INFLUENCE OF FLUVIAL ARCHITECTURE ASSUMPTIONS ON AQUIFER MODELS: LESSONS FROM THE LOWER BALONNE, SOUTHERN QUEENSLAND

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THE PROBLEM

Accurate subsurface correlation of sand bodies and other stratigraphic units is an essential component in many regolith studies and it is vital to both land management and economic geology. Applications in regolith studies include: subsurface mapping; determining aquifer hydraulic properties; and, determining the extent of salt stores. Distribution of sandstone bodies in the regolith is important in economic geology when such units host economic deposits, including mineral sands, gold or uranium. These issues are an important part of regolith studies of the Murray-Darling, Eucla, Eyre, and Perth Basins, in palaeodrainages in many locations, and in coastal deposits of north Queensland.

In most cases data about the actual distribution of such units is sparse, based on widely spaced drill holes with limited geophysical data in between. Correlation is typically by 'join the dots', however, the assumptions on how the apparently simple task of dot-joining is carried out have a major impact on unit extent and connectivity. Correlation assumptions are based on models of regolith architecture in the mind of the dot-joiner, in other words, how weathered zones and volcano-sedimentary successions are organised in space. Therefore, the accuracy of the conceptual models of subsurface architecture determines the accuracy of the correlation as only rarely will the data density be sufficiently high to allow the direct mapping of the distribution of a particular unit. This paper examines the implications of different fluvial geometries on subsurface architecture for a range of parameters.

FLUVIAL GEOMORPHOLOGY

The range of architectures that arise from different fluvial geomorphologies provides a good illustration of the problem. In this section I consider comparatively simple river systems flowing down a valley, ignoring complicating features such as distributary flow in alluvial fans or contributory flows peripheral to a basin. There are three main fluvial morphologies to consider: meandering, braided; and, anastomosing (Friend 1983).

Meandering systems consist of a single sinuous channel and are typically of low gradient rivers that transport sediment predominantly as suspended load, or, as mixed base and suspended load and with moderate variations in flow (Miall 1996). The resulting fluvial deposits are therefore mostly fine-grained but contain channel sand units. The channel will tend to migrate laterally, depositing a single, upward-fining sand sheet as it does so. The exception to this is where the channel is fixed in place by cohesive banks, see Nanson & Young (1981) for examples. Significant changes in channel position or avulsion can occur during major flood events, leading to the formation of a new channel complex. Statistical studies of width to thickness ratios of individual channel bodies (Fielding & Crane 1987) show that meandering channels are narrower with respect to their depth, following the lower and upper relationships of width = 0.95 x depth$^{2.07}$ and width = 64.6 x depth$^{1.54}$.

Braided streams are formed by moderate to steep gradient, bed load dominant rivers with very large variations in flow rates. Their deposits are dominated by coarse-grained sediments such as sands and gravel (Miall 1996) and consist of numerous interconnected channels, separated by bars. During low water only one channel may be active, but during major flow events the entire channel complex may contain water and the bars are submerged. Braided streams, therefore, deposit multi-cycle sand and gravel sheets that are very wide with respect to their thickness. Such streams are also very wide with respect to depth, with an upper limit of width = 513 x depth$^{1.35}$ (Fielding & Crane 1987), especially when unconstrained by features such as bedrock valley walls.

Anastomosing rivers are formed by low gradient suspended load systems (Gibling *et al.* 1998). Variations in flow rate can be moderate to very large. There are several channels, typically only one of which is active at any one time, although several channels may flow during peak discharge. The channels of anastomosing rivers may be highly sinuous but are generally fixed in place because cohesive banks. The resistance of banks to erosion typically arises from a combination of low erosive power, riparian vegetation, and clay-rich

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overbank and/or partly cemented deposits. Aggradation therefore occurs vertically, forming relatively narrow multi-cycle sand bodies. Avulsion results in a whole new channel system. Using the Fielding & Crane (1987) relationships, anastomosing channels have similar width to depth ratios as other high sinuosity channels, such as those in meandering streams.

FLUVIAL SAND BODIES IN THE SUBSURFACE

Each of these different styles of fluvial channel results in a different type of subsurface architecture. These are governed by three factors: depth to width ratio of the original stream channel; whether individual sand units are single or multi-cycle; and, the degree of channel migration.

Meandering streams result in relatively thin and typically single-cycle sand bodies. These have a thickness to width ratio of 1:100 (Payenberg & Reilly 2003). The relative thinness is due the extensive lateral migration that most high sinuosity streams undergo. If no lateral migration occurs because of stable banks (Nanson & Young 1981), then multi-cycle relatively narrow sand bodies can form, similar to those formed by anastomosing river systems (see below). Because of their overall high sinuosity, meandering streams sediments contain cross bed foresets with a wide range of paleocurrent orientation (Miall 1996).

Braided streams have thickness to width ratios of 1:500 (Payenberg & Reilly 2003). This is because of the great width and largely unconfined nature of braided streams relative to their depth, despite the multi–cycle nature of their deposits. Because the individual channels in a braided stream show relatively low sinuosity (Miall 1996), plots of palaeocurrent directions from foreset beds will show a lower degree of variation than for sand bodies deposited by meandering or anastomosing streams.

Anastomosing systems have fixed banks and typically (e.g., Nanson & Young 1981) form relatively narrow sand bodies in the subsurface. Makaske (2001) noted a thickness to width ratio for the sands bodies deposited by anastomosing systems of 1:10. The sediments are multi-cycle because vertical aggradation predominates over migration. Palaeocurrent orientations from foreset beds show a high degree of variation because anastomosing streams typical exhibit a high degree of sinuosity. Distinguishing anastomosing from fixed channel meandering systems in the subsurface requires the identification of two or more channels of the same general flow direction at the same stratigraphic level.

IMPACT OF ASSUMPTIONS ON AQUIFER MODELS

Figure 1 contains illustrations of how different assumptions can affect the manner in which lithological units are correlated in the sub surface. Figure 1A shows a theoretical fence of 86 m drill holes approximately 10 km apart across a depositional plain in which the sedimentary succession contains 34% sand. This similar a similar scenario to what is found in many regolith cover successions in Australia, such as the Murray-Darling Basin. The vertical exaggeration of Figure 1 is 250x.

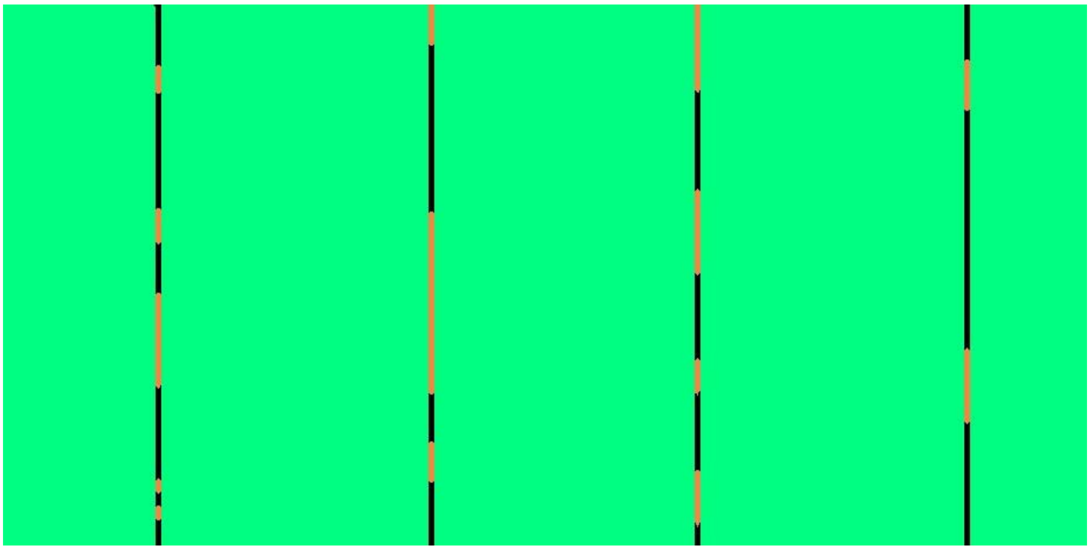

Figure 1A.

Figure 1B. In this section the sand units are interpreted as being laterally extensive bodies that continue between one drill hole and the next. Such an interpretation is commonplace and most geologists would tend towards this. It is probably a reasonable assumption where the sands are deposited by laterally continuous processes, such as in a marine environment. It is not a reasonable assumption for most fluvial environments, however, as the following illustrations show.

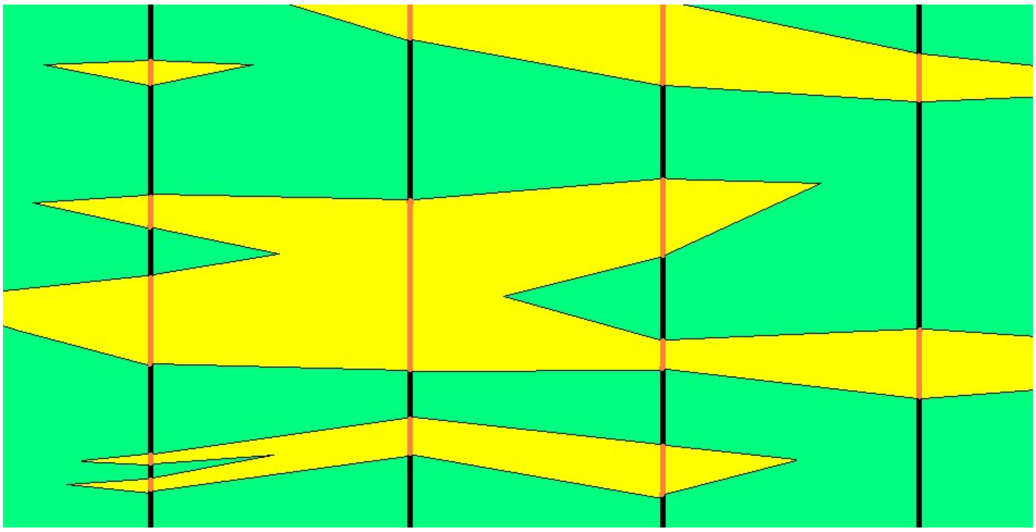

Figure 1B

Figure 1C. This section shows the probable lateral extent of sand bodies in the succession if they were deposited by braided streams with a 1:500 thickness to width ratio (Payenberg & Reilly 2003). None of the sand bodies actually interconnect laterally between any of the drill holes, although the three thickest sand bodies almost so, and might therefore merge in a real world situation.

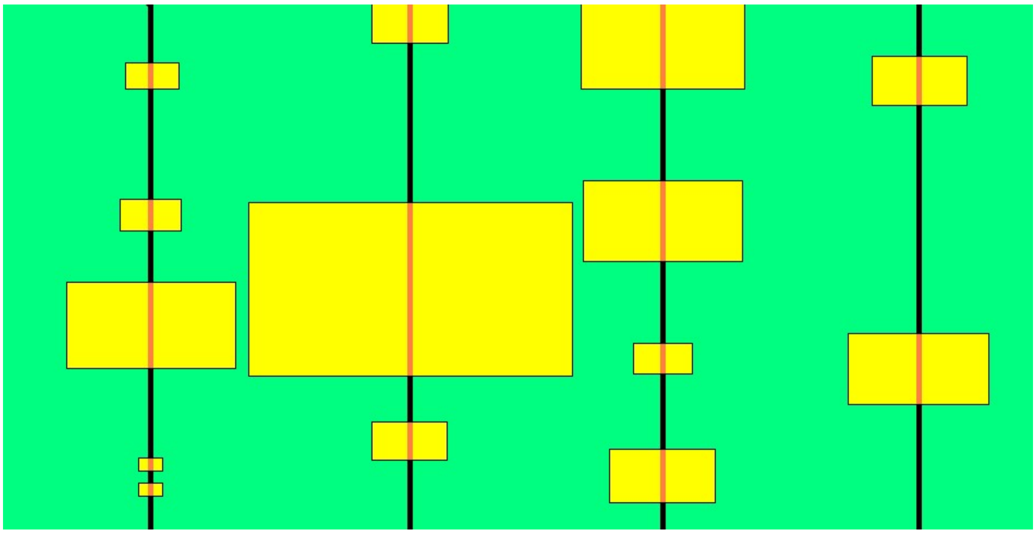

Figure 1C.

Figure 1D. This shows the probable lateral extent of sand bodies in the succession if they were deposited by meandering streams with the typical 1:100 thickness to width ratio (Payenberg & Reilly 2003). In this context it is highly unlikely that any of the sand bodies would actually be interconnected in the real world, at least laterally, although there would be good axial connectivity in deposits laid down by meandering streams.

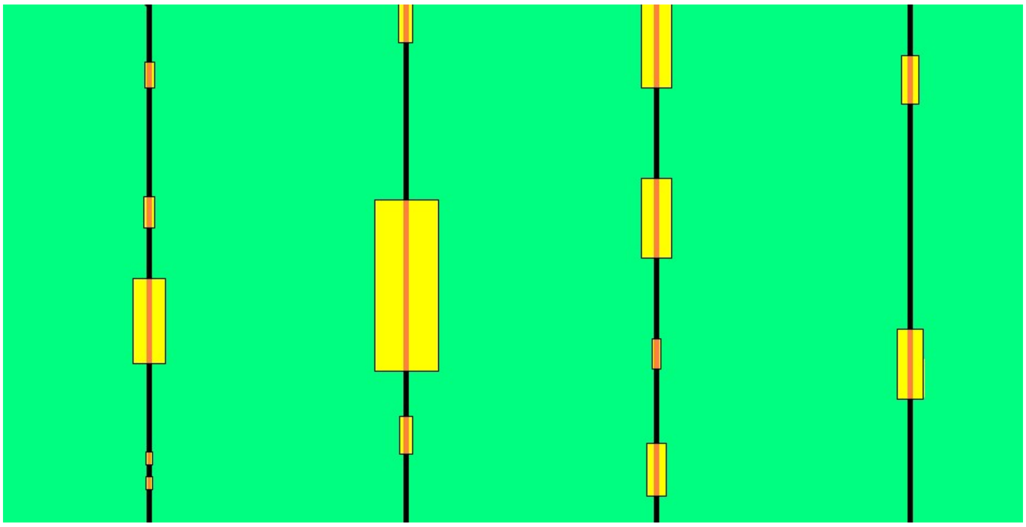

Figure 1D.

Sand bodies deposited by anastomosing streams with a 1:10 thickness to width ratio (Makaske 2001) are too thin to be shown at with the scale and vertical exaggeration of Figure 1, they would be thinner than the lines indicating the position of the bore holes. There is almost no chance for any lateral connectivity between the sand bodies, although, as meandering systems, there is going to be good connectivity parallel to the depositional axis. Many river systems in Australia, for example the Lower Balonne of southern Queensland, have precisely this type of architecture (Clarke & Riesz 2004).

PREDICTING SURBSURFACE ARCHITECTURE

Figure 1 demonstrates how knowledge of the degree of interconnectivity between sand bodies is critical to any subsurface interpretation. Determining the correct style of facies architecture to use is therefore an essential part of any reconstruction of subsurface geometry. Several indicators are available to the regolith scientist and ideally several of these indicators should be used to achieve the most robust interpretation.

The first of these is represented by scale of present landscape features. If the current surface processes are similar to those that deposited the subsurface sediments, then these can provide a guide. For example, in the Lower Balonne the modern anastomosing channels are all only a few hundred metres wide and the resulting sand bodies have widths of less than 1-2 km (Kernich *et al.* 2003). Therefore, one can predict that it is likely that the subsurface sand bodies are also likely to have been deposited by anastomosing channels of similar width, assuming that there have been no major changes to the depositional environment.

The second indicator is internal geometry of the sand bodies themselves. Although most drilling of regolith cover sediments is by RC, RAB, or air core methods that destroy the internal fabric of the sand bodies and homogenise them over the sample interval, down hole gamma logging can indicate whether such units consist of single or multiple cycles and whether these are upward fining or upward coarsening. If core is retrieved by triple tube drilling then even more detailed information of the internal architecture of sand bodies can be obtained. Anastomosing and braided systems tend to contain multiple channel units, whereas meandering systems, at least in sand-poor systems, contain single channel units encased in flood plain sediments.

A third indicator is defined by the amount of sand present in the succession. Theoretical work by Allen (1978) showed that lateral connectivity was poor in sandstone reservoirs when the overall proportion of sand fell below 50%. The fluvial component of much of the Australian regolith is dominated by fine-grained sediments, thus a high degree of anisotropy between lateral and axial hydraulic connectivity can be predicted in these cases.

Geophysics can sometimes be used to delineate the presence of individual channel units, as demonstrated by airborne magnetics in Joseph Bonaparte Gulf (Gunn *et al.* 1995) or electrical methods in the Burdekin Delta (Wiebenga *et al.* 1975). In the Lower Balonne region geophysics was of limited value as there was not a major contrast in geophysical properties between the channel and non-channel units.

Occasionally palaeocurrent data may be available, from sources such as gravel pits or other excavations, or more rarely, oriented diamond core. These data can help differentiate between high (meandering and anastomosing) and low (braided) channel sediments. In particular diamond drill core will also assist in determining whether or not sand and sandstone bodies are composed of single or multiple sedimentary cycles, and at least one or two holes should be planned in any extensive drilling program

LESSONS

A sound understanding of sedimentary architecture is vital for regolith geoscientists. If ignored, it is to their professional peril. Some of the key areas include:

- The scale of the architectural elements must be understood when planning geophysical surveys or spacing of drill holes, whether for purposes of exploration or monitoring;
- The interconnectivity of potential aquifer units, their storage capacity, and the anisotropy of potential flow paths when developing groundwater flow models;
- The likely extent of fluvial units when predicting the extent of fluvial hosted deposits such as gold, uranium or heavy minerals;
- Implications of facies must be included in hydrological modelling.

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