SEA LEVEL CHANGE AND PALEOCHANNELS IN THE PERTH AREA

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ABSTRACT
Possible causes of climatic fluctuations during the Quaternary and the resultant variations in global sea levels are described. The formation of palaeochannels in the Perth area is related to the sea level variations and channel forming episodes identified from site investigations along the Swan River. The geological and geotechnical characteristics of the channel infills are summarised and the engineering implications of the channels outlined.

1 PALEO CLIMATES IN THE QUATERNARY
The last 1.8 million years of earth history, which make up the Quaternary, are divided into two Epochs, the Holocene consisting of the last 10,000 years and the Pleistocene 10,000 to 1.8 million years before present (YBP). The Quaternary was characterised by cycles of alternate cold and warm periods that produced glacial and interglacial stages. The cyclical nature of the fluctuating climate is clearly shown by the temperature variations interpreted from the changing oxygen isotope content of pelagic foraminifera from deep-sea cores. (Shackleton & Opdyke, 1973). This composite curve of temperatures (Figure 1) shows remarkable features:

- Peaks and troughs occur at more or less regular intervals of 100,000 years.
- There is a saw tooth pattern of gradual temperature drop associated with the most pronounced glacial events, followed by a rapid warming to the interglacial maximum temperature, and
- Over a period of 750,000 years the temperature maxima and minima have nearly equal values.

Figure 1: Generalized Palaeo-temperature and sea level curve, last 700,000 years.

The possible causes of climatic change are summarized in Table 1 and additional influential factors are summarised in Table 2.

Table 1: Possible Causes of Ice Ages.

<table>
<thead>
<tr>
<th>Causes of climatic change and ice ages</th>
<th>Return Period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth’s orbit changes between highly elliptical and nearly circular</td>
<td>100,000</td>
</tr>
<tr>
<td>Earth’s axis wobbles</td>
<td>22,000</td>
</tr>
<tr>
<td>Earth’s axial tilt changes 22° - 25°</td>
<td>4,000</td>
</tr>
<tr>
<td>The Croll – Milankovitch Hypothesis</td>
<td></td>
</tr>
</tbody>
</table>
Times of temperature minima, known as glacials, have caused significant amounts of the global surface water to be locked up in the ice caps, and low sea levels result. At the end of each glacial period large volumes of water derived from the melting of ice caps and glaciers have caused a series of world-wide rises of sea level, known as an interglacial, which along with the glacial low levels are known as eustatic sea level changes. Areas remote from glaciation, like Western Australia, are affected by such worldwide eustatic changes and old marine beaches, fossil dune systems and ancestral shorelines above present sea level can be manifestations of this effect.

According to the most relevant sea level curve, which reflects global temperature changes, the magnitude of sea level fluctuations in the Quaternary in the Perth region ranged from 150 m below the present level to 9 m above it. If all the present ice on earth were to melt, it would raise sea level about 78 metres. However, it is known that the so called eustatic sea level rises are not uniform everywhere because the earth responds as a viscoelastic medium to both the released stress of unloading due to ice sheet melting and to the applied stress of the meltwater as it fills oceans and covers continental shelves. In addition local tectonism can cause significant sea level changes, and this has probably been the case in the Swan Coastal area. Cope (1975) and Seddon (1972) both envisage tilting about an east-west axis to account for the fact that landscape elements in the north of the Swan Coastal Plain are higher than the same features in the south.

2 \textbf{CHANGES OF SEA LEVEL}

Table 2: Climate Change - additional influential factors.

<table>
<thead>
<tr>
<th>Other Influential factors</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decantation</td>
<td>Isostasy</td>
</tr>
<tr>
<td>Solar Radiation</td>
<td>Sunspots</td>
</tr>
<tr>
<td>Ocean Basin Filling</td>
<td></td>
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<tr>
<td>Magnetic Field and Climate</td>
<td></td>
</tr>
<tr>
<td>Planetary Synods</td>
<td>A line up of planets</td>
</tr>
<tr>
<td>Atmospheric Transparency</td>
<td>Volcanic Dust</td>
</tr>
<tr>
<td>Terrestrial Geography Changes</td>
<td>Pangaea</td>
</tr>
<tr>
<td>Feedback</td>
<td>The Gaia Hypothesis</td>
</tr>
<tr>
<td>Giant Meteorite Strikes</td>
<td>Forest clearing,</td>
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<td></td>
<td>greenhouse effects</td>
</tr>
</tbody>
</table>

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270,000 years.

Playford (1988) provides a eustatic sea level curve for the last 140,000 years for Rottnest Island. A modified eustatic sea level curve for the Perth region is given in Figure 2 based on the eustatic curve for the world for the last 700,000 years given by Shackleton and Opdyke (Fig.1) but incorporating information from investigations of bridge sites along the Swan River and at the Narrows Interchange. There is a small but significant discrepancy between the Rottnest levels
and those from the same formations on the mainland. As can be seen from Figure 2 at the last Interglacial water level
was some 9 m above the present level based on evidence from Blackwall Reach where there are three duricrusted
surfaces. In the Perth region the Penultimate Glacial channel was about 20 m deeper than the Last Glacial channel.

3 GLACIALS AND INTERGLACIALS

The glacio-eustatic sea level curve indicates that between 340,000 Yr BP and the present time, three major high sea level
episodes (interglacials), and three major sea level lows corresponding with glacial maxima or glacial have occurred. The
sequence of interglacial stages is given odd numbers (7, 5, 3, 1) and the glacial stages are given even numbers (6, 4, 2) in
Figure 2.

During glacial periods the equilibrium of rivers is affected as the sea level is lowered, and the increased gradients cause
the rivers to cut down deeply in order to maintain grade. These episodes of incision or down-cutting have resulted in
the formation of deep buried channels (palaeochannels) that are particularly well shown in the Swan River and these
have been seen in the extensive investigations for bridge sites across the Swan River (Baker, 1956).

Sea level has been relatively high during the past three to six thousand years when a maximum occurred some 2.8
metres above present level, then dropped quickly, thus accentuating the broad Rottnest Shelf carved into the continental
platform during this and previous high stands. As a consequence the valley of the Swan River which was cut at lower
sea levels is gradually filling with sediment. Streams near the coast are at grade, and the coastline typically has long
continuous sand beaches.

4 THE SWAN RIVER IN THE QUATERNARY

The Quaternary geological history of the ancestral Swan River in the Perth-Fremantle region has been controlled by sea
level rise and fall, and only to a small extent by channel migration. The Last Glacial channel has also been constrained
by exposures of Minim Cove limestone and eolianites that were being lithified at the same time that the channel was
active on the exposed coastal plain.

During the last two glacial periods (Stages 6 and 2) the equilibrium of the Swan River was affected as the sea level
lowered, the gradient was increased and the river cut down deeply through the superficial formations of the Swan Plain
and into the underlying sediments of the Perth Basin, namely the Kings Park Formation and the Osborne Formation.

During the time of rising sea levels, as the ice sheets melted the gradients flattened and the incised channels became
infilled with soft sediments. In the last two glacial maxima when sea level was lowest, the two palaeo-Swan Channels
were cut and both have been reasonably well preserved adjacent to and under the present day Swan River channel
(which is itself of greatly diminished size).

The palaeochannels of the Swan River have been investigated by chance from Barkers Bridge to offshore, mainly for
bridge site investigations but also for harbour works. Details are given of the Causeway, Convention Centre and
Narrows Bridges showing the interaction and importance of the palaeochannels.

5 THE CAUSEWAY SECTION

Figure 3: Long Section through boreholes - The Causeway.
At the Causeway, there are two existing waterways separated by Heirisson Island, and the Last Glacial Palaeochannel is some 24 m deep and is located under the west or Perth channel. The channel infill is described in the MRD drill logs as soft “black sulphurous estuarine silt”. The Penultimate Glacial Channel is located under the eastern or Victoria Park side present channel. This older channel, which is 33 m deep and at least 200 m wide, is overlain and infilled with lenses of sand clay, gravel, clay sand and gravelly sand of the Guildford Formation, all dense or stiff. The bedrock is a black claystone-siltstone, which is the Kings Park Formation of Paleocene-Eocene Age.

### 6 NARROWS INTERCHANGE AND CONVENTION CENTRE

Downstream of the Causeway in Perth Water the location of the palaeo channels is not precisely known, except for the presence of the Stage 2 channel at Mends Street jetty, until the area of the Narrows Interchange road system is reached. Here the Last Glacial channel is a meander forming an arc of a circle located adjacent to Mounts Bay Road between William Street and the Narrows Bridge. The channel is about 28.5 m deep and is 300 m wide, forming a deep valley (known as the Mounts Bay Road Ravine or Perth Canyon) incised through into the Penultimate Glacial deposits of clayey sands (Guildford Formation), which are about 20 m thick and about 6 m into the underlying Kings Park Formation as shown in Figure 5.

![Figure 4: Locations fixed at Causeway, Mends Street, Convention Centre, Mounts Bay Ravine and Narrows Bridge, otherwise inferred.](Image)

The wide swing of the meander takes it from a northerly to a southerly direction at which stage it trends underneath the north or Perth abutment of the Narrows Bridge, and a small reverse meander then places the channel under the central piers of the Bridge.

The Mounts Bay Ravine is largely filled with dark coloured mud with some sand and shell and with some minor peat deposits underlying. The peat deposits from 20.7 m which were dated at 9,850 ± 130 YBP do not represent the time the Mounts Bay Ravine was cut but was the time of peat deposition in the already present Last Glacial channel as sea levels rose from 17,000 years YBP. The strength of the mud was low (Phi 30°, C’ 0 to 0.07 kg/sq cm). This river cut ravine filled with mud caused design problems with the bridges and embankments of the Mitchell Freeway Interchange (Jones & Marsh, 1965). Tests on undisturbed mud samples showed a well-defined strength separation between estuarine muds situated between -6 m and -12 m, and underlying marine muds (-12 m to -28 m) (Jones and Marsh, 1965). This latter are known as the 'Blue Muds', and the younger weaker sediments are known as the 'Black Muds'. (Quilty, 1974)
In the area of the Perth Convention Centre, geotechnical information is available from Main Roads WA investigations for the bridges of the Interchange, the Perth City Busport, and the site investigation for the Convention Centre itself. During pile driving it was inferred that the base of the Penultimate Glacial Channel in Kings Park Formation had been encountered at a depth of 35 m below datum at some locations on this site. This data has been interpreted in Figure 4 to illustrate a channel with a tight arcuate shape inside the Last Glacial Channel. The Penultimate Glacial Channel was interpreted as being infilled with Guildford Formation clays and sands which contrasts with the Last Glacial Channel (28.5 m deep). The latter was infilled with marine muds and overlain by estuarine muds, which did not provide the good end bearing foundation conditions for piles that the Guildford clays did. Offshore from the Barrack Street Jetty, the two glacial channels crossed and this preserved a high peak or remnant of the Kings Park Shale, including a strongly cemented upper layer known as the Mullaloo Sandstone. This pinnacle at 0.5 m below datum (low water level) was unexpected, as the Kings Park Shale is usually about -20 m to -30 m in the Perth CBD. A cross section from the Narrows Bridge to the Convention Centre is given in Figure 5. The Penultimate Channel headed westerly under the centre of the Narrows Bridge and the Last Glacial Channel. Channel 4 cuts across the South Perth Peninsula north of Queen Street and is not encountered in the investigative boreholes for the Narrows Bridge or its duplication. The infilled channel has been encountered beneath buildings in South Perth located on its path.

Figure 5: Inferred Geological Cross Section - Convention Centre - Narrows Bridge Based on Jones and Marsh (1965), Ove Arup (2001), Coffey Geosciences (2002) and original research.

7 REFERENCES


