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Assessment of the Resource Potential of leases held by Frontier Exploration in the Central Flinders Zone, Adelaide Geosyncline, South Australia.

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Introduction

Frontier Exploration has requested an independent assessment of current hydrocarbon prospects in PEL 41. In order to assess the petroleum potential and prospects, I have examined corporate data and information made available by Professor Eric Rudd and Dr Nick Lemon. These data relate to my prospect assessments in terms of a petroleum system. The fundamental components of the petroleum system are trap, reservoir and seal, together with hydrocarbon source and migration. In addition, I have independently applied a relative scale of risk to the components of two prospects; the Martins well and Willippa prospects in PEL 41.

Background Information

Frontier Exploration holds a petroleum tenement, PEL 41, over an area of gently folded Neoproterozoic and Cambrian sediments in the Central Flinders Ranges (Figure 1). The area of the original lease is shown in Figure 1 but I believe that the central portion has been relinquished with retention of the areas covering a number of the main domal features in the area, including Martins Well, Willippa, Bibliando and Blinman. Mineral rights are held over the same areas under Exploration Licence. My assessment does not take into consideration the ranking of mineral prospects.

The primary objectives of the prospects are restricted to the lower parts of the stratigraphic sequence, the Callanna, Burra and Umberatana Groups (Figures 2). Potential hydrocarbon source, reservoir and seals are present in the Tapley Hill Formation and Callanna Group with possible reservoirs in the Wilyerpa Formation and other Sturtian glacigenic rocks and in the Burra Group. Of particular interest are the diapiric and pillow structures, intrusions of brecciated Callanna Group sediments, which likely result from the movement of low density evaporite beds. The diapirs were active at the time of deposition as shown by dramatic thickness changes in their vicinity and by the inclusion of sediments derived from the diapirs in the sediments surrounding the structures. The intrusions provided early-formed domes which became enhanced during later folding. Domes of this origin provide all of the targets under consideration by Frontier Exploration, which are Bibliando Dome , Martins Well Dome and Willippa Dome. The following information is relevant to discussions relating to the hydrocarbon assessment of these domes.

Current Results of Frontier's Exploration program

Exploration by Frontier commenced exploration with two wells drilled in the Blinman area. These wells were based largely on available data made available by the Geological Survey of South Australia and maps prepared by Dr N M Lemon as part of his PhD thesis in 1988 . Detailed surface mapping has been commissioned by Frontier Exploration around the Upalinna Diapir and over the Willippa anticline. Detailed gravity surveys have been conducted over the Martins Well and Willippa structures with interpretation of aeromagnetic surveys in these areas and the Bibliando area. Three seismic reflection

profiles were collected over the Martins Well dome. The following is a summary of important information that relates to an assessment of Frontier Exploration's prospect port folio which comprises the Bibliando Dome, the Martins Well Dome and the Willippa Dome.

Drilling Results
Blinman #1

General Location:	Blinman Diapir
Objectives:	Base Metals
Total Drilling Depth:	481 m
Well Status:	P&A

Blinman #2

General Location:	Hydrocarbon Test - Eastern flank of Blinman Diapir
Objectives:	Fractured dolomites below the Tapley Hill Formation
Seal:	Shales - Tapley Hill Formation and evaporites in diapir
Source:	Shales: Tapley Hill Formation and Callana Group
Total Drilling Depth:	2031 m

Post Drilling Diagnosis: An interpretation of the sequence intersected by the Blinman #2 and the attitude of the bedding is shown in Figure 3. Drilling encountered a thicker than predicted Umberatana Group section. As a result, the well was terminated in a tight, intensely silicified Wilyerpa Formation (Umberatana Group) and it did not penetrate the objectives.

The well proved the occurrence of hydrocarbons and a diagenetic seal. Three gas shows were present within the Tapley Hill Formation. Open fractures within the shale, only partly cemented by dolomite, accounted for weak gas kicks. In addition, thin-section examination revealed traces of bitumen around sandstone grains.

H/C ratios were used to measure maturity. The maturation profile on a van Krevelen plot shows a progressive decrease in H/C with increasing maturation (see Fig. 4). H/C ratios of around 0.54 for samples from Blinman #2 suggest a vitrinite reflectance equivalence of about 2, ie., well into the gas window but not excessively cooked. The total organic carbon (TOC) profile down Blinman #2 (Figure 5) shows two zones of fair source rock; one at the base of the Tapley Hill Formation and the other around 1000m depth. The lower source interval is widespread throughout the Adelaide Geosyncline and is mapped as a separate unit, the Tindelpina Shale Member of the Tapley Hill Formation. This member represents deposition during a major transgression following the waning of the Sturtian glaciation. Widespread source rocks are commonly associated with major transgressions in the Adelaide Geosyncline. The organic source in Neoproterozoic rocks is likely of algal / cyanobacterial origin or Type I kerogen

The site for Blinman #2 was chosen to be in an area of minimal faulting but areas known to be fractured by regional faults could be viable targets provided meteoric diagenesis seals the upper reaches of the vertical fractures soon after their formation. This appears to be the case in Blinman #2. All fractures in the upper part of the hole were tight (diagenetic cement) with open fractures only apparent below 1277 metres.

Surface mapping

Outcrop of the Adelaidean sequence is generally very good in the Flinders ranges and surface mapping provides a clear indication of the structure and surface definition of prospects. An examination of Frontier Exploration's data base, published works of the Department of Mines and the National Centre of Geology and Geophysics indicate that most structures were developed by either salt diapirs or salt pillows, with subsequent episodes of folding and faulting superimposed on these features. This is certainly the case around Blinman, Willippa and Martins Well where doming is evident on satellite images, aerial photographs and regional maps. Detailed surface mapping has provided enough data to constrain section construction across the domes and predict the depth to detachment. The Busk method of section construction was utilised by Frontier's consultants to draw the shapes of concentric folds which form above a detachment surface or decollement. This section construction method is particularly applicable in the Flinders Ranges as the folds are concentric and there is a regional detachment surface within the Callanna group associated with the evaporites at that level. The broad dome at Martins Well suggests a considerable depth to detachment but the tight, pinched anticline at Willippa suggests that the detachment surface and evaporites are close to the surface.

Seismic profiles

The three seismic profiles collected across the Martins Well dome are all of very poor quality. The high velocity of the rocks from the surface and the unfamiliarity of the acquisition crew with this type of terrain appear to have added to the difficulty in interpretation. In most oilfield situations, the velocity in salt is greater than the surrounding sediments but in this case, the ancient rocks are so compacted and cemented that they show a higher velocity than salt. There are, however, indications of a salt pillow beneath the Martins Well dome. Despite the poor seismic reflectors, the doming of the sediments can be seen but this is more evident from the surface mapping than the seismic. An average velocity of around 6000m/second places the top of the interpreted salt pillow at around 3000 m depth.

Gravity surveys

Medium density gravity data were collected over the Bibliando, Martins Well and Willippa structures and interpretations made based on modelling of that data. A gravity profile over the Martins Well dome was modelled as a salt pillow at the depth indicated on the seismic sections and the modelled curve matched the measured curve well.. There appears to be a good match between gravity and seismic for the subsurface presence of a salt pillow. However, there is still risk associated with the presence of salt because gravity does not provide a unique solution: similar curves can result with parameters applied to different shaped rock geometries with varying rock properties.

The gravity data from Willippa Dome were also modelled along three profiles using shape variations of a theme which involved irregular salt intrusions above an anticlinal core. The modelled curves matched the measured gravity profiles but there is an inconsistency in the modelled shapes with respect to the surface mapping. The axis of the modelled anticline underlying the Willippa anticline trends NW-SE whereas the mapped structure at the surface trends E-W. There is no reason to doubt the surface mapping but new gravity models should be constructed with iteration between both sets of data. This may require the collection of additional gravity data or just re-evaluation of the models.

Aeromagnetic surveys

Relatively detailed aeromagnetic surveys were available for part of the area of the Frontier lease but such a survey is only of use where a clear anomaly exists which can be modelled. Detailed modelling will provide an interpretation on the depth and shape of the magnetic body causing the anomaly. The only such feature underlies the Bibliando Dome in the SE corner of the Frontier lease. Modelling suggests the possibility of a magnetic body in the shape of an anticline with a crest about 1500 m below the surface. As with the gravity models, assumptions are made about aspects of the material causing the anomaly, in this case, assumptions about magnetic susceptibility. There is no way of determining exactly what is causing the anomaly. It could be rocks of high magnetic susceptibility within the basement, a folded sill or sheet of volcanics within the Callanna Group, or a thicker and more magnetic portion of the Holowilena Ironstone, known to be within the Sturtian glacial sequence in the area. The latter interpretation may well be the case if there is sufficient thickening of the sedimentary sequence to the south of the Willippa Anticline. Regional mapping certainly suggests that thickening does occur in this direction.

The petroleum system

Trap

Surface mapping and geophysical data support the trap integrity of the Bibliando Dome, the Martins Well Dome and the Willippa Dome. All are clear anticlines with four-way dip closure over large areas,eg Willippa Dome feature displays an area greater that 315 km^2, and Matins Well Dome exhibits an area greater than 200 km^2. One of the main objectives of Frontier Exploration is to drill salt cored structures. For this reason, I have elected not to include the Bibliando Dome in this assessment until more geophysical information is acquired to confirm the nature of its magnetic anomaly at depth. The Martins Well and Willippa structures are likely to be salt-cored. The likely existence of a salt diapir at Willippa and a salt pillow at Martins Well supports the development of early traps. The timing of closed structures is likely midway through the depositional history of the Adelaide Geosyncline. The major folding event, the Cambro-Ordovician Delamerian Orogeny, enhanced the structures at the time of probable peak hydrocarbon generation and so ensured the traps were in place to receive a possible charge.

Reservoir

The viability of potential reservoirs poses the highest risk factor in the petroleum system of the Central Flinders Ranges. Such old rocks have been subject to considerable compaction and cementation and surface mapping shows most of them to be completely tight with respect to primary porosity. This is supported by most sandstones being tight with no or little porosity at the surface but some dolomites in the region, especially those which were dolomitized very early in their history, still retain intercrystalline and vuggy porosity. Dolomites associated with evaporite sequences such as those in the Callanna Group fall into this category and may still retain some porosity.

The presence of secondary fracture porosity and permeability of potential reservoirs is possible, particularly during episodes of salt-related 'tectonics' followed by superimposed tectonic folding and faulting events of those strata comprising the Adelaide Geosyncline. There are many oil and gas fields which solely relate to fractured reservoirs, some of them giant size, eg the Amal Field in the Sirte Basin, Libya which contains more than 6 billion barrels of recoverable oil. Although the sandstones there are of Mesozoic age, I do not

believe that age is an important factor when considering the formulation of fractured reservoirs whether its in the Proterozoic or Tertiary. Locally, there a strong possibility based on the drilling of Blinman #2 that secondary porosity and permeability can be related to a number fractures, especially when the well was drilled in what was thought a structurally undisturbed structural area

Seal

The integrity of seal provides another risk to the petroleum system in the Central Flinders Ranges. The risk is decreased when drilling primary reservoir objectives which have a thick salt seal because of its mobility and plasticity. Diagenetic events can also provide a seal within fractured shales as demonstrated in the drilling of Blinman #2. The same rock unit can proved a potential reservoir and seal. I believe that a diagenetic seal should be given a higher risk value than a salt seal.

Source

The viable hydrocarbon source identified in the drilling of Blinman #2 is one of the most widespread units in the Adelaide Geosyncline. While the majority of the Tapley Hill Formation is a grey shale/siltstone with poor TOC values, the basal Tindelpina Shale Member is known to be black and with a higher TOC in many areas. The core of the Martins Well dome in outcrop is upper Tapley Hill Formation with no reason to doubt that the Tindelpina Shale Member occurs at depth. The Willippa anticline shows erosion far deeper into the stratigraphy and the Tindelpina Shale Member is exposed as a rim some distance from the core of the anticline. However, other black shales are known lower in the stratigraphy with several units exposed in the core of the Worumba Anticline (and diapir) which outcrops 60 km to the west of Willippa. The Kirwan Siltstone is one such unit. As a result, there is a strong possibility that several source rocks are present in the lower portion of the stratigraphic sequence.

Maturity

As mentioned above, the only reliable maturity indicator in rocks of this age is the H/C ratio which can be plotted on a van Krevelen diagram. McKirdy et al (1976) collected samples from the Tindelpina Shale Member throughout most of the Adelaide Geosyncline and mapped H/C ratios along with other measurements to illustrate regional metamorphic gradients. Kerogen became graphitic in the areas of highest metamorphic grade around Mt Painter, the Olary Block and the eastern Mt Lofty Ranges. Additional data were collected from the Central Flinders Zone and added to the McKirdy et al map and included in the paper by Lemon et al (1993). This map is reproduced here as Figure 6. In order to provide good maturity coverage in the Central Flinders Zone, kerogen from units other than the Tindelpina Shale Member was also analysed. This map shows that the area covered by PEL 41 has the lowest maturity values recorded from the Adelaide Geosyncline. The H/C value of 0.46 comes from the Etina Formation in the Martins Well dome and suggests that the rocks here are only slightly more mature than those intersected in Blinman #2, ie in the gas window but not overly mature.

The close group of three samples SW of Martins Well is from the Worumba Area. The H/C value of 0.51 comes from the Tindelpina Shale Member in the Umberatana Group while the values of 0.34 and 0.36 come from black shales within the disrupted Callanna Group sediments in the core of the Worumba Anticline. One of those values is thought to be from the Kirwan Siltstone. Obviously, the more deeply buried sediments, those now brought to the surface by combined folding and diapiric activity are more mature.

Migration

Migration is difficult to risk in such an untested basin as the Adelaide Geosyncline but it is thought not to provide too high a risk in the cases where the reservoirs are close to the source intervals. In the case of Blinman #2, the fractured Tapley Hill Formation provided a reservoir within the source with no migration risk at all. Similarly, at Martins Well, potential reservoirs could occur in close proximity to the Tindelpina source. At Willippa, the potential reservoirs in close proximity to the Tindelpina source are breached at the surface in the core of the anticline and deeper sources from within the Callanna Group must be invoked. Mapping within the Worumba Anticline has shown that some black shales are interbedded with dolomites placing source and reservoir together but this sequence is likely to be disrupted as it is elsewhere in the central Flinders Ranges. Busk section constructions over the Willippa anticline suggest that the disrupted sequence is likely to occur immediately below the thin Burra Group sediments mapped in the core of the anticline.

Prospects and risk

Risk associated with wildcat drilling the Martins Well prospect and the Willippa Dome is considered on the basis of two target objectives which relate to pre-salt and post-salt plays.

Post-salt

Martins Well Dome

Trap: **low risk** (confirmed by surface mapping inconjuction with seismic and gravity)

Reservoir: **high risk** (a potential reservoir must have extensive fractures to be a viable target. Secondary solution could enhance porosity and permeability within carbonate beds.

Seal: **medium risk** (many shale horizons will provide seals as demonstrated at Blinman #2. A medium risk is appropriate because they could also be fractured resulting in lost or leakage of hydrocarbons to the surface.

Source: **low risk** (Although only a modest amount of organic geochemistry analysis has been undertaken, the analyses indicate a gas prone post salt sedimentary section)

Migration: **low risk** (Potential reservoirs can be sourced from adjacent shales)

Prospect Risk Status: **High Risk**

The high risk assigned to this prospect is based on the presence of an extensively fractured reservoir.

Willippa Dome

Trap: **low risk** (confirmed by surface mapping inconjuction gravity)

Reservoir: **low risk** (extensive fractures indicated by surface mapping)

Seal: **high risk** (extensive fractures and erosion indicate breaching of potential reservoirs)

Source: **low risk** (gas prone source)

Migration: **low risk** (potential reservoirs charged from adjacent shales)

Risk Status: **High Risk**

The high risk assigned to this prospect is due to the presence of extensive fracturing and breaching of the post-salt Tindelpina source and associated fractured strata in the core of the anticline. Potential reservoirs must be invoked in the remaining beds of the Callanna Group.

Pre-salt

Salt is an excellent seal and it is considered **low risk** for both the Martins Well and Willippa domes. Offshore Gabon is a good example with many pre-salt fields. Although the presence of pre-salt source rocks are likely over mature, this does not mean that gas will not be present or retained in the pre-salt traps due to the presence of salt seals. The presence of a pre-salt trap, however, is difficult to predict based on available data, especially if traps are below a regional detached surface, and for this reason both prospects are considered **high risk.**

The size of the prospects and the presence of a salt diapir at Willippa and a salt pillow at Martins Well, together with proven source rocks in neoproterzoic sequences warrants testing of these two prospects. I understand that the results obtained from drilling one of these prospects will have a direct bearing on drilling the other.

I recommend based on available evidence that the drilling of the Willippa prospect may have the overall best chance for finding commercial hydrocarbons. My reasons for recommending this are:

- The chevron-like anticline is thought to have a greater chance for the presence of a pre-salt trap than the gentle structure associated with the Martins Well prospect.
- If a pre-salt trap is present, there is a good chance that more pronounced tectonism in Willippa prospect will form a more extensive fracture system within a pre-salt potential reservoir despite a possible detachment surface.

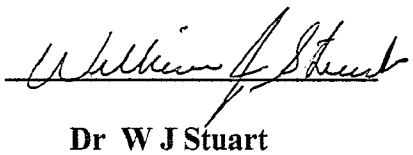
Comments

The top of the salt is predicted by Frontier Exploration to be at 1200 m below surface at Willippa Dome and 3000 m below surface at Martins Well prospect. . The current interpretation of gravity indicates a salt thickness of only 350 m at Willippa. However it is possible that the steep chevron-like folding at Willippa may have resulted in a much thicker salt interval due to the mobility of salt during tectonism. It is recommended that one remembers this possibility when formulating a drilling prognosis. It would most unfortunate to miss the opportunity of drilling into the pre-salt sequence due to the lack of drilling funds.

I have also noted that the structural axis of Willippa as shown on the geological map does not coincide with a more northwest orientated axis based on gravity. I recommend that the gravity data be reworked keeping in mind the detail of surface geology. However, based on my experience in exploring diapir and pillow structures in the Gulf of Mexico Basin and the Niger Delta, salt and shale diapirs are complex in the subsurface and can show slightly different orientation to that of shallow structure. The important fact is that a negative anomaly suggesting salt dome in subsurface coinicides with the overall surface structure; a fact that ~~augments~~ augurs well for drilling this structure.

Frontier Exploration may also wish to consider drilling one flank of the Willippa Dome to investigate possible traps adjacent to the salt diapir. The well could be later deviated at depth to test the pre-salt objective.

Wildcat wells in frontier areas are high risk ventures with the odds of encountering hydrocarbons 1 in 13. However, the rewards can be great particularly if economic volumes of gas are proven in drilling one of these large structures . For this reason and those comments I have written in this report the Willippa prospect, and the others as well, are considered high risk/high potential. The drilling of the Willippa Wildcat is made more attractive by the proximity of a gas pipeline that supplies the Adelaide market.

Signed: 

Dr W J Stuart

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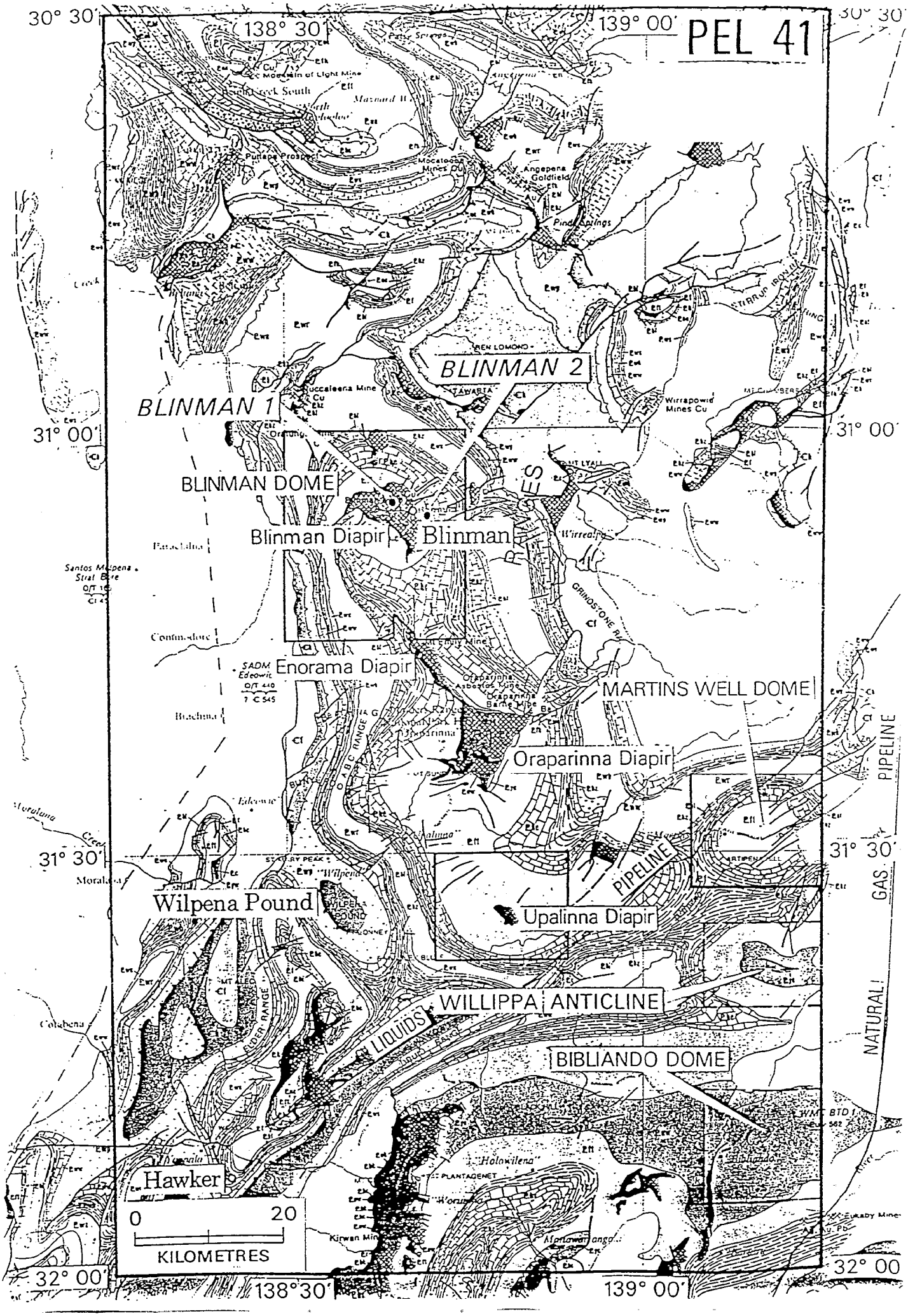

Figure 1. Geological Map of PEL 41 - showing the location of Bibliando Dome, Willippa Anticline and Martins Well Dome

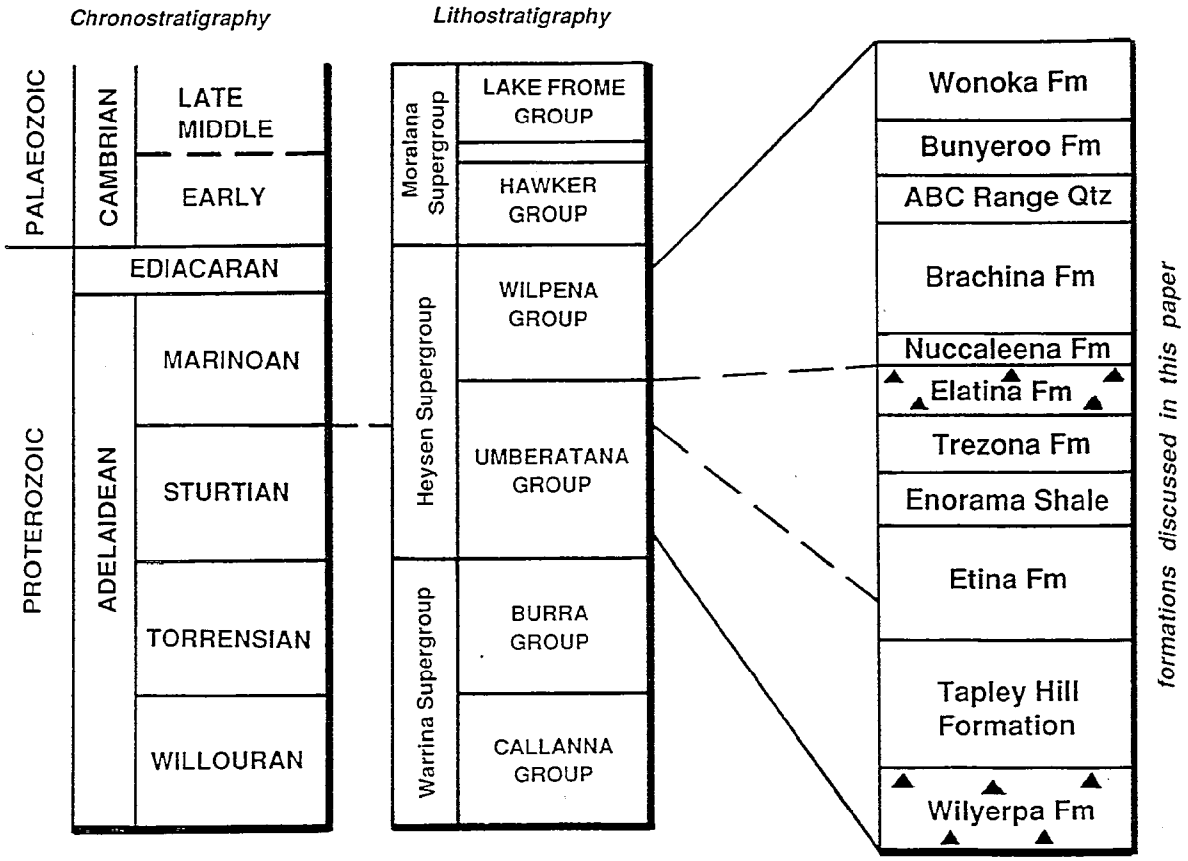

Figure 2.

STRATIGRAPHY CENTRAL FLINDERS RANGES

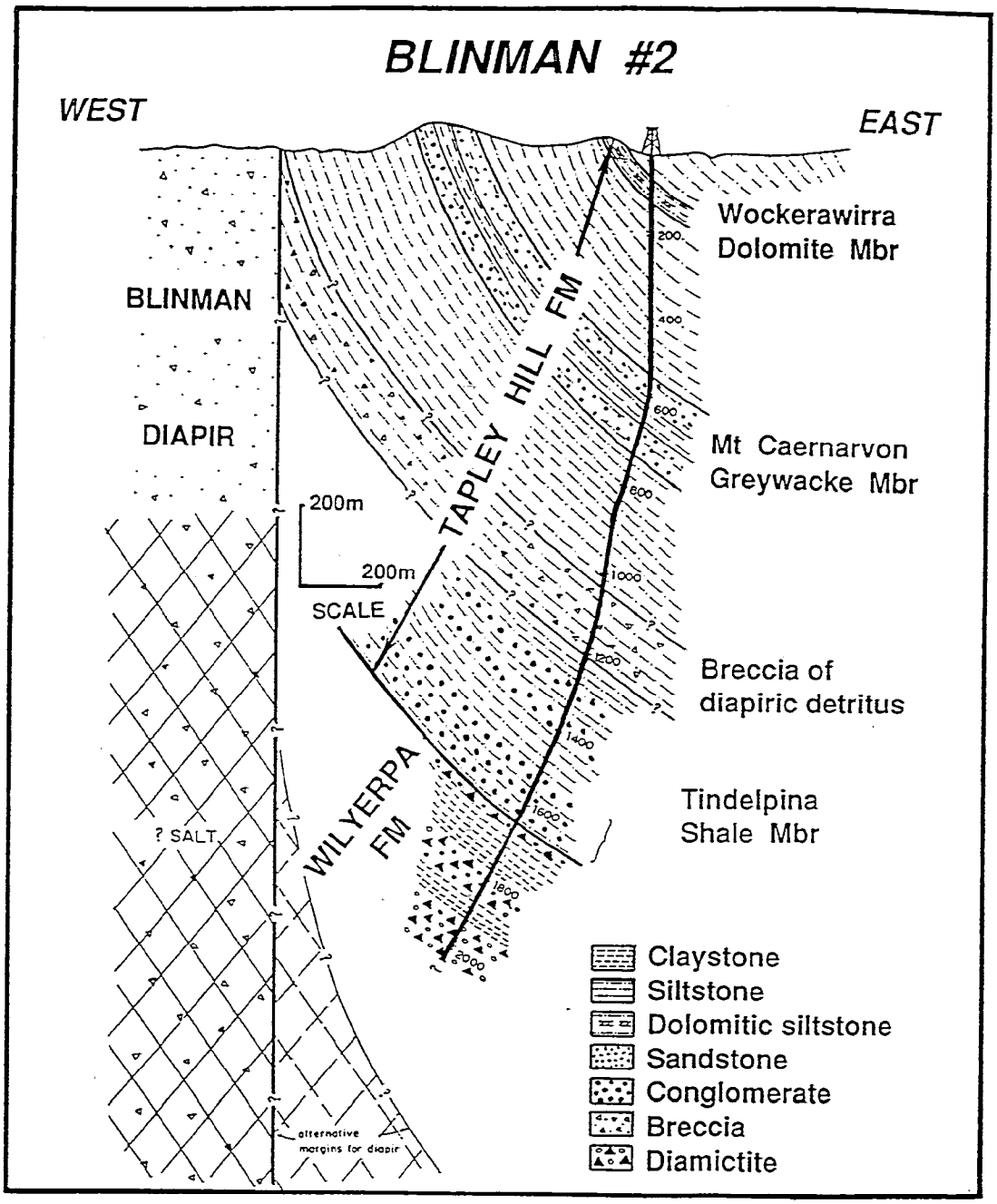

Figure 3. Geological interpretation of Blinman #2

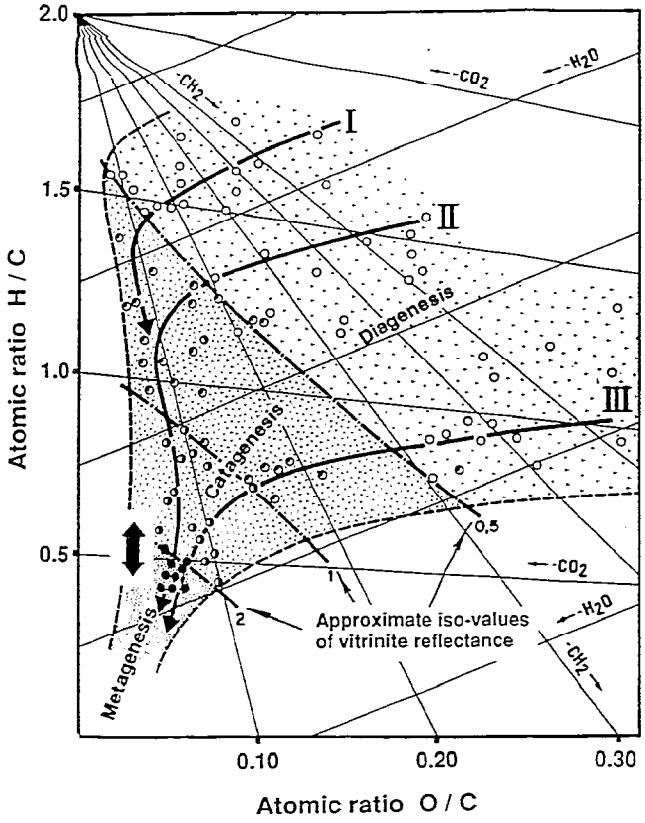

Figure 4.

MATURITY ESTIMATION FROM H / C USING A VAN KREVELEN PLOT

after Tissot and Welte (1984)

H / C RANGE
CENTRAL FLINDERS

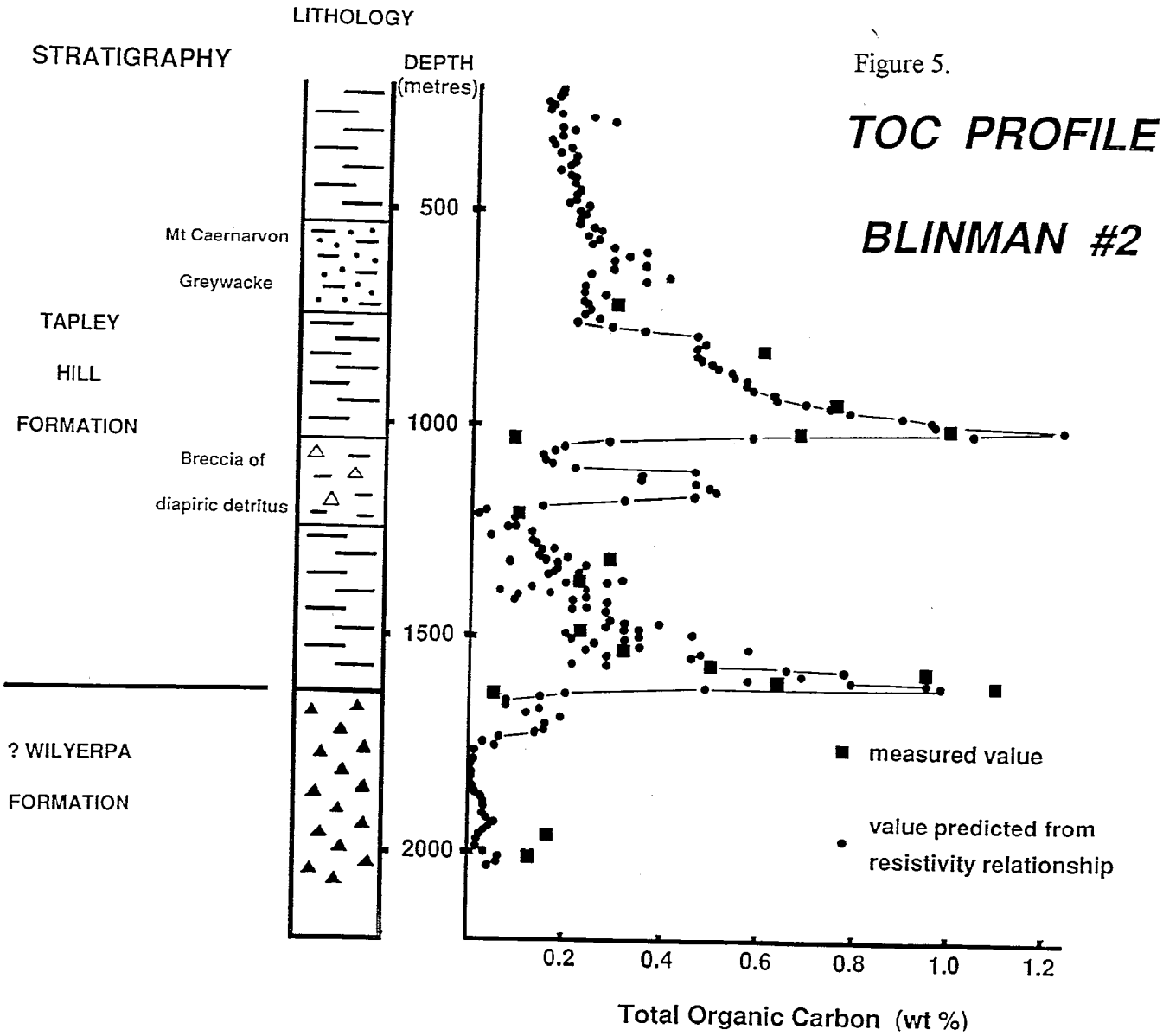

Figure 5.

TOC PROFILE

BLINMAN #2

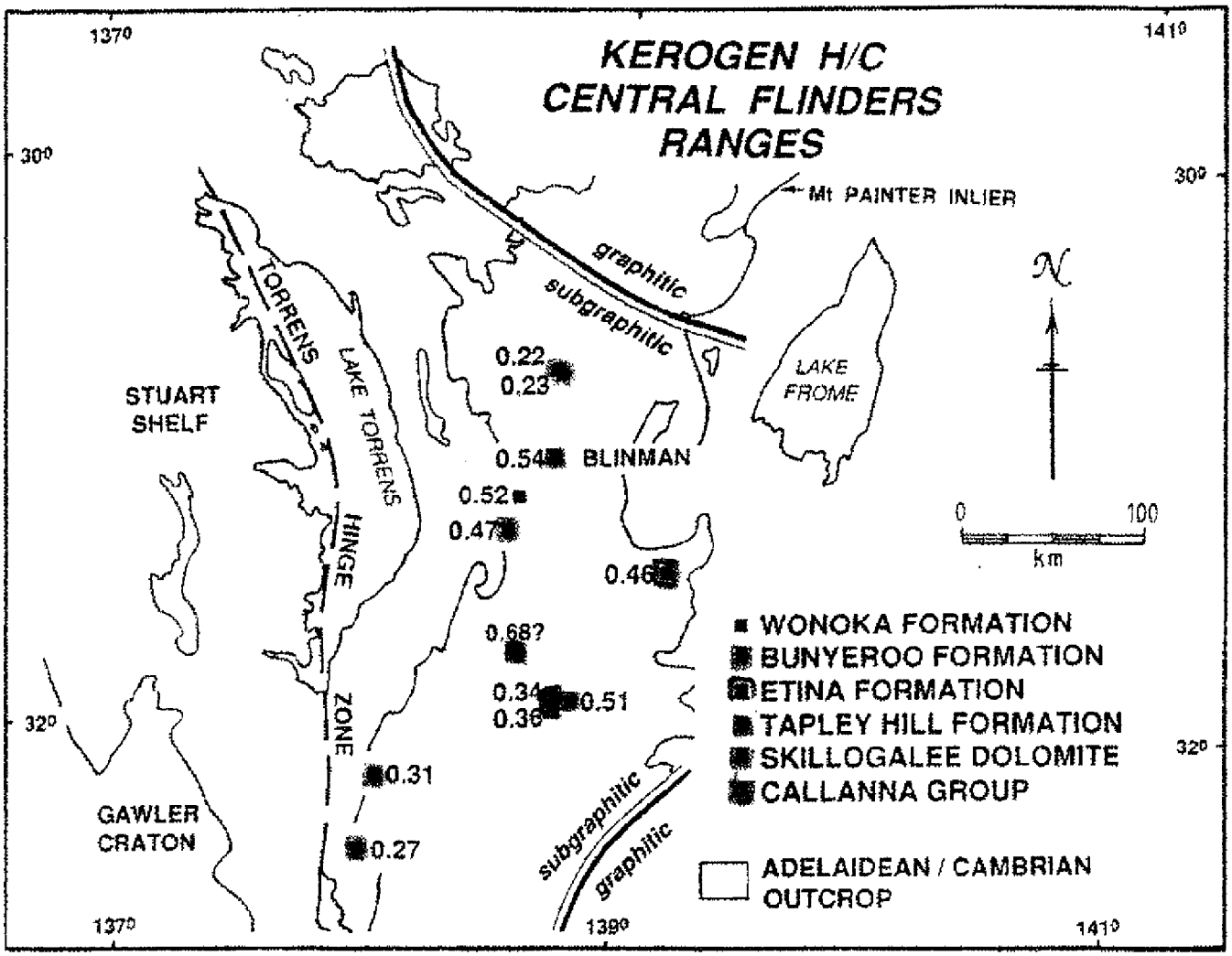

Figure 6. Map showing maturity values for source rocks in the Adelaide Geosyncline