Characterisation of the Ross River Dam Foundations

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ABSTRACT

The Stage I construction of the Ross River Dam was completed in December 1973. The reservoir reached full supply level (FSL) and then spilled in January 1974. In 1976, the left embankment was raised to Stage II level. Spillway gates were installed in February 1978 with full supply level for Stage 1A (FSL).

In the years following the first filling of the reservoir after the raising of FSL, salt scalding downstream of the northern portion of the left embankment occurred. This was attributed to foundation seepage. Investigations started in 1978 to define what remedial measures were required to ensure the safety of the left embankment. Fissured clays were first discovered in the foundations of the Ross River Dam during these investigations.

Fissures could substantially reduce the overall strength of the soil foundations. Therefore the effect of these fissures needs to be considered when evaluating the acceptable levels of reliability against embankment failure. More extensive fissuring was discovered during the current investigations and a cataloguing system was employed to characterise the foundation conditions.

A simplified layer model was adopted early on in the design but did not fully demonstrate the complexity of the subsurface conditions. Extensive use was made of historical geological data, current investigation data and the application of GIS systems. The resulting model more clearly represents the foundation conditions and high degree of variability and was used in subsequent risk assessments for the upgrade design.

1 Introduction

Ross River Dam, located 20 kilometers south-west of Townsville, was designed by the Queensland State Government which also oversaw its construction during the 1970's. It is a dual purpose dam, designed for flood mitigation and potable water storage.

This paper describes the geology of the Ross River Dam foundations and the investigation, collection and presentation of fissured clay data.

2 Background

Salt scalding downstream of the northern portion of the embankment was first noticed in 1978, following the first filling of the reservoir after the upgrade of the full supply level (FSL) (Stage 1A). The salt scalding was attributed to seepage from the reservoir through the dam foundations.

Investigations began in 1978 to determine what remedial measures were required to secure the left embankment, which extends for approximately 7 700 m. It was during these investigations that fissured clays were identified within the upper soils of the embankment foundations, resulting in an extensive investigative programme of pitting, trenching and borehole drilling to delineate the occurrence of the fissured clays.

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The investigation indicated that the fissuring was mainly concentrated between chainage 1 000 m and 2 600 m, within the upper few metres of the soil profile directly overlying a layer of indurated sand

3 Geology

There have been at least four major geological investigations completed for the Ross River Dam, including the feasibility and design stage surveys (1965-69 & 1970-74), the fissured clay investigation (1981-82), and the upgrade design investigation (2004-05).

4. Regional Geology

The Townsville-Thuringowa area is underlain by sedimentary, igneous and metamorphic rocks, including Quaternary aged alluvium.

A relatively flat coastal plain, with valleys extending into the foothills and mountains to the west of Townsville, dominates the landscape with little to no topographic relief with the exception of Castle Hill, Mt Stuart and Mt Louisa.

The dam is founded on Quaternary aged alluvium (sediment) and Permian aged rocks of the Julago Volcanics. The Quaternary aged sediments are relatively flat lying and are expected to dip, shallowly, towards the coast.

Numerous faults have been mapped by the Geological Survey of Queensland (1986), typically striking north-westerly to north-easterly. Lineament mapping using remotely sensed imagery suggests additional structures may occur closer to Ross River Dam.

Evolution of the Ross River Dam Area

The geological history of the area adjacent to, and underlying the Ross River Dam embankment, is relatively complex. Based on data collected during the surveys completed at Ross River since the 1960s, and regional mapping completed by the State and Federal Governments, the following geological history has been interpreted.

Three major Pre-Cainozoic aged geological units underlie the Ross River Dam area:

- Carboniferous-Permian Granite (Unnamed),
- Carboniferous Volcanics (Unnamed): (felsic), and
- Julago Volcanics (Permian): (felsic to intermediate with some sedimentary rocks).

These units form the geological and hydrogeological basement of the Ross River Dam area and outcrop to the east (Mount Stuart) and west (Round Mountain) of the reservoir.

Variation in sea level has had a major influence on sedimentation in the Ross River and Bohle River catchments, with prolonged periods of lowstand resulting in the deposition of sandy strata, followed by periods of highstand resulting in the accumulation of fine grained sediment (silts and clays).

The historical sea level curve is illustrated in Figure 1.

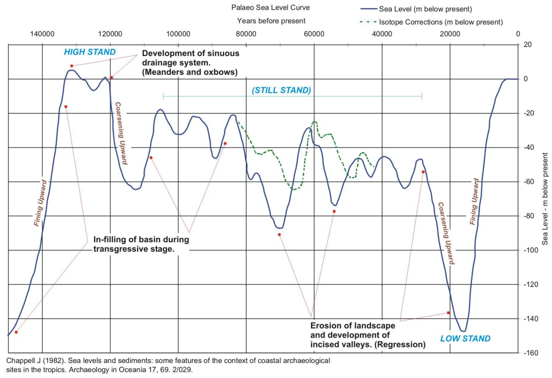

Figure 1 Palaeo Sea Level Fluctuation

Granite, with localised pockets of andesite, was identified beneath up to ~ 30 m of sediment, below the embankment of the Ross River Dam. The presence of andesitic material disseminated amongst the granite suggests that the area has undergone major structural deformation following the formation of the granite and deposition of the Julago Volcanics.

Evidence of basin stage faulting and half graben development within the Ross River and Bohle River valleys is provided in outcrops downstream of the dam (presence of alluvial fan conglomerates).

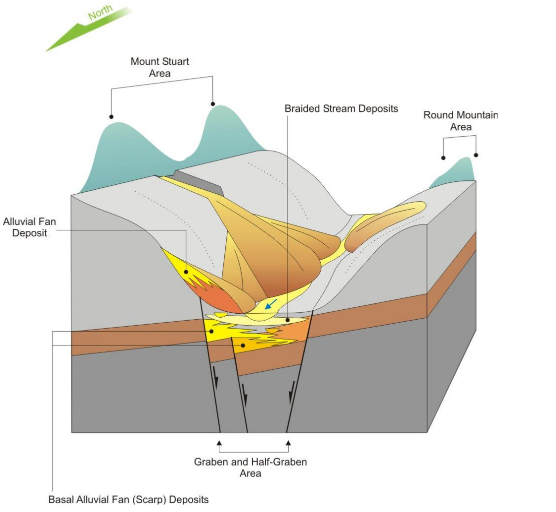

Figure 2 Conceptual model of Ross River basin development.

Within the Ross and Bohle River valley, braided streams would have developed, migrating across the plain, resulting in numerous channels overlapping, thus interconnecting a large proportion of the sediment present within the valley (Figure 3).

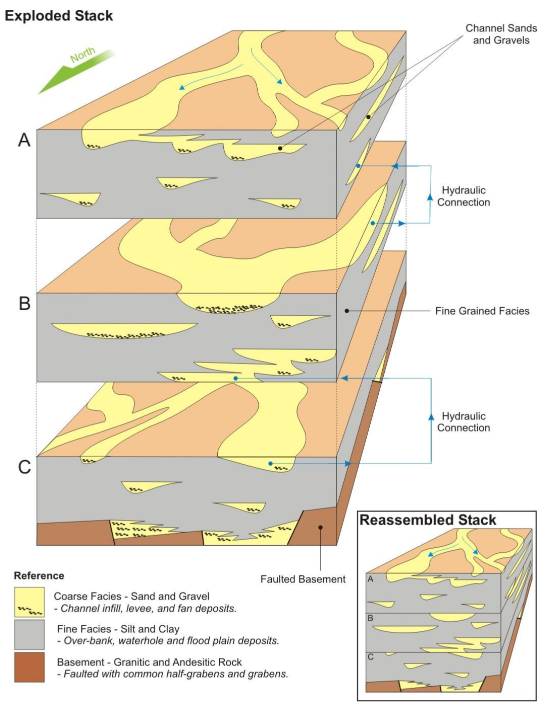

Figure 3 Block model of braided stream.

The majority of this material occupying the Ross River and Bohle Valleys is interpreted to have been deposited during a pre-glacial period (>150,000 years before present) (Trezise et al, 1989). As the valley began to infill during the last still stand (between 130 000 and 35 000 years before present) where several short periods of incision (lower sea level) and aggradation (higher sea level) resulted in the accumulation of finer grained sediments containing discreet channel sand and gravel deposits as well as silt and sand levee and crevasse splay deposits. As the relative sea level increased, the depositional system back-stepped upstream, forcing the deposition of the coarse material closer to the source. The river channels became more incised with the fine facies being deposited in the overbank areas (floodplains and levees).

Since the last rise in relative sea level (during the Holocene), the channels have continued to incise into the materials deposited during older high stand deposits (materials deposited during sea-level highs).

The modern Ross River is dominated by fine to coarse grained sand, typically sub-angular and dominated by quartz. Material less than 0.75 mm is not common in sediment sourced from the river, generally comprising less than 2% of the material.

5. Structure and Tectonics

Outcrop mapping in the area downstream of the spillway indicated that numerous faults were present in the area, with one outcrop allowing a period of extension, and subsequent basin development, to be identified.

The outcrop indicates that a large fault developed along the western side of the Ross River channel during the Permian, with several other basin stage faults developing around this time. Sedimentation patterns recorded in outcrop, including a basal conglomerate, containing sub angular, matrix supported cobble sized clasts, support the presence of such a fault. Imbrication of these clasts suggests the palaeo-flow direction was from the west to east, allowing material to shed from a fault scarp lying to the west.

6. Local Geology

The geology of the area immediately adjacent to Ross River Dam embankment has been intensely investigated allowing a detailed geological model to be developed. This model, which has been presented as a long section, has been sub-divided into five litho-stratigraphic units, underlain by the granitic bedrock.

The Ross River and Bohle River plains are comprised of a complicated sequence of basin infill sediments. The stacking pattern preserved in the sediments indicates two prolonged periods of sea level high-stand, marked by the fine grained sediments (clays, silts). Periods of low sea level are marked by sandy sediments, with the basal sands and gravels marking the original period of low sea level.

The Sediments

Surface Soil

The surface soils are dominated by silty clays that may be sandy in some areas. These soils are generally hard, dry, and dissected by sub-vertical desiccation cracks extending to between 700 mm and 900 mm below ground level. Desiccation cracks are generally rough, hackly and non-linear. A thin silty layer occurs in some areas and appears to be an anthropogenic deposit, likely to have resulted from run-off/erosion from material used during the construction of the road, embankment or berm.

Shallow Sand

The shallow sands may be intersected at varying depths, the shallowest at the surface. Depending on the location of the deposit, they may or may not be indurated, with the intensity of induration ranging from weakly to strongly cemented. There appears to be a rough relationship between the intensity of induration and the abundance of fine grained material in the sands: the more < 0.75 mm material present, the less well indurated (more weakly cemented) the material is likely to be.

The sands range in grainsize from fine to coarse, with localised gravelly zones (generally not exceeding 40 mm diameter). It is likely that the coarser fraction of sediment represents the thalweg zone of each palaeo channel.

Areas where silty/clayey sands occur in sub-continuous lateral beds, generally thickening at one end, are likely to represent old levee banks or crevasse splays.

Structured Clay

The structured clays are generally moderately to highly plastic with a varying silt and sand component. Unlike the clays forming the soils (upper 0.3 – 2.0 m), they commonly contain fissures. Contrary to the investigations completed in the early 1980s, where a particular style of fissuring appears to have been targeted during the investigation, the 2004-05 survey has identified fissuring along the majority of the embankment alignment. Fissure characteristics appear to vary depending on the composition of the soil, with a relationship apparent between the abundance of coarse grained (sand) material and the development of the fissures. When compared to location, there are three broad areas within which fissures have somewhat similar characteristics:

- Ch 700 – 3 000 m: Andesitic Clays (Chocolate Brown)
- Ch 3 000 – 6 200 m: Granitic Clays (Grey Brown)
- Ch 6 200 – 8 400 m: Granitic Clays (Grey-Brown with Blocky Fissures)

Fissuring has been identified to occur from less than 0.6 m to at least 17 m below ground level.

It appears that as depth increases, the likelihood of fissuring decreases somewhat as the sediments have undergone induration/cementation to some degree. A mottled clay layer typically underlies the structured clay and indicates diagenesis of the sediments has occurred along the majority of the embankment.

Shearing of the clayey sediment was noted to be more intense in some locations where the sediment was directly underlain by indurated sands, suggesting the clay was failing whilst trying to swell against a resistant body.

Mottled Clay

Mottled clay typically overlies the basal sand and gravel, or where this coarse basal layer is absent, weathered basement rock (granodiorite, andesite etc). The clays are generally brown in colour and may contain sandy layers and lenses of varying thickness, likely to represent overbank deposits or localised distributary channels.

This unit is interpreted to have been deposited during a sea level high stand, resulting in fine grained sediment dominating the system.

The clays have significant iron and manganese oxide throughout, likely to have increased the strength of these materials and also reducing the ability of these materials to develop pervasive defects. Where cementation has developed less intensely, ie in the structured clays closer to the surface, structuring has been able to develop with pervasive fissures common throughout the upper unit.

Basal Sand/Gravel

The basal sands and gravels directly overlie the geological basement (the granodiorite). In some areas this unit may be absent or may overlie a thin band of mottled clay. The sands and gravels vary in grain size, with material from fine sand to cobbles and boulders reported along the length of the embankment. In some areas, fining upward sequences have been recorded, indicating the deposits are of fluvial (river channel) origin.

Rock

The majority of the hard rock and hydraulic basement underlying the Ross River – Bohle River floodplain is comprised of granite/granodiorite. Intrusions, likely to be dykes, possibly being emplaced along faults or significant joints in the rock, have been identified at various locations along the length of the embankment, and range in composition from andesite to rhyolite (and 'porphyry').

Clay Analysis

The Queensland Water Resources Commission (QWRC) defined three distinct clay groups underlying the embankment between chainages 1000 to 3500 m, all of which were confined to the dark clays (andesitic clays). McConnell, 1986, described the clay types as:

1 Zones of fissuring observable with multiple mappable continuous major fissures and multiple discontinuous minor fissures. Dips are predominantly low angle with polished, slickensided fissured surfaces.

2 Multiple discontinuous minor fissures with perhaps a single undulating mappable major fissure at the base of the clay. Dips of minor fissuring predominantly steep.

3 Discontinuous minor fissures with no continuously mappable major fissures. Dips predominantly steep.

The investigation completed in 2004-05 revealed the fissuring extended beyond chainage 3500 m, with at least some form of structuring identified in almost every test pit excavated along the downstream toe of the embankment. The intensity of pervasive fissures is, however, greater between 1000 and 3500 m.

Based on the additional investigation, three distinctly identifiable groups of clays occur in the upper sediments of the Ross River and Bohle valley sequence: Andesitic, Granitic, and Green Clays. Whilst the andesitic and granitic clays are relatively common, the green clays occur in only a few locations along the alignment of the embankment.

A detailed description of each of the clays is provided below.

Andesitic Clays

The andesitic clays occur along the northern extent of the embankment, between 0 m – 3000 m, in an area close to the toe of the Mount Stuart massif.

It is likely that the clays deposited in this area were sourced from the catchment of Five Head Creek. This is supported by the lack of andesitic clays above chainage 3000 m.

The andesitic soils typically present as dark, chocolate brown clays, exhibiting significant desiccation cracking in the upper 0.7 – 1.0 m, with low angled, smooth, undulating and coalescing fissures, extending to at least 2 m below ground level.

Green Clays

The green clays have been identified in two locations along the embankment during the 2004-05 investigation. Where identified, the clays are of limited lateral and vertical extent, however appear to occupy a relatively linear position, possibly a palaeochannel.

At test pit location 807, the initial pit excavated revealed green (grey-green) clays approximately 3 m below ground level, underlying an indurated band. The clays were highly fissured with polished, glassy and slickensided fissures common throughout the clays. When additional test pits were excavated adjacent to the original pit (in some cases not more than 5 m from the original pit) to determine the lateral extent of the green clay, the clays were dominated by sand and the fissuring was not as common, pervasive, or severe, as in the original pit. Excavation adjacent to the green clays identified in MP01 revealed material that was more sandy, similar to the materials unearthed in the area of TP 807.

The green clays are interpreted to be of volcanic origin, likely to have been deposited as an air-fall tuff. These clays have been identified in only a few locations along the embankment, interpreted to have been oxbow style environments at the time of deposition.

If an oxbow existed and volcanic ash settled on the area during a period of low sea-level, the ash falling into the oxbow would be preserved, with that falling on the surrounding land being able to be eroded by wind and water thus not being preserved. This style of development also explains the lateral gradation of the material to a sandier unit. The sand is likely to have been sourced from sediment washing into the oxbow during the erosive phase. This material has since been weathered to produce the montmorillonite and kaolinite reported in the XRD. Basaltic volcanism is known to have occurred in the region (less than 65 km to the south-west), with ash (tuffs) of rhyolitic composition possible through bimodal magmatism.

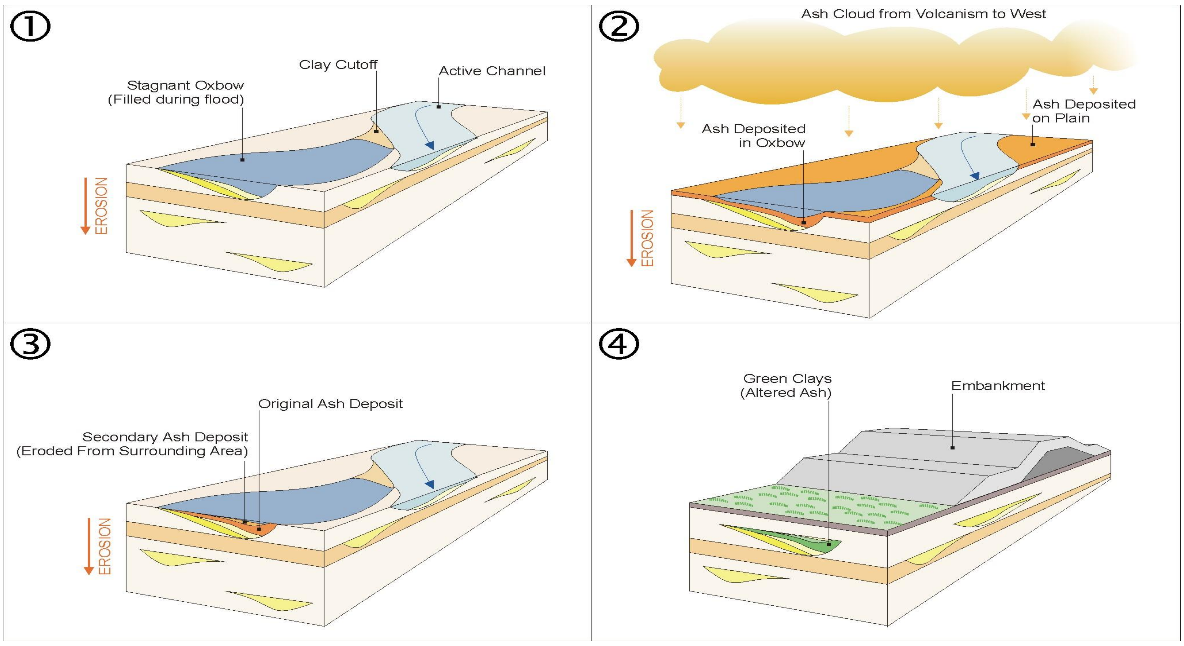

Figure 4 Development of Green Clays.

Geological mapping of the area (BMR, 1968) report flood basalts of Quaternary age (< 10 000 yBP: Toomba Basalt) and of Pleistocene age (~ 1.7 Ma, Nulla Basalt). Given arc style volcanism occurred in the area, the possibility that intermediate tuffs were erupted, deposited, and altered to the green clays (as observed in TP 807) is supported.

Granitic Clays

The majority of the elevated land surrounding the catchment is dominated by granitic rock, hence the sediments underlying the embankment are dominantly granitic. The clays contain some coarse material that was identified in the field to be dominated by quartz and feldspar.

The granitic clays are greyish-brown in appearance and contain polished to smooth fissures, however the fissuring in these clays is generally more blocky and less pervasive than in the green clays and andesitic clays.

Clay Strength

When tested, these clays report different strengths, with the andesitic material generally being of lower strength than the granitic or green clays. McConnell (1986) reported low ϕ' values, ranging between 9° and 11° when fissured, whilst in the absence of fissuring, the strength has been reported at 17°.

The residual strength of the andesitic clays is significantly lower than the green clays (ϕ' ~ 14°) or the structured clays (ϕ' ~ 15°), therefore the strength of the embankment area underlain by this material is likely to be significantly greater.

Although the green clay contains glassy, polished, and often slickensided fissures and based on field observations was expected to be that of the lowest strength, these clays were identified as having a moderate strength when compared to the andesitic and structured clays. The strongest clays identified on the site are the granitic clays, relying on their mineralogy and grading for their strength.

Clay Mineralogy

The mineralogy of the different clays was determined by X-ray diffraction completed on unexpanded and expanded samples (Table 1).

Sample	**Andesitic Clay**	**Granitic Clay**	**Green Clay**	
Depth (m)	*0.5 m*	*1.5 m*	*3.5 m*	*3.5 m*
Quartz	37.5 %	44.9 %	31.3 %	25.2 %
K- feldspar	7.2 %	9.4 %	-	-
Na-feldspar	8.5 %	5.3 %	8.9 %	7.9 %
Ca-feldspar	-	-	8.6 %	6.4 %
Montmorillonite	17.3 %	6.9 %	21.5 %	30.9 %
Kaolinite	16.6 %	28.1 %	17.5 %	18.4 %
Illite/mica	-	3.2 %	12.3 %	11.3 %
Amorphous/unknown	13 %	2 %	-	-
Total	100.1 %	99.8 %	100.1 %	100.1 %

- Denotes mineral was not detected.

Table 1Clay mineralogy determined by XRD.

The elevated quartz content in samples classified as being of granitic origin supports a granitic source. Elevated orthoclase (K-feldspar) levels in these materials also support the interpreted origin.

Amorphous (glassy) material detected in clays interpreted to be andesitic, suggest the parent rock was a volcanic deposit with siliceous material cooling rapidly, thus unable to develop a crystal structure.

Unlike the other clay materials, the green clays reported a significant amount of Ca-feldspar (anorthite), suggesting the source of the green-clay is not likely to be granitic or rhyolitic.

Montmorillonite and kaolinite suggest the presence of magnesium and aluminium rich minerals in the parent rock, likely to be rhyolitic in origin, with magnesium and aluminium sourced from biotite mica with additional aluminium from feldspar minerals.

Origin of the Clays and Variation in Mineralogy

The clays comprising the upper 'structured clay' layer of the foundation vary in origin, and are not a direct weathering product of the bedrock.

The upper Ross River Catchment is dominated by granitic rocks, with significant sized areas of intermediate (andesitic) volcanic rocks and lithified sedimentary sequences that predate the sediments of the Ross River – Bohle River valley by many 10s to 100s of millions of years. Conversely, the catchment of Five Head Creek is dominated by intermediate (andesitic) volcanic rocks with limited exposures of granitic rock.

QWRC (1982) attempted to identify the origin of the clays and suggested that stream capture was not likely to be a major contributor to the variation in clay mineralogy observed with depth. It does, however, explain the lateral variation within one stratigraphic horizon. According to QWRC (1982), varying mineralogy is likely to have resulted from variations in climatic condition during the initial weathering and transportation stage of the depositional process in addition to in-situ diagenetic processes that altered the clays.

The thick clay sequences that are present in the Ross River – Bohle River valley represent a period of prolonged elevation in sea level, allowing accumulation of sediment within a flooded area that would have occupied the majority of the valley. Coarse grained sediment would have been confined to the margins of the flooded area, or significant channels within the lake. Sedimentation within such a setting would have allowed the intermixing of fine grained material from both the Ross River and Five Head Creek catchments.

During more recent periods of elevated and depressed sea level, it appears as though the catchments of the Ross River and Five Head Creek operated independently of each other, until such time that the Ross River was effectively captured by Five Head Creek. This is supported by the presence of andesitic clays within an area adjacent to the andesitic volcanic rocks of the Julago Formation, on the Mount Stuart massif immediately east of the rockfill embankment. The original channel of the Ross River is likely to have drained along a more westerly course, possibly merging with the Bohle River (Figure 5). This catchment is dominated by different clay mineralogy, identifiable above chainage 3000 m.

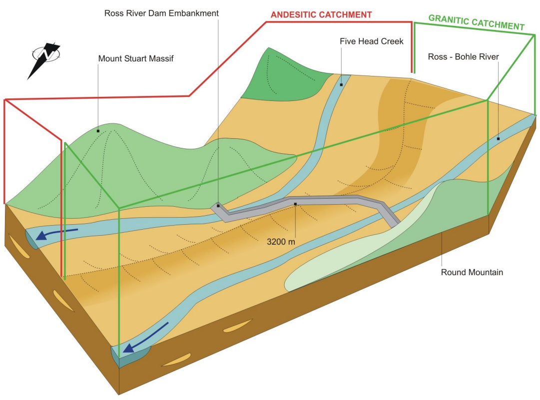

Figure 5 Distribution of andesitic and granitic clays based on stream catchments.

As illustrated in Figure 5, the andesitic sediments would have drained along the eastern side of the catchment, with the granitic sediments draining to the west. It is likely that a low watershed would have divided the valley in much the same way that the Ross and Bohle River catchments are separated today.

The approximate interpreted palaeo-catchments are illustrated in Figure 6.

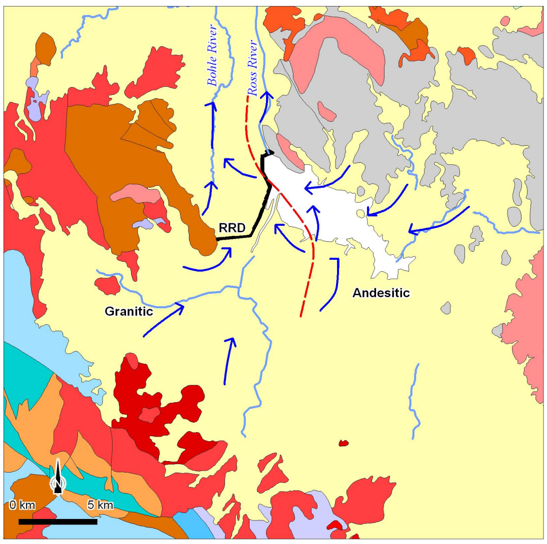

Figure 6 a) Geological units with palaeo-catchments.

Induration

Indurated zones were identified at varying depths along the length of the embankment, with an upper indurated band usually identifiable at approximately 3 m below ground level. The intensity of the induration (weakly to strongly cemented) varied with location.

Review of the bore hole and test pit logs from the previous investigations, as well as the 2004-05 work, indicated that induration also varied with depth, suggesting periods of lower piezometric surface levels, likely to coincide with periods of lowered sea level, during which cementation of the sediment/s occurred.

The dominant cement observed between chainage 1000 m and 6200 m was iron oxide. Between 6200 m and 8400 m, the iron oxide was accompanied by significant amounts of manganese oxide.

Between 6200 and 8400 m, the subsurface is dominated by a granitic intrusion which lies close to the surface.

Defects

Fissured Clays

During the excavation of the test pits and shored pits, the occurrence of fissuring and cracking of the fine grained materials was noted. A fissure classification system was adopted allowing fissures across the site to be identified and recorded consistently throughout the field stage. The characteristics were documented, along with the presence of slickensides and striations, as they are a key indicator of significant historical movement along fissure and defect surfaces.

Classification System

The fissure classification system used during the investigation was adapted from Walker, Blong, & MacGregor (1987). Data recorded includes:

- Continuity
- Fissure orientation
- Shape
- Spacing
- Surface

The modified system included two additional spacing classifications, allowing for mapping in shored pits. The original system, as seen in Figure 7, was designed primarily for use when logging core.

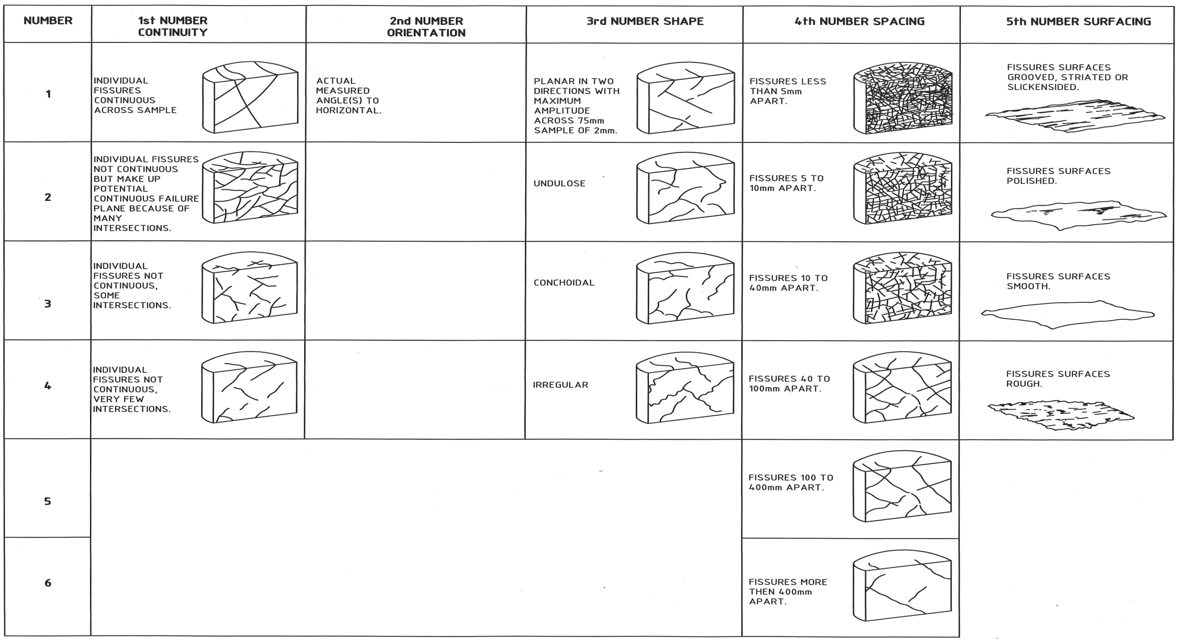

Figure 7Fissure Classification System (modified after Walker et al 1987)

Four types of fissuring/cracking were identified during the test-pitting program. Sub classes were adopted for the glassy and undulose fissures allowing assessment of strength based on the material within which they occurred. The fissure types are detailed below:

Type A: Desiccation Cracking

Type B: Glassy Fissures: subdivided into BA: Andesitic, BG: Green, & BS: Structured

Type C: Undulose Fissures: subdivided into CA: Andesitic, CG: Green, & CS: Structured

Type D: Blocky Fissure (Structured Clay)

Observations showed that as sand content increased (even by only a few percent) the severity of fissuring (smoothness, polishing, slickensiding, pervasiveness) decreased.

Type A – Desiccation Cracking

Type A defects are present in the upper 600 to 700 mm of the soil profile and appear to have developed as a result of wetting and drying (desiccation) of the soil profile. Typically, they are rough and irregular and are likely to reseal upon wetting of the soil profile. They were observed in all the soils, especially the granitic clays.

Where other material has in-filled these cracks, probably deposited during the first flush following a dry period, sub-vertical to 45° shears have developed as the soil has not been allowed to re-swell unimpeded along the original defect.

Figure 8 Type A Fissure

Type B – Glassy Fissures

The most well developed Type B fissures were identified within the greenish-grey coloured clays intersected around chainage 4100 m, generally lying below 3.0 m. The fissures in this material were typically highly polished and glassy, and severely slickensided. Upon separation of intact fissures, droplets of free moisture were identifiable although the surrounding material was dry to moist. Most fissures were stained, in part (FeO or MnO), indicating the fissures are able to conduct groundwater.

The orientation varies, ranging from sub-horizontal, through 45°, to sub-vertical. These fissures persist for at least 150 mm.

Type B fissures were also identified in the granitic and andesitic clays, however do not always display well developed slickensides or highly polished glassy surfaces. Within these soils, however, there is a significant sand component, appearing to have an effect on the ability of the clay to develop polished and glassy fissures.

Figure 9 Type B Fissure

Type C – Undulose Fissures

The majority of Type C fissures occur in the northern section of the embankment alignment, between chainage 1000 m and 3000 m. Although they display some slickensiding, they are generally smooth and planar to slightly undulating. Unlike the other fissures identified. Type C fissures tend to occur at low angles, generally being sub-horizontal to < 30° (to 45°).

Where identified, the clay within which they occur is somewhat softer than fissure-bearing materials elsewhere on site, reporting a strength of approximately 550 kPa . This style of fissuring was targeted for removal in the early 1980's. Type C fissures appear to swarm, with several fissures coalescing to form larger, semi-continuous planes.

Individually, they average approximately 0.5 m in length, however several fissures were observed to coalesce resulting in a continuous, though undulating, surface over 1.0 m in length.

Laboratory testing of these materials indicated a peak strength of 29° and residual strength of 10°.

Figure 10 Type C Fissure

Type D – Structured Clay

Type D fissures are those fissures typically occurring deeper than 4 m below ground level. These tend to be present in materials with significant sand content, with the fissures being short (< 20 mm in length) and rough. The material excavates as a blocky, hard clay. Some evidence of slickensiding and striation development has been noted. Iron and manganese oxide staining is common in this material.

It appears the presence of sand within the material has assisted in preventing the development of the more planar and pervasive fissures classified as Type B and Type C.

Figure 11 Type D Fissure.

Fissure Angles and Orientations

Throughout the field investigation program undertaken in 2004, 746 fissures were identified and measured, the majority identified in shored test pits.

As illustrated in , Type A and D fissures are relatively steep with no preferred orientation. Conversely, Type B and C fissures occur at relatively shallow dip angles, typically less than 30°, with no preferred orientation. Based on the stereonet (), it is likely that the 231 unclassified fissures will be Type A or D.

Sedimentology

Dewatering Structures

A perceived risk to the stability of the embankment was that of liquefaction of sands at shallow depth. Inspection of Mega-Pit 2 revealed the presence of a sand volcano within an indurated sand horizon approximately 2 m below ground level. Sand volcanoes usually develop during seismic events (earthquakes) or as a result of extremely rapid loading.

When a rapid load is applied, the water in the pore space is forced from the sediment, allowing the sand to consolidate rapidly. The pore water escapes upwards as the load from above forces the sediment to compact downwards. The water will flow upwards at a significant rate, entraining some of the sand in the process, resulting in the formation of a volcano shaped structure.

Once classified, each fissure was plotted on a stereonet to determine whether particular types of fissure developed in preferred orientations.

This technique also allowed the interpreted field classification to be confirmed. Unfavourable orientations for particularly weak fissure types were identifiable.

Figure 12 Sand volcano identified in MP2.

The extent of the presence of the fissures in the dam foundations and the variation of the types of fissured and the geological orientation of the foundation clays are indicated in the fissure model in Figure 14.

The fissure model provides a useful tool in determining the shear strengths of the fissured clays for various chainages along the embankment and for various depths.

The orientation and dip of the fissures are indicated in the pole plots shown in . The orientation can then be taken into account in slope stability analyses. The pole plots indicated that the fissures were randomly orientated, which supports the theory that they have developed from the effects of desiccation (shrink/swell) of the clays.

Plot of poles of fissures identified in embankment foundation, classified by fissure type.

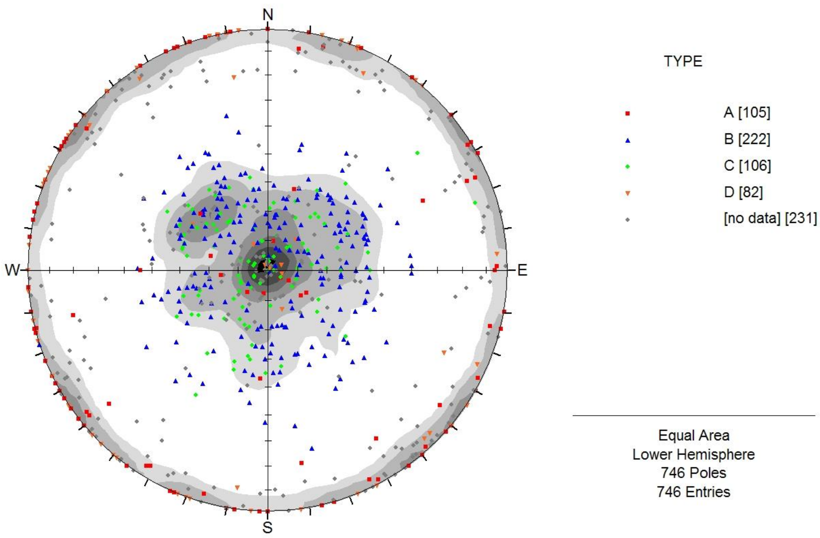

Figure 13 Plot of poles of fissures in dam foundations, classified by fissure type.

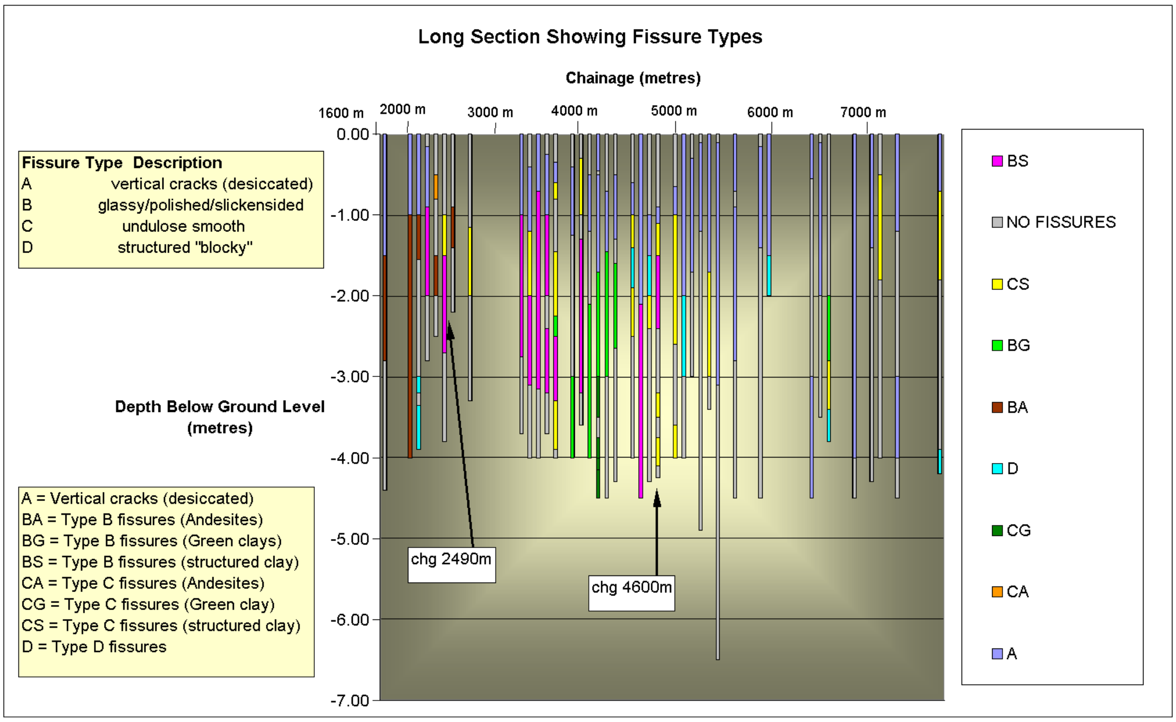

Figure 14: Fissure Variation along embankment.

7. Development of the Geological Model

Based on the original drilling programs completed in the 1960 and 1970s a broad layer cake geological model was developed, separating the foundation materials of the left abutment into six units (Figure 15). This model was updated during the subsequent investigations of the 1980s and 1990s. Geophysical surveys also supported the original layer cake model.

3.1 Evaluation of Existing Data

Soil core collected during the 1981-82 investigations completed by QWRC were reviewed to audit the logs of that era to ensure the data contained within the logs was appropriate for use in refining the geological model. All existing data was utilised where the borehole fell within 30 m of the centreline (U/S or D/S) of the embankment. Given the interpreted geological history, boreholes located further from the centreline were not relevant to the development of the long section.

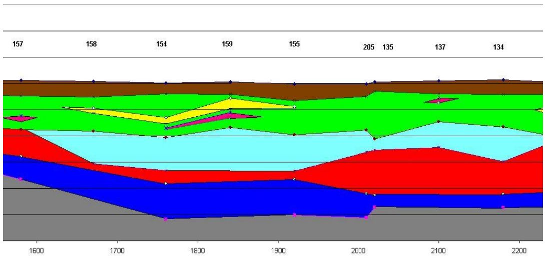

Figure 15 Extract of earlier geological model

3.2 Further Investigations

As the majority of the early investigations were focused on alignment selection and determination of remedial works, the majority of the data was unable to be used to develop the geological model as it lay too far from the embankment alignment.

Additional investigations were completed to fill in gaps in the existing dataset.

All field work was completed by geologists and geotechnical engineers, with specific training provided to allow sedimentary structures to be identified in samples and pits.

Figure 16 Shored pit used to provide access for fissure mapping.

3.3 Unified Geological Model

All boreholes and test pits completed during each of the geotechnical surveys (1960s – 2004) were spatially stored in a geographic information system (GIS) - MapInfo. Each of the geological/technical logs was scanned, saved in PDF format and hyperlinked to each of the boreholes in the GIS. This allowed instant retrieval of data simply by clicking on the borehole.

A sedimentological approach was adopted during the reinterpretation of the geological data. Initial interpretation of the data indicated that there was significant lateral variation parallel and normal to the embankment alignment, consistent with the depositional environment expected in the modern Ross River environment. Once this method was identified as being appropriate, the entire foundation was reinterpreted, resulting in the identification of numerous discreet channels as indicated in the complex geological model in Figure 17 as opposed to lateral extensive and continuous sand layers that were indicated in the earlier geological model (Figure 15).

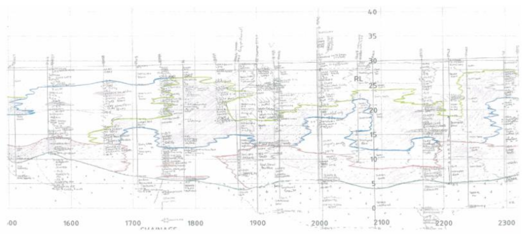

Figure 17 Extract of 2004-05 geological model

It was beneficial on this project to select a geologist with significant experience in sedimentology and basin analysis to lead the investigative team. This allowed a model to be prepared utilising information that could commonly be overlooked during engineering projects.

4 Conclusions

The use of sedimentology aided significantly in the understanding of the geology of the Ross River Dam foundations.

The geological model became the fundamental building block of the risk model.

5 References

QWRC, Report on Foundation Investigation, Ross River Dam, May 1983

McConnel, R.J., ANCOLD Bulletin No. 77, Post Construction Treatment of Fissured Clays, 1990

GHD Pty Ltd, Ross River Dam Upgrade, Geology of the Ross River Dam Report, 2005

GHD Pty Ltd, Ross River Dam Upgrade, Material Parameters and Embankment Stability, 2005

Geological Survey of QLD, 2004, Digital 1:100 000 Scale Geological Mapping: Townsville & Mingela, Geological Survey of QLD, Brisbane

QWRC, May 1982, Report on Seepage Investigation Ross River Dam

Walker, B.F., Blong, R.J., MacGregor, J.P., 1987, Landslide classification, geomorphology, and site investigations, published in Soil Slope Instability and Stabilisation, Walker & Fell (eds), Balkema, Rotterdam, 1987.

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