

**TASMAN BRIDGE**

**GEOLOGICAL REPORT ON THE BRIDGE SITE**

By

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GEOLOGICAL INVESTIGATION OF THE TASMAN BRIDGE  
SITE.

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INTRODUCTION.

This report was prepared in the first instance by Spry who carried out the field investigations and has been modified in detail by Carey. Both Carey and Spry agree on the final text.

The following geological work has been carried out:-

1. Geological reconnaissance and surface mapping around the site.
2. Examination of diamond drill cores and other samples from 39 holes drilled before construction and approximately 12 holes drilled at the bases of the piers which have been constructed.
3. Plotting, correlation and interpretations of all drill logs and available information to determine the distribution of materials across the site.
4. Correlation of seismic data with samples and interpretation of the seismic profile.
5. Brief examination of the results of the mechanical analyses, triaxial tests and compression tests on drill samples in order to estimate the properties of the Tertiary clays and sands.

The results are presented in three sections:-

1. A factual account of the materials present at the site.
2. A geological interpretation of the evidence available at the site and in adjacent areas.
3. Prediction of conditions likely at each pier position and recommendations for further investigation.

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I. MATERIALS PRESENT.

The materials at the bridge site consist of unconsolidated mud in a semi-liquid state, various unconsolidated and semiconsolidated sands, clays and gravels, consolidated rock and crystalline rock of high bearing capacity, and weathered or partially weathered forms of these.

Bedrock

Solid rock will be referred to here as bedrock; it should be noted that the term "bedrock" is synonymous with Carey's (1954) term "pre-Tertiary bedrock" but differs from the use in the geophysical report (Polack and Moss, 1958) who define bedrock (p.3) as "rock other than silt and gravel" and included Tertiary sediments with velocities of 6,500+ ft./sec to 7,500 ft./sec. in the category of bedrock.

Two varieties of bedrock (dolerite and basalt) have been found either in outcrop on the bank or in bore holes. Other consolidated old rocks (Permian or Triassic mudstones and sandstones have not been found at the site but might be expected at depth beneath a cover of sands and clays or basalt. Deep erosion of bedrock between piers 4 and 7 suggests that there might be a soft (i.e. shattered or faulted zone) in the bedrock here.

Dolerite

Dolerite outcrops strongly on both banks (see fig. 1) has been found in bore cores and in the construction of piers 20 and 21. It occurs beneath silt or gravels on the sides of the site between piers 0 and 4 (?) and between 18 and 21. A 1954 drill hole at chainage 2133 (north of pier 9) penetrated dolerite beneath basalt.

Despite its great strength in the fresh condition dolerite is not necessarily an ideal foundation material because it is prone to weather deeply. Carey (1954) stated that "even deep within the dolerite there would be zones of advanced weathering and poor bearing strength". The difficulties encountered in placing

piers 19, 20 and 21 are compatible with those met elsewhere. The upper surface of the dolerite is tough and fresh in some places but is fractured, weathered and soft in others. The weathering extends down and along joints leaving spheroidal boulders of comparatively fresh rock in a mixture of clay and calcite or may leave pinnacles of fresh rock surrounded by altered material. In general, the quality of the rock improves with depth but weathering and shattering may extend down for hundreds of feet in certain zones. The joints which control the weathering are mostly steep and may form groups along minor faults which cut through the dolerite. As a result, one drill hole might show good sound dolerite right from the surface whereas another a few feet away could meet weathered material for tens of feet. Weathering may also be flatly distributed along flat joints or certain compositional zones in the dolerite.

The seismic survey indicates a sloping surface underlain by rock (dolerite) with a seismic velocity of 15,000 ft./sec. between pier 19 and the eastern abutment. This velocity is consistent with somewhat jointed and weathered dolerite; construction at these piers met the dolerite at the depth and in the condition which would be expected from the geophysical results. Completely fresh, non-jointed dolerite has a velocity of about 20,000 ft./sec.; jointing alone may reduce the velocity to about 13,000 ft./sec. but weathering plus jointing reduces the velocity in a marked fashion and strongly weathered dolerite may have a velocity as low as 7,000 ft./sec.

Dolerite has been met in drill holes at the western abutment and at pier 1 where it is covered by shallow water and a thin layer of silt, sand and clay.

#### Basalt

The Tertiary basalt is a tough black rock when fresh, finer in grain than the dolerite and containing abundant vesicles and amygdaloids up to 2" across containing calcite, clay and zeolites.

The basalt is inferior in strength to the dolerite because of the presence of abundant vesicles or large amygdales filled with calcite or clay. There are also numerous sub-horizontal seams of calcite spaced about 2" apart. Weathering of the basalt is less irregular than that of the dolerite; shatter zones are not known, and deeply weathered zones are uncommon. Alteration to massive clay (probably hydrothermal) is found in cores at piers 17 and 9.

Basalt has been met at the site only in bore holes which have revealed a sheet extending from pier 9 to pier 17 with an upper vesicular surface at between 155 and 165 feet below sea level. It is covered by silts, gravels and sands averaging 75 feet in thickness. The maximum thickness is 70 feet at pier 9 where it occurs between -147ft. at the shallowest and -250 ft. at the deepest. In the 1954 drill hole at chainage 2133 basalt rests on dolerite at -232 ft. with the upper surface at -190 ft. In drill holes at piers 13, 14, 15, the basalt changes from vesicular to massive with increasing depth then to very vesicular and then massive. The change (at possible depths of -195 ft. at pier 10, -168 ft. at pier 12, -175 ft. at pier 14 and -182 ft. at pier 16) may be the contact between a lower and an upper flow.

The material in the bottom of the drill hole at pier 8 (-224 to -253 ft.) is not basalt in situ as originally logged, but a peculiar kind of sediment composed of angular to well rounded and water-worn fragments of basalt in a tough brown sandy-clay matrix. It is unlike any sediment seen in Tasmania and its origin is conjectural. It is not weathered, in situ basalt, nor is it a true volcanic breccia; it is a post-basalt sediment composed of basalt fragments showing small amounts of transport and weathering. Its bearing capacity would be inferior to fresh basalt but would be considerable.

#### Sedimentary Formations

The sediments overlying bedrock may be divided into two main parts which can be further subdivided. The younger,

unconsolidated part, will be referred to here as Recent silts, sands and gravels and the older, tougher material will be referred to as Tertiary sands, clays and gravels. The terms "Recent" and "Tertiary" may not be strictly accurate in the stratigraphic sense (as discussed later) but follow the terminology used in the earlier geological report and the geophysical report.

Recent Silts, Sands and Gravels:

The first layer to be met beneath the water is generally composed of soft mud but gravel and unconsolidated sands and clays are associated with it. The upper surface extends from between 0 and -155 ft. and the lower surface to -160 ft. although the lower limit is not always clear.

Between piers 11 and 17 black to brown silt occurs with a thickness of about 90 ft. It is very soft, rich in  $H_2S$  and is acid near the surface but with depth becomes stiffer, less acid, loses its smell and commonly becomes brown and contains other sediment in layers. The organic remains indicate a change from estuarine conditions in the deeper part to marine conditions in the shallower part. The base of the silt rises steadily to the eastern and western banks where it thins. The upper surface is smooth and is probably a surface of present-day deposition.

Between piers 9 and 17 the silt is underlain by unconsolidated gravels resting on bedrock but nearer the bank, on the western side, the silt rests on sands and gravels then on older sediments.

The base of this Recent silt-sand-gravel group is somewhat arbitrary, but is<sup>s</sup> indicated by the following:-

- (1) - A seismic discontinuity between an upper layer with velocities about 5,000 ft./sec. (Recent) and a lower layer with velocities ranging from 6,000 to 7,450 ft./sec. (Tertiary),
- (2) - a change in organic content from marine shell fragments to carbonized wood fragments,

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- (3) - an increase in the degree of consolidation of the sediments.

These criteria were used to delineate the layer shown in fig. 2. The lowest part consists of a discontinuous layer of gravel ("Quaternary gravel" of Carey, 1954, p.7) composed of water-worn fragments up to 2½" across of basalt, quartz, dolerite and chalcedony and occasional shells in a sandy or clay matrix. Most of the shell fragments are of mussels which at present live close to the intertidal zone and suggest that the gravel was deposited in very shallow sea water.

The gravel is overlain directly by soft silts in the eastern part (with the possible exception of pier 18) but west of pier 10, a layer of yellow and grey sands, sandy clays, clays etc. occurs between the gravel and the silt. These reach a thickness of at least 20 ft. at pier 7.

A general correlation of the seismic profile with the base of the Recent silts, gravels etc. is possible; the basal gravel occurs close to the profile and within the limit of the error (15 to 20%) indicated in the geophysical report. The shallow easterly dip of the seismic profile between piers 4 and 11 matches the dip of the layers as correlated between the boreholes.

No compressibility tests were carried out on this formation and the result of only three triaxial tests are available:

- (1) no. 8455, pier 5, depth 72 ft.
- (2) no. 6185, pier 18, depth 144.29 ft. to 145.29 ft.
- (3) no. 6185, pier 18, depth 145.57 ft. to 146.57 ft.

These show low shear-strength materials, not pre-compressed but similar in some ways to the underlying Tertiary sediments. The gravel has not been tested but the layer is thin and is underlain by plastic materials; the possibility of using this horizon as a foundation is discussed later.

#### Tertiary Sediments:

A layer of between zero and possibly more than 200 ft.

of sandy clays, clays, sands and gravels occurs between piers 2 and 9. The sediment is overlain by Recent silts etc. but its base has not been penetrated in bores at piers 4, 5, 6, 7 and 8 so that its maximum thickness and lower limit are not known.

The lowest known part of the formation (not necessarily the base) is a gravel which reaches at least 30 ft. in thickness at pier 6 and possibly 60 ft. at pier 8. The material is variable in its lithology; at pier 8 and 7 it is composed of basalt fragments in a compact brown sand-clay matrix, at pier 6 it contains water-worn and polished small pebbles of quartz in a clay or sand matrix, at pier 6 the pebbles are rough angular ones of basalt at -292 ft. but small well rounded ones of quartz at -277 ft., at pier 5 it contains water-worn pebbles of quartz etc. up to  $1\frac{1}{2}$ " across in clay matrix. The gravel is overlain by a thick mass of sand, clay with minor pebbly, clayey, sandy or silty horizons. This material is stiff and dense and tends to be grey, with blue or green tints in the deeper parts and yellow or brown tints in the upper parts. No marine fossils were found but carbonized wood fragments occur in several drill holes (149 ft. and 242 ft. at pier 7, 157 ft. at pier 8). Some of the sediments effloresce and taste strongly of alum.

Mechanical analyses show that the stiff sandy clay is a poorly sorted mixture of clay, silt and sand grades. The results of some mechanical analyses from piers 4, 5 and 6 are plotted in fig. 4. There are not sufficient analyses to recognize if there is any pattern present and it is not possible to correlate between the bore-holes. In general the material contains 30 - 45% silt and is sandier with depth.

The physical properties are discussed in some detail in a later section.

The possible presence of a separate layer at the top of the Tertiary sediments is recognized; it has some properties in common with both the Recent and Tertiary sediments. Its characteristics are:-

1. It occurs between levels of -90 ft. and -105 ft. at pier 5, -95 ft. and -120 ft. at pier 6, and -120 ft. and -150 ft. at pier 7.
2. It is a fine, yellow clayey sand,
3. It may be of lower strength than the normal Tertiary materials. Samples from between -120 ft. and -150 ft. at pier 7 are largely of unconsolidated sand.

## II. GEOLOGICAL INTERPRETATION.

There is not sufficient evidence available at the site itself to determine the relations of the different materials (dolerite, basalt, "Recent and "Tertiary" sediments) to each other and it is necessary to use our knowledge of the geology of the surrounding area. Such interpretations are useful but must be treated with caution.

### Bedrock relations.

The dolerite at the abutments and in the drill holes is identical with and almost certainly continuous with the dolerite which outcrops in the Domain to the west and Rosny Hill on the east. The Domain dolerite intrudes Triassic sediments and the Rosny Hill dolerite intrudes Permian sediments so that some complexity of structure is to be expected beneath the river, but as the dolerite is known to be transgressive, nothing more than this is necessarily implied. The relation between the Permian and Triassic sediments at Risdon, two miles to the north is shown in fig. 1. A fault zone with a throw of at least 400 ft. should pass from Risdon through the bridge site but it is concealed by the Tertiary and Quaternary cover and its exact location is not known. Both Jurassic and Tertiary faults may occur.

The relation between basalt, Permian sediment and dolerite at Shore Street Point, 4000 ft. north of the site on the east side is shown in fig. 1b. The dolerite rises sharply through the Permian, and the basalt rests on bedrock with no underlying

Tertiary sediments. This structure is probable on the eastern side of the site.

The probable relation between dolerite, basalt, and "tertiary (?)" sediments at Cornelian Bay, 6,000 ft. north of the site on the western side is shown in fig. 1c.

- (1) The sediments appear to occur in a deep narrow channel cut in basalt and dolerite.
- (2) The basalt rests directly on dolerite.
- (3) The eastern side of the dolerite has a steep slope and is strongly weathered.

#### Sediment Relations.

The relations between the "Recent" and Tertiary" sediments and the basalt have a considerable engineering significance e.g. if the "Recent" sediments are pre-basaltic they will have been considerably precompressed whereas if they are post-basaltic and Late Tertiary or Pleistocene they may not show appreciable precompression.

The Derwent Valley has a structural origin dating back to an epoch of intense epirogenic faulting which began early in the Tertiary. The faulting resulted in deep, narrow, freshwater lakes in which were deposited many hundreds of feet of clays, sandy clays, sands and coarse sediments. These sediments were at least partly covered by later basalts, e.g. at Sandy Bay, 4 miles south west of the bridge site. Little is known of the events after the basalt but it appears likely that further sediments were deposited after considerable erosion of the basalt. Sediments containing Cainozoic plant fossils occur up to 75 ft. above sea level at Moonah, Sandy Bay, and South Arm and up to 600 ft. near Richmond, all within 10 miles of the bridge site. They extend to at least 100 ft. below sea level at Seven Mile Beach. The relations between these is not known and they may be of different ages.

In Pleistocene times the whole coastline experienced changes in sea level. During glacial periods the sea level was

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probably 100 ft. - 300 ft. lower than at present and during interglacials was at least 70 ft. above present sea level. The Mary Ann Bay sandstone of Green (1960) at 40 ft. - 70 ft. above sea level, together with platforms at this level elsewhere indicates that sedimentation occurred up to 70 ft. above present sea level in some places during the Pleistocene. The present depth of the Derwent is due to Recent drowning of about 100 ft. but there is evidence that the sea level was 300 ft. below the present level during the late Pleistocene. These changes in sea level must have caused some pre-consolidation effects on the sediments e.g. high sea levels could produce sedimentation to 100 ft. or so above present sea level and thus place a load on existing sediments; lowering of sea level could cause draining and perhaps dessication of the sediments and increase their strength.

The so-called "Tertiary" sediments between piers 4 and 8 fit into the known geological framework on the area in three possible places. The sediments could be (1) Tertiary and pre-basaltic, (2) Post-basaltic and Tertiary, (3) Post-basaltic and Pleistocene.

Most of the known Tertiary sediments are pre-basaltic but if this were the case here, the sediments would have to have been deeply eroded and the basalt flow against a steep cliff of soft sediment.

The evidence favours a post-basaltic age for the sediments for the following reasons:-

(a) No Tertiary lake sediments occur beneath the basalt in bore hole 2133 nor on the shore just north of the bridge, nor at Rose Bay, Geilston Bay, Risdon Vale nor Rokeby; in all of these places the volcanics rest on basement rock.

(b) The sediments appear to rest on the basalt at Cornelian Bay. Similar sediments rest on basalt near Cadbury's factory and no basalt is known to rest on them throughout Moonah and Glenorchy.

(c) Pebbles of basalt are common in the sediments. This indicates that the sediments are later than some basalt, not necessarily that at the bridge.

(d) A layer of coarse gravel containing basalt fragments dips away from the basalt and passes beneath the sediments at piers 5, 6, 7 and 8.

The exact age of the basalt is not known but a post-basaltic age for the sediments could mean either late Tertiary or Pleistocene. It is possible that the sediments were deposited in a channel cut to about -300 ft. during a Pleistocene glacial period but this would imply that the existing channel of the Derwent, east of the Cornelian Bay cemetery, Risdon, etc. would have been cut in the late Pleistocene. It is unlikely that the sediments could be pleistocene as they appear to be lacustrine; sedimentation during the Pleistocene in this location would be expected to be marine.

The sediments at the bridge site and at Cornelian Bay resemble those at Pipe Clay Lagoon and Pittwater in their lithology, leaf content, oxidation, limonite concretion content and known vertical range. They were possibly deposited in a single lake. The clays at Pittwater have been eroded to about -100 ft. and covered with thick alluvium, (late Pleistocene ?) which appears to be much younger.

The available evidence does not allow a distinction between a late Tertiary and an Early Pleistocene age. In either case the sediments at one stage may have been loaded to at least 75 ft. above present sea level and at another stage were drained by a sea level as low as -160 ft. below sea level. Both of these effects could be expected to have produced some preconsolidation in the sediments. If we take a sample in the middle of the "Tertiary" sediments i.e. at 200 ft. below sea level at Pier 6, it is at present overlain by about 120 ft. of Tertiary sediment (with a density of about 110 - 120 lbs. per cubic ft.) Then by about 30 ft. of saturated sands and silts (with an average

density of about 80 lbs. per cubic ft.) then 50 ft. of water. The effective load at present would be 3 tons per sq. ft. if the Tertiary sediments are taken as saturated and permeable. Lowering of sea level to drain completely the Tertiary sediment would have loaded it to 6 tons per sq. ft. Sedimentation to 75 ft. above sea level without draining would give a load of 6 tons per sq. ft. and complete draining would have given a load of 15 tons per sq. ft. The geological history indicates preloading by between 3 and 15 tons per sq. ft.

It is possible to recognize the existence of pre-compression and to measure its amount experimentally by either the triaxial shear tests or the void-ratio test.

The triaxial diagrams are very irregular but indicate a value of 20 to 40 lbs. per sq. inch for previous loading, i.e. 1 to 2 tons per sq. ft.

The void-ratio tests are also difficult to interpret because of a lack of sharp curvature. They indicate that the specimens have previously been loaded to between 2 and 7 tons per sq. ft. It is concluded that in the example chosen (200 ft. below sea level) a specimen is under an existing load of about 3 tons per sq. ft. Precompression by as much as 15 tons per sq. ft. is not impossible but physical tests do not favour precompression by more than 4 additional tons per sq. ft. in the best specimens and no precompression in most.

There is no real geological evidence indicating appreciably more precompression than is shown in the tests.

#### Geological cross section

The drill hole and seismic data are summarized on fig. 2 which utilizes sheet 11D/12 and the 1961 drill holes. No attempt was made to completely re-log the holes but all available specimens have been examined. Fig. 3 shows what we consider to be the most likely interpretation with the Tertiary sediments post-basaltic. The bedrock structure given is only one of the possible interpretations and is only included to enlarge the section

and no conclusions should be based on it.

A series of profiles in fig. 5 indicate the probable topographic evolution of the valley.

#### Foundation Conditions

As considerable time has been spent on the inspection of drill hole samples and the interpretation of drilllogs and seismic data it may be useful to indicate what conditions are expected at each one of the pier positions. The evidence is only fragmentary and the following remarks must be taken only as a guide to probable conditions.

### III. FOUNDATION CONDITIONS

#### West Abutment:-

##### Facts

- (1) Water depth - 16 ft.
- (2) Drill holes, 1958/59 series; D.H. 5 chainage 3375, 25 ft. north of centre line; D.H. 6 chainage 3374, 25 ft. south of centre line. Broken dolerite between -16 ft. and -21 ft. then into fresh dolerite with thin seams of calcite.
- (3) Seismic data:-  
Refraction with 21,000 ft./sec. velocity at about -32<sup>+4</sup> ft.

##### Interpretation

- 0 to -16 ft. water
- 16 to 17 ft. silty sand with shells, few pebbles and boulders.
- 17 to -20 ft. bedrock; dolerite moderately jointed and weathered.
- 20 to -30 ft. dolerite, slightly weathered along joints.
- 30 ft. massive, strong dolerite. Weathered zones are possible (particularly parallel to the seismic traverse) but a seismic velocity of 21,000 ft./sec. indicates good rock.

Pier No. 1.Facts

- (1) Water depth - 23 ft.
- (2) Drill hole, 1958/59 series - B.H.7, chainage 3240.

Recent sand underlain by clay -23 ft. to -31 ft. Broken dolerite 31 ft. to 34.6 ft., slightly fractured to 43 ft.

- (3) Seismic data:-

Refraction at  $-50 \pm 7$  ft., 18,000 ft. per second.

Interpretation

0 to -23 ft. water

-23 ft. to 31 ft. Recent sediments

-31 ft. to -35 ft. fractured and somewhat weathered dolerite.

-35 ft. dolerite, sound, but slightly weathered along joints. No reason to suspect that point-load bearing piles could not be based between 31 and 35 ft. but as indicated in the discussion of dolerite on pages 2 and 3, sporadic and unpredictable weathered zones are possible.

Pier No. 2.Facts

- (1) Water depth - 25 ft. (?)
- (2) No drill hole data
- (3) Seismic data: Refractor 11,000 ft./sec. at  $-70 \pm 10$  ft.
- (4) Information from eastern lift span of existing bridge, 400 ft. north. Recent sediments to -90 ft., weathered dolerite to -120 ft. then sound dolerite.

Interpretation:

0 to -25 ft. water

-25 to -35 ft. soft mud

-35 to -45 ft. sand and clays } Recent

-45 to -50 ft. gravel }

-50 to -75 ft. broken and weathered dolerite.

-75 ft. to depth dolerite improving

It may be considerable more difficult to place this pier than piers 19, 20 and 21 which have already been constructed. It is possible however that the dolerite on the western side will be

weathered more evenly as well as more deeply but it seems probable that some tens of feet of weathered dolerite must be penetrated to find a solid footing. It is recommended that a diamond drill hole be located here to penetrate to 100 ft. below sea level. It is expected that point-load bearing piles could be based at -75 ft. to -100 ft.

Pier No. 3.

Facts

- (1) Water depth 35 ft.
- (2) No drill hole data.
- (3) Refractor, 9,000 ft./sec. at -80±12 ft.

Interpretation

Conditions are expected to be somewhat similar to pier 2 except:

0 to -35 ft. water

-35 to -50 ft. soft mud

-50 to -65 ft. sands and clays

-65 to -75 ft. gravel

} Recent

-75 to -100 ft. either soft Tertiary clays and sands, possibly with some gravel or well weathered dolerite.

-100 to -140 ft. weathered dolerite.

-140 ft. solid dolerite.

The dolerite-sediment interface is expected to dip towards the river at about  $25^{\circ}$ . It is recommended that a diamond drill hole be located here to penetrate to -140 ft. or to solid dolerite whichever is the deeper. The best that can be hoped is to base point-load bearing piles at -100 ft. but the depth may be greater. One interpretation which is consistent with the geological information is that the steep slope of the dolerite near pier 3 is a fault-line scarp of a graben located between piers 3 and 9. This graben could be pre-basalt or partly both.

Pier No. 4.

Facts

- (1) Water depth 45 ft.
- (2) Drill hole, 1958/59 series, D.H. 19, chainage 2814 ft.

Depth -184 ft. no bedrock.

1954 series, D.H. chainage 2,800 ft. is 450 ft. north

(3) Seismic data:-

Discontinuity 7,000 ft./sec. at -90±14 ft.

Interpretation

0 to -45 ft. water

-45 to -60 ft. soft mud

-60 to -75 ft. soft sediments

-75 to -85 ft. gravel

} Recent

-85 to -175? ft. Tertiary clays and sands

-175? to -200? ft. gravel?

-200 ? ft. weathered dolerite

The interpretation is largely based on the bedrock conditions encountered in the 1954 drill hole (2,800) which is 450 ft. to the north. Owing to the location in the approach lane of the existing lift span, no drilling has been done here but it is essential that more information be obtained in this section.

The dolerite bedrock is not likely to be met before 200±25 ft. and will probably be considerably weathered. Difficulties will be experienced in placing point-load bearing piles here and it may be better to locate skin-friction piles in the Tertiary sediments or attempt consolidation of the gravels (see later). If point-load bearing piles are to be used it is recommended that at least two and preferably three further diamond drill holes be placed just to the east and west of pier 4 to determine the depth to the dolerite surface, the dip of the surface and the degree of weathering of the dolerite.

Pier No. 5.

Facts

(1) Water depth 50 ft.

(2) Drill holes no. 6 of 1958/59 series

no. 11 of 1958/59 series is 40 ft. east on  
centre line.

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B.H. 6 went to -250 ft. and no. 11 to -290 ft. but neither reached bedrock. Correlation between the holes was good.

(3) Seismic data:-

Discontinuity at  $-93 \pm 14$  ft. at 7,000 ft./sec.

Interpretation

0 to -51 ft. water

51 to 70 ft. soft black mud

70 to 77 ft. yellow sandy clay

77 to 83 ft. coarse gravelly sand

} Recent

The base of the Recent gravel probably coincides with the seismic discontinuity.

83 to 140 ft. Tertiary sandy clay. Grey in colour but oxidized to yellow in the upper parts, brown in the lower and greenish at the bottom. The driller's log indicates that the layer becomes stiffer with depth from 83 to 190 but becomes softer below that. Recommendations for piers 4 - 8 are given later.

Pier No. 6.

Facts.

(1) Water depth 60 ft.

(2) Drill holes, 1961 series, B.H. 7; 30 ft. north of centre line 5. B.H. 8; 30 ft. south of centre line is B.H. 9; 40 ft. west of B.H. 7 on centre line is B.H. 10. Holes penetrated to -295 ft., no bedrock found. Correlation between holes good.

(3) Seismic discontinuity, 5,900 ft./sec. at  $98 \pm 15$  ft.

Interpretation.

0 to -59 ft. water

-59 to -79 ft. soft black mud

-79 to -85 ft. sandy clay

- 85 to -90 ft. sandy gravel

} Recent

-90 to -240 ft. stiff Tertiary sandy clay. This is dominantly grey but stained yellow and brown in the upper part and blue-grey or green at depth. Similar

material at similar depths in other bore holes suggests that the yellow clayey sand from -110 to -135 ft. may be lacking in strength but the driller's log indicates that the material is stiff between -90 ft. and -160 ft. Between -160 ft. and -220 ft. the material is soft and of low bearing capacity (there is some suggestion that sensitive clays may be involved); stiffness increases from -220 to -260 ft. The lowermost 30 ft. or so of gravel has a high bearing capacity but bedrock is at an unknown depth, (over 300 ft.)

Pier No. 7.

Facts

- (1) Water depth 65 ft.
- (2) Drill hole D.H. 20, 1958/59 series, penetrated 282 ft.; did not reach bedrock.
- (3) Seismic discontinuity at  $-130 \pm 20$  ft. with velocity 5,900 ft./sec.

Interpretation

0 to -65 ft. water	}	Recent
-65 to -80 ft. soft mud		
-80 to -105 ft. sandy clay		
-105 to -120 ft. coarse gravel and sand		
-120 to -150 ft. sand		
-150 to -260 ft. grey Tertiary sandy clay with pebbly horizons, compact and stiff.		
-260 to -280 ft. dense Tertiary gravel with basaltic breccia at bottom.		

The sediments increase in bearing capacity with depth but it may be possible to utilize (for skin-friction piles) the Recent sediments between -80 and -150 ft. as well as the normal Tertiary sandy clay below -150 ft.

Pier No. 8.Facts.

(1) Water depth - 65 ft.

(2) Drill hole. B.H. 5 of 1961 series and B.H. 22 of 1958/59 series. Depth 200 ft., no bedrock encountered.

Seismic data:-

Discontinuity, 6,500 ft./sec. at  $-127 \pm 19$  ft.

Interpretation.

0 to -65 ft. water

-65 to -88 ft. soft mud

-88 to -115 ft. yellowish clayey sand, some cemented  
and consolidated but at -112 ft. soft  
sand forced freely into casing.

} Recent

-115 to -118 ft. gravelly sand

-118 to -200 ft. Tertiary sand, sandy clay, gravel, gravelly sand etc. becoming well consolidated with depth.

All of the sediments from about -90 ft. down would support piles by skin friction; the dense breccia at -220 ft. might even support piles with heavy loads but it would be difficult to excavate for piles of the type being used at present, e.g. those at piers 20, 21 etc.

Pier No. 9:Facts.

(1) Water depth - 60 ft.

(2) Drill hole 1961 series B.H. 2a, 1958/59 series B.H. 3; 1954 series bore hole at chainage 2133 ft. is north of pier 9. Bedrock at -187 ft.

(3) Seismic discontinuity, 6,500 ft./sec. at  $-120 \pm 25$  ft.

Interpretation.

0 to -60 ft. water

-60 to -100 ft. soft mud

-100 to -140 ft. sandy clay and clayey sand )

} Recent

-140 to -187 ft. recent gravel overlying thick basaltic gravel which is probably Tertiary.

-187 to -230 ft. Basalt, weathered in the upper parts.

The depth to reasonably solid bedrock is about 200 ft. of which the last 50 ft. will be rather difficult to excavate for point-load bearing piles. Piles could probably be located in the Tertiary gravels but this would require further drilling on both sides of Pier 9 to check their physical properties and distribution.

Piers 10 to 17.

As these are very similar they will be taken together.

Facts

(1) Water depths - descending from 67 ft. at 10 to 105 ft. at 17.

(2) Drill holes.

Pier 10, 1958 series B.H.4, 1961, Series B.H.1

Pier 11, 1961 series B.H.4, near B.H. 1,800 of 1954 series.

Pier 12, 1961 series B.H.18

Pier 13, 1958 series B.H.8

Pier 14, 1958 series B.H. 9

Pier 15, 1958 series B.H. 10, 11, 1961 series B.H. 3

Pier 16, 1958 series B.H. 12

Pier 17, 1961 series B.H. 2

Soft Recent mud is met between the bed of the river and the following depths:- -118 ft. (Pier 10), -140 ft. (Pier 11), -140 ft. (Pier 12), -150 ft. (Pier 13), -160 ft.(Pier 14), -155 ft. (Pier 15), -150 ft. (Pier 16), -160 ft. (Pier 17).

Comparatively soft sands and clays occur beneath then there is a discontinuous layer of gravel from 0 to 15 ft. thick.

Bedrock (basalt) is met at the following depths:- -145 ft. (Pier 10), -155 ft. (Pier 11), -150 ft. (pier 12), -155 ft. (Pier 13), -160 ft. to -170 ft. (Pier 14), -165 ft. (Pier 15), -160 ft. (Pier 16), -160 ft. (Pier 17).

Pier 17 has been constructed and investigations do not suggest that conditions at piers 10 to 16 will differ appreciably nor that any great difficulties will be encountered. The basalt

bedrock is vesicular and the upper surface tends to be broken and somewhat weathered. Weathering is more pronounced at piers 10, 12 and 15. At pier 15 the upper part of the basalt from -165 ft. to -180 ft. is sound but the basalt deeper than this is strongly altered to clay; there is no reason to suppose that the 15 ft. of sound basalt should not stand the load but as the drill hole evidence is fragmentary, this variation in the bedrock should be watched during construction.

#### Pier 18.

##### Facts.

- (1) Water depth - 120±5 ft.
- (2) Drill holes. 1958/59 series, B.H. 17 (15 ft. east of pier). B.H. 13, 13A, 13B, 15, 16. Bedrock (dolerite) at -187 ft. in B.H. 17.
- (3) Seismic discontinuity, 11,000 ft./sec at -160±24 ft.

##### Interpretation

The seismic discontinuity is probably on very broken and weathered dolerite.

0 to -120 ft. water	
-120 to -145 ft. soft black mud	} Recent
-145 to -160 ft. sands and clays	
-160 to -180? ft. coarse gravel	
-180? to -210? ft. broken and weathered dolerite	
-210 ft. fresh dolerite	

It is difficult to predict exact conditions as the dolerite surface is probably very irregular. This pier appears to be close to a minor channel between the dolerite and basalt, and the gravel can be expected to be thicker and the weathering deeper. It is possible that the dolerite has been faulted and shattered here and this will increase the depth of weathering. This pier is expected to be considerably more difficult to place than numbers 19, 20 and 21 which are close by on dolerite.

Piers Nos. 19, 20, 21.

These have been constructed. Difficulties met are compatible with the information available prior to construction and no unexpected conditions were met.

#### RECOMMENDATIONS.

The foundations of the piers belong to three types, each of which may require somewhat separate treatment.

Type I. is based on dolerite in the sections from the west abutment to pier 2 and from pier 18 or 19 to the eastern abutment. Point-load bearing piles are being used successfully in this section although irregular weathering of the dolerite causes some difficulty.

Type II is based on basalt in the section from pier 10 to 17 or 18. (Pier 18 has been discussed in detail earlier). Point-load bearing piles are being used in this section successfully.

Type III is based on Recent sediments overlying thick Tertiary sediments with bedrock at an unknown level in the section between piers 2 and 9.

Four possible alternative treatments are considered:-

- (1) Point-load bearing piles to bedrock.
- (2) Skin-friction piles into the Tertiary sediments.
- (3) Consolidation of the basal zone of the Recent sediments and distribution of the load to a degree such that the formation can accept it.
- (4) Some form of submerged pontoon foundation to bear part of the load by buoyancy.

#### (1) Point-load bearing piles.

Bedrock cannot be expected in this section above -300 ft. and could be substantially deeper. The Tertiary sediments offer substantial skin friction so that ultimately a depth is reached beyond which it is not practicable to look for point-load bearing foundations. This depth has probably been exceeded at

these piers and we therefore omit further consideration of this kind of pile.

(2) Skin friction piles.

These appear to be a practical proposition in the Tertiary sediments, however it is necessary to ensure that the loads are distributed so that the transmitted load to the sediments does not exceed the strength of the material at any part of the bulb of pressure surrounding the pile. Considerable data is necessary before a design could be attempted. Bores are needed at and near each pier site in this section, drilled with split core barrels and mud or by other special techniques designed to obtain cores of semi-consolidated material for basic soil tests. These bores must be carried beyond the expected depth of the base of the piles to ensure that no lower stratum exists whose mechanical properties would allow it to creep in the stress fields which would reach it.

This section demands a much more thorough investigation than any other and the bridge design cannot be completed without such investigation.

(3) Consolidation of the Recent sand and gravels.

If it were possible to consolidate the Recent sediments so that piles could be based at this shallow level there could be a substantial saving in cost. The possibility should be investigated of consolidating the layer of gravel (5 ft. to 15 ft. thick) and sand and sandy clay (6 ft. to 15ft. thick) and of distributing the load to a degree that can be borne by this zone.

Consolidation could be by three stages:- first by cement grout, followed by a chemical grout with a final grout of acrylamide. The chemical grout could consist of an aqueous solution of barium fluoride. The natural water in the sediment contains calcium ions and sulphate radicle which would react with the barium fluoride to give barium sulphate and calcium fluoride (the relative solubilities of the salts in gms. per 100 cc. are

$\text{CaSO}_4$ , 0.03;  $\text{BaF}_2$ , 0.17;  $\text{CaF}_2$ , 0.0016;  $\text{BaSO}_4$ , 0.00023).

The resultant interstitial cementation of the gravel and sand with barytes and fluorite could convert them into tough conglomerate and sandstone.

It is possible that an acrylamide grout (AM9) might be used as a third stage in consolidating the sands and gravels. AM9 is a mixture of two organic monomers, acrylamide and methylene bis-acrylamide; it produces very stiff gels from dilute aqueous solutions by polymerization. The material retains its low aqueous viscosity until a certain period after the addition of the catalyst, then gelation is sudden. Its low viscosity permits it to be pumped into silts which are quite inaccessible to cement grout. A significant increase in strength is obtained and as the grain size of the grouted material decreases, the strength of the stabilized mass increases.

AM9 is still fairly expensive (£3 per cubic foot or £10 per gallon) but emplacement times are low and since labour and overhead contribute more than materials to the cost of grouting, the process is not prohibitively expensive.

If the proposal to consolidate the Recent sediments is pursued in preference to that of seating skin friction piles in the Tertiary sediments, then a detailed enquiry into the applicability of AM9 to this problem should be sought from the American Cyanamid Company who market the process. In the meantime we have trade literature and samples available in Hobart and these should be sufficient to run pilot tests on a series of cores.

(4) Submerged pontoon foundations.

The possibility of founding this section of the bridge on partly buoyant rafts is an engineering rather than a geological problem. It is theoretically possible but may or may not be economic.

024

TASMAN BRIDGE - GEOLOGYAPPENDIX No. 1

The 1962 boreholes at piers 2 and 3 provide some important new information (the geological interpretation has had to be based on data from the existing lift span which is 400 ft. away) and show that foundation conditions are worse than anticipated. The position and slope of the surface of the dolerite bedrock can now be located fairly well between the western abutment and pier 4; it is flatter and a little further west than suggested on fig. 3 of the report and consequently the depth to dolerite basement is a little greater than expected. The dolerite basement at piers 2 and 3 slopes at approximately  $22^{\circ}$ . This is as steep as the steepest slope on dolerite at the eastern end of the bridge; the slope at pier 21 is about  $10^{\circ}$ , at pier 20 about  $22^{\circ}$  and at pier 19 about  $22^{\circ}$ .

Pier 2

The occurrence of 46 ft. of gravel was not expected from the information available in 1961 and it was considered that point-load bearing piles could be based at between -75 ft. and -100 ft. It would now appear that piles must be based in dolerite at between -100 and -120 ft.

The section at pier 2 appears to be as follows (from an average of boreholes 2-1 and 2-2 of the 1962 series):

0	to	-36 ft.	water	}	Recent
-36	to	-38 ft.	mud		
-38	to	-52 ft.	sandy clay		
-52	to	-93 ft.	gravel		
-93	to	-104 ft.	dolerite (weathered)		
-104	ft. to	depth	dolerite (probably sound).		

025

Conditions are expected to be comparable with those at pier 19 and as difficulty was met in placing this pier it might be worth considering the possibility of skin friction holes in the 30 to 40 ft. of gravel at between -50 and -90 ft.

### Pier 3

The new position of the buried dolerite surface increases the depths predicted on p. ~~12~~<sup>15</sup>. An average of the new drill holes 3-1, 3-2 and 3-3 suggests the following section:

0	to	-41 ft.	water	
-41	to	-55 ft.	mud	} Recent
-55	to	-75 ft.	sandy clay	
-75	to	-86 ft.	gravel	
-86	to	-146 ft.	clay	
-146	to	-170 ft.	dolerite (weathered)	
-170	ft. to depth		dolerite (sound ? )	

It would appear that if point-load bearing piles are used at pier 3 it may be necessary to penetrate to at least -170 ft. The driller's log indicates dolerite at -140 ft. but the depth of weathering appears to be great.

This pier may be even more difficult to construct than pier 18 because although the depths are comparable, the dolerite surface at pier 3 has the additional complication of sloping at 22°.

### Pier 9

The Resident Engineer's letter of 30.1.62 queried the information from a borehole designated 2a. at pier 9. Samples are available of a borehole from the 1958-1959 series labelled 2a. at chainage 2114 ft. near pier 9. Borehole No. 3 of this series was also at pier 9 but at chainage 2109 ft.

Borehole No. 3 (dated 26.8.59) is represented by percussion drill samples in jars at the P.W.D. The samples range from -102 ft. to -145 ft. and include gravel samples between -143 and -145 ft. A brown clay at -145 ft. has been interpreted by the driller as weathered basalt.

The 1962 drill holes at pier 9 met what was logged by the driller as "decomposed (clayey) basalt" at depths of -137 to -159 ft. in 9/3  
-145 to -169 ft. in 9/2  
-170 to -176 ft. in 9/1

It is unfortunate that samples were not retained as we have only the driller's opinion of the percussion drill samples. Comparison with the percussion and diamond drill samples from 2a. (1958-1959 series) shows that the driller's log was not reliable on that hole. In hole 2a. the samples taken at -155.3 ft. and -167 ft. were logged by the driller as basalt but are actually part of a gravel composed of angular and rounded basalt pebbles. Diamond drill core is available between -182 and -223 ft. for hole 2a. and the first certain basalt is at -182 ft. As gravel was present at -167 ft. and diamond drill core was not recovered until -182 ft. it was assumed that the material between -143 ft. and -182 ft. was probably basaltic gravel. Even if much of it is basalt, the degree of weathering or alteration is apparently so high as to make its bearing capacity suspect above a depth of -182 ft.

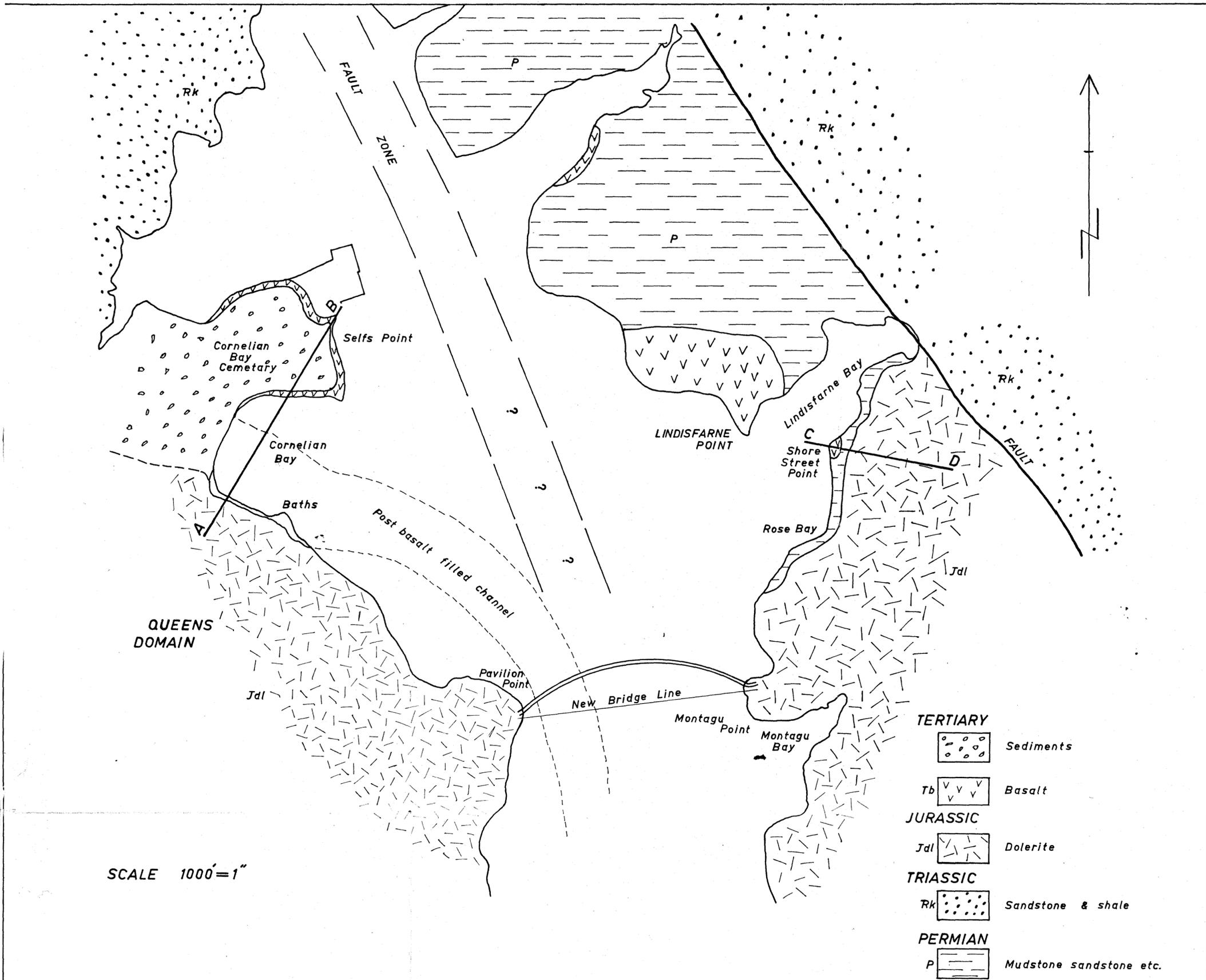
As mentioned on p. 4 of the report, a basaltic breccia occurs between -224 and -253 ft. at pier 8 but this breccia was logged by the driller as basalt. In view of this I am uncertain as to the reliability of the results of the 1962 drill holes at pier 9.

Maximum and minimum values for the surface of the basalt in the various holes near pier 9 are as follows:

<u>Series</u>	<u>Chainage</u>	<u>Borehole No.</u>	<u>Maximum</u>	<u>Minimum</u>
1958-1959	2114	2 a.	-182 ft.	-167 ft.
1958-1959	2109	3	-	-143 ft.
1962	2149	9/1	-176 ft.	-170 ft.
1962	2114	9/2	-169 ft.	-145 ft.
	50' N. of C.L.			
1962	2114	9/3	-159 ft.	-137 ft.
	50' S. of C.L.			

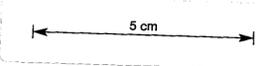
The data available are not sufficiently exact to make accurate predictions at this pier. It may be possible to base point-load bearing piles in the weathered basaltic material between -145 ft. and about -170 ft. but it may be necessary to penetrate to -180 or -190 ft. (even at depths of -190 to -227 ft. the basalt is weathered).

Alan Spry



**Fig 1 GEOLOGY OF THE BRIDGE AREA**

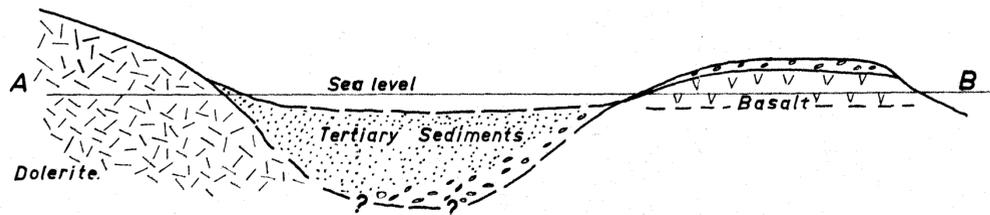
4211



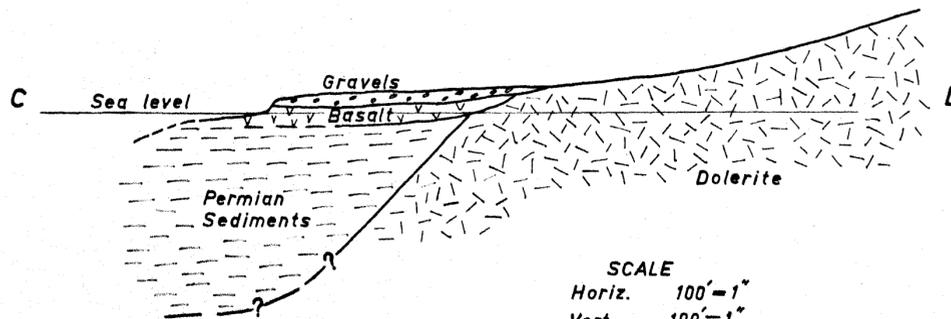
**DETAILED SECTIONS**

**CORNELIAN BAY**

**SHORE ST.**

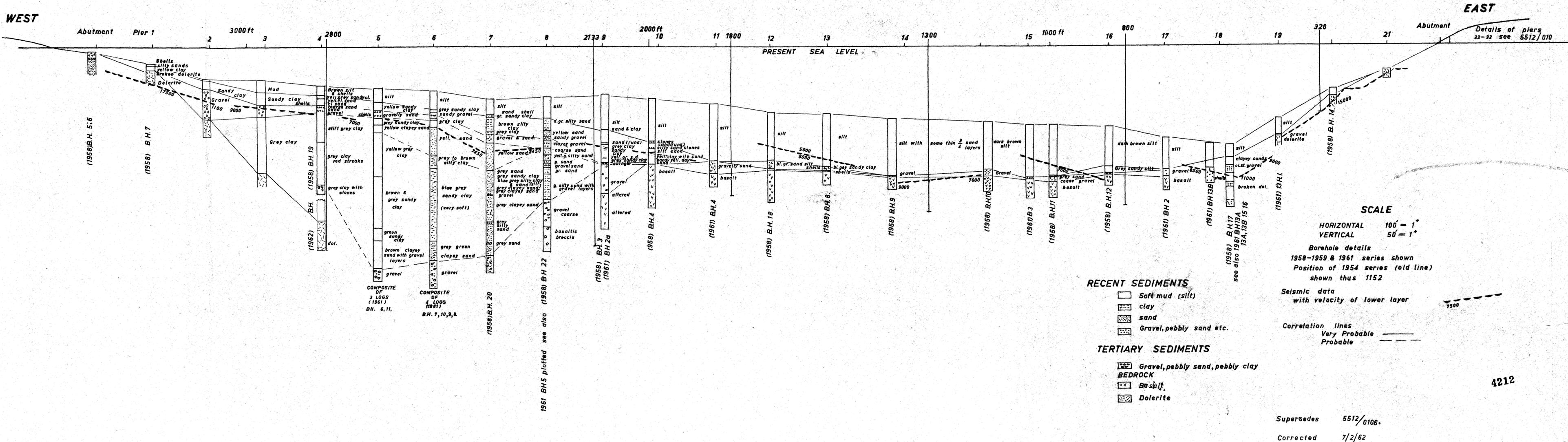


**SCALE**  
 Horiz. 50' = 1"  
 Vert. 250' = 1"



**SCALE**  
 Horiz. 100' = 1"  
 Vert. 100' = 1"

Fig 2/2 GEOLOGICAL AND GEOPHYSICAL INFORMATION





MECHANICAL ANALYSES OF TERTIARY SEDIMENTS

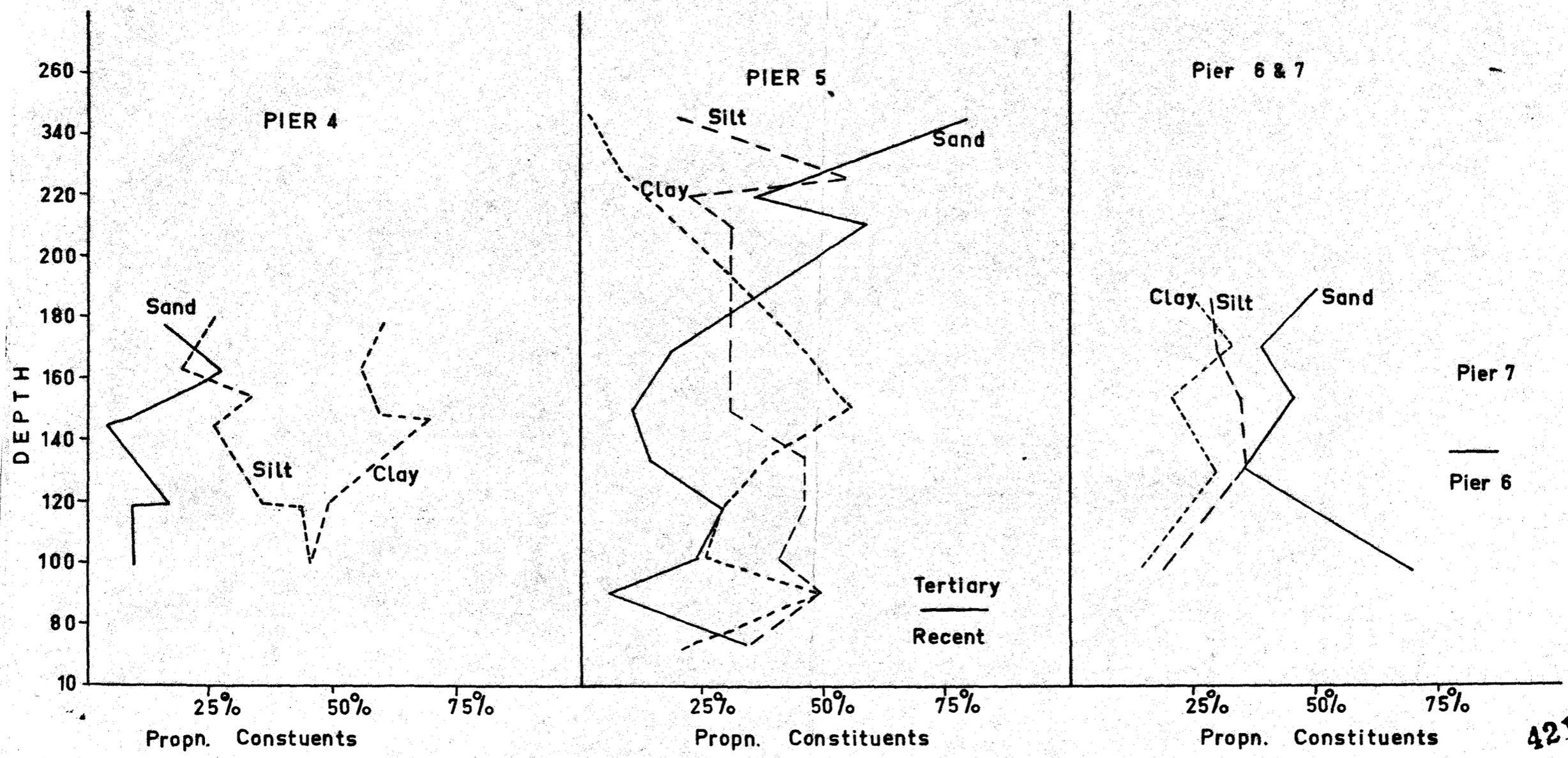


Fig 4

4214

4

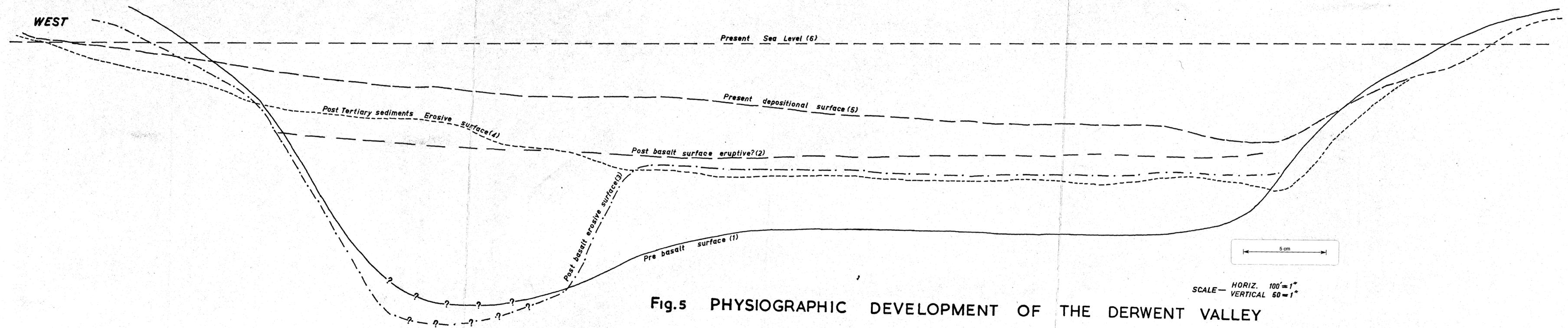


Fig.5 PHYSIOGRAPHIC DEVELOPMENT OF THE DERWENT VALLEY

SCALE— HORIZ. 100' = 1"  
VERTICAL 50 = 1"

5 cm

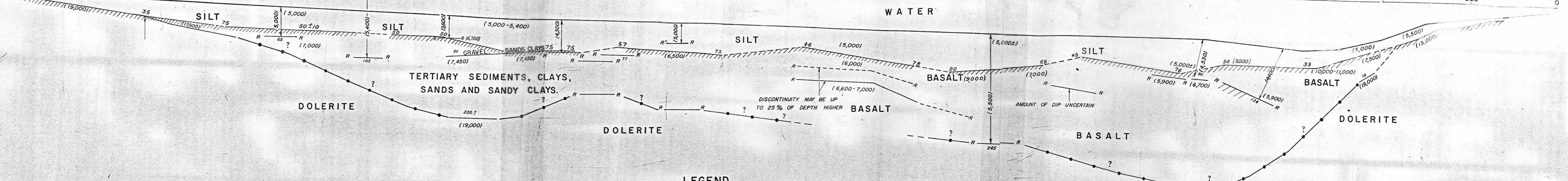
04215

62-349  
BMR

289035

WEST BANK 3,400 3,200 3,000 2,800 2,600 2,400 2,200 2,000 1,800 1,600 1,400 1,200 1,000 800 600 400 200 EAST BANK

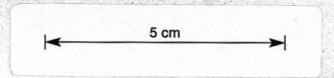
DISTANCE IN FEET FROM THE EAST BANK



**LEGEND**

- 46 ——— DEPTH DISCONTINUITY IN FEET BELOW RIVER BOTTOM
- (6,500) HORIZONTAL SEISMIC VELOCITY (REFRACTION) IN Ft/Sec.
- (5,000) VERTICAL SEISMIC VELOCITY (REFLECTION) IN Ft/Sec.
- R ——— R REFLECTION DISCONTINUITY
- ////// PROBABLE SURFACE OF BEDROCK
- ———● INFERRED TOP SURFACE OF DOLERITE
- - - - - INFERRED DISCONTINUITIES

**SECTION ALONG PROPOSED CENTRE LINE OF NEW HOBART BRIDGE**  
(FROM SEISMIC DATA) FIG. 6.



4216

INTERIM REPORT ON THE FOUNDATIONS OF THE  
PROPOSED NEW BRIDGE ACROSS THE DERWENT RIVER  
036  
AT HOBART.

BY

PROFESSOR S. WARREN CAREY.

INTRODUCTION:

The proposal is to build a new bridge across the River Derwent at Hobart to replace the existing concrete pontoon bridge. It is proposed that the centreline of the new bridge should be along the chord of the existing pontoon arc, the existing liftspan to become part of the new bridge.

Exploratory borings (percussion through the superficial silts and diamond drill through the underlying rock) have been carried out between June and October 1954. The logs of this drilling are recorded in a report by Mr. McKärcher, the engineer supervising the drilling. The samples collected during this drilling are now being studied. This report is written prior to the completion of the study of the samples. A further report giving details of the mineralogy, palaeontology and correlation of these samples and the state of oxidation revealed by them, will be presented in due course. However information immediately available places fairly clear limits on foundation conditions so that this interim report may permit design investigations to proceed in advance of the detailed geological report.

PROFILE SECTION:

A profile section of the bores with vertical scale exaggerated 10 times and a profile geological section with both vertical and horizontal scales 200 feet to the inch are submitted herewith. The latter section is drawn through the line of borings on the chord of the existing bridge and then along the centre line of the existing liftspan and approaches. The section therefore is along the centre line of the new bridge as at present proposed.

SUMMARY OF LATER GEOLOGICAL HISTORY OF DERWENT VALLEY AT HOBART.

The Derwent Valley is a valley of structural origin, dating back to an epoch of intense epeirogenic faulting in early Tertiary times perhaps 50 million years ago. The faulting resulted in deep narrow freshwater lakes which filled up with kaolinitic clays and clayey sandstones. These tertiary lake sediments were subjected to advanced dissection before basalt flows poured down the valley filling it up to a depth of some hundreds of feet. These flows were in turn deeply eroded. In Pleistocene times the whole coastline was drowned to depths exceeding 200 feet so that at this stage the Derwent at Hobart had over 200 feet of water in it. Upwards of 100 feet of silt and mud have since accumulated, but the river is still almost 100 feet deep at the proposed bridge line. All the foregoing events show up in the borings and each has an effect on the engineering possibilities of the crossing.

PRE-TERTIARY BEDROCK:

The pre-Tertiary bedrock surface is the old land surface as it existed prior to the early Tertiary faulting. Four miles south-west of the bridge, this surface would now be 5,000 feet above sea level, but it drops down rapidly on a series of faults until it is near sea level at the south abutment of the bridge and more than 200 feet below sea level in the centre of the river.

The pre-Tertiary bedrock has been reached in bores 320 and 2800 and in the excavations for the foundations of the outer pier of the liftspan, but none of the intermediate bores are deep enough to reach it although bore 2300 may have been just about to enter it when drilling had to be suspended owing to damage to the casing.

Whereas it would have been useful geologically to have pushed all bores down to reach the pre-Tertiary bedrock, it was clear that adequate foundations could be got on the Tertiary rocks so the additional expense did not appear to be warranted. Should a tunnel be contemplated as has been proposed by Hobart City Council this information would be useful, if not essential, but

in that event the centre line would almost certainly be nearly a mile downstream from the present borings, so the information would need to be sought there.

All exposures of the pre-Tertiary rocks in the bridge approaches, the liftspan foundations and in bores 320 and 2800 consisted of dolerite. It is quite possible that only dolerite occurs within this section. However, the presence of some of the associated sedimentary rocks is not unlikely. In that event, the sediments concerned would probably be low in the Triassic and would consist of quartz sandstone or shales.

The dolerite when fresh is a very strong hard rock of excellent engineering qualities. However, it is chemically unstable and hence is subject to deep weathering wherever it is shattered by even minor faults. Bore 2800 revealed that the dolerite there is badly fractured with slickensides, and it is clear that there is a fault nearby. On these grounds and on my general knowledge of the structure of the valley I would expect that even deep within the dolerite there would be zones of advanced weathering and poor bearing strength. If it were proposed to seat the concentrated loads of pier foundations directly on the dolerite, such weathered zones would be a hazard to be diligently tracked down. However, with foundations in the overlying Tertiary Rocks, the loads would be sufficiently distributed before the basement was reached, so that such deeply weathered zones as may exist in the dolerite basement no longer constitute a hazard.

#### TERTIARY LAKE SEDIMENTS:

These were met only in bores 2800 and 2300, about 100 ft. thickness in each. These lake sediments accumulated because the early Tertiary faulting which brought the Derwent Valley into being did not produce a simple trough sloping seaward, but rather a quite complex rift valley, with several steps down to the trough, tilted usually south-westwards, frequent platform-like horsts within the general down-faulted zone and many narrow

deep depressions which filled up with water and became lakes. There are sedimentary remnants of several such lakes along the course of the Derwent River. The bottoms of some of these lakes went below the then sea-level but they had barrier rims above sea level. The bottom of the lake at the bridge site extended down at least to 250 feet below present sea level, but this was probably above the then sea-level. The topwater level of the lake was at least 100 feet above present sea-level, and probably something like 400 feet above the Tertiary sea-level.

The sediments which accumulated in this lake were derived from the upfaulted blocks. Prior the faulting, Tasmania was a region of subdued relief like much of South Australia today. The surface was sandy, but deep chemical weathering throughout the Cretaceous period had produced a deep leached and fully oxidised zone overlying the bedrock. Hence the sediments which washed into the lakes contained a good deal of sand together with a lot of kaolinitic clay. Hence these lake sediments consist of cream to yellow to buff-coloured sandy clays and sands all well oxidised. This distinguished them sharply from the overlying Quaternary silts which were deposited in a strongly reducing environment.

The Tertiary lake sediments contain many plant remains and elsewhere in Tasmania there are often seams of lignite. The blue-grey colour of some of these sandy clays as recorded in the bore logs is presumably due to such organic matter.

These sediments were originally covered at least up to present sea-level and perhaps 100 feet higher by sediments and later by basalt. Hence they show a degree of pre-compression and are stiff to penetrate. They would develop considerable skin friction to piles and would satisfactorily carry a bridge foundation provided the load was adequately spread. I think a pile nest would be better than a caisson though if more concentrated loads were contemplated, triaxial strength tests on undisturbed samples should be undertaken.

TERTIARY BASALTS:

Following the filling of the lakes with sediments, the normal processes of erosion wore gaps in the seaward barriers of the lakes and allowed the newly deposited lake sediments to be eroded. Once the barriers were reduced the erosion of the new sediments was very rapid with steep-walled "bad-lands" type of valley. At the site of the proposed bridge most of the lake sediments were removed, forming a new valley down to below RL-210 (since the then sea-level was something like RL-300). The eastern wall of the valley was stripped clean of lake sediments to the pre-Tertiary dolerite whereas a substantial mass of the lake sediments were left on the west side of the valley (between D and E in bores 2800 and 2300). The profile D.D.D. represents the floor of the valley at this stage.

Basalts were now extruded. They poured down the valley in a succession of flows, each one filling the bottom of the valley, until a thickness of 300 feet or more accumulated, bringing the valley floor above present sea-level. The basalts now appear in bores 1800, 1300 and 800, as a single mass of basalt. But it is clear that a succession of flows is involved no doubt separated from each other by tens, hundreds or thousands of years of quiescence. Elsewhere in the Derwent Valley the surfaces of individual flows were weathered to soil, and forests of large trees grew on them, before the forests were killed and buried by thick showers of volcanic ash and scoria which preceded the next flow. The fossil forest trees now silicified and opalised still stand upright in the ash which overwhelmed them.

When the basalts extrusions were finally over, erosion regained the ascendancy and a new deep valley was eroded in the basalt, again to well below sea-level. The profile C.C.C. in the section indicates the lowest limits of this valley, which bore 1300 proves to have extended down to at least RL-177.

The deepest part of the valley might be as low as RL-190, between bores 800 and 1300.

The basalt when fresh is a hard rock, closely fractured by irregular contraction joints; much of it is very amygdaloidal. Interbedded with it are scoriaceous and agglomeratic layers as well as surfaces of contemporaneous weathering. The weathered zones tend to be disposed as flat or near flat sheets, not along steep fissures or fault zones as in the dolerite because the faulting was over before the extrusion of the basalts.

Where proved in the bores, the basalt would be an adequate foundation for the bridge, preferably with a pile nest. This would allow any pile which found a more weathered zone to be driven further, whereas a caisson might ride on a hard projection with consequent high local loadings in the caisson rim and basalt which might lead to subsequent settlement.

#### THE QUATERNARY GRAVELS:

Overlying the erosion profile C.C.C. cut in basalt, Tertiary lake sediments, or pre-Tertiary basement according to locations, each bore found a layer of gravel which varies from 5 to nearly 20 feet thick. Although this gravel appears on the profile section as a continuous layer, this is almost certainly an over-simplification. It probably consists of a number of lenses which accumulated during the drowning of the valley. The drowning was not a single catastrophic act, but a progressive advance of the sea onto the land which was spread over a thousand years or more - general cumulative rising of the sea, interrupted no doubt by occasional reversals when the sea-level was temporarily stationary or actually receded somewhat. At each stage and level of the sea on the way up there was time for storm waves to develop a beach shingle, which now appears as this zone of gravel. The gravels probably would in most places offer adequate bearing for heavily laden piles especially as we can be certain that there is no underlying stratum subject to undue settlement or slippage.

#### THE QUATERNARY SILTS:

The quaternary silts have accumulated with the present high sea level. They show little variation and have been deposited in a reducing environment. They should not cause

rapid deterioration of steel. They are normally loaded and could not carry any load without serious settlement. Piles or caissons would have to be carried right through them. The maximum thickness measured is 80 feet in bore 1800. The maximum depth below sea level measured is RL-159 feet in bore 1300, and there is no reason to expect their base to extend below RL-170 feet at any point of the section.

GEOLOGICAL LIMITS ON BRIDGE DESIGN.

Each abutment contains good dolerite widely exposed in good condition so any design based on a free span of the whole waterway, such as a single span arch or suspension would present no foundation difficulties. However, this would be a first order engineering structure and the cost would necessarily exclude it on foreseeable conditions.

Any pierced structure clearly demands that the piles or piers be taken down at least to the base of the quaternary silt (B.B.B. in the profiles), that is to RL-170. In order to minimise the cost of superstructure, the consultant Engineers, Messrs. Maunsell, Posford and Pavey, have suggested using closely spaced piers consisting of light steel pins driven through light caissons, the latter to be seated in the silts. Provided these pins are driven to refusal into the gravels below the silts there is no geological objection to this scheme. However, the depth of normally loaded silts now disclosed taken with the depth of free water already known may qualify the transverse stability of the structure, and also make the cost of the long piers prohibitive for the short spans. However, these are engineering questions and can properly be left to the designers.

Considering more conventional foundations I would regard a cluster of piles more suitable to the conditions here than caissons. I do not have any doubt about the adequacy of the gravels and the rocks immediately under them.

But there is a good deal of local variation both in gravels themselves and in the underlying rocks. The individual piles of a cluster are much more adaptable to accommodating the loads to such local variations than the larger caisson units. However should there be sufficient other reasons for preferring caissons, I have no doubt that with proper care in the seating of them, they could be satisfactorily used.

OTHER GEOLOGICAL HAZARDS:

Other geological hazards such as flood loads, current scour, tsunamis or seismic risk, to one or more of which many other bridges are subject, do not appear to be important in the case of the Hobart Bridge.

CONCLUSION:

Taking account of the foundation conditions only, and assuming that a single span arch or suspension is eliminated by cost, I consider that a multispan bridge borne on clusters of piles driven to refusal into the gravel zone which underlies the Quaternary Silts, is the natural solution to the conditions found.

(Signed) S. Warren Carey, D.Sc.  
Geological Consultant.

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APPENDIX II: INTERIM REPORT ON THE  
PALAEONTOLOGY OF THE 1954 HOBART  
BRIDGE BORES.

By Edmund D. Gill, Curator of Fossils,  
National Museum of Victoria.

Introduction

This report outlines the fossils found so far, and other relevant evidence from the boring records, then puts forward some interpretations and makes some recommendations. It should be emphasized that this is only a progress report, provided as arranged on work done till the end of March 1955.

Palaeontological Evidence

1. DIATOMS. From Bore 1800, R.L. -92-25 feet, Mr. B. Tindale found the following diatoms:

Actinoptychus senarius var.  
A. undulatus var.  
Auliscus caeleatus  
A. sculptus  
Biddulphia reticulata  
Biddulphia sp.?  
Campylodiscus daemelianus  
C. echensis  
C. hodgsoni  
Climacosphenia moniligera  
Cocconeis scutellum  
Coscinodiscus radiatus  
C. excentricus  
C. sp.  
C. sp.  
Cymbella gastroides  
C. sp?  
Epithemia gibbularia  
E. turgida  
Eupodiscus sp.?  
Gomphonemia intricatum  
Grammatopora macelenta  
Navicula aspera  
N. bombus?  
N. brasiliensis  
N. didyma?  
N. lyra  
N. smithi  
N. yarrensis  
Nitzschia tribionella  
N. sp.?  
N. sp.?  
Pleurosigma estuarrii  
P. formosum?  
Plagiogramma pulchellum  
Rhabdonemia adriaticum  
Surirella fastuosa

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Synedra robusta  
S. uina var. f

The queries are due to specimens being broken and so not determinable with certainty, or to necessary not being available at the moment. The former problem may be solved by further investigation, and the second will be soon. The significance of this flora is brought out by the diagram that constitutes text-figure I, a method devised by the writer for "reading" diatom floras at a glance (see Mem. Nat. Mus. Melb. 18, pp. 144-145). The flora is definitely marine. The two freshwater species are represented only by one specimen each, and were probably washed in. There is a small but definite brackish element probably washed down from the higher reaches of the estuary. Diatoms are good ecological indicators, and the rich flora from this site portrays the facies quite accurately. Sponge spicules were plentiful in this sample.

2. WOOD. Small pieces of wood were noted as follows:-

Bore 550, R.L. -139.25 - 142.25:	In gravel formation, as shown in plan 11D.
Bore 1300, R.L. -160.25'	Do.
Bore 2133, R.L. -136.5'	Do. at bottom of silt formation.

Minute plant fragments were noted when washing up some other samples, and it is pertinent to note the presence of these in the "Tertiary sediments", e.g. at 225 ft. in bore 2300. The boring records mention a "small piece of soft black coal" at 188.8 ft. in this bore, but I do not appear to have a sample of it.

3. POLLEN. Dr. Cookson has a series of samples to examine for fossil pollen, and I expect to receive her report shortly after easter.

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4. Hystriosphærideae. Dr. Cookson has recently made a special study of these fossils in Paris, and will do these from Hobart at the same time as the pollen.
5. OSTRACODS. Mrs. Betty Kellett Nadeau has examined a series of same and named the ostracods, and also some foraminifera.
6. FORAMINIFERA. Mr. A.C. Collins has agreed to do these, but has to finish some other work first.
7. RADIOLARIA. Mr. Tindale recently noted some radiolaria in a diatom spread. As far as I am aware, these are the first Quaternary ones to be noted in Australia, and I have asked Dr. Riedel, who is a specialist in this group, to examine them.
8. SPONGES have been recognised by their spicules.
9. ECHINOIDS have been recognised by their spines.
10. MOLLUSCA The shells are too broken up in the small samples sent to enable the molluscan fauna to be studied adequately and hence larger samples were requested. When these come to hand, they will be worked over. However, the sample from 54.15 ft. in bore 320 was examined. Small shells of Venericardia bimaculata chioneryx cardioides and numerous fragments of Pecten were recognised.

The following study of Bore 2300 mostly done by Mrs. Nadeau, provides interesting ecological information which fits in very well with what one would expect from the eustatic interpretation of the sedimentation.

R.L. -63.25 ft.      Diatoms common.  
 Ostracods represented by several species, mostly small. Cythere and Macrocypris present.  
 Foraminifera: Many Bulimina of one species. A few Elphidium, small Quinqueloculina, Lagena and Nonion.  
 The ubiquitous estuarine species Rotalia beccarii present, but few in number. Many arenaceous forms including a large Proteonina.

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- R.L. -82.50 ft. Diatoms - few  
Ostracods - as 63.25 ft.  
Foraminifera - Rotalia beccarii abundant,  
i.e. brackish element more prominent.  
Many Elphidium (marine). Arenaceous  
forms rare. Two specimens of large  
Quinqueloculina and two of Massilina.  
Bulimina present, but whereas at 63.25 ft.  
the last chambers were smooth and rounded,  
these lack the rounded chambers. The  
lower edges of the chambers have fine  
spines.
- Lamellibranchiata - shall crystals abundant.  
Echinodermata - present.
- R.L. -97.75 ft. Diatoms - abundant. Also abundant in  
sample from 92.25 ft. in Bore 1800.  
Ostracods common and mostly large species.  
Foraminifera rarer. Elphidium present,  
and Bulimina rare, appearing also to vary  
in proportions from those higher in the  
bore.
- R.L. -116.25 ft. Diatoms abundant.  
Ostracods as at 97.25 ft.  
Foraminifera mostly Rotalia beccarii  
showing a marked estuarine ecology.  
Matrix coarser.
- R.L. -135 ft. In process of study. Rotalia beccarii  
prominent so estuarine. Also some marine  
forms and ostracods.

Text-figure 2 sets out diagrammatically some of the  
ecological interpretations to be placed on Bore 2300.  
In the silt formation (from 119.5 ft. up) there is  
palaeontological evidence of a transgressing sea in  
that there is change in ecology from below up from  
estuarine to more marine conditions. This is interpreted  
as being a function of the Flandrian Transgression, an  
event for which there is evidence all over the world, and  
which has been checked in time by radiocarbon analyses.

#### Evidence from Bore Records

The bores reveal a deep channel in dolerite infilled  
with:

- |                                       |   |
|---------------------------------------|---|
| Oldest 4 basalt                       | } Order of these two<br>formations is not<br>proved by the bores. |
| 3 sediments of ? Tertiary age         |   |
| 2 coarse sediments - "Gravel".        |   |
| 1 a Stiff clay, silt, sandy clay etc. |   |
| Span Pier 89.5 - 96 ft.               |   |
| Bore 2750 95 - 105 ft.                |   |
| 2300 119.5 - 141 ft.                  |   |
| 2133 136 - 158 ft. probably           | absent  |
| 1800                                  | absent  |
| 1300                                  | absent  |
| 800                                   | absent  |

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550 133.75 - 18t.50.

Youngest 1 B silt above 1 a.

Whether 1a is a different formation from 1b or that these are two members of one formation cannot be determined for sure from the evidence available. In the Yarra Delta the following three formations can be readily distinguished lithologically:

3. A dark unoxidised silt deposited during the Flandrian transgression as shown by geology and C14 dating.
2. An underlying oxidised stiff clay (i.e. more compact, more water expressed, and oxidised during Mankato eustatic low sea-level).
1. Underlying 2 is a formation of gravel.

It may be that these formations can be paralleled by 2, 1a and 1b from the above list of deposits in the Derwent delta.

The bores do not prove the relative ages of formations 4 and 3 in the Derwent Delta. The side of the old valley wall between them is steep, whichever way it faces. Plan 11D shows the eastern wall of the later Pleistocene valley as steeper on the east than on the west, but this could be drawn differently from the same evidence. In Pleistocene times the valley was fairly symmetrical in cross-section, the deepest part being about the middle of the stream, whereas at present the river is deeper on the east side than on the west. The deep Pleistocene Valley is probably a function of eustatic change of sea-level. Such valleys have been observed in many places in Australia (including places on stable cratons), and in other parts of the world. The worldwide retreat of the sea in Mankato times caused deep down-cutting of streams debouching into the sea. Deposits now below sea-level were oxidised, and then during the Flandrian Transgression the valleys so cut were largely infilled with unoxidised silts. Resting on the basalt are coarse sediments which may well represent the fast flowing river in a time of marine retreat. No fossils have been found in this formation by which it can be dated, but such scraps as there are suggest a fluvial setting.

In bores 1300 and 1800 the thalweg of the Mankato Valley can be seen to be of the order of 150 feet. A similar valley in the Yarra Delta, Melbourne, infilled with unoxidised marine sediments has been shown to be of Mankato age. It has been traced by bores to over 100 ft. below sea-level, but has not been followed further because it goes beyond the area in which the Melbourne Harbor Trust is interested. However, the submarine geography of Port Phillip suggests it was affected by the last retreat of the sea, and Keble picked up a 25 fathom (150 ft.) outlet in Bass Strait. Off the Western District of Victoria, I have recognised in the Admiralty Charts a submarine platform at 150 ft. A retreat of the sea of this order would connect Tasmania with the mainland; also Kangaroo Island and New Guinea. In this connection it would be very helpful to know whether the fossil valley floor in the Derwent at 150 ft. is maintained for any distance. Are there any bores that could throw light on this matter? See text-figure 3.

#### Some Interpretations

Formation 1. Tertiary sediments. The only fossils found after careful search by two workers were minute scraps of plant remains insufficient to indicate age. If there were scraps of leaf cuticle or such remains it might be possible to get an idea of the age, but the minute fragments gave no clue. In bore 2300, samples from 225', 244', 135' and 144' were examined. As a rule, the "argument from absence" is a fallacious one, but in this case the absence of fossils is considered significant in view of the location of the sediments. They lie in an estuarine channel, and if such sediments were marine, one would expect to find some fragment of some kind of marine fossil in them.

I consider it safe to accept it as a working hypothesis that these sediments are freshwater. If they are freshwater, they could be either fluvial or lacustrine, and either Quaternary or Tertiary. No answer to these alternatives can yet be given. From the spreads used for fossil-hunting it seemed that the sorting was different from the Quaternary beds. Some circumstantial evidence may therefore come from the mineralogist., although even then there is the possibility of re-sorting.

The most likely means of solving this problem would be the examination of the "soft black coal" at 188.8 ft. in Bore 2300 for pollen. Could I have a piece please?

Formation 2. Basalt. This is older than the gravel and younger than the dolerite, but as already stated it is not known whether it is older or younger than the "Tertiary" sediments on the evidence available.

Formation 3. Gravel. It may be significant that the only fossils found in this formation are wood. This and the complete absence so far of marine fossils suggests a freshwater origin for these sediments. They may well have been laid down by the Derwent during a glacial low sea-level. They are often very coarse indicating a fast current which is in keeping with the fluvial rather than marine origin, in view of their location. If enough wood is available for C14 analysis, such an analysis would date the formation and also indicate whether or not it were a period of glacial low-sea-level. In the meantime the wood is being determined on structure. I am enquiring from one of the most progressive of the overseas C14 laboratories to find out on how small a specimen a radiocarbon analysis can be made using the latest methods.

Formation 4. Silt. This is definitely Quaternary. Its position, fossils, and chemical condition, as well as the variation in facies from estuarine below to marine at the top, show that it was deposited during the Flandrian Transgression. Diatoms are good facies indicators, and I am arranging to get a series of floral analyses done from below up so as to get a really detailed ecological profile.

Recommendations.

1. That the possibility of getting wood for C14 analysis be investigated.
2. That a large sample or better samples from different levels containing shells be submitted so that the mollusca can be studied adequately.
3. That a large sample of gravel be submitted for working over in an effort to discover fossils in this apparently unfossiliferous formation.
4. That a sample of the "soft black coal" from 188.8 ft. in Bore 2300 be submitted for pollen analysis.

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April 1st. 1955.