TR20_85_101

9. The River Derwent: Elwick Bay to Macquarie Point. Geology: Facts, deductions and problems.

D.E. Leaman

The second Derwent crossing in the Hobart Metropolitan area could be placed virtually anywhere between Macquarie Point and the south-eastern reach at Elwick Bay. The particular site will ultimately be selected on transport, planning and environmental factors. However, since cost, concept and design of the structure are affected by foundation conditions or restrictions this report has been prepared to provide a sketch of present knowledge about the river, its bed and its banks. The history of the river is crucial to an appreciation of the problems presented and this aspect is not neglected.

The report is divided into two parts. In the first all significant promontories or regions where an abutment or alignment might conceivably be required are mentioned and rock conditions described. Many localities may never be considered due to prior development but all are included so that a full appraisal of all options raised in planning discussions can be made. The second, more difficult and unquestionably more important part deals with the river and its bed. Facts are few, deductions are often dubious and outright guesses are legion. All knowledge is placed in perspective so as to underscore problems which may need resolution by geophysical survey or drilling. All maps are arranged serially so as to indicate the quality and quantity of data available.

1. RIVER BANK GEOLOGY AND ABUTMENT CONSIDERATIONS

Figure 17 provides an overall generalised indication of the known geology adjacent to the river. The coverage is presented in the form of material types. A geological sketch of the lettered localities is given below and is a generalisation applicable to a zone about 250 m wide near the point discussed.

Locality A: West of Otago Bay

Fine- to medium-grained dolerite. Although there is some rock discolouration and patchy weathering the surface exposures are in fair condition. On the foreshore wave action has opened all incipient thermal joints and a shattered appearance is presented. These minor joints can be expected to be tight within a metre of the surface. Few major joints are apparent and there is no preferred orientation. No difficulties should be experienced in this area and shallow excavation will reveal fresh, massive rock with very rare weathered zones.

Locality B: East of Otago Bay

Medium- to coarse-grained feldspathic sandstone. The sandstone contains quartz, feldspar and volcanic rock fragments. The proportion of feldspar and fragments is such that deep weathering is common. The exposed rocks, whilst reasonably firm, are oxidised and discoloured and much of the feldspar has been reduced to clay. The thick bedded sandstone dips west at about 8-10°. This picture is complicated by the presence of thin steeply dipping current beds trending NW. The whole unit is relatively massive with jointing sparse and structurally insignificant. The material should not pose any problems and its bearing capacity at depths of about 5 m would support any structure likely to be placed on it. Two possible complications may alter this conclusion. Interbedded claystone, if present, would weaken the rock mass resulting in down-dip slip failure. The problem could be overcome with deeper excavation. Small dolerite intrusions are present and excavation should pass

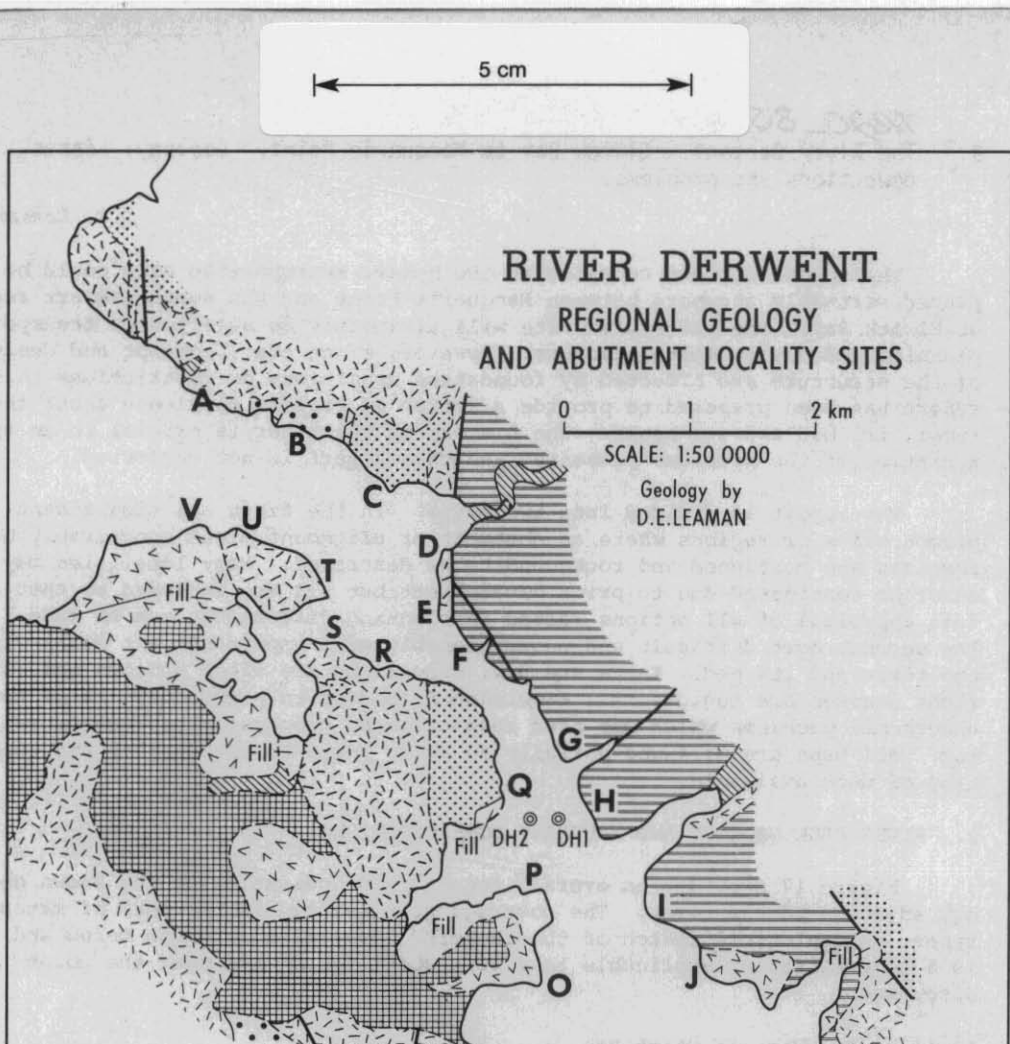
5 cm
RIVER DERWENT
REGIONAL GEOLOGY
AND ABUTMENT LOCALITY SITES
0
1
2 km
SCALE: 1:50 0000
Geology by
D.E.LEAMAN
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
Fill
DH2
DH1
Sand cover
RECENT
Alluvium
TERTIARY
Sand,clay,gravel.
Basalt.
JURASSIC
Dolerite.
TRIASSIC
Feldspathic sandstone.
Sandstone.
PERMIAN
Siltstone.
Fault.
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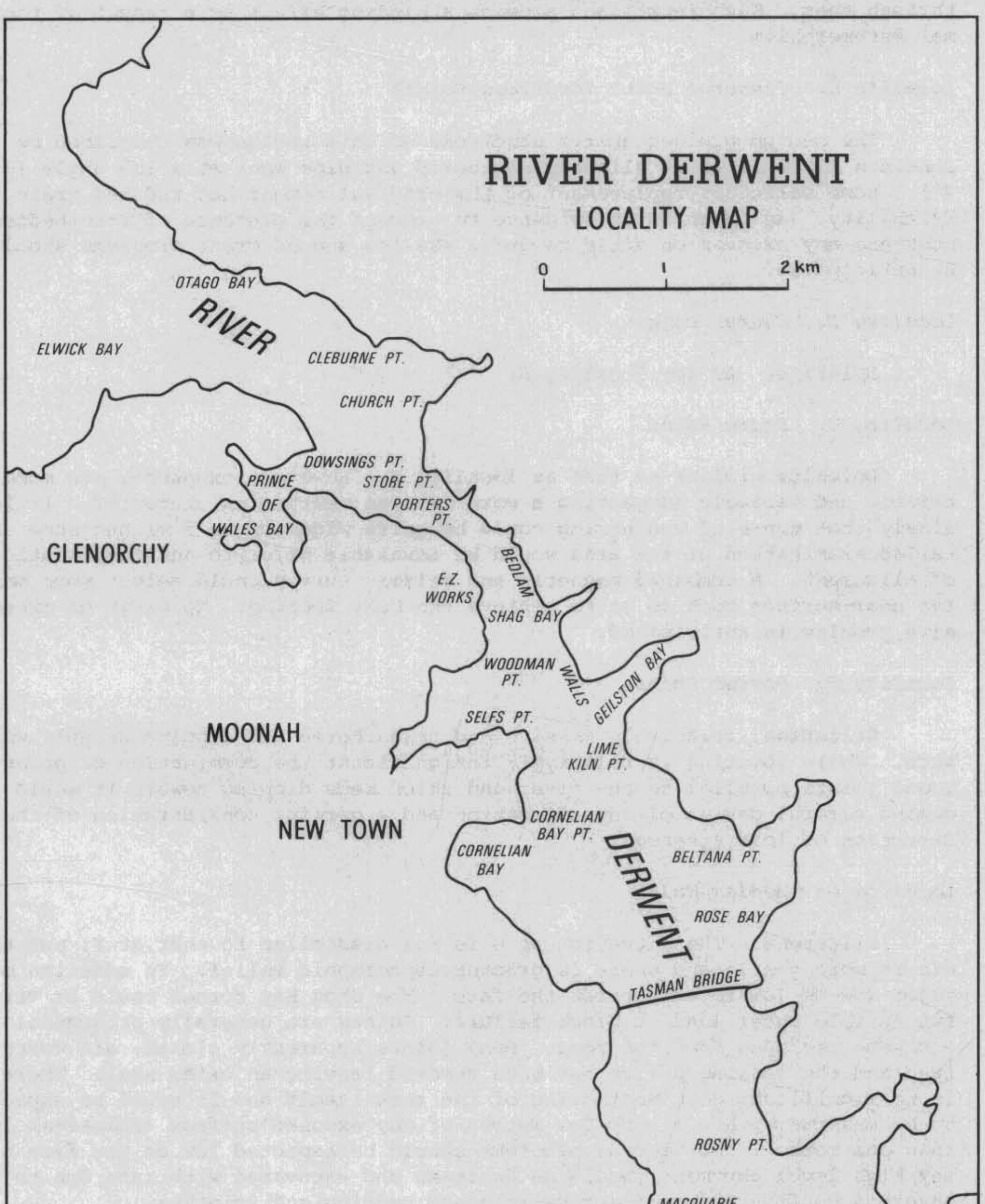
Figure 17.


RIVER DERWENT
LOCALITY MAP
0
1
2 km
OTAGO BAY
RIVER
ELWICK BAY
CLEBURNE PT.
CHURCH PT.
DOWSINGS PT.
PRINCE OF WALES BAY
STORE PT.
PORTERS PT.
GLENORCHY
BEDLAM
E.Z. WORKS
SHAG BAY
WOODMAN PT.
WALLS
GEILSTON BAY
SELFS PT.
MOONAH
LIME KILN PT.
CORNELIAN BAY PT.
NEW TOWN
CORNELIAN BAY
DERWENT
BELTANA PT.
ROSE BAY
TASMAN BRIDGE
ROSNY PT.
MACQUARIE PT.
BELLERIVE BLUFF
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4288

Figure 18.

through them. Such intrusions provide a binding effect as a result of thermal metamorphism.

Locality C: Cleburne Point (Courtoys Point)

The medium-grained quartz sandstone of this region was described by Jennings (1963). It is slightly weathered and dips west at a low angle (3-4°). Some siliceous replacement of the original cement has reduced grain friability. As there is no evidence to suggest the presence of interbedded mudstone any excavation could be quite shallow and no great problems should be anticipated.

Locality D: Church Point

Dolerite. As for locality A.

Locality E: Store Point

Dolerite similar to that at locality A. However, exposures are more erratic and variable suggesting a more diverse weathering character. It is likely that zones of weathering could be quite wide (up to 5 m) and some detailed examination of the area would be advisable prior to any finalisation of alignment. A combined magnetic and seismic survey could select more massive near-surface rock so as to achieve the best footing. No great or expensive problem is anticipated.

Locality F: Porter Point

Siltstone; relatively massive and unweathered but dipping steeply westward. While jointing is relatively insignificant the combination of occasional joints parallel to the river and thick beds dipping toward it would demand careful design of any excavation and a careful consideration of the direction of load stresses.

Locality G: Bedlam Walls

Siltstone. The situation at G is not dissimilar to that at F, but the dip is more gentle and there is greater topographic relief. In addition many major NNW-NW joints cut across the face. The Shag Bay corner could be very susceptible under load to block failure. Joints are generally orthogonal and some are open down the face. Many joints apparently closed, are weathered and the sealing pyrite has been removed leaving an oxide seal. There is no significant deep weathering of the rock itself and it could be expected to be massive within a very few metres of any exposed surface (sometimes less than one metre). No special problems should be expected low on the face but any high level abutment should be designed and excavated with care due to the observed configuration of stress-released bedding and jointing.

Locality H: Bedlam Walls

Siltstone; gently dipping, slightly corroded but which is quite a massive rock and should present few problems. There is less relief than at G and jointing problems are not significant.

Locality I: Lime Kiln Point

Siltstone. As for locality H.

Locality J: Beltana Point

Basalt. The basalt in this region is strongly discoloured and in places quite deeply weathered. Vertical joints predominate in a rock mass that is very disrupted. The rock itself is very variable and ranges from basalt to basalt scoria. Bearing properties will be variable and probably unpredictable until excavated or extensively drilled. In addition the thickness of the material is unknown and while it is possible that it may rest directly on a siltstone slope representing a previous valley side there may be clays at shallow depth. Lack of landslips does suggest that this may not be so.

Locality K: Tasman Bridge east abutment

Dolerite. This locality has been included for comparative purposes. The dolerite in this region is more massive and coarser grained than at localities A, D or E and it could be expected to have a greater bearing strength at shallower depth. However, the jointing apparent is more consistent than in the other localities. Overall, sites A or D would probably be very similar to develop.

Locality L: Rosny Point

Dolerite. Virtually continuous, massive and slightly weathered outcrops present better and simpler prospects than any of sites A, D, E or K. No problems could be expected and all joints would be tight at shallow depth.

Locality M: Macquarie Point

Dolerite or possibly sandstone depending on the exact location. Dolerite is the dominant rock in the region but it irregularly overlies quartz sandstone nearby to north, south and east. Small patches of sandstone are exposed where the dolerite has been removed. The dolerite is fine-grained and in places finely jointed and deeply weathered. The situation is similar to that pertaining at locality E and examination of the area would be necessary to select a good abutment site due to the variability apparent. The sandstone should present few problems as it is a more uniform material.

Locality N: Tasman Bridge west abutment

Dolerite. The situation here is not dissimilar to that at locality E and the site is here included to provide a comparison. Such a comment may also be taken to imply that given an appropriate excavation in dolerite the necessary bearing capacity and lateral resistance is always available and normally at very shallow depths.

Locality O: Cornelian Bay Point

Basalt. This site is superficially similar to locality J. The basalt is similar in appearance, composition, weathering and jointing. However the overall capacity of the site is controlled by the thickness of basalt which exceeds 15 m north of this locality. South of O the thickness is unknown but the basalt in the region is interbedded with clay and sand. A site developed on the point top should pose few problems in terms of excavation or support whereas a footing at sea level will need a more cautious approach until the quantity and type of supporting material has been assessed.

Locality P: Selfs Point

Fill on basalt. Basalt is present to at least 10 m below sea level.

In this region it is fresher and more massive. Site proving would still be essential as unexpected variations may be encountered. In general, basalt areas need more careful evaluation than any other and the sweeping assumptions which are often made in dolerite areas are not possible.

Locality Q: Woodman Point

Sandstone. As for locality C except that the westerly dip is here an advantage. No problems are anticipated.

Locality R:

Fine- to medium-grained dolerite which is slightly weathered and in general very similar to that at locality K. No problems are anticipated.

Locality S:

Dolerite. The material here is finely jointed, variable, very fine-grained and in part extensively weathered. Although the situation is complex with inclusions of baked mudstone and secondary intrusions the weathering is the factor requiring full evaluation. Moderate excavation might be necessary to overcome this difficulty.

Locality T: Dowsings Point

Dolerite. Conditions very similar to localities A and D. No problems are anticipated.

Locality U:

Dolerite. As for sites A, D and T.

Locality V:

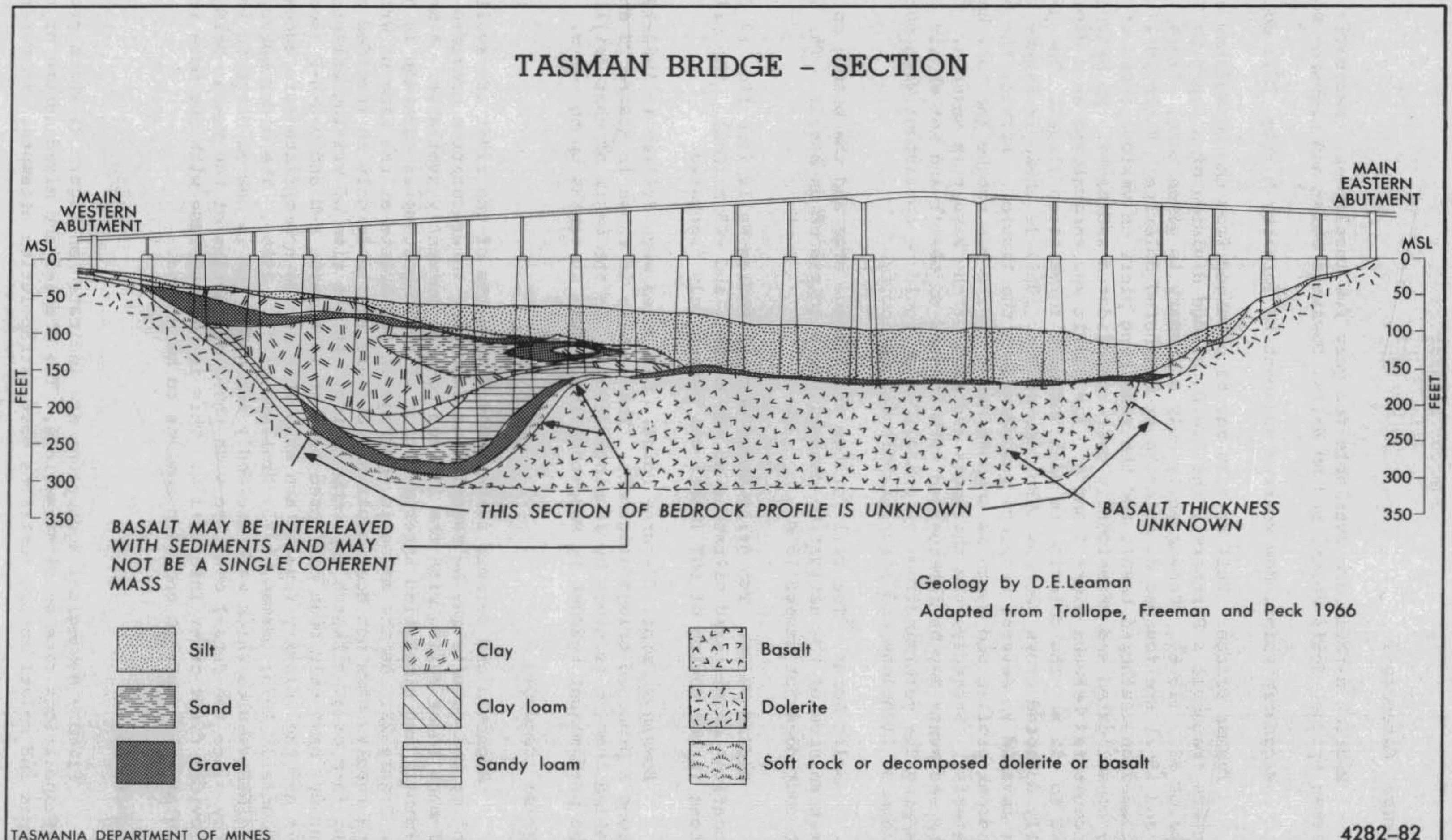
Basalt. Partly massive, partly scoriaceous. The overall appearance of the rock is reasonably good. However weathering features suggest that weathering effects may persist in depth. Jointing would not seem to be a problem here. Two important unknowns are the thickness of basalt and whether it overlies dolerite or the sand, clay and gravel which are patchily exposed to the north-west. Some drilling to resolve these problems will be essential.

In summary it may be stated that few localities will cause difficulties or have problems requiring much resolution. It is recognised that even the best locality will need to be confirmed and that particular alignments within it will need assessment prior to final design or construction. A combination of magnetic, resistivity and refraction surveys with perhaps 2 or 3 drill holes should adequately cover each specific site.

Dolerite or quartz sandstone localities are likely to be excellent and certainly would be simply assessed. Basalt localities should be treated with caution and any finality of judgment withheld until some site confirmation of conditions is available.

2. RIVER BED MATERIALS AND BEDROCK GEOLOGY

The following discussion has been categorised to allow a clear separation of fact from fancy and facilitate a fuller appreciation of the problems posed by an unusually wide and deep river valley.



TASMAN BRIDGE - SECTION
MAIN WESTERN ABUTMENT
MAIN EASTERN ABUTMENT
MSL
0
50
100
150
200
250
300
350
FEET
THIS SECTION OF BEDROCK PROFILE IS UNKNOWN
BASALT THICKNESS UNKNOWN
BASALT MAY BE INTERLEAVED WITH SEDIMENTS AND MAY NOT BE A SINGLE COHERENT MASS
Geology by D.E.Leaman
Adapted from Trollope, Freeman and Peck 1966
Silt
Sand
Gravel
Clay
Clay loam
Sandy loam
Basalt
Dolerite
Soft rock or decomposed dolerite or basalt
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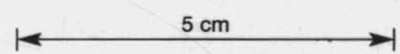
Figure 19.



5 cm

Bedrock Details

Facts: Category 1

Bedrock details are available for very few localities: Macquarie Point, Tasman Bridge, Selfs Point, Bedlam Walls, Dowsings Point and Cleburne Point.

Macquarie Point. New wharves adjacent to locality M (fig. 17): dolerite.

Tasman Bridge. Full details may be obtained from the consulting engineers (Maunsell & Partners), the P.W.D. bridge division or a paper by Trollope *et al.*, (1966). Consequently only a summary is given here. Piers 1 to 3 and 18-21 are founded on dolerite or weathered dolerite. Piers 10-17 are founded on weathered basalt and the remaining piers on various types of partly consolidated and occasionally over-consolidated sediments. No bedrock was encountered between piers 4 and 9. The basalt was encountered at a depth of -48 to -52 m. The dolerite to east and west forms steep slopes. The generally accepted cross section (Trollope *et al.*, 1966) is shown in Figure 19 but is invalid in several respects (as marked in the figure). Firstly the base bedrock profile and depth is unknown and dolerite may not be the only base material. Secondly, the thickness and form of the basalt is unknown. Thirdly the sediments may be interbedded with tongues of basalt and not wholly overlapping. The determinations of consolidation could be consistent with such a range of lithology and stratigraphic discontinuity.

Selfs Point. The fill for the oil storage area and the beacon on the western side of the navigation channel are both placed on basalt. The depth to rock does not exceed 15 m.

Bedlam Walls. Two drill holes west of Bedlam Walls (see fig. 17 for location) encountered siltstone at -48 m (DH1) and -65 m (DH2). The siltstone in the region of DH2 (west) was extensively fractured.

Dowsings Point, Cleburne Point. Six holes were drilled in 1962-1963 along a proposed bridge alignment. The section is shown in Figure 20 and detailed comment is given by Jennings (1964). On the basis of that drilling the predominant bedrock is sandstone and occurs at depths up to -48 m.

Facts: Category 2

Magnetic and seismic surveys covering parts of the river are available. Whilst the results may be regarded as facts any interpretation provided is of much lower rating with the limited control currently available. A preliminary and simplified interpretation of the magnetometer coverage is given in Figure 22. As the magnetic coverage is incomplete at the time of writing the results have not been published and are available only in recorded printout form or as a sketch map compilation. At the time of writing seismic surveys have only been conducted between localities K-N and Q-G-H-P (see fig. 17) and the velocity results are available in the appropriate references (Maunsell, 1973; Leaman, 1975; Trollope *et al.*, 1966). The older survey yielded results which were decidedly ambiguous and is now of historic interest only since the detail obtained with the construction of the Tasman Bridge provides first order information. This is not the case with the more recent Bedlam Walls surveys and much remains to be proved.

Deductions

Primary geological deductions are indicated on Figure 21 which provides extrapolations from shore situations. The complex and mixed nature of rock types and relationships restricts most extrapolation attempts. In general,

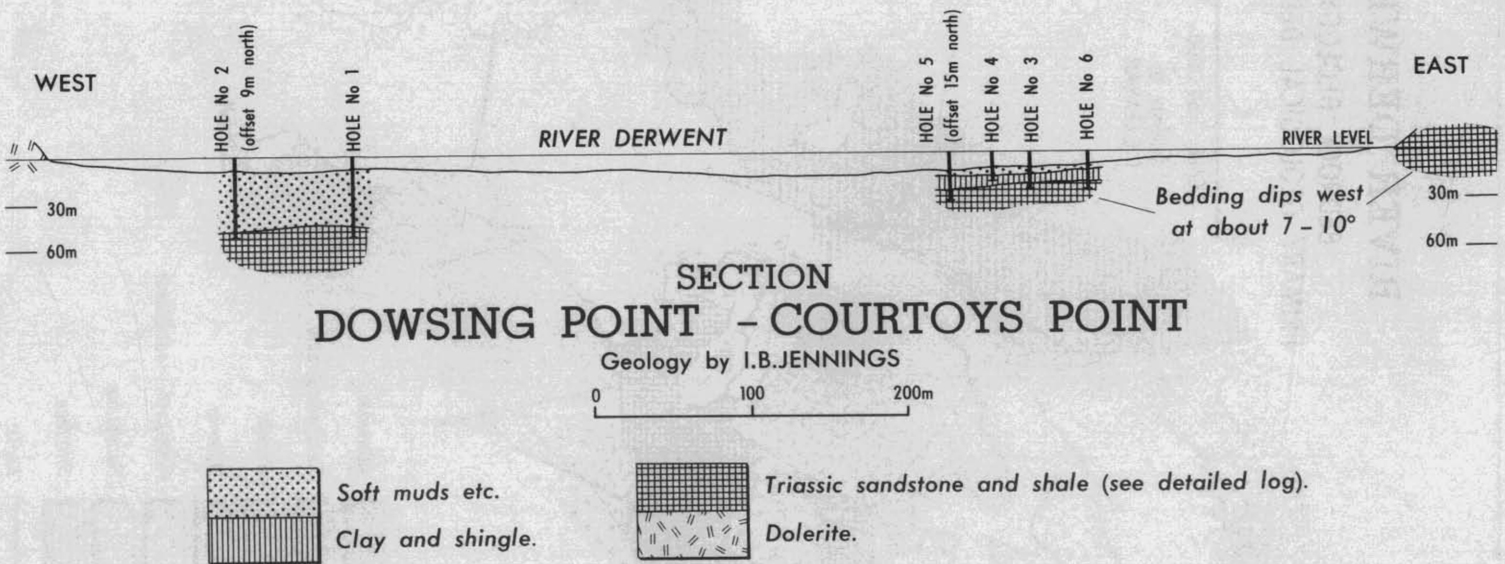

WEST
EAST
HOLE No 2 (offset 9m north)
HOLE No 1
RIVER DERWENT
HOLE No 5 (offset 15m north)
HOLE No 4
HOLE No 3
HOLE No 6
RIVER LEVEL
30m
60m
30m
60m
Bedding dips west at about 7 – 10°
SECTION
DOWSING POINT - COURTOYS POINT
Geology by I.B.JENNINGS
0
100
200m
Soft muds etc.
Clay and shingle.
Triassic sandstone and shale (see detailed log).
Dolerite.

Figure 20.

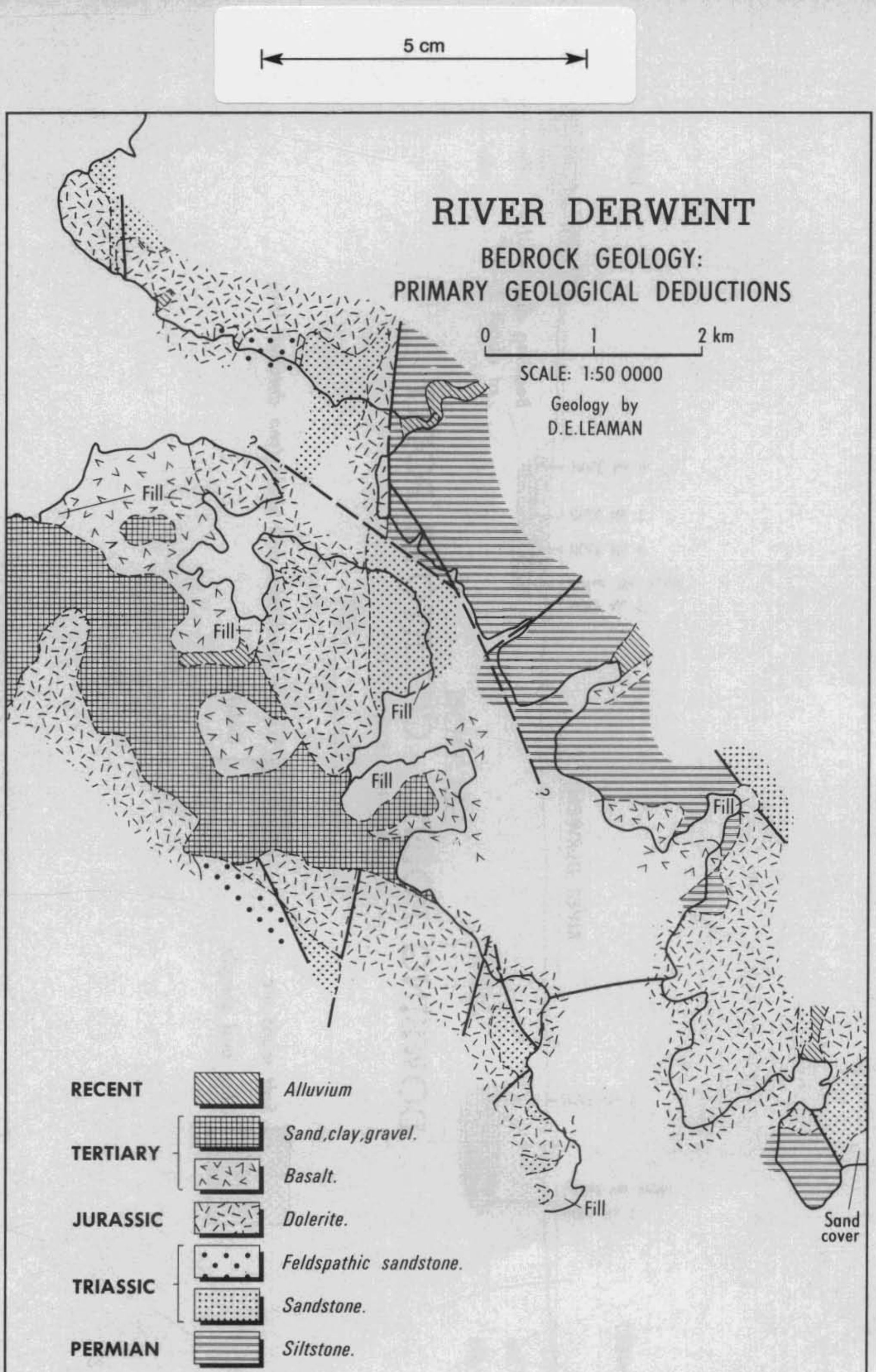

5 cm
RIVER DERWENT
BEDROCK GEOLOGY:
PRIMARY GEOLOGICAL DEDUCTIONS
0
1
2 km
SCALE: 1:50 0000
Geology by
D.E.LEAMAN
Fill
Fill
Fill
Fill
Fill
Fill
Sand cover
RECENT
Alluvium
TERTIARY
Sand,clay,gravel.
Basalt.
JURASSIC
Dolerite.
TRIASSIC
Feldspathic sandstone.
Sandstone.
PERMIAN
Siltstone.
Fault.
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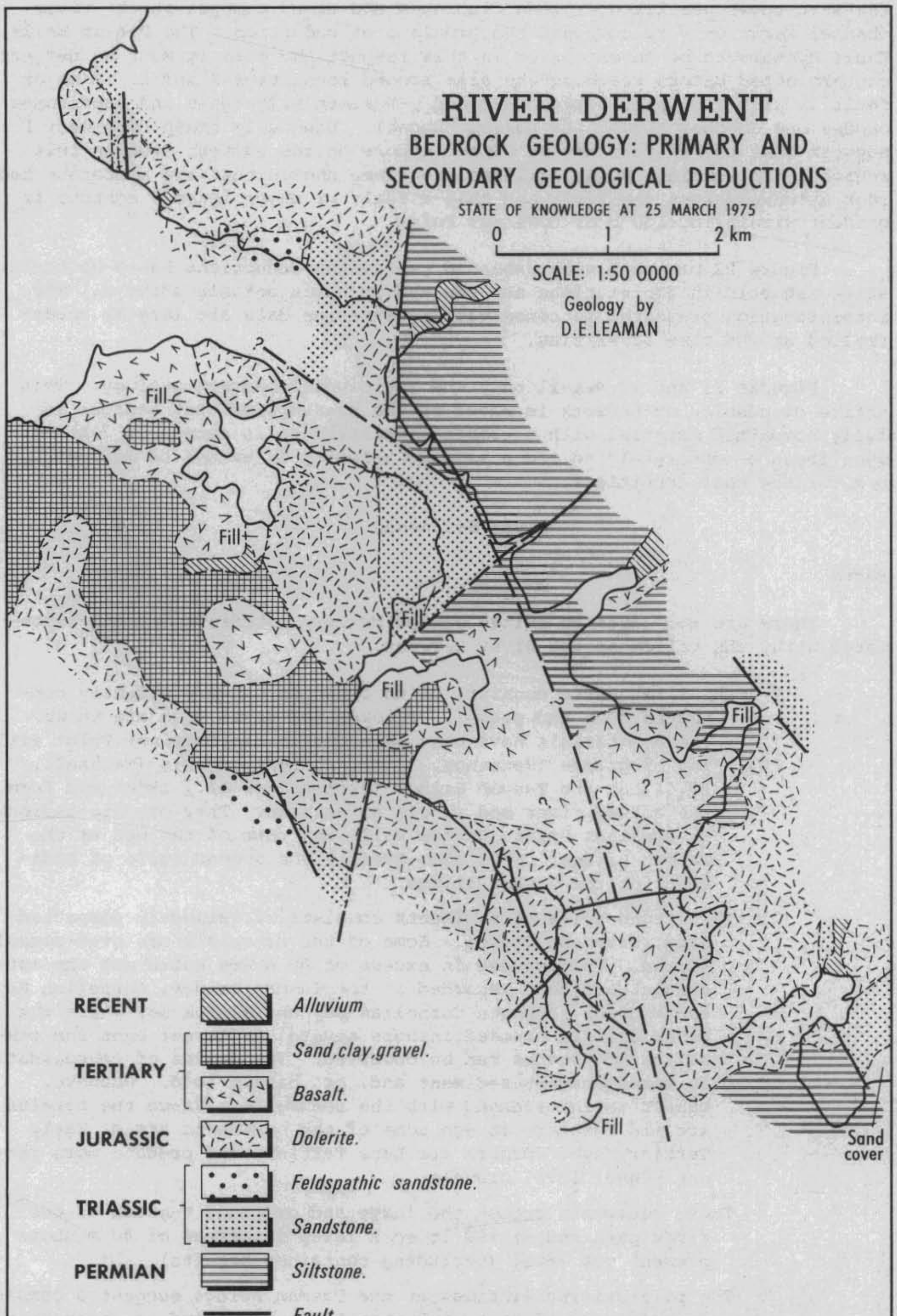
Figure 21.



RIVER DERWENT
BEDROCK GEOLOGY: PRIMARY AND SECONDARY GEOLOGICAL DEDUCTIONS
STATE OF KNOWLEDGE AT 25 MARCH 1975
0
1
2 km
SCALE: 1:50 0000
Geology by D.E.LEAMAN
Fill
Sand cover
RECENT
Alluvium
TERTIARY
Sand,clay,gravel.
Basalt.
JURASSIC
Dolerite.
TRIASSIC
Feldspathic sandstone.
Sandstone.
PERMIAN
Siltstone.
Fault.
TASMANIA DEPARTMENT OF MINES JUNE 1977
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Fioure 22.

few structures persist over long distances and trend changes in the river channel serve only to compound the problems of deduction. The Bedlam Walls Fault appears to be an exception in this respect and even it must be deflected or terminated before reaching the area around localities K and L. A major fault is also indicated between E-F and Q-R since siltstones and sandstones oppose one another across the narrow channel. Unusually steep dips near F suggest that the feature may be close inshore on the eastern side in this region. The Dowsings Point drilling programme showed that the sandstone bedrock extends across the river and that a fault or major igneous contact is present within 100-150 m of Dowsings Point.

Figure 22 presents some extended geological deductions based on qualitative magnetic interpretations and the Bedlam Walls seismic surveys. The interpretation presented is conservative since the data are largely uncontrolled at the time of writing.

Figures 21 and 22 detail only the anticipated bedrock geology. This entire discussion on bedrock is based on the presumption that bedrock is fully compacted material with a compressive strength in excess of 7 kt/m^2 when fresh or moderately so and a seismic velocity in excess of 3000-4000 m/s for the same conditions.

River Sediments

Facts

There are two distinct suites of sedimentary materials in, and associated with, the valley of the River Derwent.

(1) The first suite consists of uncompacted or very slightly compacted silt and gravel. Thicknesses up to 45 m are known. These materials have been recorded in the Dowsings Point drilling programme (Jennings, 1964), at Bedlam Walls (Maunsell, 1974), at the Tasman Bridge (Trollope *et al.*, 1966) and form the actual river bed in all situations. They overlie bedrock at Dowsings Point, Bedlam Walls and part of the bed at the Tasman Bridge. They also overlie the second suite of sediments at the Tasman Bridge.

(2) The second suite of sediments consists of variously compacted sand, clay and gravel. Some of the materials are over-consolidated. Thicknesses in excess of 80 m are known and the materials have been recorded at the Tasman Bridge, Cornelian Bay and Moonah. Between Cornelian Bay and Elwick Bay where the materials are exposed inshore several different ages and consolidation states can be observed. The degree of consolidation is determined by sediment and, or, basalt load. Onshore, basalt is interleaved with the sediments. Since the basalts are mid Tertiary in age some of the sediments are of Early Tertiary age. Others are Late Tertiary and predate more recent higher level gravels.

These sediments occupy the large and original V-notch of the river path and filled it to a level in excess of 40 m above present sea level (including contained basalts).

The pile-driving findings at the Tasman Bridge suggest a complex depositional history with more than one period of channel erosion in this suite of materials. Consequently a range of apparently incoherent consolidation figures may be observed.

No materials of this type are known between Selfs Point and Otago Bay-Dowsings Point.

Deductions

The first suite of sediments is considered to be Pleistocene in age and to have occupied a very recent channel cut by the river and which has a base level of about -50 m. This channel passes from Elwick Bay to Macquarie Point via Dowsings Point and Bedlam Walls. Its axis is on the eastern side of the river at the Tasman Bridge where the effective bedrock is basalt.

The second suite of sediments, with interleaved flows of basalt, is Tertiary in age and occupies the original valley of the river. The dendritic form of the valley and an estimate that more than 200 m of material is present was indicated by the gravity survey of the metropolitan area (Leaman, 1972). The several changes of course within this deposition series has resulted in a great range of properties for materials of the same basic lithological type at the same apparent depth in the suite. The maximum consolidation factor would be the result of a loading of >250 m at 2000 kg/m^3. The density quoted is a minimum since any basalt included in the sequence would increase this figure. Materials near sea level could be expected to show a load release effect from a prior consolidation of about 50 m at >2000 kg/m^3. At -50 m the consolidation ranges could be equivalent to 100 m at >2000 kg/m^3 or as little as 15 m at <2000 kg/m^3 depending on whether the material under examination is the 'original' valley fill or a fill in a more recent channel at a higher base level.

While the second suite of sediments in all its forms offer considerable frictional resistance to piles it cannot be anticipated that the first suite will do so to any significant degree. Coarse gravel consisting very largely of dolerite fragments can be expected above bedrock and below the recent silt. Some rock material of very local origin may also be incorporated. The basal gravel would appear to be ubiquitous but of variable thickness. A clay matrix is not unusual.

River History

Deductions

The following summary of the history of the valley of the River Derwent briefly integrates the facts and deductions given above. The stages in the evolution of the valley are tabulated and no extensive explanation is offered.

(1) The River Derwent produced a deep V-notch valley from Elwick Bay to Cornelian Bay via Moonah and then south between Rosny Point and Macquarie Point. The valley is engraved in a thick dolerite sheet to a base level at least 200 m below present sea level. Valley side slopes of 15° or more were common. By Early Tertiary times the valley and its tributaries were well formed. The position of the valley was controlled by first order graben faulting and the actual line of excavation by a series of nearly N-S trending faults in the New Town-Moonah area. Present outcrop distribution can only hint at this factor.

(2) Subsequent to valley engravure the base level rose and a cycle of deposition began. Periods of volcanism were associated with the sedimentation but the number, duration and location of flows, activity and centres can only be surmised at lower levels.

(3) The base level rose ultimately to around +50 m and the whole sedimentary sequence was capped with basalt. However, before this occurred there were several fluctuations of base level between 0 and -80 m in which reworked sediments were deposited. All this sedimentary activity was restricted to the Tertiary valley system via Moonah.

(4) It is likely that with a base level at +50 m the ridge between the hills at East Risdon and the Zinc Works-Lutana would have been submerged. Quite recent faulting in this region, typified by the Bedlam Walls Fault which has many youthful features, made it possible for the river to cut through the ridge from above at a time of high base level. Having done so the original path was totally short circuited. With a substantial base level fall in the early Pleistocene erosion of the ridge was accelerated and the present valley position confirmed. The Pleistocene base level in this section of the river was at least -50 m. (It is possible that some of the less consolidated materials found west of pier 8 at the Tasman Bridge could be early Pleistocene but the absence of such materials north of Selfs Point and basic geomorphologic evidence tend to exclude this conclusion).

(5) Recent silt, including Pleistocene gravel and silt, were then deposited in the fresh Pleistocene valley directly on newly exposed and often very steep side slopes. No deep weathering was possible due to climatic and flow factors.

(6) During the Pleistocene, base levels again rose to +10 to +20 m and some higher level gravel may be observed along the valley. In recent times the base level has again dropped slightly but the residual effect is a large deep estuary representing the drowned valley of a moderate sized river.

This history, which allows for all known facts, predicts fresh bedrock profiles between Elwick Bay and Bedlam Walls with a significant cover of silt but an absence of consolidated clays and sands. It also suggests that profiles south of Cornelian Bay Point will consist of weathered dolerite slopes (dating to lower Tertiary times), a substantial fill of clay, sand and basalt with a cover of silt. The older materials (clay, sand, basalt) can be expected to form a symmetrical V-shaped fill in the original valley although in detail there may be complex arrangements of sediment and basalt (see fig. 18. The Pleistocene and, or, Recent valley will be a shallow scoop within the older fill and could occur virtually anywhere in the upper levels. At the Tasman Bridge it is toward the eastern side and on basalt, but this need not be general and is probably the result of recent inflow south of Selfs Point having been on the eastern side of the valley.

Implications of the Interpretation

A number of direct implications may be stated on the basis of the above discussion and summary.

(1) The river profile south of Selfs Point-Cornelian Bay Point is likely to be very variable in terms of depths, types and configuration of materials and the experience at the Tasman Bridge would be typical in terms of foundation and piling conditions.

(2) The river profile north of Selfs Point is likely to be simple in that silt, some gravel and abbreviated bedrock weathering profiles can be expected. The problems of piling a hard rock interface should be assessed. Slight lateral support for

piles would be provided by the silt, however friction piling would probably not be possible. Conversely, where the bedrock is at shallow depth, good foundations will be available with few problems.

Further Evaluation

(1) Only limited information is currently available about the density, viscosity or friction properties of the silt and these properties should be assessed in future holes.

(2) There remain significant gaps in knowledge about bedrock distribution and type (fig. 22). Appropriate coverage of magentic methods, in particular, with better controlled interpretation in site or problem areas would prove useful.

(3) Seismic surveys at any particular site can provide some information on the form and thickness of the sedimentary suites. Whilst reflection surveys are the more appropriate in the difficult circumstances prevailing in the Derwent estuary refraction surveys can provide useful information.

Surveys of one or other type are essential to evaluate the thickness and distribution of the sedimentary suites. At the present time information of this type is restricted to three localities and with the exception of the Tasman Bridge site is very limited.

Refraction surveys will also be needed in particular site investigations to confirm the quality of the local bedrock and estimate thickness of weathering.

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APPENDIX 1

Notes on the use of geophysical methods for riverside or bed investigations.

Only four geophysical surveys have been undertaken along the section of river under discussion. Three utilised refraction techniques and were on or near bridge lines: Tasman Bridge (B.M.R.: see Trollope *et al.* 1966); Bedlam Walls bridge site (Leaman, 1975; Maunsell, 1973). All three were found to be deficient in first attempt interpretive conclusions. The first two references apply to hydrophone cable surveys whilst the third survey was a hydrophone repeated shot on bottom attempt and was marginally more reliable since there was less interference from scarp reflections. The older Tasman Bridge survey proved difficult to resolve and there was a general lack of penetration due presumably to limited shot distances. Seismic velocities related to weathered basalt and stiff clay were recognised but the distribution indicated was general. The Bedlam Walls surveys were found to be difficult to interpret due to scarp and slope conditions. There were other problems. Firstly, difficulty was experienced in obtaining useful reciprocal time distance curves due to slope conditions. As a result only maximum or minimum interpretations were possible with variations of up to 100%. In addition there were major variations in refractor velocity indicating faulting, intense fracturing or deep weathering. Coupled with the slope problems the interpretations of both surveys over-estimated the depth to fractured bedrock in mid river and there were displacement problems on the eastern side of the river. This was especially the case with the standard surface cable layout. Secondly there was a suggestion in the submerged hydrophone survey that the silt velocity was less than the water velocity. Neither the author nor B.T. Johnson (for Maunsells) could account for the suggestion, discussed it, and tended to dismiss it (see also Leaman, 1975). However, such a velocity is possible and is occasionally experienced in marine surveys. Allowing for up to a 10% reduction in velocity the significant error apparent in the surface hydrophone survey could be explained. This velocity property and the probability of a 'hidden layer' wedge, should be borne in mind and considered in future surveys. Adjustment of interpretation to allow for such a low velocity wedge could resolve the 'overdeepened' interpretation in mid river and the error in step position to the east.

The following list summarises the velocity characteristics of the various materials likely to be encountered in refraction surveys in the region under discussion.

Material	*Seismic velocity (m/s)*
Water	1500
River silt (suite 1)	∿1400-1500
Sand, clay (suite 2)	1600-1800
Weathered basalt	1700-2500
Basalt (fractured-massive)	2200-6000
Weathered dolerite	1700-2500
Dolerite (fractured-massive)	2200-6000
Sandstone (weathered-massive)	2000-4500
Siltstone (fractured-massive)	2000-5000

One further problem can create problems for refraction interpretations. Positioning of shots and hydrophones is often difficult due to conditions of wind and tide. The result is often a curved shot and hydrophone line with shot distances affected by catenary loadings in the shot wire. Since the shot is usually the only feature which can be reasonably surveyed in normal conditions other positions can be in doubt. Whilst these errors may not be significant they are nevertheless contributing factors in deficient interpretations. For all the reasons stated seismic refraction surveys can provide good appraisals of rock conditions (indicated by velocities) but only fair estimates of depth where no control is available. Where problem areas indicated in the first order interpretation are drilled the second order interpretation can be usefully enhanced. This process is essential, in the difficult conditions prevailing in much of the River Derwent, if economic and valid assessments are to be made.

The fourth geophysical survey utilised by the discussions in this report was an integrated but currently incomplete magnetic survey with a nominal reliability of 50 nT. A total anomaly range in excess of 3000 nT has been recorded. No detailed interpretation has yet been undertaken and the simple first interpretation indicated on Figure 22 is qualitative and shore related. The data is currently available only in recorder output or draft map form. The method is not as direct and useful as the refraction method in any conditions but has the distinct advantage of being able to provide areal sketches of rock distribution rather than point statements of depth or quality. For this reason, when given some firm control, the method is capable of yielding useful broad conclusions.

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