# HYDROGEOLOGICAL INTERPERTATION OF AIRBORNE GEOPHYSICAL DATA
## LAKE MUIR UNICUP CATCHMENT, WESTERN AUSTRALIA

AGRARIA
LIMITED

BY

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# 1 INTRODUCTION

## 1.1 Wetlands

European land management practices have impacted upon most West Australian wetlands, apart from some of those in major conservation reserves, in the deserts and in parts of the north that are not readily accessible to livestock. In particular wetlands in southwestern Australia are under threat of raising saline watertable following clearing of natural vegetation for agriculture since 1830s.

Salinisation and excessive inundation of wetlands following clearance of catchments and eutrophication due to leaching of agricultural fertilisers are the most pronounced side-effects of European land management practice adopted during the last 100 years. In the study area stock grazing has impacted upon wetlands due to degradation of catchments and associated increase in runoff leading to a rise in the watertable. In the last twenty years the water level of Lake Unicup has risen about a metre and half (pers. comm. Dave Gardiner).

The Lake Muir catchment is dotted with numerous lakes and swamps to the east and north of Lake Muir. They form a natural wetland assemblage in poorly drained country between the Tone and Frankland Rivers and Lake Muir. To the north of Muir's Highway are Kulunilup Lake, Little Unicup Lake, Unicup Lake, Yarnup Swamp, Kodjinup Swamp, Noobijup Lake, Pindicup Lake, and south of Muir's Highway are Byenup Lagoon, Neeranup Swamp, Tordit-Garrup Lagoon, Poorginup Swamp and one of the largest lakes in the southwestern Australia, Lake Muir.

Lake Muir Catchment is classified as one of the recovery catchments by the WA State agencies. In order to understand the hydrogeological regime of the area CALM approached Agraria for the hydrogeological interpretation of the area utilising the airborne magnetic and radiometric data collected in May 1998. This report highlights the hydrogeological interpretation of the airborne geophysical data and the other available data sets.

## 1.2 Significance and Objectives

Lake Muir catchment is an excellent example of a complex of lakes, swamps and flats in relatively undisturbed condition, exhibiting a wide range of hydrological characteristics including progressions in salinity between adjacent lakes. An ecologically significant peat swamp, Cowerup Swamp lies 1km north of Lake Muir within the study area.

Figure 1.1 Cowerup peat swamp north of Lake Muir.

The present study looked in detail into the formation of the lakes and influence of geology and structural control on the groundwater systems in the area.  The overall aim of the CALM study is to preserve the lakes and the swamps in the catchment area in their present condition.

# 2 LAKE MUIR-UNICUP SURVEY AREA

## 2.1 Location

The nearest major town to the Lake Muir catchment, Manjimup is about 300 km southeast of Perth. Lake Muir Catchment covers about 65000 hectares and lies about 50 km east of Manjimup. The airborne geophysical survey covers about 730sq.km area of the broad valley flats and the low hilly regions saddled between Tone River to the northwest and Frankland River to the southeast (Figure 2.1).

## 2.2 Climate

The study area has moderate to wet temperate climate. Rainfall isohyets have general northwest trend, with mean annual precipitation increasing from more than 600mm to over 900mm (Wilde & Walker, 1984). Median and mean annual rainfall at Rocky Gully 723 mm and 715 mm respectively, mostly falling in May-September; annual evaporation is 1300 mm (Roger P. Jaensch in 1992).

## 2.3 Regional Geomorphology

The area falls within the South West Physiographic division (Swanland) of Juston (1934) and is comprised of two main physiographic units namely, Darling Plateau to the north and Ravensthrope Ramp to the south.

The Darling Plateau lies 300m above mean sea level. Fairbridge and Finkl (1978) concluded that Darling Plateau is an exhumed peneplain formed during the Proterozoic (Wilde and Walker, 1984) on which extensive lateritization developed due to climatic variations during Tertiary. The main features of the Darling Plateau are gently undulating plains dominated by gravelly and sandy soils with ferruginous duricrust and associated broad minor valleys with swampy floors (McArthur, 1991).

The Ravensthrope Ramp is an uplifted landscape gently sloping towards the south coast (Cope, 1975). Metamorphic rocks of the Albany-Fraser Orogeny are exposed in places across Ravensthrope Ramp. In this landform drainage development is young and deeply incised. Marine transgressions of Eocene and Miocene left sedimentary deposits on these physiographic units.

## 2.4 Regional Geology

The study area is covered by 1:250,000 Pemberton-Irwin Inlet Geological map. High-grade gneiss and granitic intrusion of Albany-Fraser Orogen underlie most of the area. The Yilgarn Craton lies north of these rocks. The orogen was divided into the Biranup Complex and Nornalup Complex.

The Biranup Complex comprises of high-grade quartzo-felspathic gneisses and layered basic intrusions whereas Nornalup Complex has less intensely deformed high-grade orthogneiss and paragneiss with granitic intrusions. Marine transgressions during Eocene and Miocene filled the hollows in the irregular Precambrian basement with shallow marine, lacustrine and alluvial deposits. (Figure 2.2)

## 2.5 Existing Borehole Data

Two sets of drilling information exist for the study area. One drilled by Water and Rivers Commission and the other done for individual farmers by the Agriculture Department. Most of the bores drilled for farmers are shallow to a maximum of 9 meters and groundwater

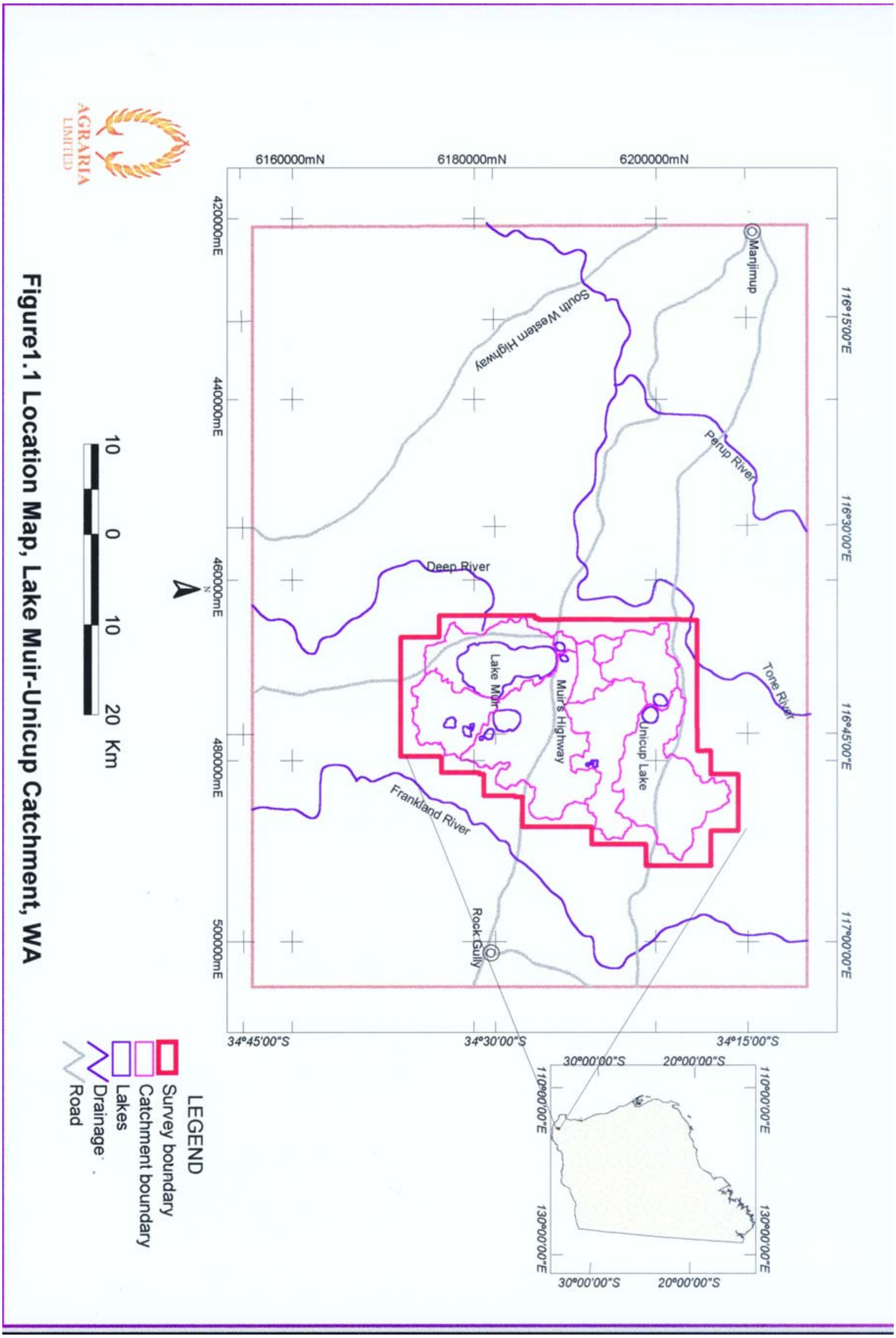

Figure 2.1 Location map of Lake Muir project, WA.

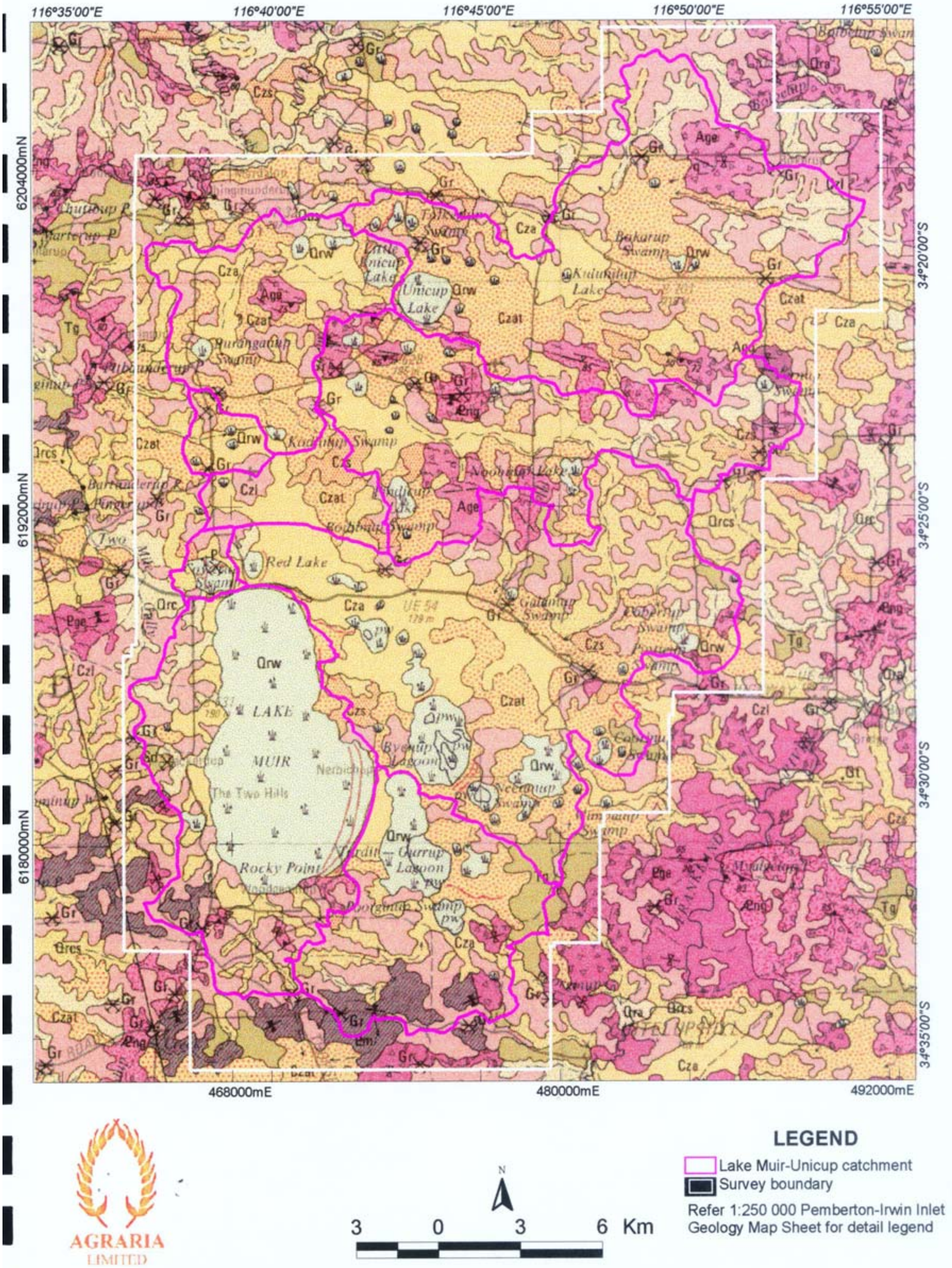

**Figure 2.2 Regional Geology modified from 1:250000 Pemberton-Irwin Inlet geology mapsheet SI/50 - 10, GSWA, Lake Muir, WA.**

Figure 2.2 Regional geology modified from 1:250000 Pemberton-Irwin Inlet geology map sheet SI/50-10 GSWA, Lake Muir, WA.

information was collected for only one year. More than sixty bores were drilled by Water and Rivers Commission but the complete database was not available to this study. Where data was available it was examined to attempt to establish the relations between perched and regional aquifers. Lack of complete data hindered this process. Probably the hydrogeological map which is being prepared by Water and Rivers Commission might reflect these relationships.

## 2.6 Salinisation

Clearing of the native vegetation until early eighties in the study area resulted in rising water levels leading to water logging and secondary salinity.

The origin of the salts in the regolith according to Hingston and Gailtis (1976) are accumulated from oceanic aerosols in high rainfall areas. Dimmock et.al (1974) found that salt storage increases with decreasing rainfall. It ranges from 17kg/$m^2$ above 1000mm/yr to 95kg/$m^2$ at 600mm/yr. Johnson (1987a) estimated that it takes about 7000 to 13,000 years to account for the measured salt storage in the regolith in the zones of higher rainfall areas of southwestern Australia.

Salt leached from the soils is the primary source of salinity in the stream salinisation (Schofield et.al., 1988). Johnston et al (1980) described two soil salinity profiles.

1. Monotonically increasing profile where the salinity increases linearly from near surface to certain depth, beyond which is fairly constant.

2. Bulge profile, where maximum salinity is concentrated at an intermediate depth.

One third of the soil salinity profiles reported from Manjimup woodchip area are monotonically increasing type (Schofield, 1988). In the same area Johnston *et.al* (1980) reported that the salinity increases from the divide and upper slopes towards the valley and upper slope gully sites. Tsykin (1988) reported that high salt storage results from poor drainage and low salt storage was due to unimpeded drainage

## 2.7 Vegetation

Semeniuk (1996) studied vegetation in the Lake Muir catchment and concluded that most of the vegetation in the wetland areas does not show change in vegetation structure and composition indicating that the salinity levels are quiet stable in the area. The local areas where Semeniuk reported changes in the salinity are around Lake Noobijip, 2 km north of Red Lake and the northern shore of Byenup Lake.

In the present survey area trees which have died due to waterlogging/salinity were observed in the swamps to the south of the Wingebellup road, south of Pinidicup road and in the swamps to the southwest of Unicup Lake.

Figure 2.3 Dead trees in water logging area

# 3 AERIAL GEOPHYSICAL SURVEY

Agraria-World Geoscience undertook an aerial geophysical survey in May 1998. Magnetics, radiometrics and DTM data were collected at 150 m line spacing with a flying height of 60m and traverse lines aligned at 000° - 090°. Tie lines were flown at 1500m interval aligned at 180° - 270°. Magnetic and radiometric data were collected at 6m and 60m intervals respectively in May 1998. Recent airborne geophysical surveys conducted under National Dryland Salinity Project at Lake Toolibin in Western Australia (Pracilio *et al*, 1998), and Balfes Creek in Queensland (Street *et al*, 1998) showed the potential of airborne surveys in understanding hydrogeological process in catchments prone to salinity.

The aim of following section is to provide a greater understanding of data interpretation and how various data sets are used for land management. The following outlines background information relating to what magnetics, radiometrics.

## 3.1 Magnetics

The magnetic characteristics of rocks are usually due to the presence of minor amounts of magnetic minerals contained in them (Strangway, 1967). Although all minerals are magnetic to some extent, those of significance are the oxides of iron in the solid solution series magnetite-ulvospinel, heamatite-ilmenite; and magnetite-maghemite plus the iron sulphide, pyrrhotite.

The magnetisation observed in a rock is made up of remanent and induced components. The presence of an applied field creates the induced component. In the weak magnetic field due to the earth, this induced component is proportional to the earth's field (Doell & Cox, 1967). The constant of proportionality is called magnetic susceptibility. Magnetic maps are usually interpreted assuming that the magnetisation of the rocks is primarily due to induced magnetism and parallel to the present field. This is because without laboratory measurements it is impossible to separate the induced and remanent components and for the most part the induced component is dominant. However remanent magnetism may not be parallel to the earth's field and may be stronger than the induced component.

Irrespective of the type of magnetism, rocks with a more basic chemistry such as are found in dykes of dolerite and/or gabbroic composition usually contain a higher content of minerals that have significant magnetic susceptibilities. The presence of high concentrations cannot be assumed to give rise to significant magnetic responses. Iron minerals that have significant magnetic susceptibility, particularly the magnetite-maghemite solid solution series, cause these responses (see paragraph above). Thus the ferricrete/laterite ironstone caps may not give a magnetic signature unless they contain significant quantities of maghemite.

In the aeromagnetic method, as used in this survey, a magnetometer sensor mounted in a stinger at the rear of the aircraft measures the total magnetic field of the earth as the aircraft flies at 60 metres above the ground. Short wavelength variations in the magnetic field are due to variations in the magnetic mineral content of the rocks near to the surface of the ground. Longer wavelength variations are usually due to deeper sources.

The capability of aeromagnetic data in resolving separate discrete magnetic bodies depends upon distance from the sensor to the sources. If the sources are separated, by a distance greater than the sensor-source distance, then they should be resolvable as separate bodies from the Total Magnetic Intensity (TMI) data. If they are separated by less than roughly half the sensor source distance then they will not be resolvable and will form a single anomaly. At intermediate separations filters, such as a first vertical derivative (1VD), can make separate bodies resolvable.

Traditionally magnetics has been used to detect anomalies, particularly in oil exploration where magnetic data were used mostly as isolated lines and analysis was carried out on anomaly shapes by geophysicists. In the 1980's high resolution surveys combined image processing and better navigation equipment to produce maps which could be interpreted by geologists for direct geological mapping. The process is best described by the course notes developed by Isles of World Geoscience Corporation and Valenta of Victorian Institute of Earth and Planetary Science and others (Isles et al, 1997). Geologists rather than geophysicists now interpret magnetic data.

Elsewhere in the wheatbelt of Western Australia ground and airborne magnetic surveys have been used for salinity by mapping position of dolerite dykes, which cause localised salinity (Engel et al, 1987; Townrow, 1989; Anderson, 1994) and large scale fault zones which cause regional salinity problems (Clarke et al, 1998).

### 3.1.1 Presentation and Filtering of Magnetic data

Airborne magnetic data has been traditionally presented as maps of contours and or stacked profiles, although images have become the normal presentation in recent years. While TMI maps are used, interpreters find that combining the TMI with various presentation of filtered data is the best approach for interpretation (Isles et al, 1997). Combinations of TMI and image(s) that highlight the high frequency or near surface information are considered to be the most useful for salinity. Typically these use various derivatives of the magnetic field such as a first or second vertical derivative (1VD or 2VD).

In this study, reduced to pole (RTP) magnetic images were used to reduce the amount of asymmetry in the magnetic field responses. In order to extract the most information, the following images were used:

- TMI image without RTP in colour
- 1VD without RTP in greyscale
- RTP TMI with a sun angle from 00 degrees, which will enhance E W structures in colour,
- RTP 1VD in colour
- RTP 1VD in greyscale,

## 3.2 Radiometrics

Gamma-ray spectrometry (radiometrics) measures the natural gamma radiation emitted by radioactive daughter decay of three elements - potassium (K), thorium (Th) and uranium (U) - from within approximately the top 30cm of the earth's surface. The maps prepared from radiometric surveys provide information about the soil parent materials and other properties such as surface texture, weathering, leaching, soil depth and clay types (Bierwirth et al, 1996a).

In contrast to other remote sensing techniques used for soils, radiometrics has some clear advantages. These are:

- dense vegetation will not significantly reduce the radiometric signal,
- DEM modelling of soils in flat areas is inadequate and
- radiometrics measures the top 30 to 40cm and not just the surface (Bierwirth et al., 1996a).

Cook et al. (1996) used gamma radiometric surveys as a guide to soil mapping in the West Australian wheat belt and found that the variation in radiation corresponded to the distribution of soil-forming materials over the landscape. Radiometrics were used to distinguish between highly weathered residuum and fresh granitic material. Radiometric data also distinguished between doleritic, laterite and granitic soils (Cook et al, 1996).

The radiometric elements measured are derived from a number of sources in rocks and regolith. Where shallow bedrock is present radiometric responses tend to be higher (except in sandstone areas) and relate to the properties of the bedrock (Bierwirth et al, 1996b). In areas where soils have formed, the signature is related to physical and weathering processes (Bierwirth et al, 1996b). In areas of transported material radiometrics can reflect the transport and depositional history. The following is a summary of radiometric data and its relationship to soil properties.

High potassium is often related to potassium feldspars and mica particularly from granite and granitic soils (Wilford et al, 1992). Potassium is fairly mobile and tends to be leached during the weathering process. During hydrolysis potassium is released and is used in the formation of illite, absorbed onto other clays and removed from fluid migration (Wedepohl, 1969 in Bierwirth et al. 1996b). High potassium has been associated with illite, other clays and alluvial soils (Bierwirth et al,1996b, Nash 1997; Slater and De Plater, 1997). Potassium released during weathering can be taken up in the formation of K-bearing minerals such as illite or absorbed onto other clays (eg montmorillonite) under suitable conditions (Dickson and Scott, 1997). The efficient uptake of potassium by clays is reflected in the low potassium content of sea water (380ppm) (Dickson and Scott, 1997). Studies are underway relating $^{40}$K as measured by radiometric surveys to plant available potassium. It appears as yet there is no direct relationship. However $^{40}$K constitutes about 0.02 per cent of natural potassium and as $^{40}$K is detected by the decay of the parent isotope it is a direct measurement of total potassium in the ground (Dickson and Scott, 1997).

An increase in both thorium and potassium has been related to an increase in silt content and recent deposition (Slater and De Plater 1997; Bierwirth et al, 1996a & b). Thorium also allowed for the discrimination between cracking (montmorillonite with low Th) and non-cracking clays (illite, kaolinite with high Th) in the Wagga Wagga Catchment New South Wales (Bierwirth et al, 1996b). This was attributed to radon gas expelling from the cracks and diminishing the signal (Bierwirth et al, 1996b).

Thorium and uranium are present in the heavy mineral zircon, apatite, sphene and monazite (Wilford et al, 1992, Dickson and Scott, 1997). Thus, higher thorium and uranium signatures are often associated with the laterite profile due concentration of heavy minerals left as a lag in the weathering process and also due to secondary minerals concentrating thorium and uranium (Smith and Pridmore, 1989; Cook et al, 1996; Dauth, 1997). Uranium and thorium can be absorbed by clays or co-precipitated with iron oxides (Dauth, 1997, Dickson and Scott, 1997). Thus high thorium response often seen over laterite ironstone areas, which is sometimes referred to "scavenging" of thorium by iron may also be due to heavy mineral concentration. Uranium and thorium may also be transported with colloidal clays (Dickson and Scott, 1997).

Higher uranium counts can also relate to carbonate precipitating within Tertiary palaeodrainages due to discharging groundwater (Arakal and McConchie, 1982 in Dauth, 1997; Smith and Pridmore, 1989). In the wheatbelt of Western Australia elevated uranium channel counts can occur over areas of groundwater discharge. This effect is due to disequilibrium of the decay series. In both uranium and thorium decay there is a series of daughter products before the end products of non-radiogentic $^{206}$ Pb or $^{208}$ Pb. Radium is one of the longer lived of these daughter products and can be mobilised particularly in water of high salinity (Dickson and Scott, 1997). In the U series $^{226}$Ra has a half life of 1600 years and so can be deposited to form apparently coherent bodies separate to its parent. Radium deposits are common around salt lakes and in elevated uranium channel counts may be recorded over saline seeps due to this disequilibrium effect (Dickson and Scott, 1997).

Uranium can be precipitated under reducing conditions forming uranium deposits under favourable conditions.

A low total count indicates the presence of sands (Cook et al, 1996) which have a very low concentration of radioactive isotopes. In addition, a thin layer of water will completely attenuate gamma radiation and water bodies will appear dark blues to black on radiometric ternary images. Vegetation usually has only minor effects except in tropical rainforest conditions where it can reduce the signal by up to 15%.

### 3.2.1 Presentation of Radiometric data

Radiometric data were imaged as single channel spectrometer data, total count and as a Ternary composite. Images used for Lake Muir interpretation included:

- Ternary radiometrics,
- Total Count radiometrics,
- Potassium (as percentage),
- Thorium (ppm); and
- Uranium (ppm).

Ternary images are a convenient way of viewing all three channels of radiometric data at once. These images are somewhat variable depending upon the data and the image processor. The image is an RGB composite with K = red, Th = green and U = blue. The brighter the colour the higher the measurement in that particular channel. For example, with the absence of uranium and thorium, high potassium will generally appear as bright red which may look pink and low potassium as dark or deep red. High in all channels will appear as white and low in all channels should appear black, but may take a deep blue. Mixtures of colours such as yellow (blue and green) indicate elevated thorium and potassium.

Total count radiometrics reflects the total radiometric response across the spectrum. A single isotope often dominates total count images. For example, in lateritic terrain thorium can dominate. Single channel radiometric data can be presented as counts per second or converted to isotopic concentrations in the soils.

# 4 INTERPRETATION

## 4.1 Interpretation Process

Hydrogeological interpretation for a given area should include the integration of all available data sets which can be interpreted for surface and sub-surface information such as air photo/satellite interpretation, magnetic/radiometric interpretation, meteorological and drilling information.

Aerial photo interpretation was not involved in the present project as landform and structural interpretation had already been completed by Agriculture WA (Ruhi Ferdowsian). This interpretation was made available in digital form although no explanatory notes were provided at the time of interpretation stage of this project. Unfortunately the structural history of the area could not be determined from the lineament mapping and aerial photo interpretation. Aerial photographs interpreted at 1:25,000 can be used to delineate Landforms and the surface water movements for hydorgeological purposes. Landform interpretation when associated with the radiometrics can be a powerful tool in regolith mapping. However, in the present study and radiometric data were interpreted independent to the landform interpretation.

A broad landform interpretation was carried out based on Digital Elevation Terrain and radiometric data and the area was divided into five different landforms. Magnetic interpretation provided the necessary input into the complex geological history of the area. Fieldwork and the other available drilling information helped in the hydrogeological understanding of the area.

## 4.2 Sub-Catchments of the Area

Boundaries of the Muir Catchment and sub-catchments were supplied by CALM (Figure 4.1)

The sub catchments are

1. Unicup catchment
2. Mordalup catchment
3. Noobijip catchment
4. NW of Noobijip catchment
5. Pindicup catchment
6. Muir Catchment
7. Tordi Garrup catchment

## 4.3 Geological Interpretation of Magnetic Data

### 4.3.1 Geology

The Albany–Fraser Orogen lies along the southern and southeastern margin of the Yilgarn Craton. It is characterised by high-grade gneisses, granitoid intrusions and polyphase deformation. The study area is within a section of the Albany-Fraser Orogen characterised by high-grade quartzo-feldspathic gneisses and layered basic intrusions called Nornalup Complex overlain by later sedimentary and superficial deposits.

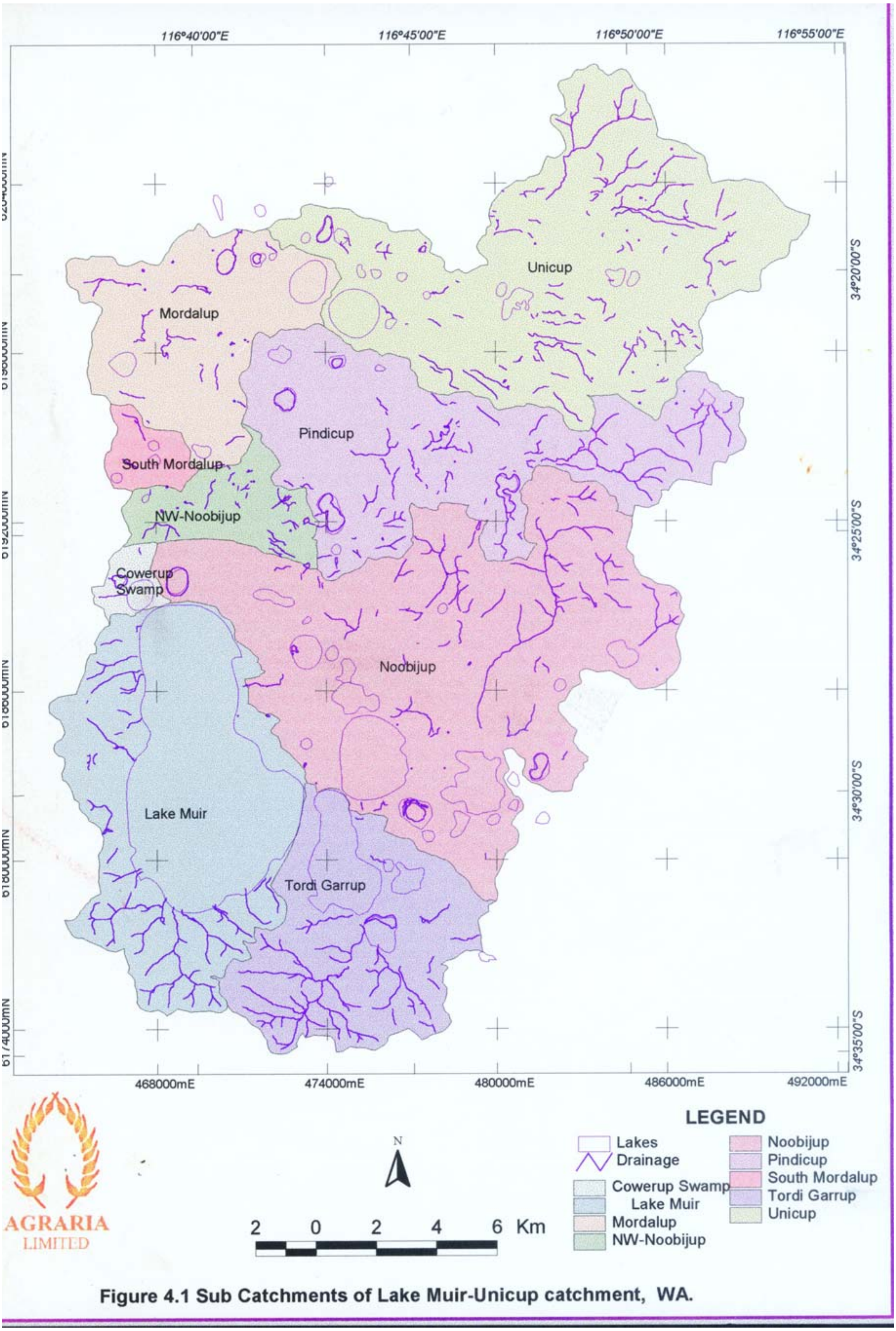

Figure 4.1 Sub Catchments of Lake Muir-Unicup Catchment, WA

Gee (1979) suggested that the Proterozoic rocks of the Albany-Fraser Belt are resulted from high-grade metamorphism and plutonic activity, accompanied by strong tectonism.

Marine and non marine sediments (Werillup Formation) occupy hollows in the Precambrian basement. Alluvial and lacustrine deposits such as conglomerate, quartz grit sand and clay are mapped to the south and northwest of the project area (Wilde and Walker 1984). Yellow and grey coloured sands probably deposited during late Tertiary over weathered Precambrian basement are now preserved in some of the upland depressions and saddles. Shallow marine conditions caused clayey and siltstone deposits upto 30 m deep which could be still preserved around Bokarup swamp area (McArthur 1991).

In the study area little outcrop was found during field visits. A quartz diorite was observed along the eastern boundary north of the Yarnup swamp. Most of the area is lateritized and covered with extensive Bluegum plantations preventing determination of the extent of the unit in the field. In the magnetic data the signature of this unit does not differ from the surrounding granitic gneiss.

### 4.3.2 Magnetic Interpretation

Magnetic data were interpreted for the structural information and also to delineate different lithological units in the area. The east west foliation trend of the Albany-Fraser belt is strongly reflected in the magnetic data. The low magnetic zone to the north of the survey could be the shear zone parallel to the Manjimup lineament or part of the lineament. The low fuzzy nature to the north and at other places could be due to the sediments deposited on the Precambrian basement during Tertiary period. Depth slices, a process highlighting different frequencies in order to understand the deeper and shallow magnetic signatures, were prepared to delineate the upper Tertiary sediments, if possible from the magnetics. However, since the sediments over the basement are thin, less than 30 – 40 m their thickness and extent could not be determined with confidence.

Litho-units interpreted from the magnetic data are:

Anb: Fine to medium grained layered gneiss with varying proportions of quartz and felspars and biotite. Compositional layering observed with the variation of biotite content.

Ang: Coarse grained granitic gneiss with variation in the texture at places with stronger gneissic banding.

Age: Medium grained granitic rocks Granite to Granodioritic in composition

Q/Ag Shallow marine sediments deposited on the granitic rocks

Png: Strongly deformed granitic gneiss

Pnd: Sheared granitic gneiss. Shear zones trending EW and NNW SSE.

Pm: Migmatite strongly contorted banding.

Pgd: Strongly deformed granitic gneiss with conjugate folding.

Dykes: Dykes associated with deformed Archaean granitic rocks in the area are metamorphosed and lie sub-parallel to the shear foliation and gneissosity as observed in the field.

The solid geological interpretation of the area was presented in the figure 4.2

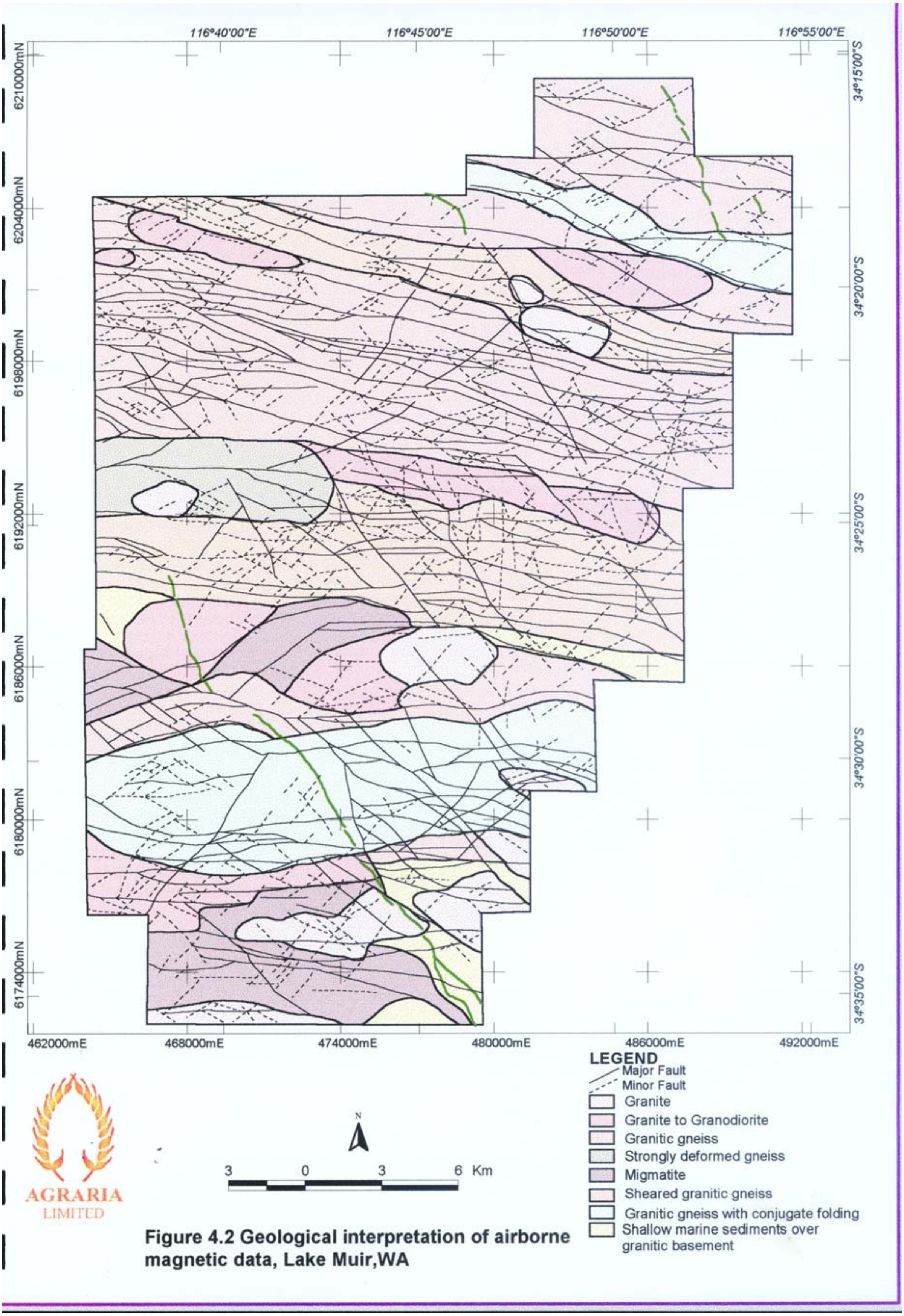

Figure 4.2 Geological interpretation of airborne magnetic data, Lake Muir, WA

### 4.3.3 Structural History

The northern boundary of the Albany-Fraser belt is marked by two linear magnetic lows which appear to define Manjimup lineament interpreted by Wilde & Walker(1984). Other major faults in the study area trend parallel to the Manjimup lineament. The magnetic foliation of the gneiss also trends parallel to this direction. Conjugate shear zones, formed at the same time but aligned in different directions, were observed at places

Figure 4.3 Conjugate shearing in the gneiss

Some of these major Precambrian faults were later reactivated during the break-up of Gondwana supercontinent. The break-up of Austalia from Antarctica along the what is now the south coast of Western Australia started during Early Cretaceous (Kelly, 1990). During breakup the Australian continental margin would have been drawn downwards followed by an uplift of the southern coast along what is known as Ravensthrope Ramp during Oligocene. The uplift around Lake Noobijip and south of Lake Muir could be reflections of this last major tectonic uplift. Major faults reactivated during the Tertiary are identified in the interpretation as late and reactivated faults. These reactivated faults tend to be higher in the crust in crystalline rocks leading to more brittle failure and can be good groundwater aquifers.

The influence of the Darling Fault to the west is reflected as numerous northwest to southeast fracture zones similar to the major Boyup-Brook fault. These splays off the Darling Fault cut across all the major east–west trending faults. Dominant trends of minor fractures and faults in the area are 050-230°, 030-210° and 000-180°. Other brittle fracture trends are 060-240°, 010-190°, 070-250°, 240-320°.

Figure 4.4 Late north south faults cutting across east west trending gneissic foliation

## 4.4 Landforms

### 4.4.1 Landform Evolution

At the beginning of the Cainozoic Australia experienced tropical wet climate. Thus well developed drainage systems (see figure 4.5) were active at that time (Kelley 1990). During the Cainozoic however due to the drift of the Australian continent northwards climates have become increasingly arid. In addition landforms have changed significantly since Mesozoic times. Three wide spread marine transgressions which occurred during Early Cretaceous, Eocene and Miocene are known (Kelley 1990). Churchill (1973) suggested that the maximum extent of the Eocene transgression coincide with the present day 300m contour and Lloyd (1968) interpreted the Miocene shoreline to extend to present day 200-250 m contours.

The Eocene marine transgression covered the hollows on the palaeo surface with sea and many of these depressions became traps for shallow marine sediments. The present Lake Muir is interpreted to have been an inlet like the present day inlets along the south coast. In the late Eocene climates were trending towards aridity leading to reduced the water flow in the rivers and deposition of siltstone and clay deposits.

The tilting of Ravensthrope Ramp during Oligocene created a barrier to the south flowing drainage system. This blockage resulted in extensive sedimentation and the formation of chain of present day lakes as the last vestiges of the palaeodrainage system (Figure 4.5). This inland basin thus filled with shallow marine, lacustrine and alluvial sediments.

Uplift along the fault north of the Lake Noobijip and the cessation of the drainage flow probably has created Lake Noobijip. The subsequent erosion of the uplifted block eroded the marine sediments and a new drainage has developed. Subsequent lateritization in a fluctuating wet and arid conditions has left a deeply weathered laterite mantle over most of the landscape.

The extent of the Tertiary alluvial flats and Eocene sands indicate that the present drainage is different to that of the Tertiary (Wilde & Walker 1984). The Miocene and Pliocene periods were transitional during which aridity spread from the centre of Australia. Extensive consolidated grits and hardpans were formed during this period. The broad alluvial tracts mark an early stage in the dissection of this surface, although some of these deposits are weakly lateritized Wilde & Walker (1984)

Lowering of the sea level with general cool climate mark the period between 10 –5 Ma. The cooling meant that patterns of wind and water circulation comparable to those of today were beginning to develop (BMR,1990). Probably the present course of Frankland River was developed during this phase.

### 4.4.2 Landform Classification

Broad classifications of the landforms for the study area were interpreted from radiometric and Digital Elevation Model data (Figure 4.6.)

The landforms recognised are

| | |
|---|---|
| 1. Low Hills: | Low hills situated to the south of the Lake Muir are the eroded remnants of uplift during the Tertiary. |
| 2. Laterite Caps: | Laterite caps formed due to the wet climatic conditions during early Tertiary. The laterite terraces to the northeast are controlled by major NNW-SSE major faults in the underlying gneissic rocks. Laterite developed on the granitic rocks is identifiable due to the |

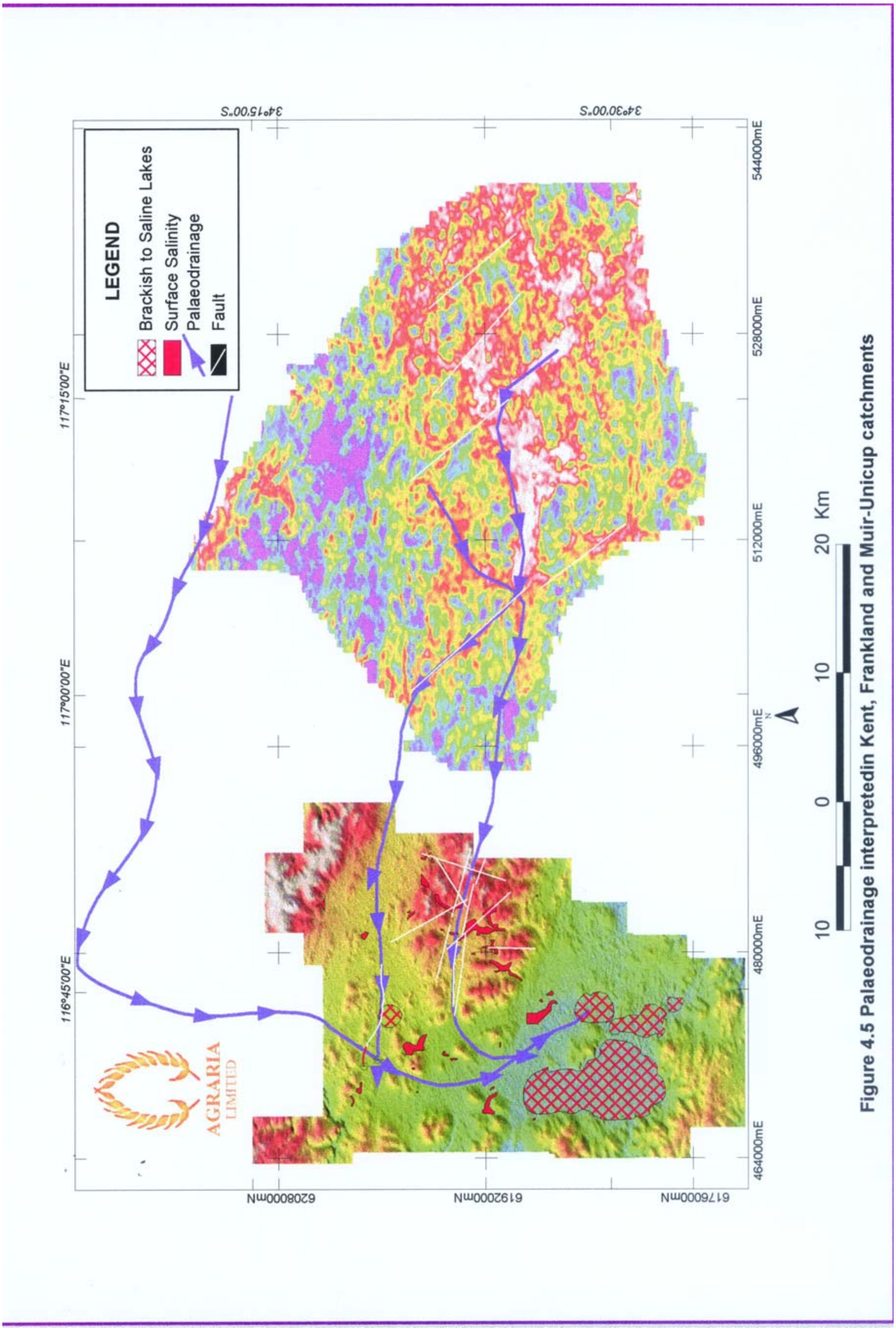

Figure 4.5 Palaeodrainage interpreted in Kent, Frankland and Muir Unicup catchments, WA

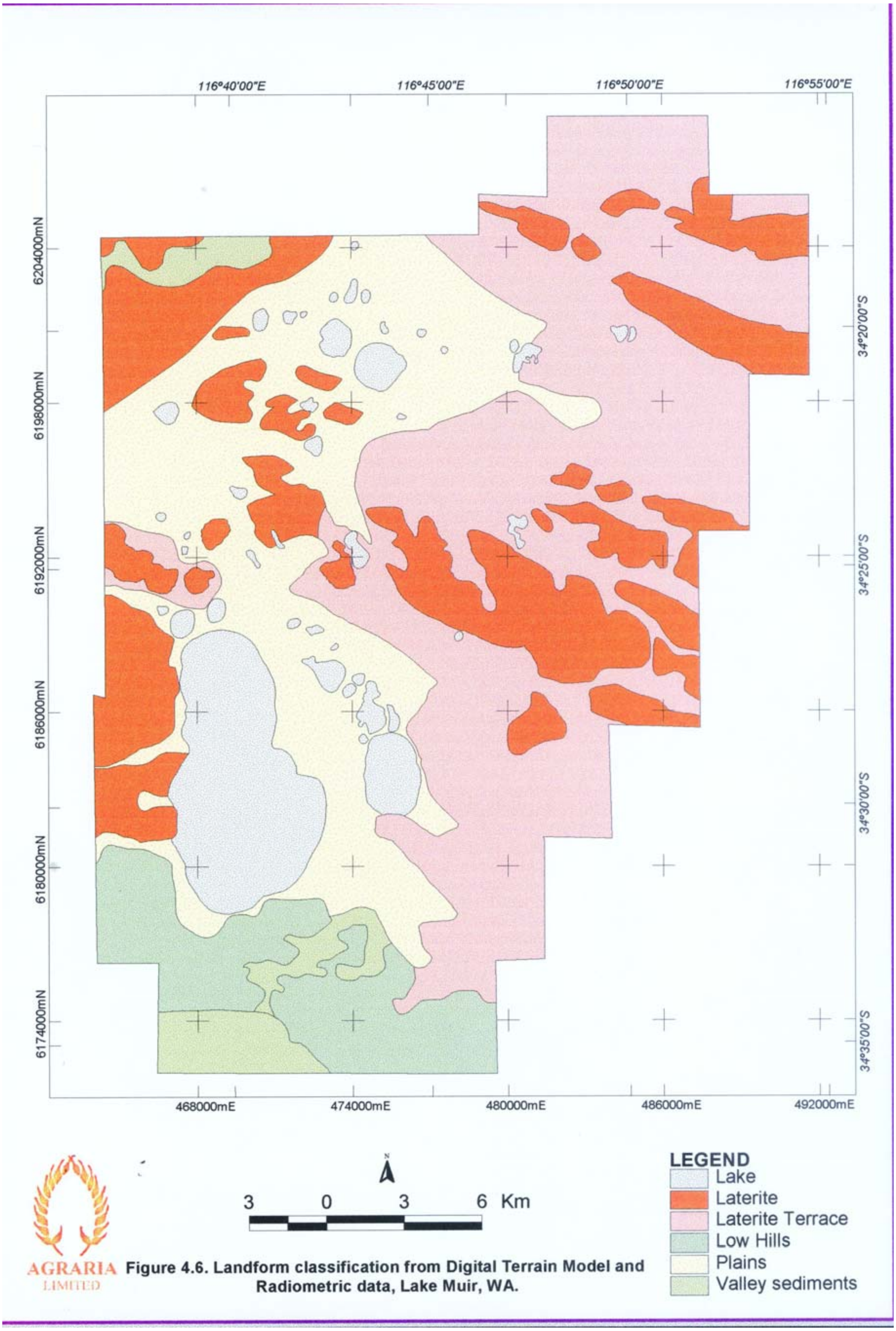

Figure 4.6 Landform classification from Digital Terrain Model data and radiometric data, Lake Muir, WA

ovoid type of weathering which reflects the spheroidal weathering of the granitic rocks.

| | |
|---|---|
| 3.Tertiary Erosional Terrace : | Area adjacent to the laterite hills often with eroded caps consists of ferruginous soil with pisolite with pallid zones and spark at shallow depths often exposed in farm dams.. |
| 4. Plains/Flats: | Low lying areas in the landscape covering the probable palaeo-river channels filled with Late Tertiary and Quaternary sediments. |
| 5. Inland Playa Lakes: | The present ground water discharge areas such as lakes and swamps are interpreted as Inland Playa lakes. |

## 4.4 Regolith

The development of the laterite regolith in the upper reaches of the catchment of the study area is the result of weathering of the basement rocks since the Mesozoic. Typical laterite profiles are present in the rises and low hills. The 1:250,000 geology map shows that some of the low hills south of Noobijup Lake are covered by alluvial, lacustrine and shallow marine sediments strongly lateritized in part overlying the early Tertiary Werillup Formation and Plantagenet Group.

The sediments in the valley and low-lying are have been deposited by slow flowing drainage systems as the drainage became blocked by rises along the south coast.. Swamp, peat, alluvium and colluvial deposits are of recent age occupying the plains, flats and slopes.

## 4.5 Soil Interpretation

McArthur (1991) described the landforms and soil types in the area as

- Gently undulating lateritic plateau with minor valleys and interfluves with gravelly or sandy yellow duplex soils and
- Swampy terrain dotted with numerous lakes and swamps with yellow solonetzic soils and low interfluves with gravelly yellow duplex soils

Two sites where the samples were studied are to the south west of Bokarup swamp and to the south of Lake Muir as yellow duplex soil and gravelly yellow duplex soil are given in Table 4.1 and Table 4.2 (see figure 4.7 for location)

Table 4.1(adapted from “Reference soils of southwestern Australia, McArthur, 1991)

| **Sample No.** | **Horizon** | **Depth (cm)** | **Morphological Description** |
|---|---|---|---|
| 1 | A1 | 0-4 | Dark greyish brown loamy fine sand; thin algal crust; massive; sandy fabric, porous; weakly coherent; few rusty root channels; regular clear boundary to |
| 2 | A21 | 4-14 | Light brownish grey loamy fine sand; massive. Sandy fabric; porous; brittle (dry); weak coherence; few rusty root channels ; clear boundary to |
| 3 | A22 | 14-30 | Very pale brown fine sand; single grain; loose; very weak coherence; clear boundary to |
| 4 | A2B1 | 30-55/65 | Light yellowish brown fine sand; single grain; loose; 16% large irregular elongate ferruginous nodules very sharp to |
| 5 | B2 | 55/65-70 | Strongly mottled pale brown, yellowish brown, and dark yellowish brown fine sandy clay; strongly prismatic and domed; cutans on prism faces; dense inside; prisms 10-15 cm diameter, 11% gravel; very sharp boundary to |
|  | C | 70 | Rock Pallinup silt stone |

Table 4.2 (adapted from “Reference soils of south-western Australia, McArthur, 1991)

| **Sample No.** | **Horizon** | **Depth (cm)** | **Morphological Description** |
|---|---|---|---|
| 1 | A1 | 0-5 | Greyish Brown loamy sand; 20% gravel |
| 2 | A2 | 5-10 | Yellowish brown loamy sand; 50% gravel |
| 3 | A2 | 10-15 | Yellowish brown loamy sand; 60% gravel |
| 4 | A2 | 15-20 | Yellowish brown loamy sand; 70% gravel |
| 5 | A2 | 20-30 | Yellowish brown loamy sand; 80% gravel |
| 6 | B1 | 30-35 | Light yellowish brown light clay; 60% gravel |
| 7 | B2 | 35-50 | Brownish yellow medium clay; massive, 10% gravel |
| 8 | B2 | 60-70 | As above; 10% gravel |
| 9 |  | 80-90 | Light yellowish brown medium clay; massive; 10% gravel |
| 10 |  | 90-105 | Light yellowish brown light clay; 10% gravel |

### 4.5.1 Soil Classification

An interpretation of the soils for the area was carried out from the radiometric data.

Boundaries were drawn between areas of distinct radiometric signature using total count, single channel and ternary images. The radiometric boundaries were then compared with the DTM and previously mapped geology in order to assign a rock / soil type to each region.

The soil pattern as observed during the field visit appears monotonous with lateritic uplands and grey/ yellow sands. However the radiometric signature shows the complexity of the lateral variations in the soil. Physically it is not possible to delineate all the variations from the data into different soil types. The landscape is extremely old and the present soils have been modified by different climatic and depositional conditions over many millions of years combined with marine transgressions during Tertiary.

Eleven classes were interpreted from the data broadly covering all the soil varieties and outcrop in the area

Qra: Alluvial sands, gravels and mixed sandy clays and clayey soils. Tertiary alluvial flats covered with Quaternary alluvium.

Qrw: Swampy and lacustrine deposits developed during late Tertiary.

Qrc: Colluvium including valley filled deposits lateritized and podzolized.

Qsp: Thin veneer of sands with bands of ferruginous pisolites over laterites and Precambrian rocks.

Qc: Quaternary Alluvium more clayey soils along drainage and valleys.

Qas: Quaternary alluvium more sandy nature ( Grey, white sands and sandy loam soils).

Czl: Larterite and laterite gravels, at places covered with thin veneer of grey and yellow sands.

Czl-1: Laterite mixed with loamy and clayey soils.

Czs: Sands and sandy clays over laterite and over highly weathered Precambrian soil profile.

Czt: Laterite terrace adjacent to the uplifted block developed during Tertiary period, structurally controlled.

O/c: Outcrop and sub-outcrop areas with thin sandy and clayey soil covers.

The radiometric ternary was used in particular for the classification of the data. The laterite formations on the hilly areas appear in the data as blue/green indicating high Th and U. The Tertiary Plains/Flats covered with alluvium and gravels show dark reddish brown indicating low potassium with no uranium/thorium to dark blue indicating sands and gravels.

High U areas in parts of the Noobijip, NW Noobijip and Pindicup sub-catchments coincide with the areas that are subject to inundation and or groundwater discharge. Some aspects of radiometric data need further investigation such as high potassium signature in the Lake Little Unicup and Lake Talkerup. The clayey soils deposited on the lakebed may contain high potassium. But the drainage around these lakes is poorly developed to trace the source of the potassium. Another explanation (Ben Rose pers.comm.) was the high signature could be due to the bird droppings. High potassium along the eastern boundary

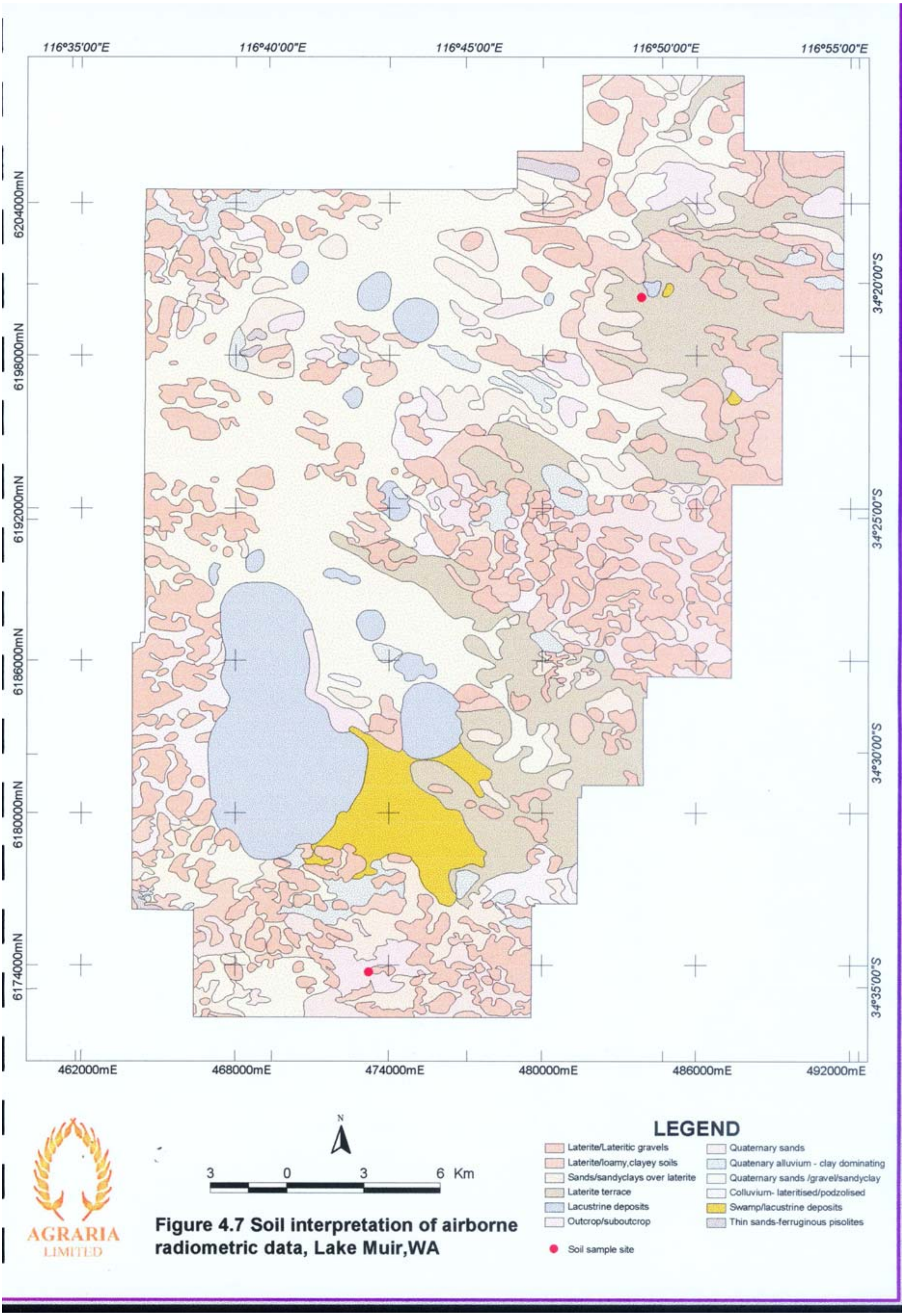

Figure-4.7 Soil interpretation of airborne radiometric data Lake Muir, WA of the Lake Muir could be explained due to the presence of gneissic outcrops along the eastern margin and feldspar rich sand dunes along the edge.

## 4.6 Hydrogeology

Groundwater in the area occurs as regional groundwater system as well as perched aquifers (Semeniuk 1996). The regional hydraulic gradient in general increases from south to north. The saprolite derived from gneissic rocks shows quartz and feldspar-rich layers which represent the original quartzo-feldspathic metamorphic banding in the rock. Some of these layers may be more permeable and form significant regional aquifers.

The marine sediments since Eocene transgression are deposited on top of the weathered profile of basement rocks and may contain unconfined and perched aquifers. The interactions between the perched and the regional unconfined aquifers and the conducting properties of the Tertiary sediments are important aspects in understanding the groundwater movements.

The late NW to NE trending faults cutting across EW trending major faults have influence on the groundwater movements as they are tend to be more open and are groundwater carriers.

### 4.6.1 Hydrogeological History

Anderson et.al., (1993) interpreted present day topographic data to show that the Gordon and Frankland rivers flowed further west in the past. These palaeo-rivers flowed into the present Lake Muir area probably prior to the last uplift of the Ravensthorpe Ramp. No supporting studies were carried out to support the theory. The proposed palaeo-river system would have been filled with Late Tertiary to Quaternary sediments following formation of the Ravensthorpe Ramp. Studies carried out at Toolibin (Pracilio et.al., 1998) shows that palaeo channels of similar age are filled with Tertiary sediments with higher hydraulic conductivity than the surrounding sediments.

Blocked drainage coupled with arid climatic conditions during early Tertiary resulted in more sedimentation thus filling up the earlier channel flows and gave rise to the lake system in the area. These sediments on the older weathering profiles have resulted in perched aquifer systems. The late movements along some of the east west trending faults and the minor faults and fractures formed as splays off the Darling fault have given rise to the fractured aquifers.

Thus three aquifer systems are present in the area.

1. Perched aquifer system in the Tertiary and Quaternary sediments,
2. Unconfined to semi-confined aquifers in the Precambrian weathering profile and
3. Fractured rock aquifers

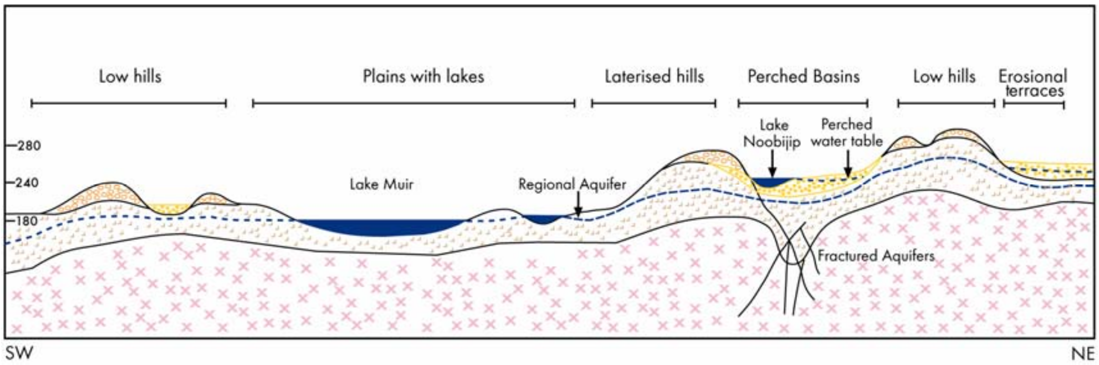

Figure 4.8 Cross section showing different aquifers in Lake Muir, WA

## 4.7 Recharge and Discharge

Groundwater recharge in the area is mainly due to the precipitation. The perched aquifers in the area are recharged readily after rainfall.

The regional groundwater flow is due south towards Lake Muir and Byenup Lagoon. As there is no proper outlet for the groundwater from this area groundwater movement will discharge in the low-lying areas and along the faults and fractures which have surface expression.

The Low hills, Terraces adjacent to the hills and the Laterite caps act as areas of higher recharge and the Plains and Inland playa lakes are the regional discharge areas. Smaller discharge zones may occur in the hills and terraces eg. along faults and fractures. In addition areas not discharging on the plains and playa lakes will act as recharge areas. Recharge and discharge zones are interrelated and depending on the prevailing climate and water table conditions the same zone can be recharge or discharge zone.

Various groundwater recharge studies in the last three decades show that recharge could be due to

- coarse textured soils (Bettanay 1964)
- preferred pathways such as root channels, veins of quartz (Peck 1980)
- soils that are highly permeable (Nulsen and Henscke, 1981)
- matrix and macropore (Gee and Hillel, 1988)
- coarse textured palaeochannel sediments in the valley (Geroge 1990).

Studies so far show that depending on the gradients the entire catchment could be a recharge or a discharge zone.

The bore information supplied has only one year water level data and this lack of long-term water level information hinders proper evaluation of recharge conditions.

## 4.8 Dominant Structural Controls and Groundwater flows

Works done by and Domencio and Schwartz (1990) showed that the water table replicates the surface topography and water moves from topographically high to low areas, the major structures may disrupt the groundwater flows (Clarke 1998).

During the field visit two saline seeps investigated showed structural influence where the major east west faults are cross cut by the northeast trending minor late stage fractures. Strong control of structures was observed in the recent studies carried out at Lake Towerrinning (Clarke,1998), Lake Toolibin (Pracilio *et al*, 1998) and at Balfes Creek (Street *et al*.,1998).

Some east west structures have been reactivated during the Tertiary rendering them open for groundwater movement, although groundwater may not move at the same rate along these major structures. The early eastwest faults in the study area which are likely to have been reactivated were interpreted from the indications of fault scarps on the digital topographic data.

The northwest southeast splays from the major Darling Fault also influenced some of the minor fractures developed in the area.

## 4.9 Hydrogeology of Different Sub-Catchments

### 4.9.1 Unicup Catchment

Unicup catchment covers about 11490 ha to the north east of the study area. To the northeast and southeast of the catchment low hills rising over 300 m and 290 m AHD acts as higher recharge areas for the low lying terrace in between which is subject to inundation. This corridor is dotted with swamps and Bokarup and Kulnilup lakes lying further east of the Unicup Lake. McArthur (1991) suggested that there could be Eocene sediments up to 30 m deep overlying the Precambrian weathered profile in the Bokarup region. Magnetic signature in this area is fuzzy which could be due the presence of such sediments.

Most of the structures in the area are east west trending major faults and the minor cross cutting faults have northeast southwest trend. The major faults in this area seem to be early structures and have not reactivated by later tectonic events. Thus these faults may not be good aquifers. The regolith developed over the Precambrian basement is largely covered with the Tertiary sediments except on the low hills where the laterite development is predominant. The nature of the soils in the area as described by McArthur (1991) are


20 11'98

Figure 4.9 Unicup Lake

yellow duplex soils. Soil classes interpreted from radiometric are laterite and associated gravelly sandy and clayey soils formed during Tertiary.

#### 4.9.1.1 Groundwater Movement

The general direction of the surface and sub-surface water movement is due west towards the Unicup Lake. The upper sandy layers are transmissive and the lower clays could be the aquicludes with accumulation of salts in the clays. The groundwater in this catchment could be in two separate aquifers. The perched aquifer in the Tertiary sediments and the second regional aquifer in the pallid zone and saprolite of the Precambrian weathered basement. The groundwater movement is mainly controlled by the gradient and the geological structure seems to have lesser influence. However, since the direction of the groundwater flow and the structural trend are in the same direction it is difficult to assess the influence of one over the other.

The surface salinity recorded in the area is mostly along drainage lines The saltscalds to the north and west of Yarnup swamp appears to be caused by the roads which might be hindering the water flow. The area west of the scalds is cleared area which may have increased the water levels in the area. However, the minor faults in the area are to be considered before treating the salinity in this area.

### 4.9.2 Pindicup Catchment

Pindicup catchment covers about 7900 ha south of the Unicup catchment. Low hills rising up to 280 m AHD cover about half of the catchment area. Most of the area below 230 m contour is subject to inundation. Major lakes present are Pindicup Lake to the west and the Noobijip Lake to the east southeast. Other smaller lakes lie to the west of the catchment. The magnetic signature for the catchment is fuzzy along the northern boundary and to the west and some sediment may be present in these areas. However overall Tertiary sediments in this area do not appear to be thick or may have been eroded. The major eastwest faults in the area were reactivated during Tertiary and the late northwest southeast and northeast southwest faults appear to be brittle and influence groundwater movement in the area. The radiometric data shows laterite and lateritic gravels and sands above 210 m AHD and Quaternary alluvial flats to the west of the area. The laterite and the sands covering them are transmissive and are good recharge zones to the underlying aquifers. The clayey zones may form local barriers to the groundwater movement.

#### 4.9.2.1 Formation of Lake Noobijip

The palaeo Frankland and Gordon rivers are interpreted to have influence on location of present day lakes. The probable palaeo-river to the north of the present Noobijip Lake flowed to the west. Groundwater as well as surface waters prior to Tertiary flowed to the north towards palaeo river from the catchment around the Noobijip Lake. During Eocene period this area was under shallow marine conditions. The Tertiary uplift along the fault north of the Lake blocked the drainage and the present Noobijip Lake was formed. The modern drainage system formed on the uplifted block resulted in the erosion of the Tertiary deposits from the uplifted block and exposed the old weathering fronts of the Precambrian rocks which had been lateritised during the Tertiary (Figure 4.10).

#### 4.9.2.2 Groundwater Movement

The groundwater movement to the north of the Lake is interpreted to be to the west whereas in the Lake region groundwater appears to move towards north. High salt contributions could come from an interpreted late northsouth late fault south of the lake. The magnetics under the uplifted block indicates that the weathered zone on the basement may be thin.

The bore hole data supplied by the Water and Rivers Commission indicates the water levels in the bores to the north and south of the lake are around 12 m bgl. The deep water table could be the regional aquifer in the weathered Precambrian basement. The sediments sitting on top of this weathered zone may contain perched aquifers and the Noobijip lake may be the surface expression of this perched water system. These perched groundwater systems may be relatively fresh when compared with the regional more saline groundwater.

The high salinity around the lake appears to be more fault controlled and saline groundwater discharge appears to be associated with fault zones. Regional groundwater movement may be blocked due to the uplift. Subsequent clearing of the natural vegetation in the area resulted in increase in recharge. As the regional aquifer is under pressure outlets are late brittle faults which could be the pressure valves for the groundwater depending on the hydrostatic pressure conditions prevailing in the area.

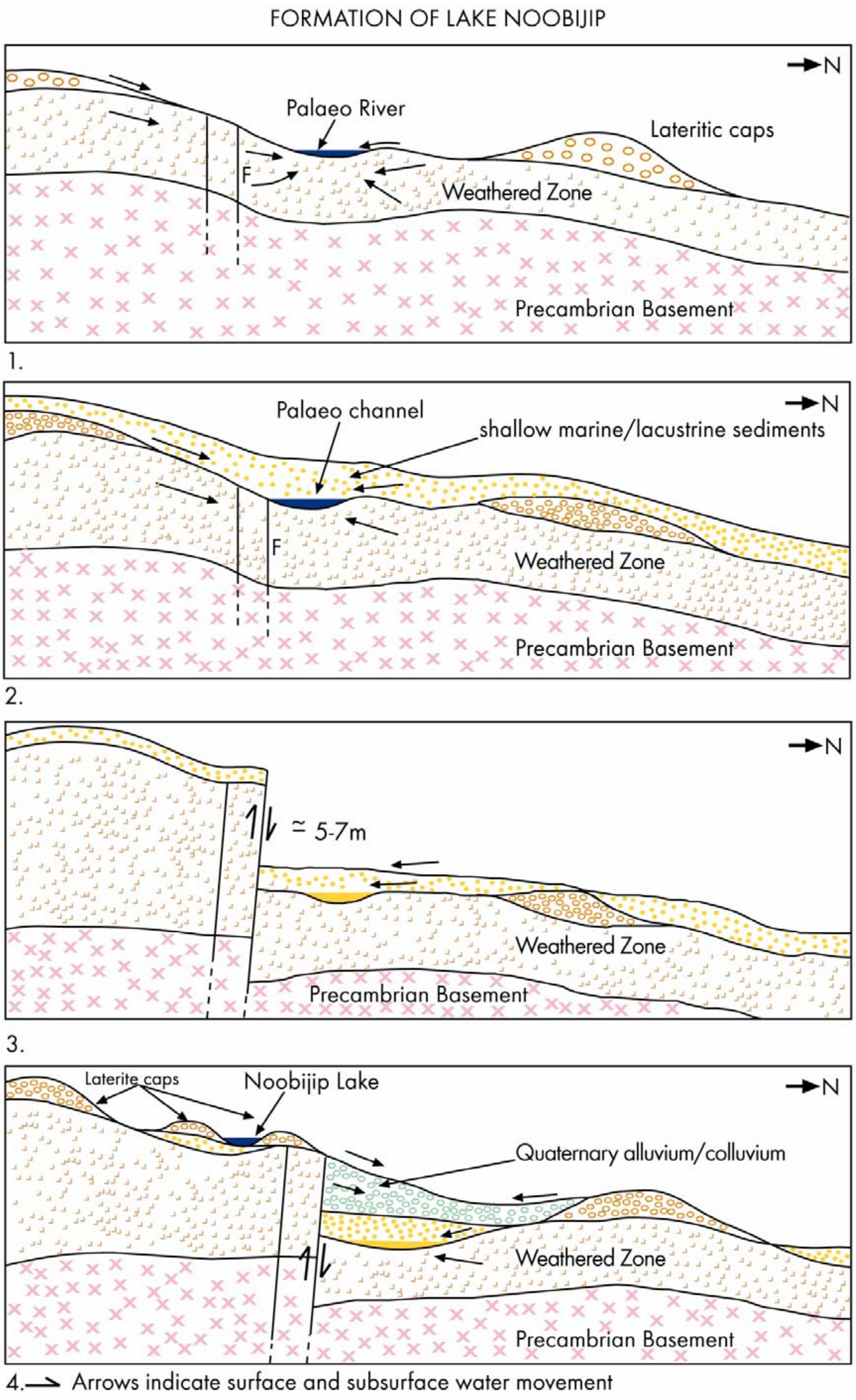

Figure 4.10 Formation of Lake Noobijip, Lake Muir catchment, WA

### 4.9.3 Noobijip Catchment

Noobijip catchment covers about 13820 ha to the northeast of Lake Muir. Contrary to the name Noobijip catchment does not cover the Noobijip Lake which falls in the Pindicup Catchment. Uplifted hills occupy the northeastern part and rest of the area is covered with Quaternary alluvium over Tertiary sediments. The magnetic signature shows fuzzy nature in patches and particularly along the east west fault in the centre of the catchment. Tertiary sediments may be present in local depressions and probably not very thick. The basement is comprised of strongly deformed gneiss and granite. Major east west structures at the centre of the catchment appears to be reactivated.

The radiometric data shows the dissected lateritic hills followed by lateritic terrace and the Quaternary alluvial flats. The high uranium between the 180 and 190 contours to the south of the Muirs Highway indicates that the area is likely to be discharging groundwater. Most of the flats below this area are subject to inundation.

#### 4.9.3.1 Groundwater Movement

The reactivated faults are more transmissive in terms of groundwater movement. The late northeast and northwest faults seems to be controlling the spread of salinity in the higher reaches of the catchment to the northeast. As discussed in section 4.9.2.2 the saline water may be from regional aquifer carried to the surface through the faults. The salinity from the Water and Rivers Commission bores in the lower catchment indicates the salinity is comparatively less than the salinity in the upper reaches. Either the salinity has not yet spread to the lower reaches or the groundwater movement is more structurally controlled and more compartmentalised. Sediments and the open fractures are the controlling factors of the groundwater movement in the area.

### 4.9.4 Tordi-Garrup Catchment

Tordi-Garrup catchment lies to the east of the Lake Muir and covers about 5500 ha. Main features of this catchment are the Byenup Lagoon in the lower plains and the southern uplifted hills rising up to 230 m AHD. Besides the hills to the south of the catchment the rest of the area is either subject to inundation or covered with lakes. Magnetic data shows fuzzy signature to the south and east of the catchment indicating Tertiary sedimentary deposits may be present over the basement. The major structures dominating are east west and the late stage faults trend northwest and northeast cutting across the early east west faults. A dyke trending northwest and northeast cuts across the catchment. Dissected laterite profiles with sands and clayey soils are seen to the south and the Quateranary alluvium with dominating clayey soils in the Lagoonal and swampy area in the lower reaches.

#### 4.9.4.1 Groundwater Movement

Ground water in Tordi-Garrup catchment is present as perched aquifer in the overlying sediments and a regional aquifer in the weathered pallid and saprolite zones of Precambrian Basement. The regional aquifer could be under considerable pressure as it appears to be confined spatially. Most of the area acts as discharge zone except for the hills to the south. Groundwater in the thick Tertiary sediments are more controlled by the type and sediments they are contained. Alternating sand and clay beds which are common for the shallow marine and lacustrine conditions may cause perched aquifers.

### 4.9.5 Mordalup Catchment

Mordalup catchment is to the northwest of main Lake Muir catchment and covers about 4650 ha. Low sporadic hills rise up to 240 m AHD and the remainder of the area is covered with Tertiary alluvial flats and Quaternary alluvium. An interpreted palaeo-channel pass through the sub-catchment. The magnetic data shows little fuzzy responses in patches indicating thick sediments at places. Two lithological units, a coarse grained granitic gneiss and medium to coarse grained granite, are interpreted from the magnetics in the Mordalup catchment. The major east-west and the late northwest and northeast structures dominate in the northern half while there is less faulting to the south. The soil type observed in this area is similar to what Smith (1948) described as “Murdellup sand”. The soil profile observed in the dams are sands followed by brownish clayey soils underlain by mottled clay yellowish to white in colour. Typical Murdellup soil profile given by Smith (1948):

Table 4.3 (adapted from Smith 1948) Mordellup sand

| Horizon | Depth (cm) | Description |
|---|---|---|
| A1 | 0–20 | Dark grey sand with organic matter |
| B1 | 20-40 | Dark grey-brown clayey sand with much ferruginous gravel |
| B2 | 40-150 | Mottled clay, grey, yellow-brown and white |

Table 4.4 (adapted from Smith 1948) Murdellup sand (deep phase)

| Horizon | Depth (cm) | Description |
|---|---|---|
| A1 | 0-25 | Grey sand with organic matter |
| A2 | 25-60 | Light grey sand |
| B1 | 60-90 | Dark grey-brown clayey sand with heavy ferruginous gravel |
| B2 | 90- | Mottled clay, grey, yellow brown and white |

The radiometric response shows the dissected laterite on the hills and the alluvial sandy soils in the flat area.

#### 4.9.5.1 Groundwater Movement

Groundwater movement in the flat areas is interpreted to be more vertical than the horizontal. South of the Mordalup catchment is subject to inundation and indicates it is a discharge area. It is important to understand whether there is a palaeochannel and the type of sediments in the channel in order to understand the groundwater movement in this region. The present drilling data is not sufficient to confirm or dismiss the concept of a palaeo channel.

### 4.9.6 South Mordalup and NW Noobijip Catchments

These two catchments are to the south of the Mordalup catchment and cover about 2360 ha of area. Nearly 80% of the south Mordalup catchment is under natural reserve and to the south where the area is clear is subject to inundation. Geology interpreted for these catchments comprises of strongly deformed and sheared gneiss and granite. NW Noobijip shows the Tertiary sediments to the south of the catchment. Radiometric signature is fairly uniform indicating the alluvial flats and the laterite hills.

#### 4.9.6.1 Groundwater Movement

The general direction of the groundwater movement in the area is due south. Perched aquifers in the Tertiary sediments may be present to the south of the NW Noobijip catchment.

### 4.9.7 Lake Muir catchment

Lake Muir sub-catchment covers about 8900 ha out of which Lake Muir is about 4450 ha. West and south of the catchment are covered by low hills. The drainage development on the hills to the south is well defined. The geology of the area is complex and has undergone high-grade metamorphism. Complex folding in the outcrops along the eastern boundary of Lake Muir indicates more than one deformation phase. The major faults in the area trend east west in general and a north-northwest trending dyke is interpreted to the north of the lake. Soil interpretation from the radiometric data indicates the dissected laterite with sands and clayey soils along the drainage. Soil type described by McArthur as gravelly yellow duplex soils (Table 4.2).

#### 4.9.7.1 Groundwater Movement

The surface and sub-surface water movement is towards the Lake Muir.

The lake dries up in summer and the depth of the lake is not more than two meters (Dave, Pers.comm.). The outcrops on the eastern edge indicate a shallow basement. Tertiary sediments may present at places in the lake.

## 4.10 Salinisation

The surface salinity manifestations mapped by CALM are shown in figure 4.11. Besides these salt scalds Lake Muir, Lake Poorginup, Lake Byenup, Lake Tordit, Lake Unicup and Lake Yarnup are known for brackish to saline waters. The salinity mapped in the Noobijip and Pindicup catchments around Lake Noobijip are manifesting in the valleys of the hills and along the streams above 220 m AHD.

If these salt scalds are due to a regional rising water table than the salts scalds should be more evident in the Plains at lower elevations. However other controlling factors appear to result in salt scalds at higher elevations. Interpretation of magnetic data suggests that east-west faults in the area are recently reactivated and cut across by later stage north- west trending brittle faults. It is evident from the data that the salinity in this area is more structurally controlled.

In addition an older QUESTEM electromagnetic survey carried out for the Kent and Frankland River catchments shows the direction of the palaeo- river flowing towards the west into the Lake Muir Catchment (Anderson, 1994). The river was blocked by Tertiary uplift. (Figure 4.5).

Late stage faults are the controlling factors of salinity to the east of Noobijip Lake. Faults trending north south and northeast southwest faults also appear to have control on the present salinity. Saline groundwater tends to move along these fault zones and come to he surface in lower lying parts of the landscape. A saline seep visited during the field trip, north of Cobertup swamp lies at the intersection of crosscutting faults

The saline scald to the south of the Muirs high way appears to be controlled by the roads. Compaction of the soils while road construction can cause the reduction in transmissivity of

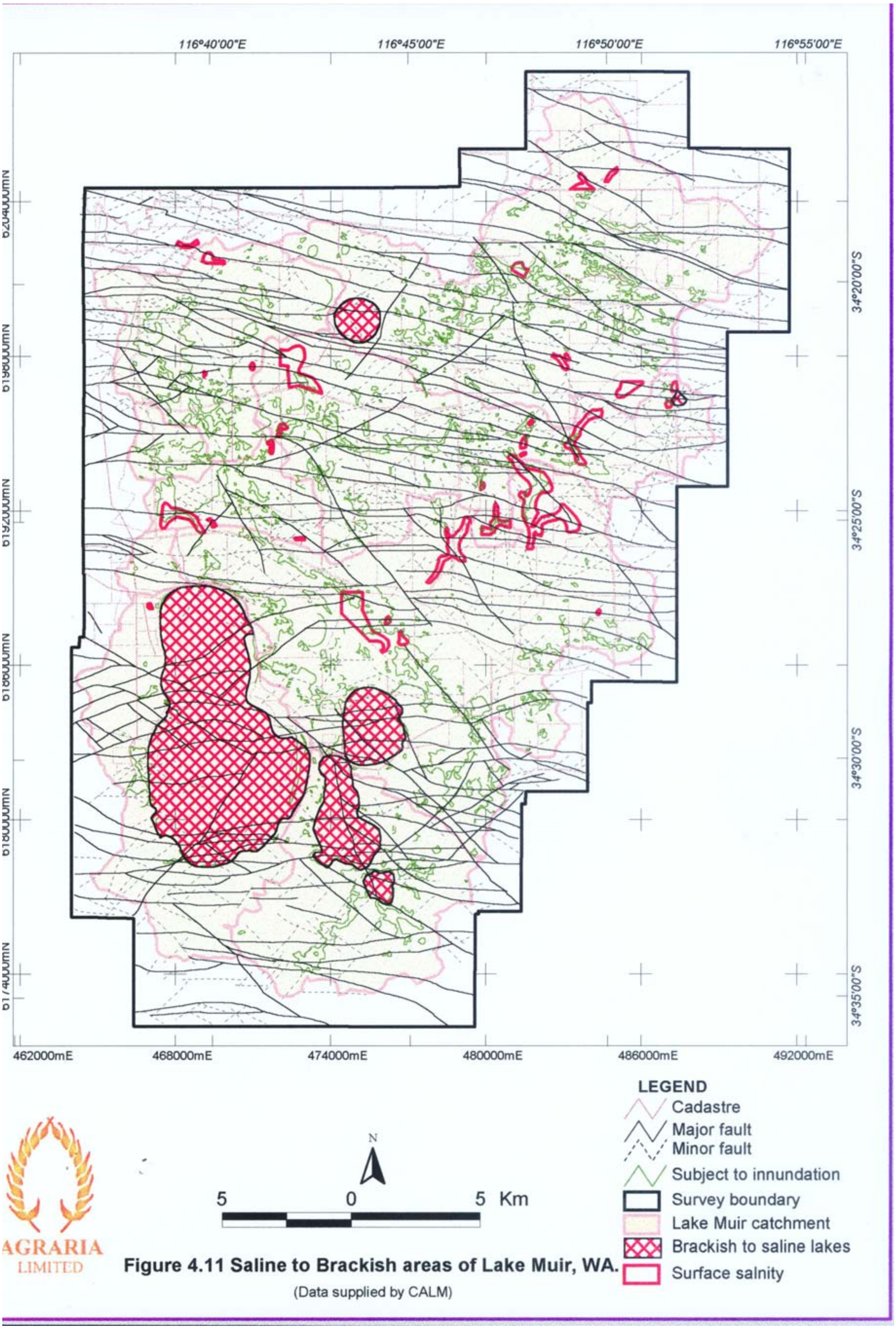

Figure 4.11 Saline to brackish areas of Lake Muir, WA.

soil and results in water logging and subsequent evaporation salt scalds. Other scalds appears to be either evaporational or due to man made structures.

Saline springs are also reported along some of the lakes but not located accurately with GPS. In order to assess the nature of these springs firstly they are to be located and should be seen in the light of other data sets. They may be discharge sites from an underlying palaeochannel.

Recent studies carried out under National Dryland Salinity Program highlight the effective use of the airborne geophysics in identifying the salinity hazard areas. A simple classification of recharge and discharge areas and planting different species in the recharge and discharge areas will not effectively tackle the problem. Some of the reasons for the salinity discharge identified are bedrock highs, faults and dykes, change in the soil texture confluence of streams and man made structures such as roads etc (Pracilio 1998). In the Present study the scalds so far mapped appears to be controlled by structures both geological and man made.

## 4.10 Vegetation

In the lake Muir catchment still large parts of the catchments have reserve forests and native vegetation is preserved. Areas cleared by farmers for pastoral purposes are turning into blue gum and pine tree plantations because of lower productivity of these soils under pasture. The density of the blue gum plantations are upto 1300 stems / ha which is more than double than the native vegetation which would be about 400 stems/ ha( Simon Abbott pers comm.). These plantations could have positive or negative impacts on the wetlands depending upon the amount of the groundwater utilised. If the plantations use the saline waters from the aquifers than saline waters could be maintained at depths and the surface saliniity resulting from rising water tables could be checked. If the fresh water from the surface and the shallow aquifers is consumed by the plantations wetlands may starve for water and eventually dry out. However these are only assumptions and needs further studies to understand the effects on the groundwater systems and wetlands by installing piezometers regular monthly monitoring of the groundwater levels in the piezometers.

Figure 4.12 Blue gum plantations south of Pindicup road dead trees in the front are due to shallow bedrock.

# 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

- In this study airborne geophysical data sets viz. magnetic and radiometric data were interpreted to understand the hydrogeological regime of the area.

- The magnetic data was interpreted to show that the major basement rock units are gniesses and granites of the Albany Fraser origin. These rocks show a very strong east - west metamorphic banding.

- Late stage faults were interpreted from the data as likely sites of brittle faulting and likely to have enhanced groundwater movement.

- Radiometric data were interpreted to delineating different soil varieties and an eleven-fold classification was done.

- Landform evolution for the study area went through different phases and the present landscape primarily reflects the changes since Tertiary.

- Well developed laterite weathering profiles are typical in this terrain.

- A palaeodrainage system existed in the Mesozoic as an outlet to the sea for the palaeo Frankland and Kent River systems.

- The palaeo rivers actively flowing during Mesozoic period became choked with shallow marine to lacustrine and alluvial sediment due to uplift along the south coast and marine transgressions in the Eocene and Miocene.

- Formation of the chain of lakes in the area is attributed to the upliftment of the southern coast during early Tertiary and the blockage of a preexisting drainage system that formed the palaeo Frankland and Kent Rivers.

- Perched aquifers occur in the sediments, unconfined to semi-confined regional aquifers are present in the weathered profile and hardrock aquifers in the late stage faults and fractures.

- Tertiary marine transgression during Eocene and Miocene also deposited shallow marine sediments on the Precambrian weathered zone where they may contain perched aquifers. These sediments are still preserved at places but often eroded away exposing the underlying weathered Precambrian basement at higher elevations.

- Low hills, erosional fronts, and laterite caps have higher recharge and Plains and Inland playa lakes as more likely to be discharge areas.

- Groundwater movement is generally towards south. The groundwater in the perched aquifers appears to be relatively of better quality than the aquifers in the Precambrian weathered zone.

- Groundwater appears to be controlled by geology and late stage structures such as faults and fractures.

- A hydrogeological map was created to show surface and sub-surface water movement.

## 5.2 Recommendations

Following recommendations are mandatory in order to do effective wetland management in the catchment.

- Airborne EM techniques could identify the areas that need immediate attention to tackle the salinity. The power to see the subsurface salt storage would assist in planning the strategies for the wetland management

- Piezometers should be established in each subcatchment both in upslope areas and downslope areas to monitor changes in the groundwater levels. Both perched and deeper aquifers should be monitored. Monitoring of groundwater levels on a regular monthly basis to develop a water level database. Also should be monitored for sudden storms and their effects on the water table.

- Studies should be carried out in order to assess the impact of Bluegum plantations on the groundwater in long term.

- Water harvesting for intensive agriculture and horticulture has the potential to divert fresh surface water. Hence all the existing drains and the future works should be assessed for their impact on the wetlands and the watertable in the area.

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