

## Bell Bay Quarry - Geotechnical Review

Delta Materials Pty Ltd

Scoping Study

MINEHOBAA00268AA

13/08/10

Mr John Purkis  
Chief Operating Officer  
Delta Materials Pty Ltd  
Level 5, Elizabeth Street  
Sydney, NSW 2000

**Attention: John Purkis**

Dear John,

**RE: Bell Bay Quarry - Geotechnical Review**

Coffey Mining is pleased to present this review of the available geotechnical data from the Phase 1 drilling program. The review summarises the relevant geotechnical data for future quarry design and stability studies to be done as part of the detailed feasibility study late in 2010. The report provides general guidelines to quarry final wall and production face stability to assist conceptual quarry planning.

If you require any further information regarding this report, please contact the undersigned.

For and on behalf of Coffey Mining Pty Ltd



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Don Miller  
Principal Engineering Geologist

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**Author(s):** Don Miller Principal Engineering Geologist (FAusIMM, FIQ)

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#### Document Review and Sign Off




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Primary Author  
Don Miller




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Reviewed By Mick Pfitzner

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## 1 INTRODUCTION

Delta Materials Pty Ltd is undertaking a resource definition study for a potential extractive industry quarry located in the Tippogoree Hills in the north-eastern Tamar Valley in Tasmania, Australia. Delta Materials Pty Ltd was granted an Exploration Licence 6/2009 by Mineral Resources Tasmania on August 25, 2009 for a five year tender over some 17 km<sup>2</sup> in two areas.

This report reviews the geotechnical data available for the more northern of the two areas. That data comprises initial site surface mapping and a Phase 1 drilling program comprising 21 cored diamond drill holes (BB19-01 to BB10-21) which were completed during an 11 week campaign from March to May 2010. The collar locations for these drill holes are shown in Figure 1. Drilling totalled 2460.9 metres of HQ3 and NQ2 core. Delta Materials staff or contractors logged the core and entered, audited and compiled the results of that logging. That data was made available to Coffey Mining on 16 July 2010.

### 1.1 Scope of Work

Delta Materials Pty Ltd has commissioned Coffey Mining to undertake a review of the available geotechnical data to determine preliminary conclusions regarding the potential quarry wall stability for quarry planning to support the preliminary quarry plan that utilises 45° overall slope angles for all final quarry faces. That plan has been used to determine preliminary recoverable reserve estimates.

The program of work, as set out in an email to Delta Materials (09/07/10), was:

1. **Rock Strength Analysis** - Determine if there are rock strength variations within the dolerite sill. The magnetic susceptibility results show a strong mineral differentiation with depth and this may have an impact on rock strength, particularly in the bottom 20 m of the sill. This zone will be in the toe of slopes that can be in excess of 100m high and it will be important to determine any weakening in this region.
2. **Rock Mass Structure** - Major joint sets will be determined from the limited oriented core results. The relevance of the data collected to date as representative of the whole rock mass will need to be assessed. The analysis will be supplemented with the analysis of alpha angles to determine the consistency of development of varying dip defects. This may also allow domaining of the rock mass.
3. **Kinematic Stability Analysis** - With a high strength rock, bench stability will be determined by kinematic conditions, that is, the ability for large wedges to affect bench stability. This will be determined for a variety of wall orientations as no firm final wall plan exists. The aim of this analysis will be to maximise long term stability and access along the final wall berms. This analysis will yield appropriate bench scale

geometry from which overall slope geometry can be determined given the varying depth of the quarry.

4. **Major Faults** - The major faults will be investigated from a rock quality perspective to determine their expected properties. This may have a major influence as the faults may end up being the bounds to the final pit, which is the final walls may about the faults.
5. **Recommendations** will be made as to specific issues that can be addressed in the phase 2 drilling to improve the confidence in wall stability and design.

The data, analyses and conclusions from this preliminary analysis will be updated in December when a second phase of drilling, planned for September to November, is completed.

## 1.2 Geological Setting

The potential resource at Bell Bay comprises Middle Jurassic dolerite. This resource is part of *"about 15,000 km<sup>3</sup> of dolerite estimated to have intruded into post orogenic, flat lying Carboniferous-Triassic sedimentary rocks which comprise the Parmeener Super Group stratigraphy of the Tasmania Basin"* (Reference 2).

The geological setting for the proposed quarry development has been described by Boronowski and Morrison (Reference 1). This report describes the physical geography of the area as being *"dominated by the Tippogoree Hills, a northwest-southeast trending strike range of dolerite capped hills extending for at least 8 km and forming the eastern margin of the Tamar Graben, a rift basin which contains the Tamar River. In the resource area the dolerite hills range in elevation from approximately 50-250 metres above sea level and the landscape is dissected by ephemeral creeks which drain in a generally south westerly direction into Lauriston Reservoir, Howell Reservoir and the Tamar River* (Figure 1).

*The dolerite on Tippogoree Hills is broadly stratiform and appears to have intruded into a unit of Triassic sandstone and micaceous mudstone, stratigraphically near the top of the Parmeener Super Group rocks preserved in the region. The entire sequence of Permo-Triassic sediments and Jurassic dolerite is structurally NW-SE aligned, conformable with the strike of the Tamar Graben. Numerous small scale faults are mapped within the sedimentary units and implied through the dolerite due to the fabric defined by airphoto lineaments. A major east-west structure is apparent in the approximate position of Bridport Road but south of Bridport Road the mapped faults show only minor local disruption to the stratigraphy. Several dip and strike readings in Permian sedimentary rocks north of Tippogoree Hills consistently show a dip to the southwest, towards the graben axis, at an average dip angle of 18°. It is likely that the dip of the dolerite and host sedimentary rocks is controlled by graben faulting and will be conformable with the strike trend of the regional dolerite-Triassic sediment contact dipping approximately 11° to the southwest."*

In this area the dolerite is up to 173 metres thick (BB10-13) although this varies greatly with topography.

*“The dolerite sill shows a consistent internal stratigraphy expressed as a decrease in grain size and change in texture from top to bottom. Drill core commonly shows a coarse grained, more graphic textured dolerite at the top of the hole, grading down to medium grained ophitic textured dolerite (the most common type overall), and with a relatively thin chilled margin above the basal contact. The chilled margin dolerite is darker in colour, finer grained and has a slightly glassy and fine porphyritic texture. It is always more magnetic than the overlying dolerite. The fine grained chilled margin dolerite is present in every hole, whereas the gradation from coarse grained down hole to medium grained dolerite was not observed in every hole, but is sufficiently widespread to support the interpretation that the deposit is a single sill.” (Reference 1).*

## **2 AVAILABLE DATA**

### **2.1 Surface Mapping**

Surface mapping of dolerite outcrops over the area of the Exploration licence was conducted in October 2009 by Boronowski and Morrison. Delta Materials has made available spreadsheets of the defect orientation data collected as part of that mapping program. In total some 419 joint orientation measurements were recorded. In that mapping program joints were classified as “main” or “secondary”. Boronowski has indicated that “main” joints are those with the largest continuity observed at each particular mapping location. Secondary joints were those less well developed.

### **2.2 Drill Core Logging**

The Phase 1 drilling program comprised some 21 diamond drill cored boreholes in the area. A series of major northwest-southeast striking fault zones were intersected with 11 moderately dipping (nominally 55° plunge) boreholes with a further 10 vertical drill holes drilled primarily in the regions between the major faults (Figure 1). Geotechnical data including defect orientation relative to the core axis (alpha angle), aperture, roughness, infill and weathering were recorded for selected defects in the core. The records are not exhaustive but represent the major defects observed in the core. For the moderately plunging drill core the orientation of selected defects was also recorded by the bearing of the defect relative to the bottom of core (beta angle). This was only possible where core orientation was successful for each drill run and again for selected defects. It proved impossible to obtain successful core orientations in the faulted rock so data with both alpha and beta orientations, that necessary to determine true orientations, is restricted to the dolerite and sediment rock mass away from the faults.

From 2868 defect records only 144 defect measurements have recorded both alpha and beta data allowing true orientations to be calculated. The breakdown of the recorded geotechnical data is given in Table 1.

Table 1 Recorded Geotechnical Data from drill core

Defects recorded	By Type	By Lithology	By Location	Oriented
2868 defects	2753 Joints	2656 Dolerite	1763 Rock mass	129 Oriented
				1634 Un-oriented
			893 Fault	893 Un-oriented
		97 Sediments	71 Rock mass	14 Oriented
				57 Un-oriented
			26 Fault	26 Un-oriented
	2 shear			2 Un-oriented
	37 vein			4 Oriented
				33 Un-oriented
	5 Fault			2 Oriented
				3 Un-oriented
	9 Contact			9 Un-oriented
	48 Bedding	48 Sediments	Rock mass	14 Oriented
				34 Un-oriented
	10 Breccia zone			10 Un-oriented

### 3 GEOTECHNICAL ANALYSIS

#### Data Analysis

The drill core geotechnical data has been classified as to lithology and whether the core is in the major fault zones or in the rock mass. The down hole depths used to classify this were taken from data supplied by Delta Materials (file:120-Drilling-Ph1-Summary-1006117.xls) and are summarised in Table 2.

**Table 2 Downhole Geology (supplied by Delta Materials)**

DDH No.	Azim	Dip	Dolerite – sediment contact	Fault zone start	Fault zone end	Hole length
BB10-02	45	55	74.85	0	36.8	164.3
BB10-02	0	90	69.4	0	134.9	134.9
BB10-03	222	54	59.5	0	77.2	164.2
BB10-04	0	90	125.5	0	0	125.5
BB10-05	0	90	74.2	0	0	83.3
BB10-06	0	90	91.9	0	0	98.6
BB10-07	0	90	47.7	0	0	59.2
BB10-08	50	55	110.5	0	50	118.2
BB10-09	230	55	13.4	0	63.6	63.6
BB10-10	54	55	119.4	0	59.4	125.5
BB10-11	234	54	130.2	0	92.8	134.4
BB10-12	0	90	138.8	0	0	143.4
BB10-13	0	90	173.3	0	0	173.9
BB10-14	0	90	133.65	0	0	134.9
BB10-15	0	90	88.1	39.4	65.9	90.8

DDH No.	Azim	Dip	Dolerite – sediment contact	Fault zone start	Fault zone end	Hole length
BB10-16	0	90	119.7	0	0	122.9
BB10-17	0	90	87.7	0	0	90.2
BB10-18	230	55	82.4	0	33.2	86.2
BB10-19	230	55	72.6	0	29.5	74.8
BB10-20	50	55	117.6	0	93.5	121.2
BB10-21	50	65	113.2	0	87.4	114.6

### 3.1 Defect Orientations – surface mapping

The data from the surface mapping provided by Delta Materials has been plotted on the stereonet (Figure 3) as a compilation of all data (Figure 3a) and those classified by Delta Materials as “main” (Figure 3b) and “secondary” (Figure 3c). That Figure shows that there is no significant difference in orientation between the “main” and “secondary” classifications. The data clearly shows strong development of sub-vertical north-south striking joints (designated as Set 1) and east-west striking joints (designated as Set 2) and under both classifications suggesting that the local development (length and spacing) seen at the surface mapping sites is variable.

The Figure also shows that there are sub-vertical joints striking northeast-southwest (designated as Set 4) as well as numerous other sub-vertical orientations.

This data shows a typical pattern of major joint set development, with additional sub-vertical orientations, all due presumably from cooling of the dolerite.

The data set is biased against moderate to flat dipping defects.

### 3.2 Defect orientations – oriented drill core

The defect orientations recorded from the oriented drill core are plotted on the stereonet as Figure 3, as joints from the dolerite rock mass (Figure 3a), joints from the sediment rock mass (Figure 3b) and veins, faults and bedding from the sediment rock mass (Figure 3c). This data is all from the moderately plunging drill holes that were all sited in the fault zones in the Phase 1 drilling program (Figure 1). As all these holes were collared in the centre of the wide fault zones and as core orientation was only possible outside the fault zones (due to the broken nature of the fault zones themselves) this means that the oriented defect data all comes from

depth (in typically fresh rock) but which is within 30 to 60 metres of the fault zone contact. There is thus no data available from the main rock mass remote from the faults at this point in time. The drill holes were all drilled either plunging northeast or southwest (nominally normal to the strike of the faults) and this means that the data recorded is biased against moderate dipping defects that strike in the same direction.

The data as supplied contains some errors in the determination of the beta angle, in particular, the majority (80%) of the bedding orientations all are incorrect with the up dip apex measured to instead of the down dip apex. These have been corrected in this analysis.

An audit of 25% of the 130 joint orientations available, using the core photos supplied, suggests that in some holes there are up to 12% errors. These errors cannot be accurately corrected from core photography as the core photographs were not taken with the reference line consistently in view and the core re-assembled. No attempt has been made to correct the joint orientation readings.

### 3.3 Defect orientations – summary

The surface and down hole data show that:

1. There are 5 joint sets developed in the dolerite rock mass (at least in the rock mass close to the major northwest-southeast striking faults). The mean orientations for these are given in Table 3. The fact that three of these joint sets are also found in the surface mapping suggests that these joint sets are developed throughout the dolerite rock mass and may be related to cooling of the dolerite. The surface mapping would be biased against the moderate to low dipping joints recorded in the drill hole data and it is suggested that these joints are probably also regionally developed throughout the dolerite rock mass in this area.

Two sub-vertical joint sets (designated sets 1 and 2) are orthogonal and strike north-south and east-west respectively. A third sub-vertical set (designated set 4) strikes northwest-southeast, sub-parallel to the regional faulting trend. Two moderate to low dipping joint sets (designated 3 and 5) dip to the north and south west respectively.

2. Two joint sets are found in the sediments below the dolerite rock mass and these have a similar orientation to those found in the dolerite rock mass (designated sets 4 and 5), suggesting they are regionally developed joint sets. These two joint sets are roughly orthogonal and have a similar strike to the northwest-southeast trending and vertical regional faults. This, and the fact they are also present in the dolerite rock mass, suggests they were developed at the same time, post dolerite intrusion and are tectonic in nature.
3. Bedding in the sediments (at depth) shows a general trend of low dip to the southwest. There is some scatter in the bedding data which may reflect local small scale folding. The measured mean orientation of the bedding from the drill core, 13° to the southwest,

conforms to the gross orientation of the top of the sediments as determined from the contact locations determined from each of the 21 drill holes.

4. The orientations of all five joint sets appear to have been rotated by the same amount as the bedding, suggesting that the major joints sets were orthogonal to the bedding when created and have now been rotated slightly to the northeast along with the bedding. This conformance lends credence to the regional nature of the joints sets measured. Thus it is considered that the measurements taken, although limited in number, are representative of the rock mass in the area.
5. On the basis of the joint orientations, and the absence of any data on joint spacing, it is assumed that the rock mass in the area is all one structural domain.
6. There is insufficient information to determine the orientation trends for veins and minor faults.

**Table 3 Major Defect Orientations (not in order of importance)**

<b>Defect</b>	<b>Location</b>	<b>Mean Orientation (dip/dip drn)</b>
Joint Set 1	Dolerite rock mass	81°/091°
Joint Set 2	Dolerite rock mass	86°/353°
Joint Set 3	Dolerite rock mass	46°/345°
Joint Set 4	Dolerite rock mass Sediment rock mass	84°/038°
Joint Set 5	Dolerite rock mass Sediment rock mass	47°/229°
Bedding	Sediment rock mass	13°/192°

The development of some of these major joints can be seen in the limited exposures in the small TasPorts quarry developed in the eastern edge of the area. These exposures are shown in Figure 4 which is annotated with the major joint sets as exposed.

### 3.4 Defect properties

For the oriented defect data, the defect properties of aperture, roughness, infill and weathering have been classified according to the joint set designation. This is shown in Table 4.

The remaining data (where the alpha angle only is available from vertical and un-oriented core) has been classified into two groups, those with alpha angles greater than  $24^{\circ}$  (representing true dips of less than  $66^{\circ}$ ) and those with alpha angles less than  $24^{\circ}$  (representing true dips of greater than  $66^{\circ}$ ). These two groups represent joints sets 3 and 5 and any unclassified moderately dipping joints and joint sets 1, 2 and 4 and any unclassified steeply dipping joints, respectively. The defect properties of aperture, roughness, infill and weathering for these two groups are also shown in Table 4.

This data in Table 4 shows reasonable consistency across each joint set and suggests that the majority of the joints, regardless of joint sets designation are, slightly rough and undulating with 0.1 to 1 mm of hard infill. There are similar numbers of moderately to slightly weathered to fresh joints as would be expected for drilling that is collared at surface and extends to depth. The oriented core data reflects only fresh and unweathered joints simply because all the data is from depth only.

Table 4 Joint Property Data

Dolerite_Rock mass Vertical Hole Data						Dolerite Rock mass Inclined Hole Data					
For Alpha >24°				For Alpha <=24°							
Dips < 66°				Dips >= 66°							
Sets 3,5,unclassified				ets							
Samples = 546				1,2,4,unclassified							
				Samples = 599							
Aperture	Description	Freq	%		Freq	%	Set 1	Set 2	Set 3	Set 4	Set 5
0	5-10 mm	4	1%		11	2%	38	8	15	16	15
1	1-5 mm	129	24%		217	36%					
2		0	0%		0	0%		4		3	1
3		1	0%		0	0%					
4	0.1-1 mm	353	65%		259	43%	37	3	15	11	6
5	< 0.1 mm	9	2%		9	2%				1	5
6	none	50	9%		103	17%	1	1		1	3
		546	100%		599	100%					
Roughness	Description	Freq	%		Freq	%					
0	slickensided	6	1%		18	3%					
1	Smooth Planar	4	1%		12	2%					
2		1	0%		1	0%					
3	Slight rough, Undulating	519	95%		535	89%	36	7	15	16	13
4		0	0%		1	0%					
5	Rough, undulating, stepped	16	3%		29	5%	2	1			2
6	Very rough, stepped	0	0%			0%					
?	unclassified	0	0%		3	1%					
		546	100%		599	99%					

### 3.5 Joint Spacing

The geotechnical data recorded does not record each joint which means it is not possible to accurately determine the spacing of joints within each of the identified joint sets. The logs include RQD measurements for the core. This parameter can be used to estimate fracture intensity ( $J_v$ ) in the rock mass.  $J_v$  is the volumetric joint count, that is the number of joints per cubic metre. The breakdown of the core records are given in Table 5.

**Table 5 RQD Classifications**

Records	By lithology	By location
1324 (2464.01 m)	1147 (2047 m) Dolerite	669 (1327.1 m) Rock mass
		478 (690.0 m) Fault
	177 (417 m) Sediments	110 (284.3 m) Rock mass
		67 (132.7 m) Fault

The results of the RQD analysis are shown in Table 6.

**Table 6 RQD Analysis**

Statistic	Dolerite Rock mass	Dolerite Fault	Sediment Rock mass	Sediment Fault
Minimum	0	0	0	0
24% quartile	55	0	35.5	0
50% quartile	77.5	20	67.8	21.6
75% quartile	92.8	40	88.7	44
Maximum	100	100	100	94
Interval Weighted Mean	70.4	25.0	60.3	28.3
Weighted Standard Deviation	27.2	25.2	32.9	28.4

The data clearly shows that, whilst there is a wide scatter of results, the RQD data recorded in the rock mass is significantly higher than those recorded in the faulted zones, irrespective of the rock type. The dolerite and sediments (rock mass or fault) cannot be distinguished in terms of RQD.

The relationship between RQD and Jv is:

$$RQD = 115 - 3.3 Jv \text{ (Reference 3)}$$

Based on this relationship and the median (50% quartile) values determined above the volumetric joint counts are estimated at:

**Table 7 Volumetric Joint Count Estimates**

<b>Lithology</b>	<b>Location</b>	<b>Jv (joints/m<sup>3</sup>)</b>
Dolerite	Rock mass	11.4
Dolerite	Fault	28.8
Sediment	Rock mass	14.3
Sediment	Fault	28.3

The Jv values for the dolerite and sediments both indicate that 50% of the rock mass (that is not faulted) will have volumetric joint counts lower than 14 joints per cubic metre. The absolute value estimated from the RQD alone are high, with limited exposures in the TasPorts quarry suggesting values of 6 to 10 is more appropriate to the dolerite rock mass.

Whilst the geotechnical data has recorded individual defects in the core from only selected depths the records do provide an indication of the joint frequency, albeit one that cannot be separated to determine the individual joint set frequencies. Analysis of the records is given in Table 8 to provide an estimate of the length weighted mean joints per linear metre in the plane of the drill holes.

Data in Table 8 (vertical drill holes) predominantly reflects the joint density from joint sets 3 and 5, as the remaining sets are sub-vertical and biased against in vertical drill core.

**Table 8 Joint Frequency Analysis - Vertical Drill Holes**

<b>Lithology</b>	<b>Location</b>	<b>Drill holes</b>	<b>Length</b>	<b>No joints</b>	<b>Mean Joints/m</b>
Dolerite	Rock mass	4,5,6,7,12,13,14,15,16,17	998.6 m	1110	1.1
Sediment	Rock mass	12,13,14,15,16,17	9.75	31	3.1
Dolerite	Fault	2,3,15	188.6	245	1.3

The inclined drill holes also sample the sub-vertical joint sets and the data from these holes is given in Table 9. The increased joint density compared to the vertical drill hole data set is shown for the dolerite in the data in this table. Data for the sediments is very limited in comparison but taking both data sets it would appear that the sediments in the immediate contact zone with the base of the dolerite are more jointed than the dolerite itself.

**Table 9 Joint Frequency Analysis - Inclined Drill Holes**

<b>Lithology</b>	<b>Location</b>	<b>Drill holes</b>	<b>Length</b>	<b>No joints</b>	<b>Mean Joints/m</b>
Dolerite	Rock mass	1,3,8,10,11,18,19,20,21	453.6	589	1.5
Sediment	Rock mass	10,11,18,19,20,21	14.3	36	2.5
Dolerite	Fault	1.8.9.10.11.18.19.20.21	489.9	768	1.6

### **3.6 Rock Strength**

Some 900 point load strength tests (both axial and circumferential) were conducted during logging of the core by Delta Materials staff. The breakdown of these tests is in Table 10.

**Table 10 Point Load Strength Test Classifications**

Total tests recorded	Valid tests (Delta Mat. Review)	By lithology	By location	By type
900	794	786 Dolerite	590 Rock mass	292 Diametral
				298 Axial
			296 In Fault	98 Diametral
				100 Axial
		8 Sediment	8 Rock mass	4 Diametral
				4 Axial

The data, predominantly tested from NQ core, is shown in Figure 5, which shows that the point load strengths are widely scattered for each of the major classification. Both axial and diametral test results have been combined as testing in this manner is usually only relevant in bedded/schistose material, and the results appear in Table 11.

**Table 11 Combined Axial/Circumferential Point Load Strength by Rock Type**

Rock Type	Count	Is(50) MPa	Is(50) MPa	Is(50) MPa
		25% quartile	50% quartile	75% quartile
Dolerite rock mass	587	6.7	9.6	11.6
Dolerite in fault	197	5.4	9.7	11.9
Sediment rock mass	8	0	0.1	0.3

On the basis of the data in Table 11 there is no obvious difference in point load strength between the test results in the dolerite in faulted and rock mass domains. However, the point load strength tests conducted in the fault zone were on the harder and more competent pieces of core. Delta Materials personnel estimate that some 27% of the Central Fault is competent dolerite and the remainder is poor quality rock and breccia. For the dolerite rock mass, the results indicate that 75% of the tests indicate a point load strength greater than 5.4

MPa, that is, strong rock with an expected unconfined compressive strength in excess of 100 MPa (assuming unconfined compressive strength is 25 x point load strength), and nearly 50% of the tests indicate a point load strength greater than 10 MPa, that is, extremely strong rock with an expected unconfined compressive strength in excess of 250 MPa.

The point load data shows a significant decrease in point load strength in the bottom 15 metres of the dolerite sill compared with strengths determined above 15 metres from the base of the dolerite. The circumferential tests indicate point load strengths of 8.4 and 10.4 MPa. However, whilst there is a reduction in strength at the base of the dolerite that reduction in real terms see the rock have an estimated unconfined compressive strength go from 260 MPa to 210 MPa, still a very strong rock.

There is very little data available for the sediments. Whilst 8 tests were recorded, 3 of these have zero values but are still recorded as valid tests. The results indicate that the sediments immediately below the dolerite are extremely weak with an expected unconfined compressive strength of less than 1 MPa. Point load testing is, however, unreliable at these low strengths. Observations by Delta Materials personnel indicate that the material is sandstone with some laminated mudstones and can be broken easily by hand, confirming a very low (less than 1 MPa) unconfined compressive strength.

### **3.7 Fault Properties**

There has been no specific sampling of the faults for geotechnical properties. Observations by Delta Materials personnel of the core recovered from the Central fault indicate that 70% or more of the material is poor quality. Observations by Coffey Mining of the conditions of a large fault exposed in the TasPorts quarry suggest that the faults may contain highly slaking material which breaks down completely on exposure. This may be a result of significant chlorite and smectite alteration. This could also be expected in the main faults in the area. Drilling and surface mapping has delineated three major northwest–southeast striking fault zones (Figure 1). The zones are shown in cross sections developed by Delta Materials as 60 to 80 metres wide and vertical. In addition, a northeast-southwest striking fault is also interpreted (Figure 1). This is less well defined and appears in sections developed by Delta Materials without significant width and dipping steeply to the north.

The data in Table 8 and Table 9 indicates that the joint density (measured as RQD) is double that of the surrounding dolerite rock mass.

### **3.8 Groundwater**

At this stage in the evaluation of the Bell Bay Quarry a detailed groundwater investigation has not been undertaken and Delta Materials personnel report that groundwater levels are not well defined. It is reported that the groundwater table is only just below the surface in some of the drill holes drilled to date. Some holes near faults were reported as making water in early 2010. At this stage in the evaluation of the quarry, the rock mass is considered to be saturated and the fault zones are considered to be re-charged regionally.

## QUARRY WALL STABILITY

From the data currently available for the dolerite rock mass it can be concluded that the rock mass will comprise a very strong (greater than 100 MPa unconfined compressive strength) to extremely strong (greater than 250 MPa unconfined compressive strength) rock intersected by joints that are very widely spaced (0.6 – 2 metres) and very long, usually exceeding 5 metres and are slightly rough and undulating. The rock mass will be blocky with five major joint sets developed throughout. Two of those joint sets are orthogonal, dipping sub-vertically and striking north-south and east-west. Another two joint sets are also orthogonal both striking northwest-southeast with one set sub-vertical and the other set dipping moderately to the southwest. A fifth set has a moderate dip, striking more east-west. All five joint sets appear regionally developed and have orientations consistent with being formed before the slight (13°) tilting of the sediments and dolerite to the south-west.

The sediments immediately below the dolerite contact appear more strongly jointed and are, based on very limited data, appear considerably weaker with an estimated unconfined compressive strength of less than 1 MPa. This zone will form a weak layer in the quarry floor should it be exposed in the toe of the proposed quarry developments. Given the expected wet groundwater conditions it can be also be expected that this zone may have positive pore water pressures, further reducing its shear strength on exposure.

At the time of writing this report there are no detailed quarry development plans available. However, Delta Materials has suggested that the quarry will be developed between the major northwest-southeast striking fault zones and these fault zones will not be quarried. This suggests that the final quarry walls will strike northwest-southeast and northeast-southwest. The latter will be bounded by the inferred faults with the same orientation. In this scenario it is anticipated that the quarry production faces will be northeast-southwest and advance to the southeast. Delta Materials have also indicated that they plan to have the final walls at a 45° overall angle. The individual batter geometry is yet to be determined and will be a function of equipment selection and geotechnical considerations but a reasonable geometry would see batters 15m high, angled at nominally 70° and berms 10 m wide.

Given this scenario it is possible to make some general comments on the expected wall stability for both final walls and production faces. These comments can be taken into consideration during detailed mine planning and design.

### 3.9 Overall wall stability

Delta Materials advise that they are planning on final walls at 45° inter-ramp angle. Given the plan to not quarry the major fault zones this means that the final walls in the central and northern zones will be bounded on three sides by major fault zones (see Figure 1). The final wall heights are indeterminate at this time as the final wall locations are not available but the wall heights are expected to exceed 60 m and in one area could exceed 100m. This geometry has been modelled to assess the potential for complete wall failure. This is most likely on the

northeastern walls as the base of the dolerite/top of sediments dips out of the quarry wall to the southwest. The walls will abut the fault zones which are assumed to be saturated and so high water pressures could be built up behind the slope.

Using the limited data (RQD, point load strength) available, the rock mass strengths for the dolerite and the top of the sediments have been estimated using the program Rocscience RockLab. This software estimates the rock mass strength given the unconfined rock strength (estimated from the point load strengths), the GSI geological strength index, a measure of rock blockiness and expected excavation conditions, the intact rock parameter  $m_i$ , from published tables for standard lithology and the expected disturbance due to blasting. The assumed values and the estimated rock mass strengths are given in Table 12.

**Table 12 Estimated Rock Mass Strength Properties**

Lithology	Strength (MPa)	GSI	$m_i$	Disturbance	Estimated Cohesion, Phi
Dolerite rock mass	>250	Very blocky, Good surface 55	16	Good blasting 0.7	$c = 1350 \text{ kPa}$ , $\Phi = 58^\circ$
Dolerite Fault	>100	Very blocky, good surface 55	16	Good blasting 0.7	$c = 0 \text{ kPa}$ , $\Phi = 50^\circ$ (assume cohesion zero)
Sediment rock mass	<1	Blocky, surface good 65	12	Good blasting	$c = 90 \text{ kPa}$ , $\Phi = 18^\circ$

The results of the analyses, conducted using the software RocScience SLIDE are shown in Figure 6, representing four base cases. The estimated Factor of Safety (FOS) for each case is given in Table 13.

**Table 13 Estimated FOS for northeast wall abutting major fault zone**

Case	Description	Estimated FOS
1	45 ° overall slope in dolerite, 60 m high. Sediment exposed in toe, bedding slope 13°, vertical fault zone immediately behind slope. Dry conditions	1.3
2	45 ° overall slope in dolerite, 60 m high. Sediment exposed in toe, bedding slope 13°, vertical fault zone immediately behind slope. Drawdown of groundwater	1.2

Case	Description	Estimated FOS
	table at 26° from toe of slope regardless of lithology.	
3	45 ° overall slope in dolerite, 60 m high. Sediment exposed in toe, bedding slope 13°, vertical fault zone immediately behind slope. Drawdown of groundwater table at 26° from toe of slope in dolerite but fault assumed fully charged.	0.9
4	45 ° overall slope in dolerite, 60 m high. Sediment exposed in toe, bedding slope 0°, no vertical fault zone immediately behind slope representing north west, south-west walls. Drawdown of groundwater table at 26° from toe of slope.	6.5

The analysis shows that, for the worst case north-walls adjacent to the fault zone, the FOS are only just acceptable even for dry slopes. Where a groundwater table exists, and is drawn down by the quarry excavation, the FOS is below normally accepted limits for significant pit walls. Where water is recharging the faults the extra head of water is sufficient to produce failure of the wedge of dolerite on the sediment contact.

This study indicates that dewatering of the quarry will be required possibly involving an active groundwater pumping system. Certainly the indications are that dewatering of the major fault zones where they abut the final walls will be needed using horizontal drain holes as a minimum. Reducing the slope angle in the modelled geometry will have little influence on the overall stability as the stability of the wedge of dolerite is determined primarily by the low friction sediments at the base and the potential groundwater pressures. Design of the dewatering system will require rock mass permeability testing which is not available at the time of writing this report. For future studies it should be assumed that horizontal drainage in the north eastern faces at least will be required with a layout to be assessed during detailed feasibility study. The analysis also suggests there may be scope to increase the factor of safety by leaving a skin of dolerite in the quarry floor and not exposing the low strength sediments. That skin may be only a few metres thick as the dolerite is still very strong near the base. There is not sufficient certainty in the assumed rock mass properties of the sediments and dolerite to accurately determine this skin thickness at this time.

The analysis also estimates an acceptable FOS for a dolerite slope remote from the faults and where sediments are not dipping out of the slope. This is the case for the north west, south-east and south-west walls. In this case a normal drawdown of groundwater has been assumed.

### 3.10 Batter Stability

Drill hole data and limited exposures in the TasPorts quarry indicate that batter stability will be controlled primarily by the large and extensive jointing developed throughout the dolerite rock mass. At this stage there is a reasonable estimate of the orientations of the major joint sets but very limited data on spacing and length of these sets. The exposures in the TasPorts quarry indicate that joints belonging to sets 1 and 2, both sub-vertical joints, are long, exceeding typical 10 m batter heights and spaced at 1 to 5 metres. Thus large blocks may be formed in the batters which, if they fail, could result in significant loss of berm width (and thus access) and/or serious safety concerns. The limited data means that detailed kinematic analysis of possible wedge failures in the batters is not warranted at this time as the block size is indeterminate and the orientations of proposed final and production faces is not known. However, comments can be made on general stability conditions from block exposed in various wall orientations which can be used for preliminary wall design.

The dolerite rock mass contains five major joints sets as described above. Delta Materials have prescribed the final overall slope angles, at this stage of studies, as 45°. We assume that batters are 70° and some 15 metres high. To achieve the 45° design this requires a berm width of 10 metres. In general losing 2 metres off the crests of the batters would not be an operational problem but losing 5 metres would be, as access could then no longer be guaranteed.

#### 3.10.1 South-west walls

Table 14 describes the geometry for the major joint sets for this wall orientation.

**Table 14 Major Joint Set Conditions for south west faces (dipping to north east)**

Joint set	Expected conditions
1	Cuts at 45° to slope, does not daylight in 45° (overall) or 70° (batter) slopes.
2	Cuts at 45° to slope, does not daylight in 45° (overall) or 70° (batter) slopes.
3	45° strike to batter face and most members of the set will daylight out of the slope.
4	Strikes sub-parallel to the slope and does not daylight out of the slope
5	Dips into slope.

For the batters, major wedges can be formed with a combination of joints from sets 3 and 1 (those members of the set with lower dips to north east). These wedges can be large and can result in overbreak of the crests exceeding 10 m for a 15 metre high batter. Joint lengths of 10 to 20 metres are required to form the largest wedges. Observations in the TasPorts quarry

and the local railway cutting suggest that this is possible for joint set 1 but members of joint sets 3 were not obvious in either of the exposures so the length characteristics of joint set 3 are unknown.

For multi-bench failures, the major wedges would need very long joints in excess of 50 metres would be required. There is no data to suggest whether these joint lengths exist in the rock mass.

The crests will be affected locally by joint sets 1 and 2. These sub vertical sets could result in jagged crests with the loss of a few metres. This behaviour is evident in the TasPorts quarry (Figure 4.)

### 3.10.2 South-east walls

Table 15 describes the geometry for the major joint sets for this wall orientation.

**Table 15 Major Joint Set conditions for south east faces (dipping to north-west)**

Joint set	Expected conditions
1	Cuts at 45° to slope, few members will daylight out of the slope.
2	Cuts at 45° to slope, few members will daylight out of the slope.
3	45° strike to batter face and most members of the set will daylight out of the slope.
4	Cuts perpendicular to the slope
5	Cuts perpendicular to the slope

For the batters wedges can be formed with combinations of sets 3 and 1 (west dipping members). These wedges can be moderately sized and loss of up to 6 metres from the crest for a full batter height wedge could be experienced. Joint lengths of 15 to 25 metres are required to form these scale wedges. Observations from the limited exposures suggest that these lengths are possible for joint set 1 but are unknown for joint set 3.

For multi-bench scale wedges only a small proportion of the sets 3 joints would be shallow enough to daylight in the slope and exceed the friction angle. This is considered unlikely.

The crests will be affected locally by joint sets 1 and 2. These sub vertical sets could result in jagged crests with the loss of a few metres.

### 3.10.3 North-east walls

Table 16 describes the geometry for the major joint sets for this wall orientation.

**Table 16 Major Joint Set conditions for south east faces (dipping to north-west)**

Joint set	Expected conditions
1	Cuts at 45° to slope, few members will daylight out of the slope
2	Cuts at 45° to slope, few members will daylight out of the slope
3	Dips into face
4	Cuts perpendicular to face
5	Dips out of face with similar strike to walls

Large planar sliding blocks can be formed on joint set 5 in combination with sub-vertical joints from sets 1 and 2. These planar blocks could be extensive and extend across the 10 metre berm width as joint set 5 has been observed in the TasPorts quarry as a major joint set with trace lengths exceeding 20 metres (Figure 4).

The crests will be affected locally by joint sets 1 and 2. These sub vertical sets will result in jagged crests with the loss of a few metres.

### 3.10.4 North-west walls

Table 17 describes the geometry for the major joint sets for this wall orientation.

**Table 17 Major Joint Set conditions for north west faces (dipping to south-east)**

Joint set	Expected conditions
1	Cuts at 45° to slope, few members will daylight out of the slope.
2	Cuts at 45° to slope, few members will daylight out of the slope.
3	Dips into face
4	Cuts perpendicular to face
5	Cuts perpendicular to face

Large scale wedges do not appear feasible with the joint set orientations currently proposed. The crests could be affected locally by joint sets 1 and 2. These sub vertical sets could result in jagged crests with the loss of a few metres.

#### 4 CONCLUSIONS AND RECOMMENDATIONS

There is limited geotechnical data available for the dolerite and sediments that may be exposed in the proposed Bell Bay quarry development. The information regarding the sediments is currently inadequate to allow detailed slope design to be undertaken. Further drilling and sampling is therefore required to supplement this data and to allow detailed feasibility studies to be undertaken. The existing data set is suitable for scoping or conceptual levels of study and is only considered sufficient to provide indicative slope designs. Current designs have the quarry developing with walls bounded by the northwest–southeast fault zones, the northeast-southwest fault and at an overall slope angle of 45°.

Data includes orientation records for exposures of dolerite throughout the area, some 21 drill holes that have been logged routinely for RQD and field strength parameters. Selected indicative defects were also logged for orientation, roughness, mineral infill and aperture. This geotechnical logging was carried out by Delta Materials staff.

The data available indicates:

- The dolerite rock mass is very blocky being intersected by five major joint sets plus random oriented joints. Limited exposures and drilling indicate the joints are spaced such that the average joint spacing on a face is likely to be in the order of 1 to 2 joints per metre. Currently the data suggests that there is only a single geotechnical domain in the dolerite.
- The dolerite rock mass is saturated with current groundwater levels close to the surface.
- The rock mass is intersected by a series of parallel, vertical and wide (60 to 80 metre wide) fault zones. Within these zones the dolerite rock strength is reduced although it still classed as very strong. The joint density increases to 3 joints per linear metre. The same major joint sets orientations are expected in the faults although this is conjecture as no joint orientation measurements were available for the faulted dolerite. Exposure of a major fault in the TasPorts quarry indicates that the fault zones contain highly slaking mineralogy and have a predominance of sub-vertical joints. The fault zones are interpreted as regional features and are expected to be water carrying.
- The sediments below the dolerite are not well sampled but the data that does exist suggests that it has very low strength and has a jointing pattern in which some of the major joint sets developed in the dolerite also exist in the sediments. In addition, the sediments have bedding as a weakness plane.

- Given the current design of the quarry with 45° overall slope angles the quarry walls appear to be stable with the exception of those in the northeast that abut and are developed parallel to the major fault zones. In this area the combination of the sediments dipping out of the slope and groundwater pressures can combine to reduce overall slope instability.
- Local batter stability will be affected by the extensive jointing developed in the rock mass. Analysis of the kinematic stability of combinations of these joints indicates that those batters dipping northeast and southwest are likely to be the most problematic from the point of view of the potential for large wedge or planar block failures to occur. These wedges can be of a size to remove significant widths of the berms rendering the berms inaccessible. Batters that dip to the southeast appear to have the least potential for large wedge block failures to occur.

It is recommended that, in the second phase of drilling that is planned, consideration is given to:

- Sampling the sediments at least to 20 metres below the dolerite, in some drill holes, to obtain samples for unconfined compressive strength and elastic properties and direct shear testing of the bedding.
- Sampling of the dolerite to obtain samples for unconfined compressive strength and elastic properties testing to confirm the point load field index tests results recorded to date. That sampling should also include representative samples of the dolerite in the fault zones.
- Sampling of the fault zones to determine the extent and cause of slaking behaviour in the fault zones.
- The logging of every instance of jointing in selected drill holes so that joint spacing by major joint set can be determined.
- Mapping of the TasPorts quarry to determine joint length statistics and use this information to validate the global geotechnical model.
- Drilling of at least two drill holes to the northwest or south east to reduce the bias introduced by the current northeast and southwest plunging drill pattern
- Determine the groundwater conditions particularly in the fault zones and determine the permeability of the rock mass and fault zones so that drawdown behaviour can be confidently predicted and groundwater pumping designed.

## 5 REFERENCES

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## Figures