

MODELS AND METHODS OF PALAEOSHORELINE/CHANNEL DEPOSITS IN EXPLORATION -ASPECTS OF AUSTRALIAN CASES

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ABSTRACT

The precise geometric definition of palaeoshorelines/channels is important in the exploration for placer, uranium, and groundwater exploration in Australia. This can be achieved through the combination of several geological and geophysical methods. Major refinements in remote sensing and geophysical techniques, data processing, sedimentology and computer-aided interpretations are today aiding the derivation of effective, economic and efficient models for exploring prospective terrains. New discoveries of world-class beach placer deposits in the eastern margin of the Eucla Basin, for example, have demonstrated the success and effectiveness of using these models by recognising the geoscientific signatures of placer-bearing shorelines. An improved understanding of placer models provides an important step toward the development of predictive exploration models that will enable the industry to prospect buried beach placers economically.

INTRODUCTION

Most discovered placer or sandstone-uranium deposits worldwide are in buried coastal and channel settings. Due to geological complexities and the difficulty in identifying shoreline/channel sediments, delineation of palaeoshoreline/channel has often proven too great a challenge in the exploration for such deposits. Successful exploration in these areas requires robust exploration models that integrate geological and geophysical techniques in a buried landscape evolution framework. In exploring and studying unknown buried shoreline/channel deposits, one of the major difficulties is how to explore for such deposits beneath many metres of overburden over quite large areas without using systematic drilling, which means *fastest*, *most effective*, and *cheapest*. As exploration is a lot more than science alone and the goals of exploration are economic, it is important for a explorer to have a good understanding of all the other disciplines that relate to the economic viability of ore deposits - these need to be studied and processed based on the geoscientific signatures and models of the mineral-bearing palaeoshorelines and channels.

MODELS OF PALAEOSHORELINE/ CHANNEL DEPOSITS

Placer models encapsulate information on the form of placer deposits (eg. strandlines in shoreline environments and drowned channels), their ore mineralogy/geochemistry (eg. placer gold, ilmenite-FeTiO₃, rutile-TiO₂, zircon-ZrSiO₄, diamonds, monazite -REE), host rocks (eg. medium-coarse sands, gravels), tectonic setting (eg. cratonic margins), depositional settings (eg. sand spits, barrier islands, coastal dunes, drowned fluvial deposits or lag deposits), and other characteristics (eg. longshore drift). Transgressive and regressive sea level fluctuations may well have reconcentrated any beach placer deposits in sandy palaeoshoreline deposits. So in terms of providing an informative picture of many aspects of placer deposits, models are extremely valuable. More commonly, however, a model is an attempt to systematize limited information, and to derive some generalizations. Placer mineralisation is characterised as detrital mineral grains concentrated in coastal marine and drowned channel sediments, particularly in storm ridge/barrier, and energy changed depositional settings. Mechanical transport and deposition play important roles in trap sites. Controls on their distribution are mainly coastal barrier systems adjacent to palaeorivers draining source regions. The major known mineralised period worldwide is Tertiary to Quaternary, though there may be potential mineralization associated with the worldwide Cretaceous flooding period associated with global sea level rise.

Sedimentary uranium mineralisation in Australia is mostly in Cainozoic basinal palaeochannels (e.g., Eucla and Eyre basins) developed on or proximal to Precambrian cratons (e.g., Gawler and Curnamona cratons containing 10-100 ppm uranium, well above the crustal average of 2.8 ppm U). Deeply weathered basement rocks were incised during Tertiary times and the sediments in these palaeodrainage networks now form several significant uranium provinces in Australia. Sedimentary uranium models need to incorporate information on the form of the deposits (eg. fluvial environments), their ore mineralogy/geochemistry (eg. uraninite - UO₂ or coffinite - USiO₄), host rocks (eg. oxidised and reduced sands, clays), tectonic setting (eg.

weathered cratons), depositional settings (eg. drowned fluvial deposits at redox fronts), and other characteristics (eg. sediment sources and transportation).

Sedimentary uranium mineralisation is characterised as uranium concentrated in medium to coarse-grained sediments at redox fronts, with pyrite and carbonaceous matter playing an important role in providing a reduced environment. The uranium mineralisation is associated with reduced conditions, and similar to elsewhere in the world, the host sediments to the uranium mineralisation often contain pyrite and organic (plant) matter that is either disseminated or forms lignite seams. Tertiary continental sediments in Australia are important favourable hosts because of the high organic content in channel sediments due to widespread colonisation by land plants during this time. The presence or absence of uranium mineralisation is primarily a function of the distribution of the Tertiary drainage with respect to a cratonic source containing elevated uranium content.

EXPLORATION MODELS

Remote Sensing Signature

Although **DIGITAL ELEVATION MODELS (DEM)** do not directly show the distribution of palaeo-landforms, they may indirectly show associations where modern and ancient relief landscape elements are linked. Specially processed (eg., density plot and perspective) images can enhance the understanding of palaeomorphology traced by DEM. With increasing resolution of images, the details interpreted from the images are likely to increase. Processed **LANDSAT TM** satellite imagery is useful in defining spectrally anomalous regions when appropriately draped over a DEM to enhance terrain visualisations, as it shows a high degree of correspondence to the surficial regolith-landforms and allows spectrally homogeneous units to be equated with terrain units. The enhanced surficial geological features using the ratios of Landsat TM bands are useful for separating and identifying different materials, but are problematic for linking to subsurface palaeoshoreline features. Compared to the Landsat imagery (7 bands), **ASTER** and **HYPERSPETRAL REMOTE SENSING** contains more spectral bands (14 bands) and can potentially distinguish most surficial features related to the palaeoshorelines/ channels. The detector and orbital configuration of **NOAA-AVHRR** night-time data make it a very useful remote-sensing method in that it detects temperature variations in subsurface sediments related to the elevated moisture content of channels. Coastal barriers are highlighted relative to the surrounding depressions (eg., lagoon and channel) due to the large temperature drop during night-time cooling in moist lagoon/ channel fills. The positions of palaeoshorelines/ channels can be highlighted when draped over DEM, and by referring to geological and drillhole data.

Geophysical Signature

South Australia palaeoshorelines/channels are not typically visible on regional **MAGNETIC** data, due to their limited magnetic mineral content (eg. Magnetite, maghemite, magnetised ilmenite). In contrast, processed vertical derivative regional aeromagnetic data at 250 m line spacing over the eastern Cobar Uplands clearly display magnetic palaeochannel sediments containing maghemite concentrated in low order late Neogene palaeodrainage lines (Chan et al, 2005), and dispersed remobilised magnetic palaeovalley sediments associated with high order palaeodrainage lines. When the processed magnetic imagery is draped over a DEM and regolith landforms mapped, buried palaeosediments containing magnetic layers in low relief areas can be distinguished from similar eroded palaeosediments that are variably inverted in relief.

The fundamental principle governing the use of **GRAVITY** as an exploration tool for palaeoshorelines is that a significant density contrast exists between the shoreline-sediment and the underlying and surrounding materials. With the use of detailed gravity surveys, gravitational anomalies can in some cases be used to define the thickness and extent of sedimentary features such as palaeochannels or coastal sediments, due to this contrast in density (eg., sand and clay having a density of 1.8g/cc, fresh granitic bedrock having a density of 2.7 g/cc; Berkman, 1995).

RADIOMETRIC data does not generally lead to better identification of buried palaeo-shorelines/ channels. due to the limited effective depth of the method (usually 0.3 m) and variable behaviour of radioactive materials. Radiometric data can however, be used in conjunction with Landsat, NOAA, DEM, AM and AEM images, to establish associations with underlying lithologies and outcropping units.

ELECTROMAGNETIC (Airborne – AEM & Transient - TEM) data measures the electrical conductivity of the ground both laterally and vertically, and thus, can be used to measure the ground conductivity as a function of depth. As the conductivity of the rocks is dependent on their porosity, moisture content and the conductivity of the groundwater within them, the EM method gives a very strong response to channel and lagoonal sediments containing saline brines but very low signal strengths over dry barrier sand and bedrock. Electromagnetic data may also be able to map varying clay content in the sediments and thus discriminate lagoonal from barrier facies.

Shallow **SEISMIC** reflection and refraction imaging are widely used for investigating the subsurface structure, particularly in sedimentary terrains, and are therefore useful for delineating palaeocoasts or palaeochannels. Seismic reflection surveys can be used to define the geometry of interfaces in the sediments and the underlying basement. Seismic refraction surveys are useful to detect variations in the composition of the sediments or the underlying basement because refraction profiling provides a robust image of variations in the seismic wave velocities (Drummond, 2002). By integrating the two techniques, it is possible to determine the depths, variability of materials, and morphologies of both shallow layers and deeper geology (Drummond, 2002).

GROUND PENETRATING RADAR (GPR) is useful for delineating the geometry, structure and thickness of sandy shoreline/channel deposits by providing a high-resolution image of subsurface features in the form of a cross-section view. This essentially shows the variation in ground electrical properties, although it is only suitable for shallow investigation (up to tens of metres in the best conditions). These can be correlated with physical changes such as the beach sand/bedrock interface, the boundary between different clay/sand types (including heavy mineral sand and sand), and the water table. Features in the GPR section correlate with stratigraphic boundaries where different rock types correspond to significant variations in the electrical properties.

Geochemical Signature

Anomalous concentrations of Au, As, Fe, Sn, Ti, Zr, REE, Th, Y and U in shoreline or channel sediments may be detected by applying CHIM (geochemical) technology (Luo et al., 2004).

Sedimentological Signature

Evidence from sedimentology is combined with evidence from other geological and geophysical characteristics to arrive at a general reconstruction of palaeoshoreline/channel architecture and history (Hou et al., 2003). To gain a regional understanding of the depositional, environmental and palaeogeographic frameworks, a grasp of the stratigraphic and geographic evolution of the palaeo-coasts/ channels is required (Hou et al., 2006). For this, the sequence stratigraphic method, supplemented by studies in palaeoclimate, mineralogy, petrology and geochemistry of the sediments, has proved invaluable. This is exemplified by the interpreted Early Cretaceous proximal estuarine to shallow marine and fluvio-lacustrine sediment sequence deposited in a wet and cold sub-polar climate with likely ice rafting that was deposited over much, if not all, of the Cobar Uplands in eastern Australia (Chan et al, 2005).

3D Computer Modelling

The palaeochannels interpreted from GIS data sets can either be viewed as 3D plume diagrams, mapped onto surfaces or else visualised as slices, such as the palaeochannel and palaeolandscape, with the exploded layers separating variously aged palaeosurfaces (Hou et al., 2004). The 3D visualisation models of palaeovalley landform are crucial to our understanding of landscape evolution and of the major controls on the dynamics of palaeorivers.

TEST DRILLING is necessary and critical to check the palaeochannel architecture interpreted from the multi-source geoscientific data in a region. Petrographic analysis of samples from less expensive shallow air core drilling traverses across identified possible palaeovalley systems, as in the eastern Cobar Uplands, has helped to identify two main sediment sequences and their architecture in this region (Chan et al, 2005). Samples logged with **PIMA II** (Portable Infrared Mineral Analyser) can confirm the palaeochannel modelling by identifying palaeosurfaces (Hou and Alley, 2004). PIMA has been instrumental in distinguishing highly weathered clay-rich Palaeozoic bedrock from clay-rich Mesozoic sediments and from redeposited clay-rich Cainozoic sediments in the air core drill hole samples from the eastern Cobar Uplands (Chan et al, 2005).

DISCUSSION AND CONCLUSIONS

Palaeoshoreline/ channel deposit models are important for exploration as they integrate many different aspects of associated mineral deposits. The mineral exploration largely relies on extrapolating knowledge from modern coastal-fluvial sedimentology using a combination of geological and geophysical interpretation techniques. Better understanding of geological controls/background is most important in choosing exploration methods. When working on a project, therefore, observations should be made without attempting to force them into a model: the model is modified to fit the data, rather than the opposite.

Information embedded in the subsurface varies enormously depending on complex (palaeo-) landscape evolution history and local geological controls that often complicate the responses evident in geoscientific data sets. As such, some information that is easily interpretable by one technology (e.g. NOAA or AEM) may not be mappable or evident using other technologies (e.g. DEM or LANDSAT). It is therefore an important practice to integrate and then refine the information derived from a combination of technologies. Remotely sensed images, combined with DEMs, are the first and best choice of imagery data sets available to help interpret palaeoshoreline-landform characteristics because they are relatively inexpensive, provide a synoptic overview, sample a broad section of the electromagnetic spectrum and are easily interpretable in terms of readily identifiable ground features. GPR, shallow seismic, airborne and ground electromagnetic, induced polarization, resistivity and ground and airborne magnetometer surveys are also useful.

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