest trending faults of the G11 terminate against and are perpendicular to their north-northeast trending counterparts.

Offshore, the G5 gravity corridor can be traced

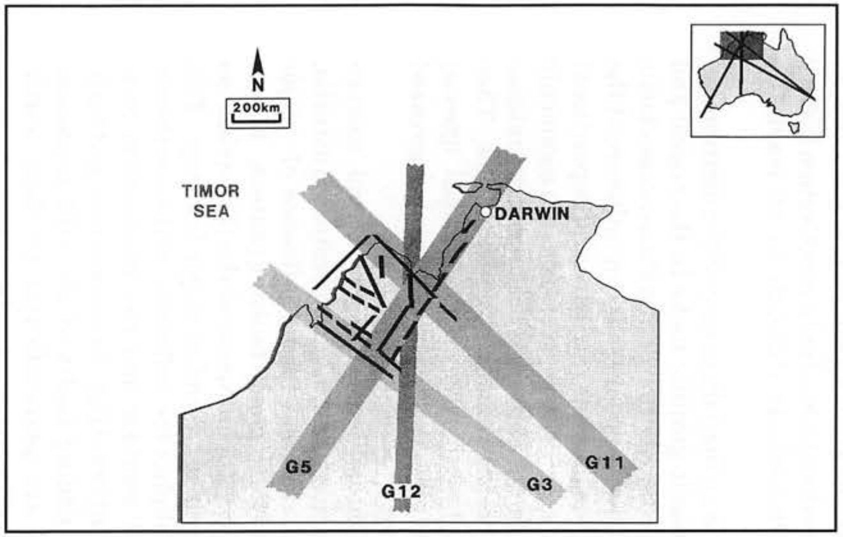

Figure 4. Composite cartoon of mega morphotectonic lineaments of northwestern Australia (Hills 1956a, 1956b) and continental scale gravity lineaments for the same region (O'Driscoll 1989, Elliott, Unpubl.).

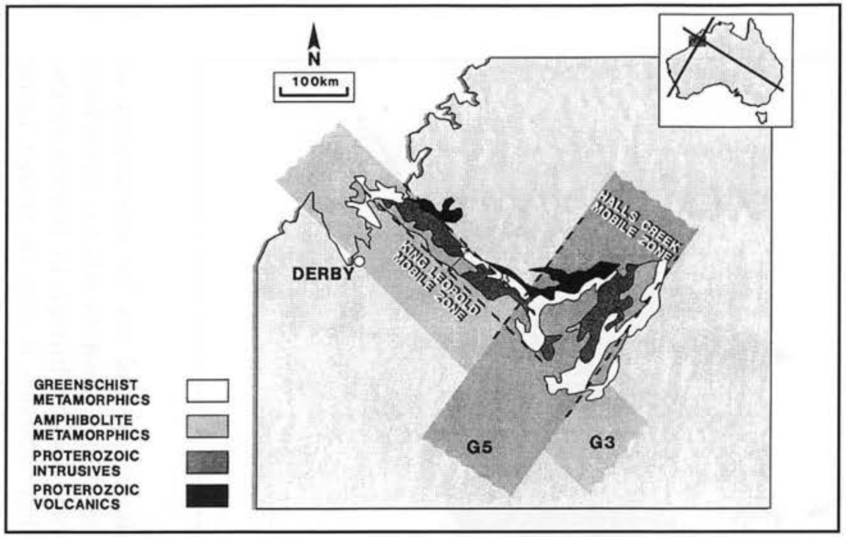

Figure 6. Ingredient map showing distribution of Proterozoic igneous and metamorphic rocks of the southern and southwestern Kimberley region (Source: Geological maps of the West and Central Kimberley, 1976 (1:500,000)).

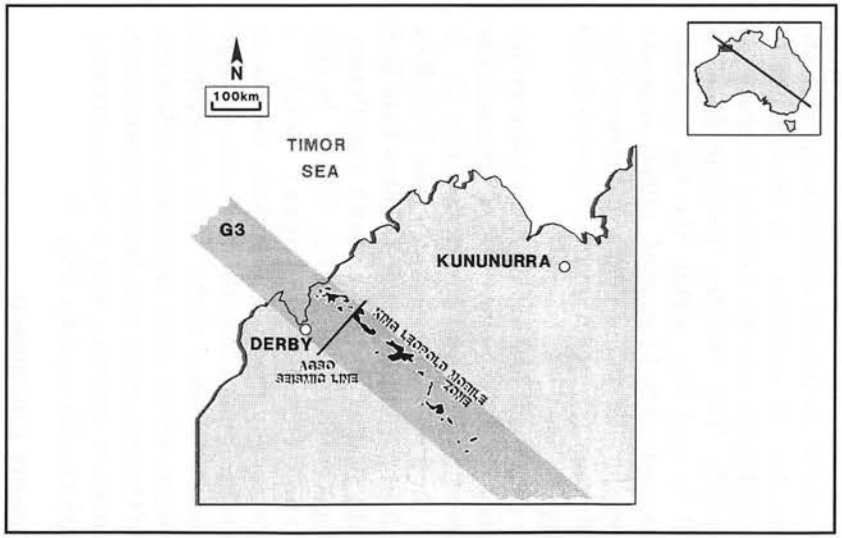

Figure 5. Ingredient map showing distribution of Proterozoic granitic rocks in the southwest Kimberley region, northwestern Australia. The approximate position of a deep seismic line shot and interpreted by the Australian Geological Survey Organization (AGSO), is depicted with black line (Source: Geological map of the West Kimberley, 1976 (1: 500,000)).

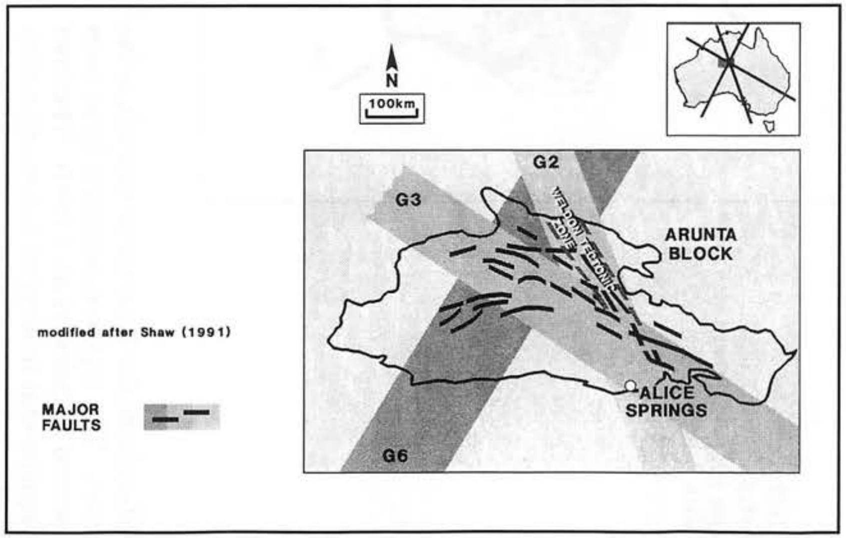

Figure 7. Generalized faulting pattern of the Proterozoic Arunta Block, Central Australia. Continental scale gravity lineaments G3, G2, and G6 are annotated. The "Weldon Tectonic Zone" shown in dashed line is interpreted by Shaw *et al.*, 1984, to represent a major structural discontinuity (Modified from Shaw *et al.*, 1984).

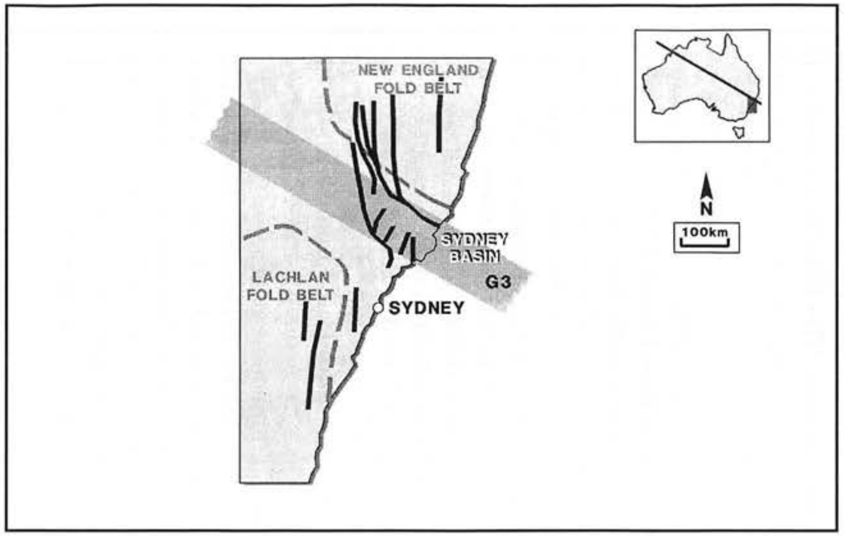

Figure 8. Diagram showing the west-northwest influence of the G3 gravity lineament on the predominantly north south faulting of the Sydney Basin region, eastern Australia. The lineament separates two major Palaeozoic fold belts, the New England fold belt to the north and the Lachlan fold belt to the south (Source: State Geological Maps of New South Wales (1:2,500,000)).

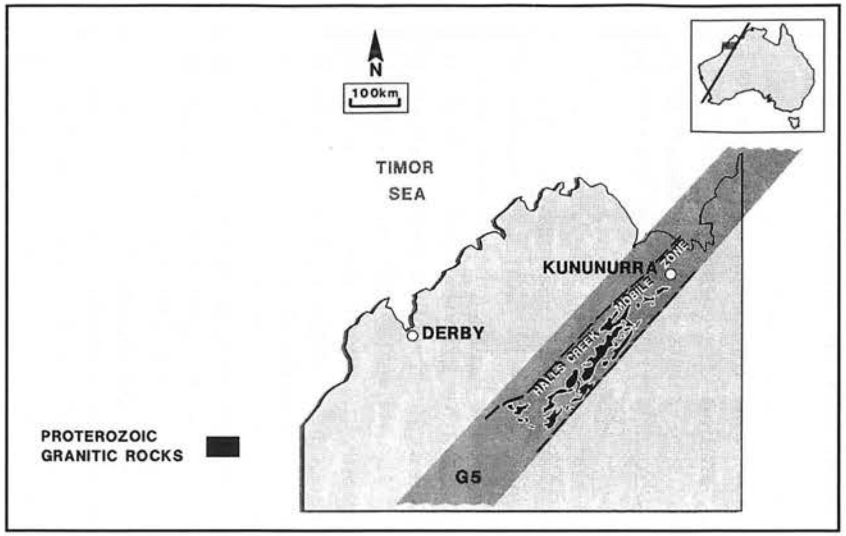

Figure 9. Ingredient map showing the distribution of Proterozoic granitic rocks in the East Kimberley region of northwestern Australia. The G5 lineament is coincident with the Halls Creek Mobile Zone in this region (Source: Geological map of the East Kimberley, 1976 (1:500,000)).

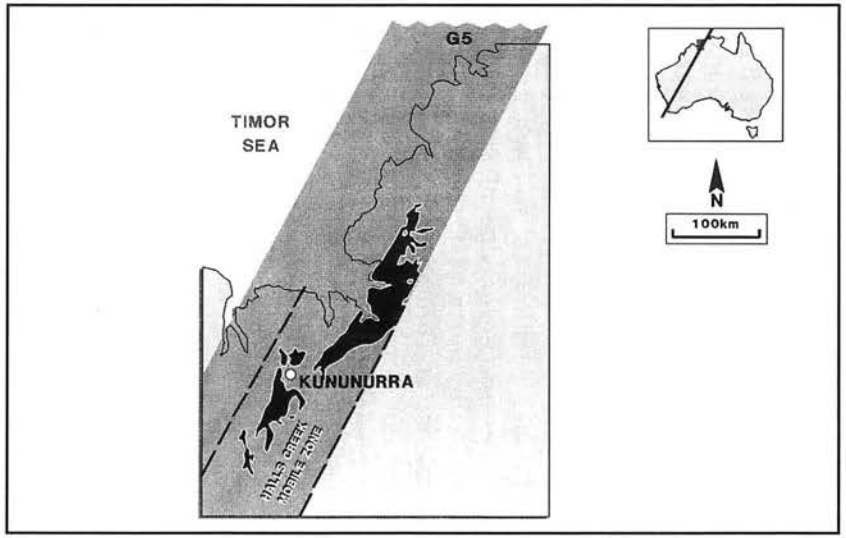

Figure 10. Ingredient map showing the distribution of Proterozoic clastic sediments in the Cambridge Gulf region of northwestern Australia. The G5 lineament is coincident with the Halls Creek and Fitzmaurice Mobile Zones in this region. There is also a relationship with the onshore Bonaparte Basin (Source: Geological map of the East Kimberley, 1976 (1:500,000)).

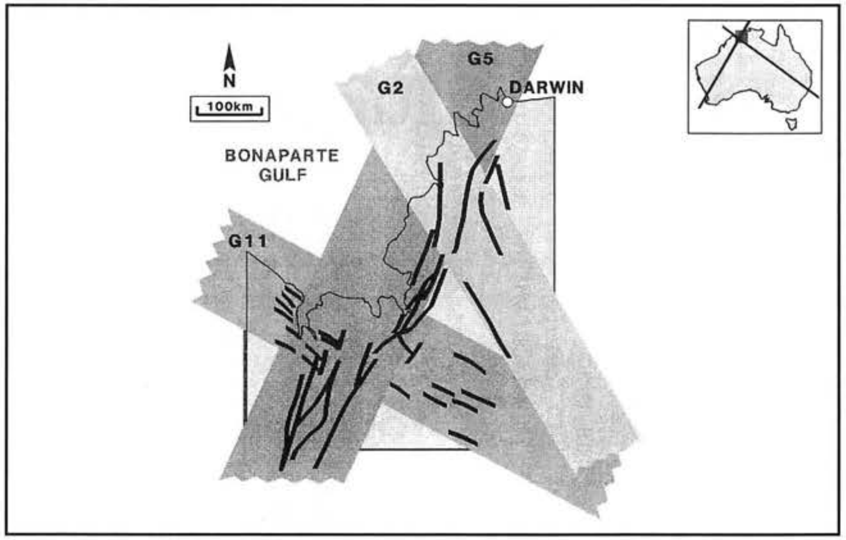

Figure 11. Generalized faulting of the northwestern region shows a strong north-northeast influence by the G5 and a northwest influence of the G11. The intersection zones illustrates an intersecting interference pattern of northwest fault terminations of the G11 against the G5 north-northeast faults (Source: State geological maps of Western Australia and Northern Territory (1:250,000)).

in a northeast direction into the Arafura Basin using Seasat and aeromagnetic data (Fig. 12). The western edge of the G5 lineament appears to have had an important controlling influence on the overall basin morphology. The east-northeast trending Malita Graben terminates against the western edge of the lineament where it swings into a parallel north-northeast orientation and becomes the Calder Graben. The recent morphology reflected in the bathymetry has also been influenced by the underlying gravity feature. The Lyndoch Bank Fault System is coincident with the western edge of the G5 and is documented by McLennen *et al.*, (1990) as a Pre-Cambrian fault system that has been reactivated in the Mesozoic and then again in the Cenozoic.

LINEAMENT INFLUENCE IN NORTHWESTERN AUSTRALIA

The regional tectonic history of offshore northwestern Australia appears to be strongly influenced by several continental scale gravity lineaments. This relationship is illustrated by Figure 13.

The G2 gravity corridor can be interpreted from gravity data sets as extending across the continent in a north-northwest orientation from South Australia. In northwestern Australia it is coincident with the southwest edge of the Darwin Shelf, a prominent gravity anomaly. The influence of the G5 on the faulting trends has been discussed earlier and the eastern edge of the Bonaparte Basin is associated with the eastern edge of the G5 corridor. The Palaeozoic depocentre of the southern onshore Bonaparte Basin is situated within the intersection of the G5 and G11 lineaments. The G11 corridor appears to have influenced the southern edge of the Bonaparte Basin with major boundary faulting parallel to and within the lineament. The northern edge of the G11 is coincident with the northwest trending Sahul Syncline which is interpreted by O'Brien *et al.*, (1992) to represent a major crustal discontinuity, possibly an upper/lower crust interface. The southern edge of the G11 coincides with another major crustal discontinuity suggested by O'Brien *et al.*, (1992) to represent the Browse Basin/Timor Sea boundary. The T1 corridor is parallel to the northeast trend of the structural elements associated with the Late Palaeozoic/Mesozoic rifting of the western margin of Australia. The T1/G11 intersection is a zone of complex faulting and the location of the major Timor Sea petroleum fields.

LINEAMENTS — AN AID TO EXPLORATION IN AUSTRALIA

Lineaments are important, not just to the understanding of the tectonics of a region, but also as an aid to exploration. Throughout the world, the spatial distribution relationship between both mineral and hydrocarbon resources and lineaments has been recognised.

Figures 14 and 15 demonstrate that the same spatial relationship occurs in Australia. These Figures were constructed by plotting a number of significant mineral and hydrocarbon accumulations together with major gravity and geological lineaments. At a regional scale, a clear association exists between the deposits and the lineaments, particularly at the lineament intersections. The barren intersections suggest that a certain combination of geological and geochemical conditions are not present or that the areas have not yet been thoroughly tested. However, it would appear that at lineament intersections the required geological conditions are most favourable.

In northwestern Australia, the relationship between major lineaments and economic accumulations is striking (Fig. 16). The Figure shows both continental scale gravity interpreted lineaments and two important topographic lineaments, the T1 and NS1. A strong relationship exists between lineament intersections and economic accumulations. The NS1 lineament can be identified onshore using satellite imagery and offshore, it aligns with a prominent basement feature in the aeromagnetic data of the Vulcan Graben (O'Brien *et al.*, 1992). The intersection zone of the NS1 with the G11 and T1 lineaments is the location of the major petroleum accumulations of Jabiru, Challis, Skua, Puffin and Montara. Onshore it is coincident with the only significant Canning Basin oil discoveries together with the Ellendale and Noonkanbah diamondiferous lamproites. The Argyle diamond mine, one of the largest in the world, is situated at the intersection of the G11 with the G5 and G12 corridors. The strong association between diamondiferous lamproites/kimberlites and lineaments suggests that the latter acts as a deep zone of weakness allowing vertical emplacement of mantle material

At a more local scale, O'Driscoll (1986) noted that major ore deposits tended to be situated where a west-northwest trending lineament intersected another lineament or host rock lithology. He documented a characteristic structural signature of sinistral flexure that he termed a "Tethyan Twist".

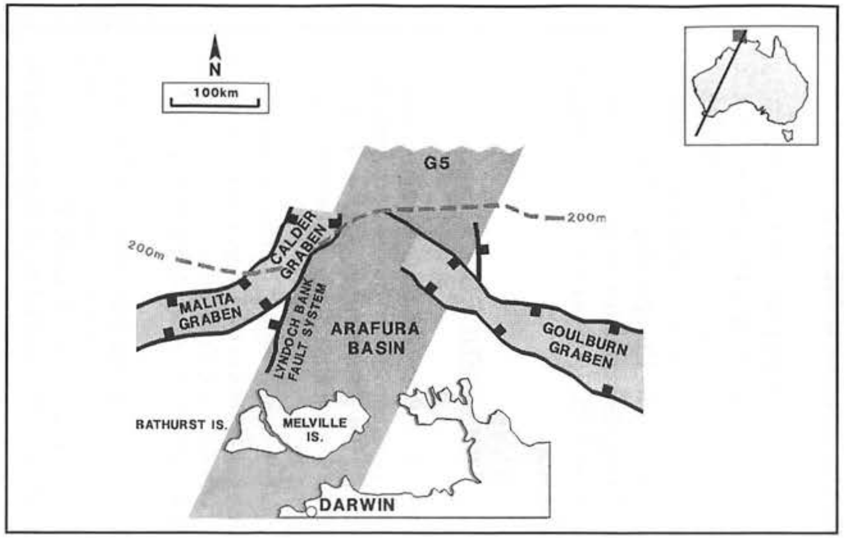

Figure 12. Schematic tectonic elements diagram of the offshore Arafura Basin. The western edge of the G5 appears to be of particular importance against which the Malita Graben terminates and becomes the north-northeast trending Calder Graben. The Lyndoch Bank fault is interpreted as a reactivated PreCambrian system. The bathymetric 200 m contour suggests a very recent influence of the lineament (Modified from McLennen *et al.*, 1990).

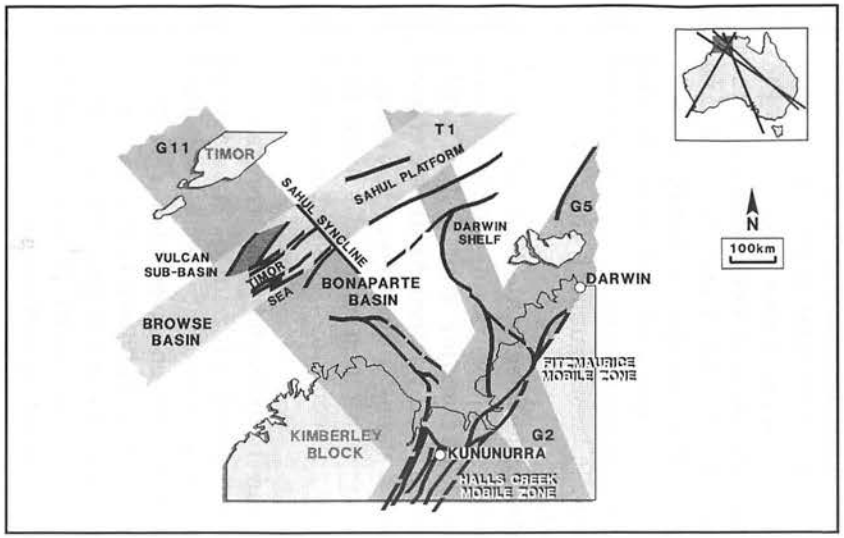

Figure 13. Schematic tectonic elements diagram of northwestern Australia showing the influence of major lineaments on the regional tectonic pattern.

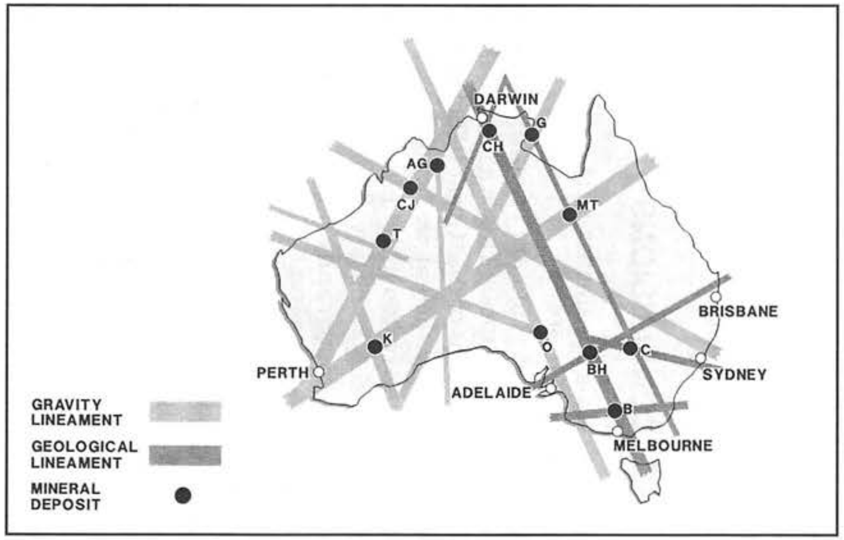

Figure 14. Schematic diagram showing the spatial distribution association between major mineral occurrences and continental lineaments. Note the coincidence of major mineral deposits and lineament intersections. **AG**=Argyle Diamond Mine, **CJ**=Cadjebut Pb-Zn, **T**=Telfer Au, **K**=Kalgoorlie Au/Kambalda Ni, **O**=Olympic Dam Cu-Au-U, **BH**=Broken Hill Ag-Pb-Zn, **C**=Cobar Cu-Au, **B**=Bendigo Au, **MT**=Mt Isa Pb-Zn, **G**=Groote Eylandt Mn, **CH**=Coronation Hill Au.

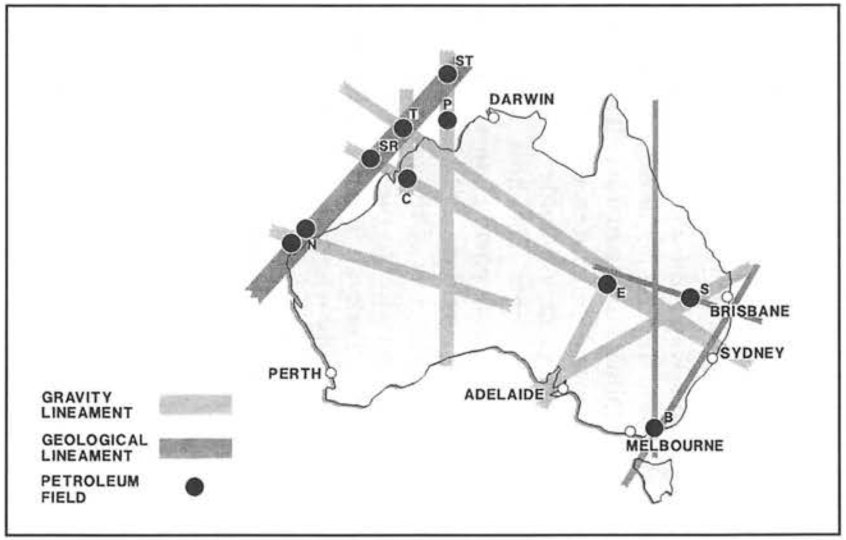

Figure 15. Schematic diagram showing the coincidence of major petroleum occurrences and continental lineament intersections. **B**=Bass Strait fields, **S**=Surat Basin fields, **E**=Cooper-Eromanga fields, **P**=Petrel/Tern discoveries, **ST**=Sunrise/Troubadour discoveries, **T**=Timor Sea fields, **C**=Canning Basin fields, **SR**=Scott Reef Discovery, **N**=Northwest Shelf fields.

He found this pattern to be repeatable at a number of scales from regional geological patterns to local mine scale. He also noted that all major nickel deposits in Western Australia and the Olympic Dam Cu-Au-U deposit in South Australia, displayed this structural signature (O'Driscoll, 1989a).

The Burra and Kapunda copper deposits in South Australia were the first major copper deposits produced in Australia's mining history. The Burra ore is hosted in banded dolomites and calcareous shales in the Proterozoic Adelaide Geosyncline region of South Australia. The host rocks are situated within and trend parallel to the north-northwest G2 gravity corridor. O'Driscoll (1986) noted, that although the axis of the ore remained north-northwest and parallel to the G2, there was a sinistral flexure, a "Tethyan Twist", of the host rocks at the mine locality where it was intersected by a west-northwest lineament (Fig. 17a).

The Kapunda copper deposit (Fig. 17b), also lies within the north-northwest trending G2 corridor. Here the ore envelope displays the characteristic sinistral flexure where it is crossed by a west-northwest trending lineament. At this site, a significant left lateral strike slip fault, parallel to the interpreted lineament, has been mapped in the mine.

Preliminary work carried out along the B1 lineament in northwestern Australia suggests a similar signature at the Sorby Hills Pb-Zn deposit (Fig. 17c). Here the north-northeast trending ore envelope shows a sinistral flexure where crossed by the B1 lineament, a component of the continental scale Gll gravity corridor.

CONCLUSIONS

1. Continental scale lineaments can be interpreted from gravity data sets.
2. Deep crustal lineaments are often reflected by recent morphotectonics. This was highlighted by Hills' observations of the "Great Relief Model" of Australia. Deep ancient crustal features are periodically reactivated throughout time and their influence can be observed as disruptions to the recent topography and bathymetry patterns.
3. The presence and location of gravity lineaments are supported by geological observation.
4. Lineaments have influenced a wide range of tectonic processes. Continental scale gravity lineaments appear to have acted as zones of crustal weakness and therefore will be sites of preferential high heat flow and energy release. As a result, lineaments will be regions of concentrated igneous and metamorphic activity. They will also be areas of concentrated tectonic activity leading to the formation of depocentres and regions of preferential uplift and erosion. As they are weakness zones, they will be the sites of reactivation and depending upon the stress regime at the time, will behave accordingly. For example, a lineament may behave as a compressional zone in the Proterozoic and then later as an extensional regime in the Palaeozoic under a different stress orientation.
5. Continental scale lineaments have influenced the tectonic framework of northwestern Australia. The major continental scale lineaments in northwestern Australia appear to have had a strong influence on the regional tectonic framework and also influenced the distribution of economic resources in the province.
6. Mineral and hydrocarbon occurrences are spatially associated with lineaments and in particular, lineament intersections. This relationship can be observed at a variety of scales from continental down to prospect level. The discovery of the world class Olympic Dam deposit using lineament tectonic models highlights the need for further investigation of this important economic relationship.

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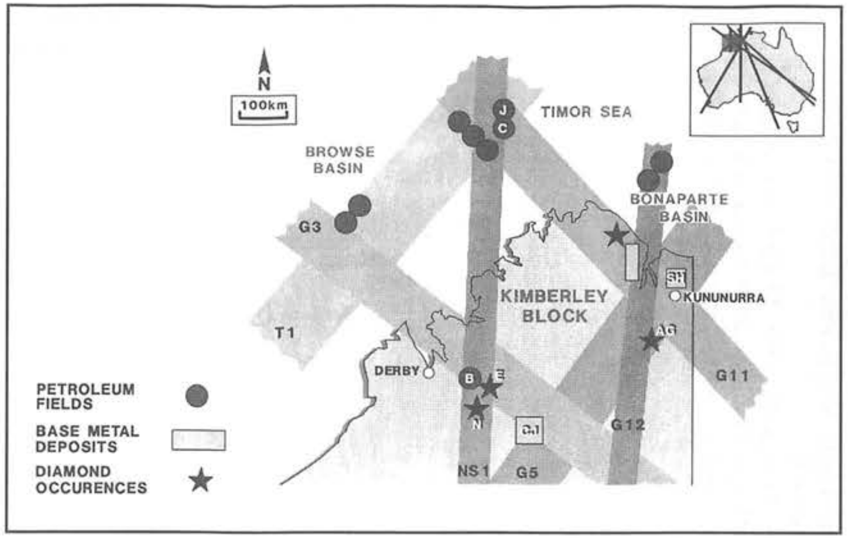

Figure 16. Schematic diagram showing the coincidence of major mineral and hydrocarbon accumulations and continental lineaments in northwestern Australia. **J**=Jabiru oil, **C**=Challis oil, **B**=Blina oil, **CJ**=Cadjebut Pb-Zn, **SH**=Sorby Hills Pb-Zn, **AG**=Argyle diamonds, **E**=Ellendale diamonds, **N**=Noonkanbah diamonds.

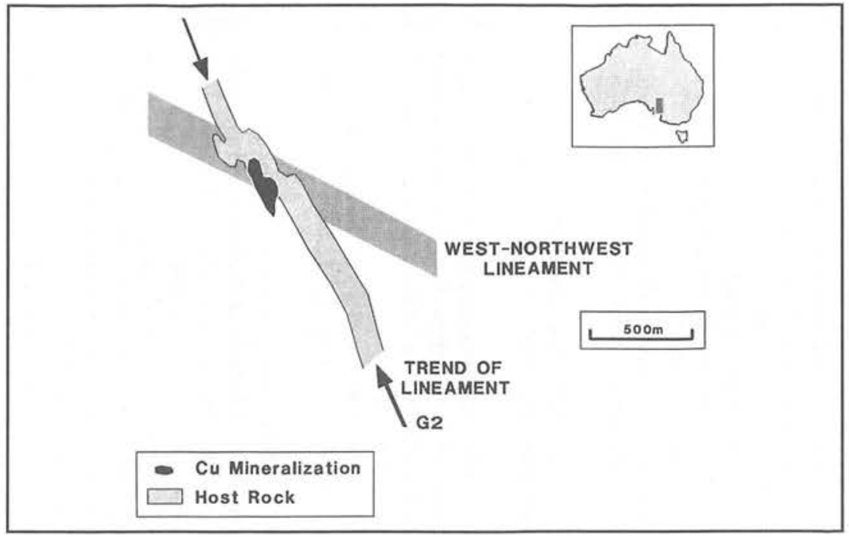

Figure 17a. Example of the "Tethyan Twist" at the Burra Cu deposit, South Australia. The north-northwest trending host rocks parallel to the G2 corridor show a sinistral flexure where crossed by the west-northwest lineament (Modified from O'Driscoll, 1989).

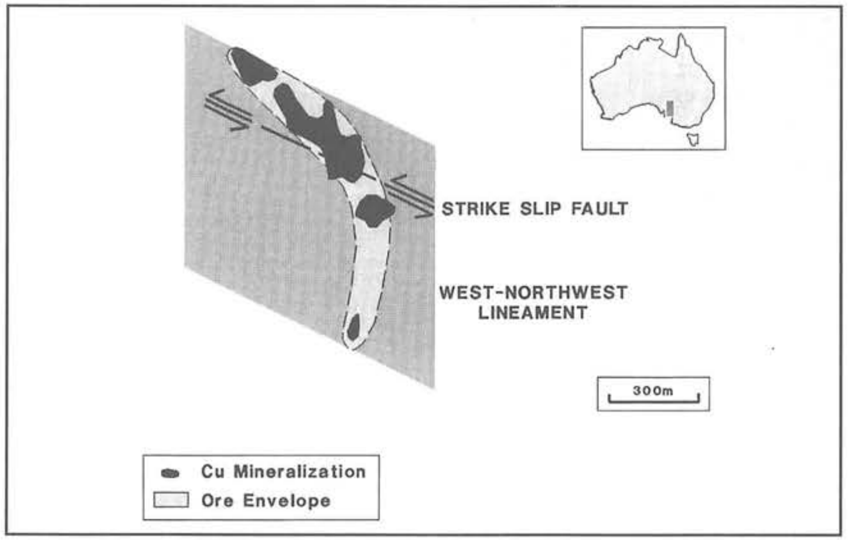

Figure 17b. A sinistral flexure of the Kapunda Cu deposit ore envelope where it is crossed by a west-northwest trending lineament. A sinistral strike slip fault parallel to the lineament has been mapped in the mine (Modified from O'Driscoll, 1989).

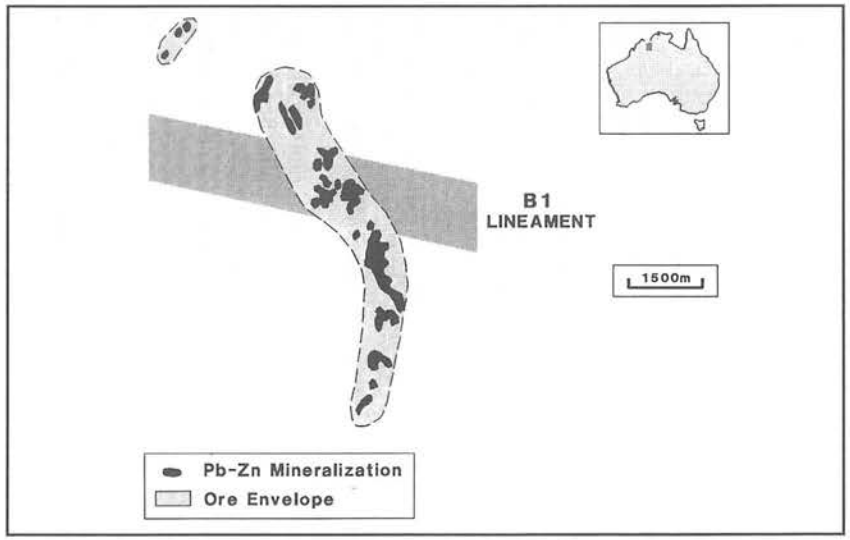

Figure 17c. A sinistral flexure of the ore envelope at the Sorby Hills Pb-Zn deposit in northwestern Australia where it is crossed by the B1 lineament (Modified from Jorgensen *et al.*, 1990).

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