PALYNOLOGY IN SEDIMENTARY ENVIRONMENTS: EXAMPLES OF APPLICATION IN DIAMOND AND HEAVY MINERALS EXPLORATION IN SOUTH AUSTRALIA

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INTRODUCTION

Palynology is a well-established tool for dating sediments that can also provide critical data for interpretation of past climate, palaeo-vegetation and depositional environment. For mineral exploration in sedimentary terrains this information may be fundamental to correlation of sediment packages, sequence stratigraphy and the recognition of tectonic displacements. Palynomorphs including pollen, spores, dinoflagellate cysts, acritarchs, zoomorphs, fungal spores, algae and microscopic seeds transported by water or wind are found in a broad range of sedimentary rocks. Samples for dating come from a variety of sources that include drill core, cuttings, outcrop and trench or pit excavations. Counts of between 200 to 1000 grains per sample are required to permit statistical analysis of the data and to support a robust interpretation. In South Australia over 500 drillholes have been investigated, with nearly 11,000 samples processed and analysed for palynological content (Figure 1). Much of these data are captured on the *Biostrat Database* incorporated within PIRSA's SAGeodata. From this dataset, a full list of taxa, zonation, age, depositional environment and palaeovegetation reconstructions can be produced for many parts of the state. This provides a local context to aid interpretation of new data from sites being actively explored.

The recent focus by mineral exploration companies on diamond and heavy mineral sands prompted consideration of separation and retention of the heavy mineral fraction from samples submitted for palynological analysis. Over the past two years, a process of *palymineral* processing has been developed to extract heavy minerals during palynological preparation. The heavy mineral fraction from each sample is catalogued and is available for mineral identification, chemical analysis and dating where suitable minerals are present. The heavy mineral suite provides information on the sediment source that, when combined with the palynological data, provides a timeframe for deposition, environment and climatic conditions. For diamond and heavy mineral explorers, this provides additional evidence on the pattern of mineral dispersion over time that can be used to reconstruct sedimentary environments, to model sites for placer deposits or to identify likely source areas of primary mineralisation. For palaeochannel sandstone-hosted uranium exploration, the heavy mineral suite can assist with identifying the source area of sediment input and help to confirm continuity of a productive sediment package.

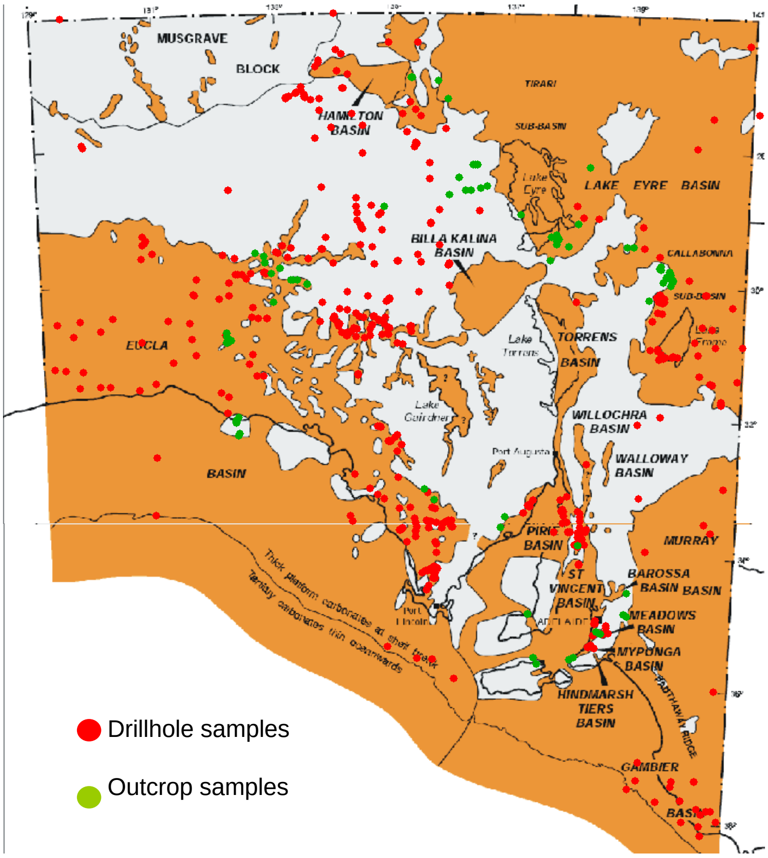

Figure 1: Distribution of Tertiary basins in South Australia showing locations sampled for palynology.

In: Roach I.C. ed. 2005. *Regolith 2005 – Ten Years of CRC LEME*. CRC LEME, pp. 299-303.

METHOD FOR HEAVY MINERAL SEPARATION

Sixty samples have been processed for both palynology and heavy minerals in the development of a laboratory procedure for heavy mineral separation. These include samples collected from drill core, cuttings, outcrop and trench excavations. Sub-samples are taken and weighed (usually between 10 and 15 g) and are crushed into particles ranging in size from around 150 µm to 2 mm. These are treated with hot hydrofluoric acid (48% HF) for one hour (or longer if necessary) followed by hot hydrochloric acid (32% HCl) for half an hour to remove any silica gel. The acids are then washed out and the sample split into two parts using heavy liquid of SG 2. The light fraction containing organic matter is further processed for palynology. This includes the removal of extraneous organic matter and other unwanted particles and the remaining sample containing pollen and spores is concentrated and mounted on slides for analysis. The heavy fraction is collected and washed in distilled water and dried in the oven. Once dry, the sample (typically between 5 and 10 g at this stage) is poured into a separating funnel with a solution of lithium heteropolytungstate, made up in water to SG 2.85, and allowed to separate for approximately 40 minutes. The light fraction is decanted and the heavy mineral fraction collected by sieving through a 10 µm sieve. The heavy minerals are washed with distilled water and dried ready for identification. All heavy liquids used in the process are recovered for reuse. All SGs of heavy liquids are checked and recorded prior to separations.

DIAMOND EXPLORATION

Fossil Hill - Willochra Basin

Flinders Diamonds Ltd’s Springfield project includes the Calabrinda Prospect where diamond and diamond indicator minerals recovered from a shallow Tertiary sedimentary basin are interpreted to have a proximal source. Fossil Hill is located on the south side of Calabrinda Creek near Simmonston, on the northern edge of the Willochra Plains, between Hawker and Quorn. The geology of the area shows a gypsiferous siltstone and soil unit below a Tertiary calcrete cap, which are underlain by a sandstone unit over Cambrian siltstone (Figure 2). Dating the sediments and reconstruction of the depositional environment is integral to regolith mapping in the area, with emphasis on understanding the landscape evolution and tracing a primary source for the diamonds.

Palynological analysis and dating of samples from the gypsiferous siltstone and underlying sandstone at Fossil Hill indicate a Late Miocene - Early Pliocene age and minor to moderate marine influence. Significant numbers of Chenopodiaceae, Asteraceae and Casuarinaceae are consistent with changes in vegetation occurring during Pliocene times in other areas, and provide further evidence for the development of more widespread savanna vegetation. A cool climate and winter rainfall regime is indicated, with few trees. Reduced precipitation on the Willochra Plains is a likely factor for the open vegetation. A date of Late Miocene to Early Pliocene differs from previous interpretation (Eocene) and suggests that this area was not a depositional centre during the Eocene. Marine influence is moderate with development of an estuarine environment progressing to relatively fresh water-lacustrine conditions evident on the southern side of Fossil Hill. The gypsum-rich siltstone/soil is consistent with lake-margin deposits and low rainfall conditions. The sediment mineralogy is dominantly quartz with few heavy minerals. Rare pyrite crystals and non-magnetic opaques were identified. The well-rounded quartz grains indicate mature sediment, extensively reworked or transported considerable distance from source. Diamond indicator minerals reported in these sediments are most likely introduced from a local kimberlite source. The

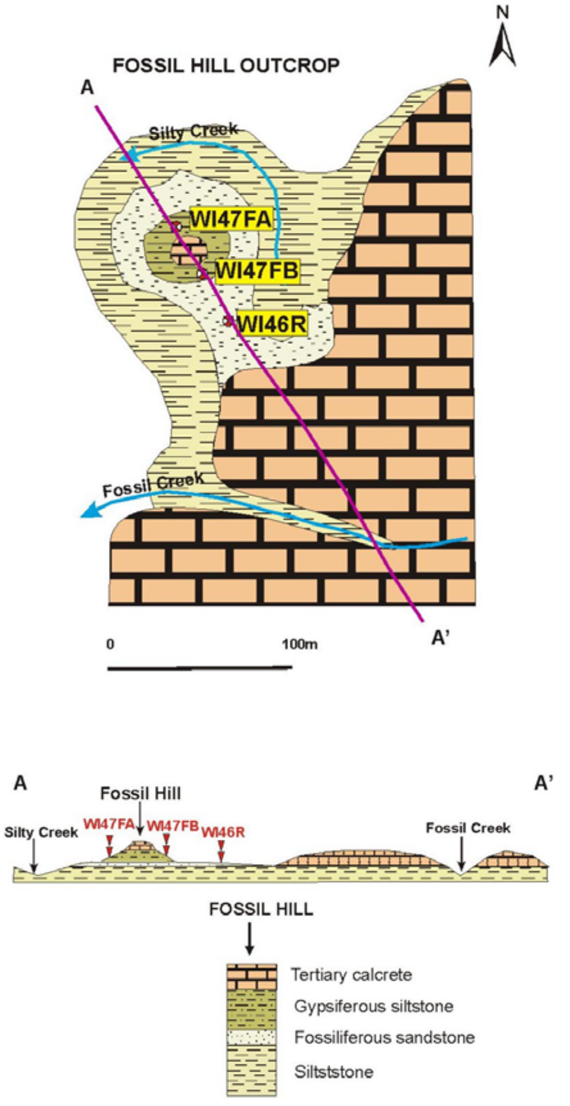

Figure 2: Fossil Hill – geology, palynology sample sites and cross section.

palynology indicates marine connection with either the Pirie or St Vincent basins rather than a local crater lake scenario. The marginal marine-lacustrine environment makes it unlikely that transport direction of heavy minerals will help in locating the kimberlite source.

Meadows Basin

The Meadows Basin is a small, narrow, intramontane basin situated 30 km south of Adelaide in the Mount Lofty Ranges (Figure 1). The Basin has been investigated principally for groundwater resources. Tertiary and Quaternary stratigraphic units are unnamed and consist of clastic sediments with minor sand and lignite intercalations. Palynological analysis and dating of 10 cutting samples from Meadows Bore 1 indicate the presence of Late Miocene-Early Pliocene lignitic clay, lignite and carbonaceous siltstone. These overlie Early Permian fluvial sand. The presence of sediments of Late Tertiary age had not been previously documented in the area. Analysis of pollen species across lignitic clay and carbonaceous siltstone showing high counts for Casuarinaceae, Nothofagaceae and Myrtaceae permits identification of several stages of vegetation evolution. The presence of *Nothofagus* subgenus *Brassospora* in sediments from Meadows Bore 1 is consistent with wet rainforest conditions. A more variable climate is indicated toward the top of the sequence; *Nothofagus* almost entirely disappears and is replaced by Asteraceae, Chenopodiaceae and Restionaceae. The Meadows Basin is interpreted as a refuge for rainforest taxa that survived during Late Miocene-Early Pliocene times in inland South Australia. Meadows Bore 1 has been proposed as type section for the area, recording changes in vegetation and climate during the last 5-10 million years. A marked reduction of *Nothofagus* and Podocarpaceae towards the top of the sequence provides strong evidence of cooling, also supported by the presence of a few dinoflagellate cysts whose modern relative is found in cold-temperate zones. The depositional environment was largely swamp-bog-lacustrine, with some marine influence (estuarine to near shore) recognised near the top of the sequence. The non-clay fraction of the sediment is dominantly well-rounded to sub-angular quartz (80-90%) with reddish iron oxide staining. The heavy mineral fraction includes minor greyish-black tourmaline prisms, dark red rutile, trace of zircon and pinkish garnet.

Chapel Hill

Palynological analysis and dating of sediments from the Chapel Hill area, which host the Echunga alluvial diamonds, can be correlated with the upper sequence from Meadows Bore 1. Open woodland with Casuarinaceae and *Acacia* developed on saline, low nutrient soils, with minor marine influence. The climate was dry and arid. The heavy mineral assemblage is dominated by staurolite, which indicates sediment transport from higher-grade metamorphic rocks east of the Meadows-Williamstown Fault.

PALAEOENVIRONMENT DURING HEAVY MINERAL SANDS ACCUMULATION IN EUCLA BASIN SHORELINES

Palynological analyses and dating of core and cutting samples from over 150 drill holes from the Eucla Basin show the presence of Early, Middle and Late Eocene sediments, as well as Late Miocene-Early Pliocene deposits. The presence of oldest non-marine sediments of Early Eocene age in the onshore palaeochannels has been documented only by palynology (CRAE RCH2 drillhole, 80-133 m interval). The palynofloras are correlated with the *Proteacidites asperopolus* Zone, Early Eocene. The overlaying sediments are correlated with Lower and Middle *Nothofagidites asperus* Zones, Middle and Early Late Eocene in age. The Middle Eocene facies of the Pidinga Formation is non-marine. Middle *Nothofagidites asperus* Zone, Late Middle-Early Late Eocene, is widespread across the Basin (from Nullarbor Plain 6 drillhole to Wilkinson 1 and SDA 12 drillholes), with moderate marine influence decreasing towards the eastern margins of the Eucla Basin (Hou *et al.* 2003). Sequence stratigraphic framework of these sediments, assisted by palynological analyses, provides new evidence of Eocene marine transgressions and deposition in the region. Diverse shoreline facies are recognized in the region (Middle, Late Middle-Early Late Eocene and Late Eocene) and their extensions have been mapped with the aid of palynological data (Hou & Warland 2005).

Late Miocene-Early Pliocene sediments are present over a wide area. Palynological analyses of seven cutting samples from drillholes KIN 20, KIN 21, KIN 22, KIN 45, CAR 034 and CAR 037 (Figure 3) indicate Late Miocene-Early Pliocene age (Stoian 2004), correlative to *Monotocidites galeatus* spore-pollen Zone (Macphail 1999). *Monotocidites galeatus* taxon is rare in most of the samples. Open woodland with eucalypt and Casuarinaceae developed on low nutrient soils is the dominant association. The eucalypts are diverse and species with modern affinities belonging to *Eucalyptus gardneri*, *E. stricklandii* and *E. accedens* are present in moderate frequencies. They represent a mallee or similar small tree, generally tolerating a mean annual rainfall of < 400 mm. The shrub layer is dense and consists of *Casuarina* and *Banksia*. Marine influence in varying degrees is present in most sites. The one sample examined in CAR 037 records a non-marine environment. At KIN 20 there is a mixture of freshwater dinoflagellate and freshwater algae *Botryococcus* with marine dinoflagellates living in coastal/littoral zones, as well as estuarine and oceanic environments.

This suggests the presence of a nearby shoreline with water depths of 20-60 m. Above this interval in KIN 20 the oceanic transport of cold-temperate dinoflagellate cysts into the estuarine sediments record rising sea level and marine transgression with open marine taxa flooded into the estuary. Open marine conditions are more pronounced in KIN 21, where the water depth exceeded 60 m. Here estuarine dinoflagellate cysts are present together with cold-temperate oceanic species. The water temperature was warmer at KIN 45, as indicated by the presence of neritic warm-temperate dinoflagellate cysts in association with freshwater, estuarine and oceanic taxa. AT KIN 22, lacustrine conditions prevailed, with no apparent marine influence. Further SW, at NALARA NR 3, cool-temperate oceanic dinoflagellate cysts are present and marine influence is pronounced with water depths again exceeding 60 m. At KIN PC2, a narrow interval of warm estuarine sediment, similar to that in KIN 45 is replaced by oceanic dinoflagellate cysts in overlying sediment that indicate marine transgression and return to cool-temperate conditions as the water level rose.

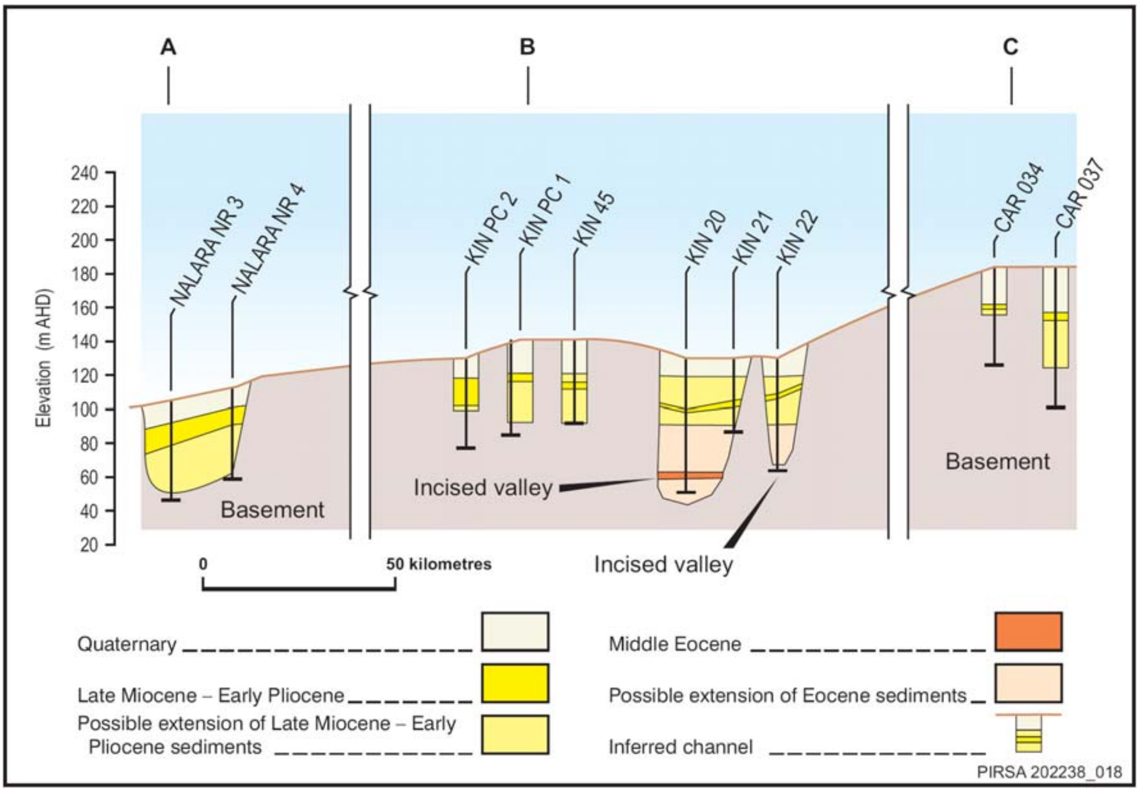

Figure 3: Diagrammatic cross section of selected drill holes investigated from the eastern Eucla Basin.

On land the palynological evidence is for an arid climate with open forest communities including dry sclerophyllous forest and coastal communities. By this time the vegetation of Australia changed from *Nothofagus*-dominated forest during Eocene-Oligocene to open woodland dominated by Casuarinaceae, eucalypt and grasses. Low nutrient soils became increasingly widespread and favoured expansion of Casuarinaceae, Chenopodiaceae and Asteraceae. Open woodland with *Casuarina* was dominant in coastal areas along with non-*Eucalyptus* species, *Acacia*, Proteaceae, Chenopodiaceae, Asteraceae and Gramineae. *Triporopollenites chnosus* pollen has no modern relative, but this proteaceous pollen is present in high relative numbers in all samples examined. By association, this plant tolerated arid conditions and low-nutrient soils, and played an important role in the local plant communities.

The correct assignment of age to sediment packages, the recognition and timing of sea level change and the interpretation of facies have been crucial for modelling shoreline evolution along the margin of the Eucla Basin and potential sites for heavy mineral accumulation. Important breakthroughs in this area have come from palynology investigations at PIRSA. While samples examined from these sites generally predate procedures developed for *palymineral* separation, there is a case for this processing with future samples so as to improve correlation between shoreline sediment deposits, palaeo-river inputs, and identification of primary bedrock source. The significance of widespread marine transgression in the Late Miocene-Early Pliocene is an outcome of these investigations (Figure 4).

CONCLUSIONS

Palynology is an important tool for dating sedimentary rocks that can also assist mineral exploration for commodities, particularly those associated with sediments. There are advantages in having samples analysed for both palynology and heavy mineral content. In future, samples analysed at PIRSA for palynology will routinely have the plus SG 2 fraction retained and indexed. These will be available for separation of the heavy mineral fraction on request that can then be used for:

- Mineral identification, particular for diamond indicator grains;
- A source of zircon grains for age determination of sediment source; and,
- Chemical analysis by electron microprobe.

Examples outlined in this paper for diamond and heavy mineral sands exploration underline the importance of palynological dating and environmental reconstruction combined with heavy mineral identification in assisting with provenance studies, source rock lithology, sediment transport distance, tectonic movement and sea level change.

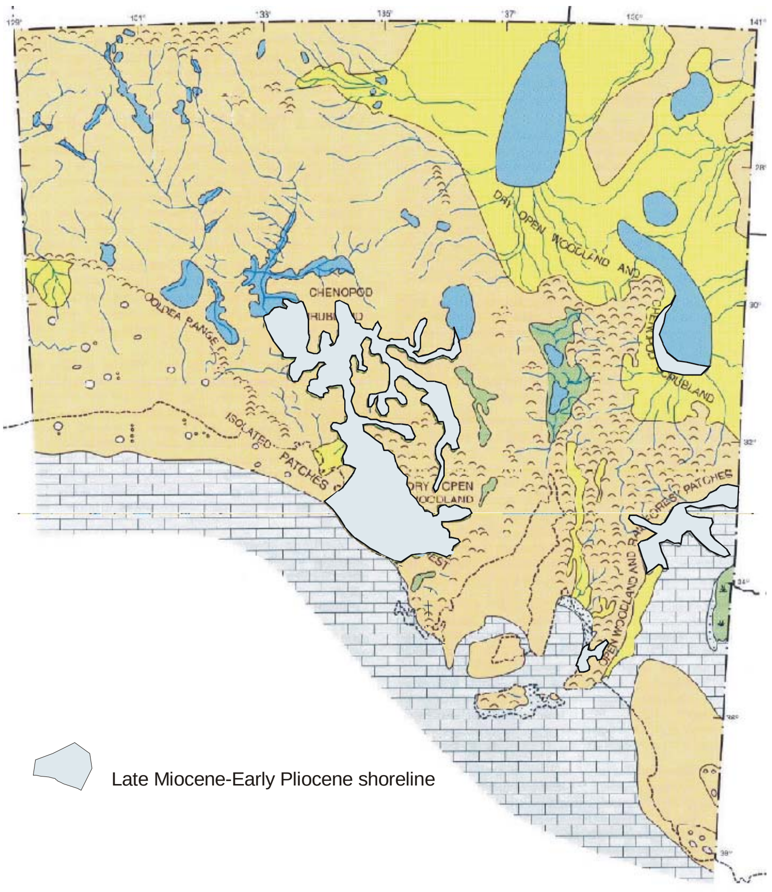

Figure 4: Late Miocene-Early Pliocene marine transgression (modified from Benbow *et al.* 1995).

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Acknowledgements: Flinders Diamonds Ltd and Orogenic Exploration Pty Ltd provided support and encouragement for palynology research. John Howard and Richard Russel, consultant geologists to Flinders Diamonds Ltd, provided many of the samples for palynology and heavy mineral separation.