TR14-117-134

28. Whitewater Creek dam site, Kingston: subsurface investigations, 1969

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The 1969 programme of investigation was based largely on the recommendation of an earlier report (Moore, 1968) with the addition of:

(1) Trenching between BH 2 and BH8 to bedrock, to determine whether a continuous fracture zone connected the two holes.

(2) A trial grouting programme in part of the valley floor to determine whether cement grouting could seal off the leakage caused by intense jointing.

(3) Two diamond drill holes on the lower site. These holes to be drilled to 100 ft and pump tested to determine the permeability of the Triassic sandstone which underlies the lower site and reservoir area.

RESULTS

Trenching

A trench 500 ft long, 15 ft wide with an average depth of 6 ft was dug between BH 8 and BH 2 by using a D.9 Caterpillar bulldozer equipped with a ripper, a D.6 Caterpillar Traxcavator, Harman shovel and a Fordson back hoe. After it was dug, the trench was sluiced, pumped and finally cleaned manually to expose bedrock (plate 1). The trench was photographed stereoscopically from both banks for mapping purposes. The trench gave continuous exposures between BH 8 and BH 2 revealing that no continuous shatter or closely jointed zone was present along the valley floor as had been feared in 1967. Indeed most of the trench, especially from the cut-off wall to the centre line, was composed of hard grey siltstone and sandy siltstone. These sediments were coarsely bedded; the thickness of the beds varies from 1-4 ft. These competent beds would appear to provide very suitable foundations on which to place a rock fill dam.

The above sediments are cross-jointed; tight vertical E-W and N-S joints are the most common. Some large open E-W vertical joints were also exposed in the trench (plate 2). Frequently these E-W joints bisect or divide into two sub-parallel joints with brecciated blocks between the joints.

These thick sandy siltstone beds are generaly separated by thin mudstone beds into which the siltstone grades. These mudstone beds are seldom more than ½ inch thick and when thicker weather to form clay. Several such clay beds over 1 inch thick were exposed in the trench with an exceptional thickness of 6 in of clay exposed on the S wall of the grout cell trench.

Two thin, white and green, fossiliferous mudstone beds with fenestellids were found in the trench. These mudstones are lithologically identical to the mudstone beds found at outcrops in Whitewater and Boddys Creeks and also in BH 8 and BH 15.

The presence of these beds on the valley floor indicates that the spur which the dam is to straddle appears to belong to the Malbina Formation of the Permian succession rather than the Ferntree Formation as was thought in 1967.

West of the cut-off trench are large exposures of fissile siltstone and mudstone, which are closely-bedded, hard, dark grey in colour when fresh but greenish grey when weathered.

The fissile siltstone and mudstone is intensely cross-jointed, forming areas in the trench of low outcrops with small angular blocks scattered on the trench floor.

This intense open jointing in the incompetent siltstone and mudstone is probably due to relaxation joints which formed and opened when the valley was eroded by Whitewater Creek. Such zones of joints are thought to have caused the high water losses when BH 2 and BH 6 were drilled and pump tested in 1967.

Such a theory would explain the presence of artesian water in all the holes drilled on the valley floor and would also explain why the zones of high leakage are confined to the valley floor and do not occur in the abutment drill holes even though the siltstone and mudstone do occur in these cores.

Pit

A pit 12 ft deep was dug by the Harman shovel in the old sand pit near the junction of the two tracks leading down to Whitewater Creek (fig. 37). It was hoped that this pit would offer some explanation of the source of the superficial grey sands that cover much of the reservoir area particularly of Whitewater Creek upstream from the dam site.

The following section was exposed in the pit:

Depth		*Description*
ft in	*ft in*	
0 0 –	2 0	Grey unconsolidated sand.
2 0 –	5 0	Orange iron-stained clay with a very low percentage of sand.
5 0 –	10 0	Soft, grey and white streaked clay, a mudstone with fossil impressions towards the base.
10 0 –	12 0	Soft, rotten, yellow fossiliferous mudstone.

This section was clearly underlain by Permian sediments and provided no explanation as to the source of the sands.

Benches

Three benches were cut by the bulldozer. The first two benches were cut in order to locate the upstream and downstream faults. This method proved most successful on the downstream fault where Permian and Triassic rocks were found separated by a clay crush zone (Bench 2, fig. 37). On the upstream bench (Bench 1) continuous outcrops of grey siltstone were exposed to the northern end of the spur where some clays were then exposed near Whitewater Creek. It was thought possible that these clays were weathered fault crush. They were further investigated by BH 15.

Bench 3 was designed to expose bedrock along the centre line in the spillway area on the northern abutment. Bedrock was exposed close to the surface at both ends of this bench but even when using the ripper, the bulldozer could not reach bedrock in the central area of the trench. BH 12 was sited in this central area; the depth of weathering encountered in this hole was exceptionally deep and comprised two zones of weathering.

Quarry site

Several quarry sites in areas of dolerite outcrop were selected by surface examination. Sites 1a and 1b were investigated first because of their proximity to the upper dam site. These two sites were on two low, flat-topped interfluves between Whitewater Creek and two of its small tributaries. Good outcrops of dolerite occur in these streams with Permian siltstone occurring in Whitewater Creek both above and below the dolerite. Large dolerite boulders and a few flat outcrops occur on the steep slopes forming the noses of the interfluves above Whitewater Creek.

From surface exposures the structure of the interfluves appeared to be that of low, westerly-dipping Permian sediments intruded by a concordant sill of dolerite of a minimum thickness of 100 ft, or a thick dyke of dolerite intruding along a vertical fault in the Permian sediments.

Four survey lines were cut, levelled, and measured down the slopes of these two quarry sites. Extended proton magnetometer traverses were undertaken along these lines with readings taken every 50 ft (figs 37, 38). The results of the magnetometer traverses indicated that the dolerite was a sill dipping to the W rather than a dyke, and that dolerite was present from the top of slope to beyond Whitewater Creek.

Seismic exploration was concentrated on Site 1a, since it had greater potential reserves due to its steeper slopes and greater height. Eleven spreads approximately 300 ft in length, with geophones 50 ft apart, and two small weathering spreads were fired (fig. 37).

High velocities (16,000-22,000 ft/sec) were recorded from the spreads on the slope but on approaching Whitewater Creek and the valley flats, some very low velocities were recorded.

The high velocities were interpreted as indicating hard, unweathered dolerite close to the surface with a minimum vertical thickness of 100 ft and forming the slope of the spur down to Whitewater Creek. The low velocities on Whitewater Creek and valley flats were thought to be due to a faulted contact with a crush zone of dolerite against Permian sediments. From the results of the drilling just completed in the reservoir 600 ft E of the seismic lines, it may now be necessary to re-interpret the seismic results where these low velocities occur.

One hole was drilled from the top of this spur to a depth of 100 ft and a core was obtained of unweathered, unjointed, hard dolerite. From the limited evidence of this drill hole (Quarry DDH 1) it appears that Quarry site 1a should provide more than an adequate amount of suitable dolerite rock fill for a dam of a similar size and type as Risdon Brook. Detailed grid drilling will be required to confirm this conclusion.

Drilling

A Mindrill F.20C was used for the angle drilling and a Gemcodrill trailer-mounted rig was used for all vertical drilling. A total footage of 1,951 ft was drilled, including 491 ft of angle drilling at 45°.

Augers were used in conjunction with diamond drilling on the Gemcodrill rig in the saddle and reservoir areas.

In addition, six grout holes were drilled in the grout cell to a depth of 120 ft using a percussion rig. In addition forty auger holes were drilled to depths varying from 3 to 48 ft using a tractor-mounted Proline auger drill.

The location of these holes and those drilled in 1967 are shown in Figures 36 and 37.

Bore Hole 15

This hole was sited opposite the supposed crush zone exposed by benching on the southern bank of Whitewater Creek and was directed towards the rock outcrops exposed on the bench. The fault separating the fossiliferous mudstone of the valley and grey siltstones forming the spur was successfully penetrated by this bore hole.

The degree of crushing of the mudstone and the width of this fault zone was similar to that found on the same fault in BH 8 of the 1967 programme. Considering the intensity of fracturing as indicated in the drill cores for these two holes (BH 8 and BH 15), the water losses were very low.

Bore Hole 11

BH 11 was located S of the centre line at a level at which the basalt/sedimentary contact would be penetrated, and close to the fence line along which boulders of what was then considered to be sub-basaltic tuffs and baked sediments had been found when the area was mapped in 1967 (Moore, 1968, p. 66). BH 11 penetrated 40 ft of baked red and brown clay with abundant angular rock fragments of dolerite, basalt, Permian mudstone, quartzites and schists. Samples of this core were examined by the Mines Department petrologist, G. B. Everard, who suggested that these sediments were river gravels that had only been transported a short distance (see p. 142).

Three thin layers of basalt, 6, 12 and 24 in thick, occur in the baked clays in BH 11 at depths of $6\frac{1}{2}$, 29 and 34 ft. The baked clays are thought to be valley-fill sediments either associated with the margins of the basalt flows or within the basalt flows. This appears to be the origin of similar sediments cropping out on the Channel Highway S of Doctors Hill. From the brief study of the three cores in these sediments there appears to be a complex history of several cycles of erosion, deposition followed by extrusion of lavas with the overlying layers of basalt now removed by recent erosion.

Basalt extends from 40 ft to 88 ft 6 in. Within this section, which is deeply weathered there are clay bands at 51-55 ft and 80-88 ft which are only recognisable as basalt because of the remnant vesicular structure. Below this is an 8-inch organic layer and below this again is a soft white sandstone. Beneath the white sandstone is an 18-inch thick bed of green mudstone with shear polish on a 45° joint face. This mudstone overlies 8 ft of micaceous quartz sandstone with graphite. The sandstone is well-bedded. Both this sandstone and the mudstone above it are Triassic sediments whereas the white sandstone is thought to be a Tertiary sediment.

The succession encountered in BH 11: 40 ft of valley fill sediments, 40 ft of basalt, 8 ft of Tertiary sandstones overlying Triassic sandstone, revealed two important new facts:

(1) A block of rocks was present beneath the basalt and this block was probably fault-bounded extending into the area (of no outcrop) covered with grey sand in the orchard.

(2) A deep Tertiary valley filled with Tertiary sand, basalt, clay and gravel was located in this Triassic block.

Re-orientation of the investigation programme

Even though the water losses from the pump tests in BH 11 were low, except for the upper 12 ft, these results were not thought to be typical of such Tertiary sediment-filled valleys. It could also be anticipated that such sediments would change in facies rapidly over short distances both vertically and laterally.

If the valley encountered in BH 11 entered the reservoir area it would provide a most effective leakage zone especially as the distance around the southern dam abutment from the reservoir to BH 11 was very short. Additional leakage paths could also be provided by the fault contacts of the Triassic sandstone against the Permian siltstone especially as it appeared likely that the Triassic block encountered in BH 11 extended into the reservoir area near the orchard.

The major aims of the investigation now became the determination of the extent of the Triassic sandstone block and the location of the Tertiary valley within it. This necessitated a considerable change to the original programme.

It was still thought desirable to continue the trial grouting programme because if the leakage in the zones of intense jointing along the valley floor could not be sealed by grouting this could also cause the abandonment of the site. The likelihood of a Triassic sandstone block in the reservoir area of the upper site made it even more desirable to have some knowledge of the permeabilities of these rocks in the Whitewater Creek area. This information would still be obtained by drilling the two holes on the lower site.

It was decided that the finance available for drilling the second hole on the upstream fault and that for the downstream fault BH 9 would be used in drilling angle holes into faulted contact between BH 4 and BH 11. The drilling on the quarry site would be reduced to one hole and drilling on the centre line of the dam site would be reduced to the minimum. All funds saved by these changes would be used in the reservoir area to try to locate the Tertiary valley which appears to have been cut into Triassic sediments.

Geology of the reservoir area

Of the two problems, locating the extent of the Triassic sandstone appeared to be the simpler for the following reasons:

(1) If as was suspected, the Triassic rocks comprised a fault-bounded block extending into the reservoir area, it must be confined to the area of no outcrop in the orchard W of BH 11 and S of Whitewater Creek where continuous outcrops of Permian were now exposed from the dam site to the quarry site.

(2) To the S of the reservoir if the Triassic sandstone was to crop out from beneath the basalt, the most likely position would be in the saddle separating Doctors and Parks Hills. Parks Hill is thought to comprise a continuous, though faulted, succession of Permian sediments extending from the Lower Permian formations through to the Grange Formation and finally the Malbina Formation (Paxton, 1958).

The palaeontological and stratigraphic study confirmed that the Permian sediments exposed on the Channel Highway, S of Doctors Hill, to Howden turn-off were Lower Permian and most of the outcrops exposed on the H.E.C. track climbing Parks Hill belonged to the Grange Formation with Malbina sediments below the dolerite on the track at the top of Parks Hill (Clarke, 1968). This Parks Hill section is lithologically different from that of the Permian sediments found in Whitewater Creek and Boddys Creek catchments and there are thought to be two major faults trending in a N-NNE direction through this region separating the Whitewater Creek area from the Parks Hill succession.

One of these major faults passes through the saddle between Parks Hill and Doctors Hill (fig. 39). A thin dyke of dolerite indicates its trace S of the saddle and then the fault swings beneath the basalt E of the Lower Permian sediments exposed on the Channel Highway. North of the Doctors Hill saddle area the fault runs along the base of the dolerite sill on which the quarry is located through Boddys Creek and on to the Leslie Valley road to the saddle close to the Lucas' homestead. On this narrow saddle from which the basalt has been eroded, Triassic sandstone is faulted against Permian siltstone, and is now known to occur on the saddle between Doctors Hill and Parks Hill.

(3) From the 1967 mapping, boulders of basalt were known to be scattered in the orchard and a small patch of red soil with basalt boulders occurs around the old house. It had been concluded when mapping the region that the basalt flows from Doctors Hill and the vicinity of BH 11 once covered the orchard area and had since been eroded away leaving this residual patch near the old house. The grey sands covering this area were thought to have been derived from thin Tertiary sands probably beneath the original basalt flow.

In BH 11, the Tertiary valley was associated with the basalts and it appeared that there were only two major directions for this valley to run, either through the saddle or towards the old house in the orchard.

Magnetometer surveys and proline drilling in the orchard and saddle areas

It was decided to map the basalt/sedimentary contact in detail with the proton magnetometer using stations 10 ft apart working out from the known basalt/sedimentary contact that must lie between BH 11 and BH 4 and from the outcrops of basalt on Doctors Hill towards the Permian outcrops on Parks Hill. Where the instrument located this boundary, the position was marked on the ground and proline holes were drilled approximately 100 ft apart on the magnetometer lines on either side of the contact (fig. 40).

It was hoped to produce a sub-surface map of the orchard and saddle area by this method. This combination of the magnetometer and the mobile Proline drill proved most successful. Ten magnetometer traverses were made which connected approximately with the quarry magnetometer traverses. Forty proline holes were drilled (figs 37, 40).

From this work an outline of the sub-surface geological map (fig. 39) of the upper dam site was obtained and this geology was confirmed by later diamond drilling using the Gemcodrill rig in the reservoir and saddle area (Res. BH 1-BH 6 and Saddle BH 1, BH 2).

In the saddle area W of the basalt the Tertiary valley was found to be cut into Triassic sandstone faulted against Permian. White unconsolidated sand with a considerable percentage of clay, clearly a Tertiary sediment, with depths of 33-48 ft, with no lithological change, occurred in Proline 13, 14 and 35. Tertiary sand was suspected in Proline 6 occurring below Permian mudstone talus at depth of 24 ft. Triassic sandstone was hit in Proline 36 and at a later date two or three small blocks of Triassic sandstone were found in the ground. Hard rock was encountered at 4 ft in Proline 37 and 38; small fragments of Permian Grange Mudstone were recovered.

Basalt was found to extend in the orchard area from BH 4 towards the old house. North of this basalt a wide area of Triassic sandstone and mudstone was faulted against Permian mudstone. The trend of this fault was NW-SE and it appeared to join with the N-S fault upstream from the dam site, because in Proline 22 white fossiliferous mudstone fragments were recovered and outcrops of the grey, sandy siltstone occurred in the nearby small N-S stream. This fault was angle drilled in BH 11a and BH 11b and this confirmed the trend of the fault. BH 11b was sited between Proline 4 and 5 and BH 11a between Proline 1 and 2.

Bore Holes 11a *and* 11b

The cores from these two adjacent holes were quite different. BH 11a passes through a simple uncomplicated fault pattern:

Depth				*Description of core*
ft	*in*	*ft*	*in*	
0	0–	24	0	Tertiary valley fill clay with angular pebble fragments and clay derived from the weathering of basalt showing a vesicular structure.
24	0–	61	6	37 ft of Triassic sandstone with the bottom 2 ft crushed and broken.
61	6–	66	6	15-inch crush zone of green mudstone with shear polish and slickensides, 12 in and fault pug, 3 in. The core recovery was only 20% in this run.
66	6–	81	6	Very crushed, broken and brecciated Permian siltstone and mudstone.
81	6–	95	0	Broken Permian siltstone becoming less broken unless a joint was encountered.
95	0–	109	6	Unbroken Permian siltstone.

The water pressure tests were not very high for this hole and across the fault zone only 12 gal/min at 68 lb/in^2 pressure, were lost.

BH 11a was sited along magnetometer line A between Proline 1 and 2 and drilled at an angle of 45°. The writer's interpretation of the core is summarised below:

Depth				*Description of core*
ft	*in*	*ft*	*in*	
10	0–	30	6	Valley fill with baked clay containing angular fragments of dolerite, basalt, etc.
30	6–	35	6	Basalt.
35	6–	40	6	Valley fill sediments.
40	6–	65	6	Clay, sand, decomposed basalt and sandstone.
				Tertiary
65	6–	80	6	Fine white sandstone, siltstone and gritty mudstone. Tertiary sediments below the basalt.
80	6–	85	6	Transitional beds of fine white sandstone of suspected Tertiary age.
				Triassic
85	6–	95	6	Closely bedded fine sandstone with micaceous mudstone beds interbedded with sandstone. Triassic sediments.
95	6–	100	6	Brecciated sandstone with mudstone blocks within the sandstone changing gradually to mudstone containing sandstone blocks. Core hard and it appears that sandstone has been remobilised and filled up the spaces within the mudstone.
100	6–	104	6	Black mudstone with close veining and shear polish and 1-inch pug layer at the base.

Depth ft in ft in	Description of core
	FAULT
	Permian
104 6–120 6	Closely-bedded sandstone interbedded with mudstones which appear very similar to Triassic sandstones except for 2 ft block of Permian siltstone with characteristic turbidite and slump structures.
	Ferntree Formation
120 6–128 6	Closely-bedded grey-green sandstone with grey siltstone at its base 20 in thick containing typical Permian siltstone turbidites, slump and consolidation structures. No erratics present in this 20 in of core which is thought to be Permian.
	Risdon Sandstone
128 6–149 0	2 ft of grey massive siltstone with turbidite and slump structures passing through a 10-inch transitional zone into dirty grey massive sandstone with mudstone flakes.

The interpretation favoured by the writer is that one fault is present at 104 ft 6 in between the Triassic and the Permian sediments and even though some of the closely bedded sandstones are of Triassic type they are Permian sediments and the sandstone at the bottom of the core is the Risdon Sandstone at the base of the Permian Ferntree Formation. This sandstone in the core of BH 11a appears lithologically very similar to the Risdon Sandstone drilled downstream from the Risdon Brook dam site.

Another possible interpretation of the core of BH 11a is that the drill passed through two faults giving a repetition of Triassic sandstone faulted against Permian siltstone which in turn was faulted against Triassic. This interpretation makes the sandstone at the bottom of the core of BH 11a Triassic in age.

Difficulties of interpretation do exist in the area of BH 11a and Proline 2.

In Proline 2, 3 ft of red baked clay of the valley fill associated with basalt was drilled followed by 18 ft of fine yellow mudstone underlain by 12 ft of yellow sandstone which from the auger samples appeared to be Triassic. If this sandstone at the bottom of the Proline 2 is Triassic, a NE-SW fault must be present throwing down the Triassic sandstones against Permian near the basalt (fig. 39). If this sandstone in Proline 2 is Tertiary sandstone derived from Triassic and appearing like Triassic in the pulverised core produced by the proline, a fault need not be postulated and Proline 2 marks the boundary of the Tertiary valley as shown in Cross Section 6 (fig. 42).

It was because of this difficulty of interpretating correctly the pulverised material from sandstone produced by the proline drilling that Res. BH 2 was drilled using the Gemcodrill rig. This hole confirmed that these sandstones were Triassic in age and similar to those found beneath the basalt in other reservoir holes (Res. BH 1, 3, 4 and 5).

Saddle Bore Holes 1 *and* 2

Two holes were drilled in the saddle area with the Gemcodrill in an attempt to reach the bottom of the Tertiary valley (fig. 41). In the Saddle BH 1 located on Proline 35 white unconsolidated sand occurred to 70 ft; no bottom

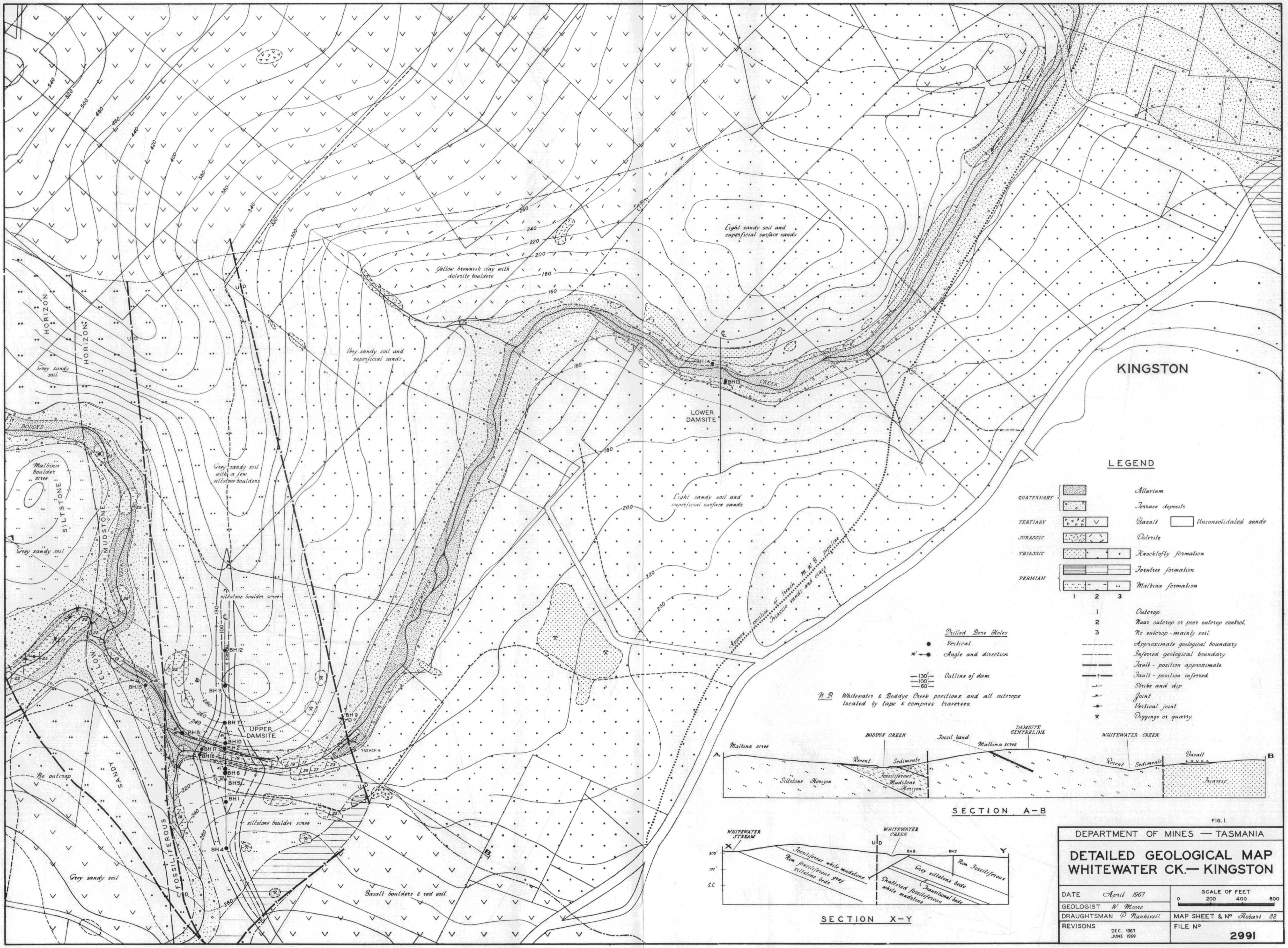

FIGURE 36

Tech. Rep. Dep. Mines Tasm. No. 14

5 cm

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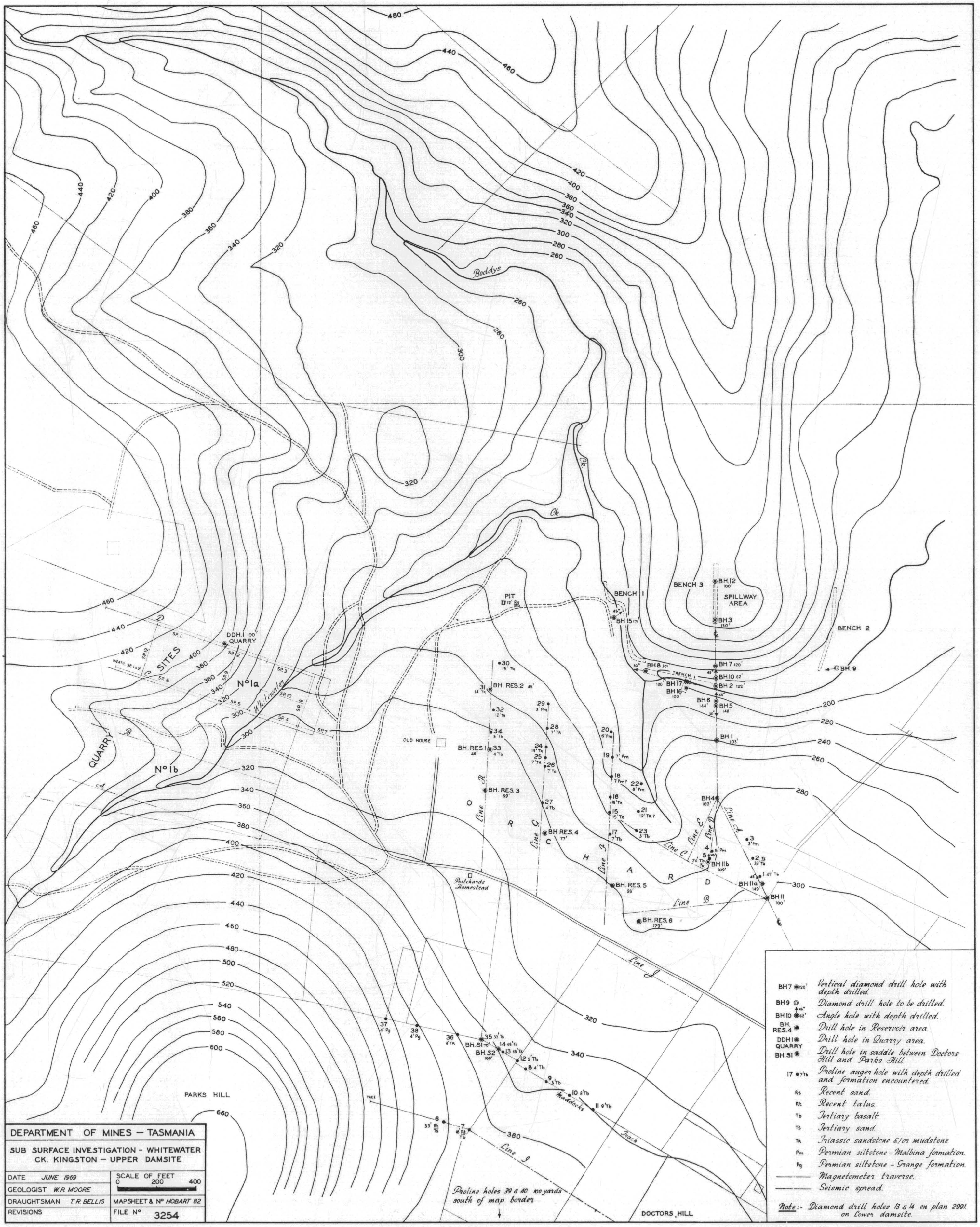

FIGURE 37

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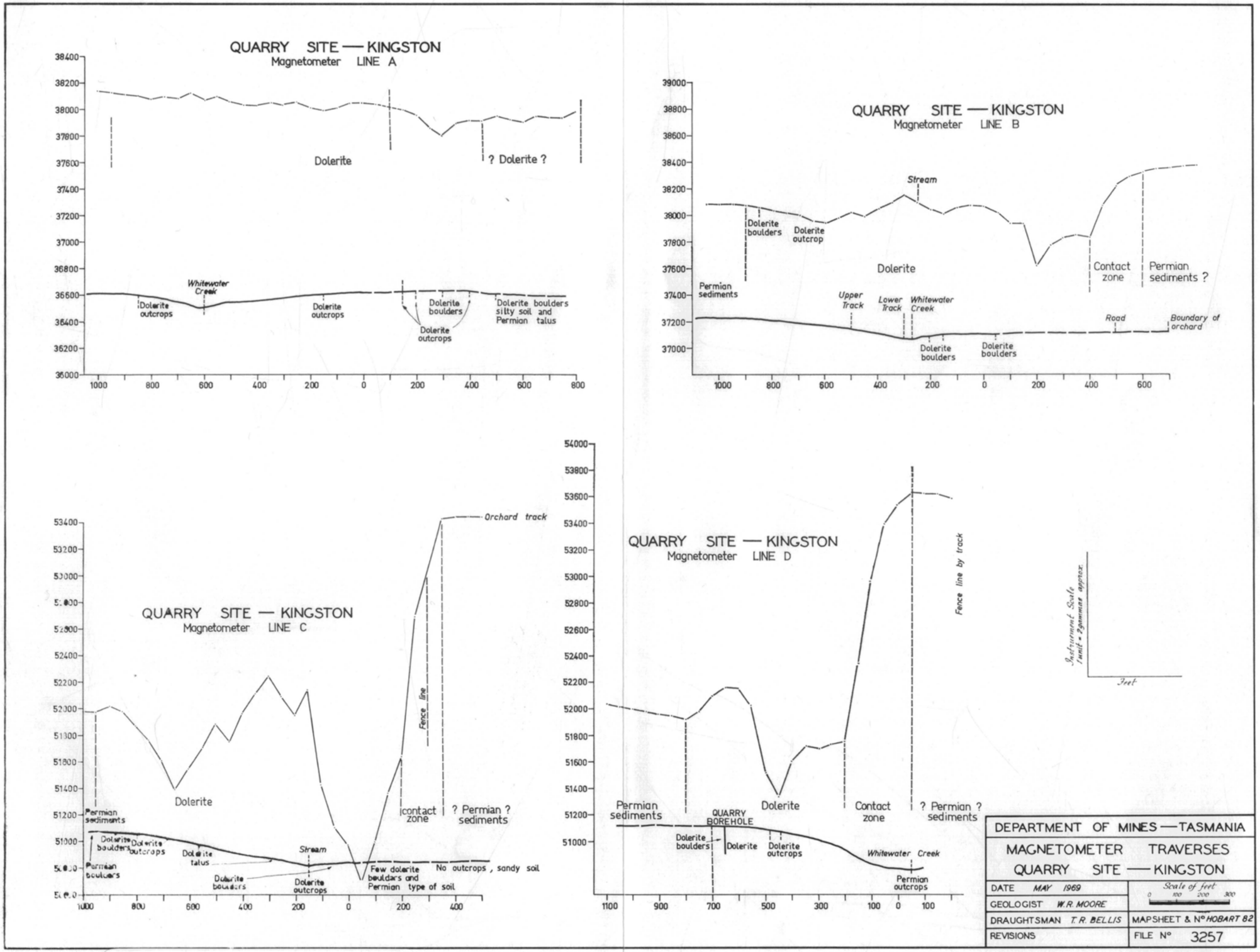

5 cm

FIGURE 38

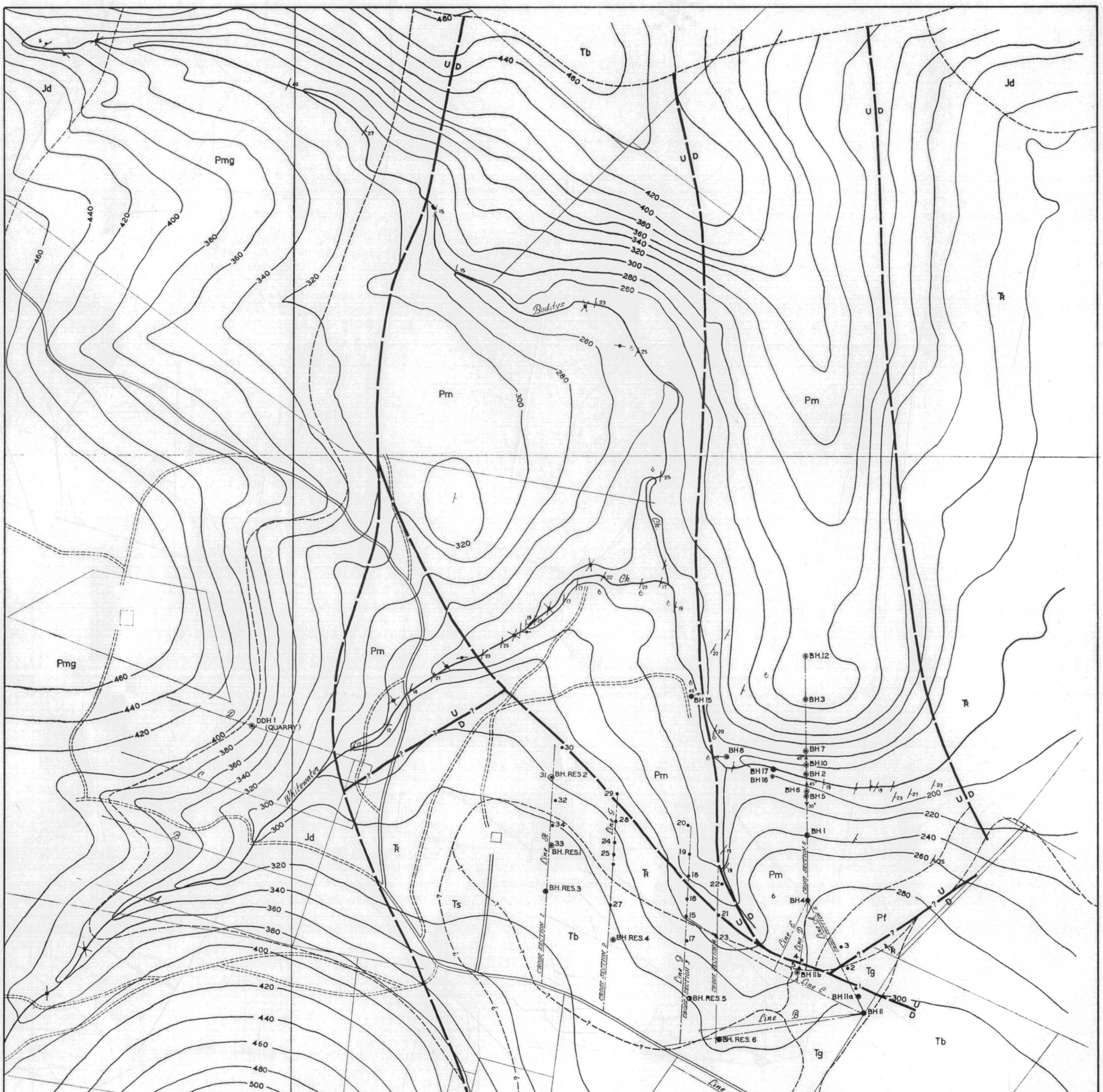

FIGURE 39

TECH. REP. DEP. MINES TASM. NO. 14

5 cm

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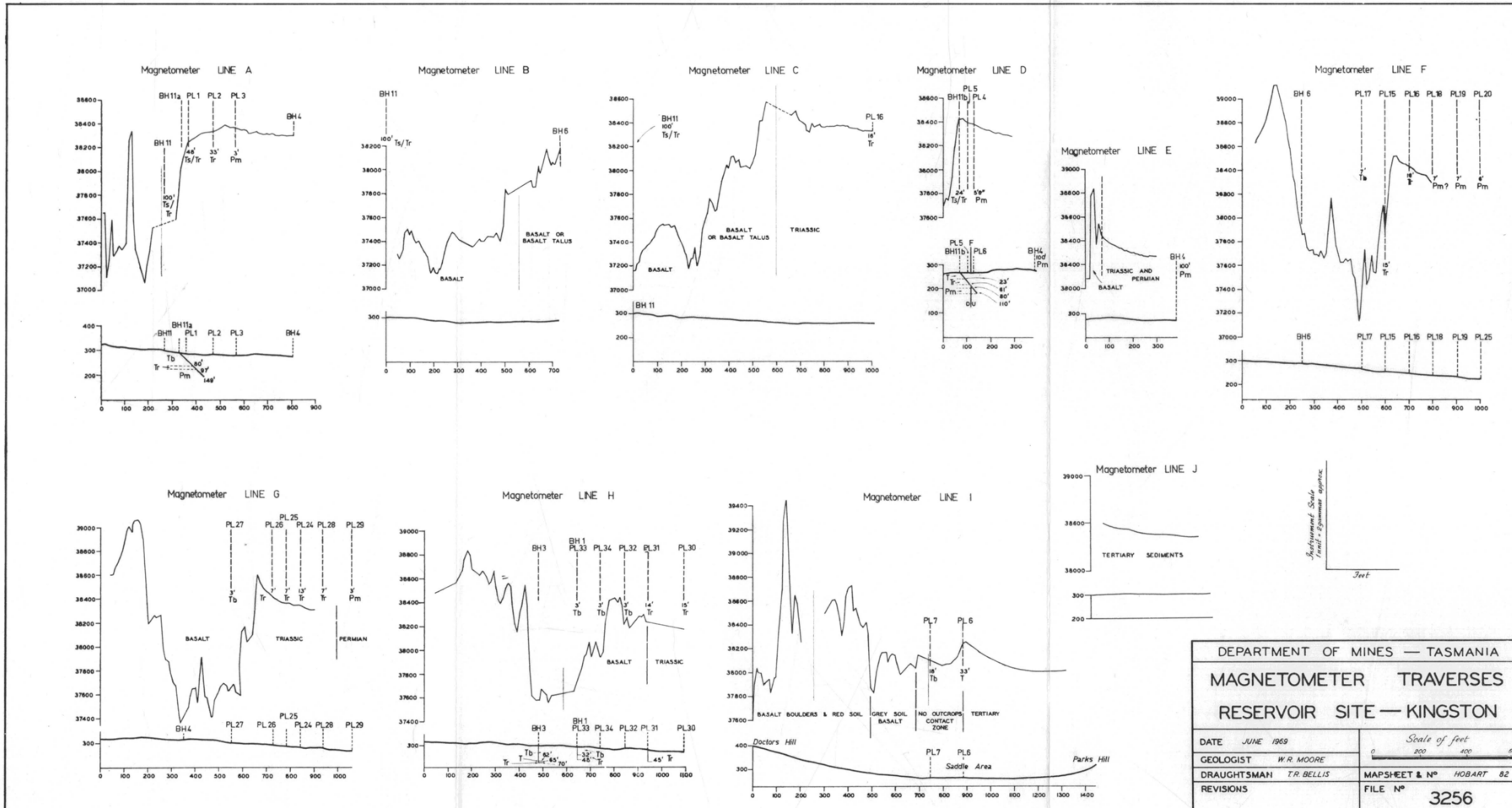

FIGURE 40

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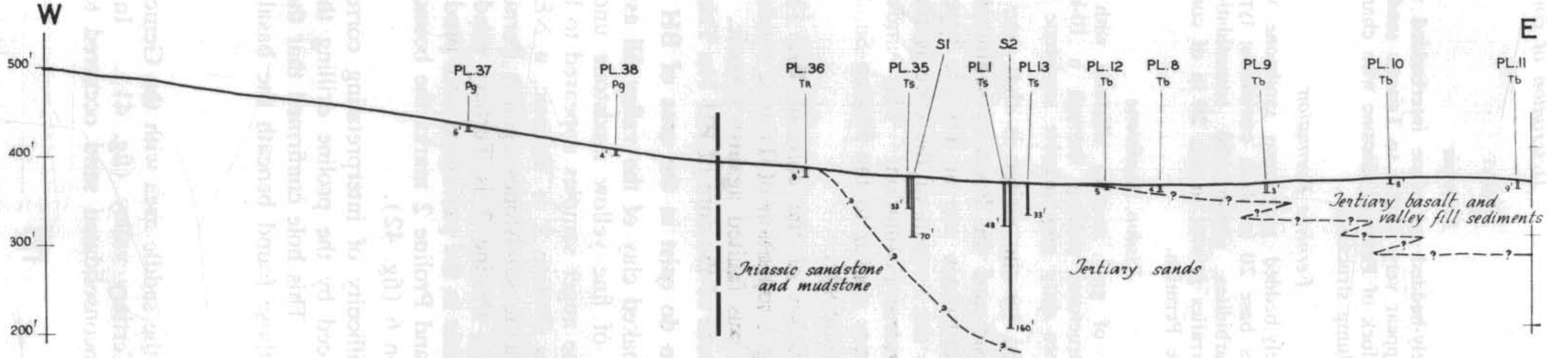
5 cm



EAST-WEST CROSS SECTION – SADDLE AREA

0 100 200 300 400 FT.

FIGURE 41

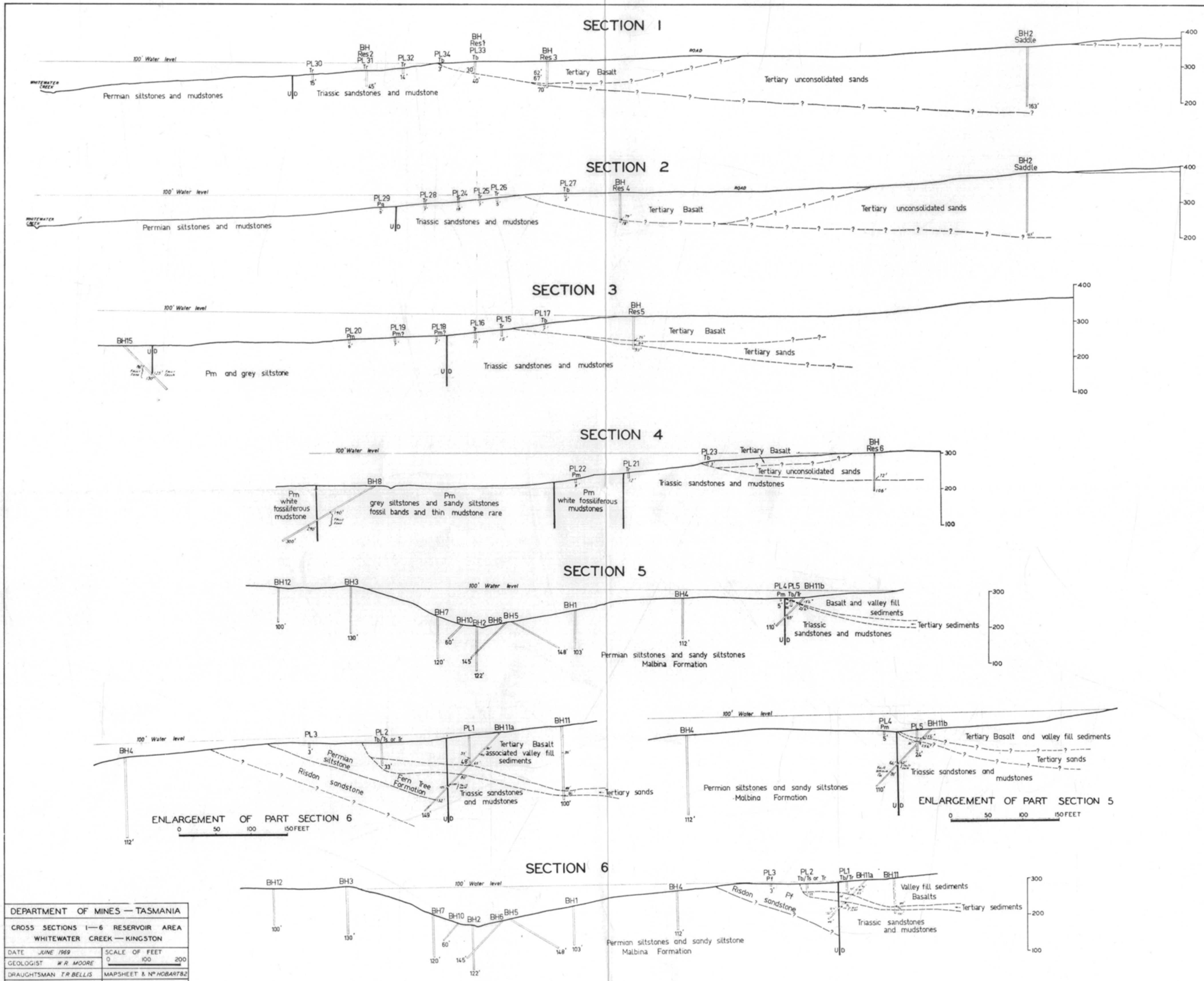


FIGURE 42

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was reached. In Saddle BH 2 closer to the basalt contact and in the middle of the saddle, 153 ft of white, unconsolidated, fine sand mixed with a varying amount of clay was found. At this depth bottom was reached and coring commenced and continued to 160 ft. The sand had changed abruptly to a hard white, cross-bedded feldspathic sandstone. This sandstone was 1 foot thick and underlain by 5 ft of soft grey-white muddy sandstone with fragments of lignite embedded within it. This section of the core is interpreted as a Triassic sandstone boulder embedded in soft, muddy, Tertiary sandstone. The Saddle BH 2 was abandoned at 160 ft without reaching the bottom of the valley.

At this locality the valley was below the 200 ft contour (the level of Whitewater Creek at the upper dam site centre line). Consequently there was no justification for continuing this hole. The cross section through the saddle shows a very steep boundary at the western side of this valley, which was probably cliffed like the sandstone outcrops at North West Bay.

Reservoir drilling: Reservoir Bore Holes 1 to 6

The funds now remaining allowed for 400 ft of drilling in the reservoir area. This footage could be doubled if augering was possible. Three holes were to be drilled to locate the Tertiary valley and three holes were to be drilled along magnetometer line H. These latter holes were aimed at determining:

(1) The correctness of the sub-surface geological interpretation derived from the magnetometer work and proline drilling.
(2) The attitude of the base of the basalt.
(3) The type of sediments beneath the basalt.
(4) The nature of this contact and its leakage potential.

Res. BH 2 was drilled entirely in Triassic sandstone and mudstone. Thirty-two feet of mainly unweathered basalt overlay Triassic sandstone and mudstone in Res. BH 1. There was a sharp contact between the basalt and the Triassic sandstone and no Tertiary sediments were present. Drilling losses at the contact were low and appeared to be confined to the weathered and leached bottom of the basalt which had decayed to a clay while still retaining a vesicular basalt structure. Water losses when the hole was pump-tested were 7-8 gal/min at 45 lb/in^2 pressure.

Sixty-two feet of basalt was encountered in Res. BH 3. The basalt was rusted but not deeply weathered from 0-24 ft and then rusted again from 33-43 ft. The base of the basalt was leached and decayed with a 4-inch clay band at its base. Six inches of grey-white clayey sand, of similar lithology to that present in the saddle area, and gravel with quartzite and sandstone pebbles underlie the basalt. Interbedded Triassic sandstone and mudstone underlies the gravel. Leakages were higher at this contact but were only 9-10 gal/min from 50-70 ft.

The results from these drill holes enabled three important facts to be deduced:

(1) A rock bar composed of Triassic sediments overlain by basalt existed between the reservoir area and the deep Tertiary valley to the S.
(2) The bottom of the basalt dipped towards this valley.
(3) No Tertiary sediments occurred beneath the base of the basalt at the 100 ft reservoir water line (300 ft contour).

In Res. BH 3, allowing that all the drilling loss when crossing this contact was confined to Tertiary sediments the maximum thickness of the Tertiary is 3 ft. Therefore where the basalt/Triassic contact reaches ground surface in the reservoir no Tertiary sediments are likely to be present and if they do occur they would be expected to be very thin.

(4) The water losses at this contact were very low when both holes were pump-tested.

Three holes were then drilled along the 100 ft reservoir water line towards BH 11 to try and locate the Tertiary valley. Res. BH 4, situated 374 ft E of Res. BH 3, was similar to Res. BH 2 with no Tertiary sediments present at the contact. The basalt in this hole was 78 ft thick and the basalt/Triassic contact (fig. 42, Section 2) dipped SE.

Res. BH 5 was drilled 100 ft E of Res. BH 4 and penetrated 78 ft of basalt and 9 ft of Tertiary sand overlying Triassic sediments. Even with this thickness of Tertiary sediments the water losses when pump-tested were not greater than 9 gal/min for 90 lb/in^2 pressure (fig. 42, Section 3).

Res BH 6 was sited 300 ft from BH 11 and close to the magnetometer line B (fig. 40). In this hole a succession of valley fill clay and basalt was anticipated. No basalt was encountered and 72 ft of unconsolidated sand mixed with a low percentage of clay was augered. This sand is very similar lithologically to the sand present in the Saddle BH 1 and 2. At 72 ft very coarse steeply dipping Triassic sandstone was penetrated. Similar unconsolidated sand is now thought to account for the very flat magnetometer profile present in line I, on the saddle in line J, and for low seismic velocities at the bottom of the quarry site (fig. 42, Section 4).

From the information available the western side of this deep Tertiary valley appears to run in a south-westerly direction from BH 11a and 11b between Res. BH 5 and 6 and then swings in a wide curve towards Pritchard's homestead and then southwards through the saddle between Doctors Hill and Parks Hill.

It is possible that a tributary valley is present between the road into the orchard and the dolerite sill to the W. The slope direction of the valley is unknown but it is thought to be more likely towards the saddle area and SE towards North West Bay.

Drilling on the centre line, upper dam site

BH 7, 10 and 12 were drilled on the northern side of the valley in the abutment and spillway areas of the proposed dam. A succession of mottled silty sandstone and siltstone was penetrated in all three holes.

Some strong and open vertical jointing was encountered in BH 7 at 20-35 ft which required casing before drilling could be continued. These Permian sediments are similar to those drilled in 1967 on both valley sides and are considered suitable foundations for a rock fill dam.

In BH 10 drilled into the northern valley side from the valley floor no areas of intense open joints were encountered as had been found to present in nearby BH 6 and 10 drilled into and under the valley floor. The zones of close jointing would appear to be restricted to the valley floor area.

PLATE 1. Trench between cut-off wall position and dam site centre line, Whitewater Creek.

5 cm

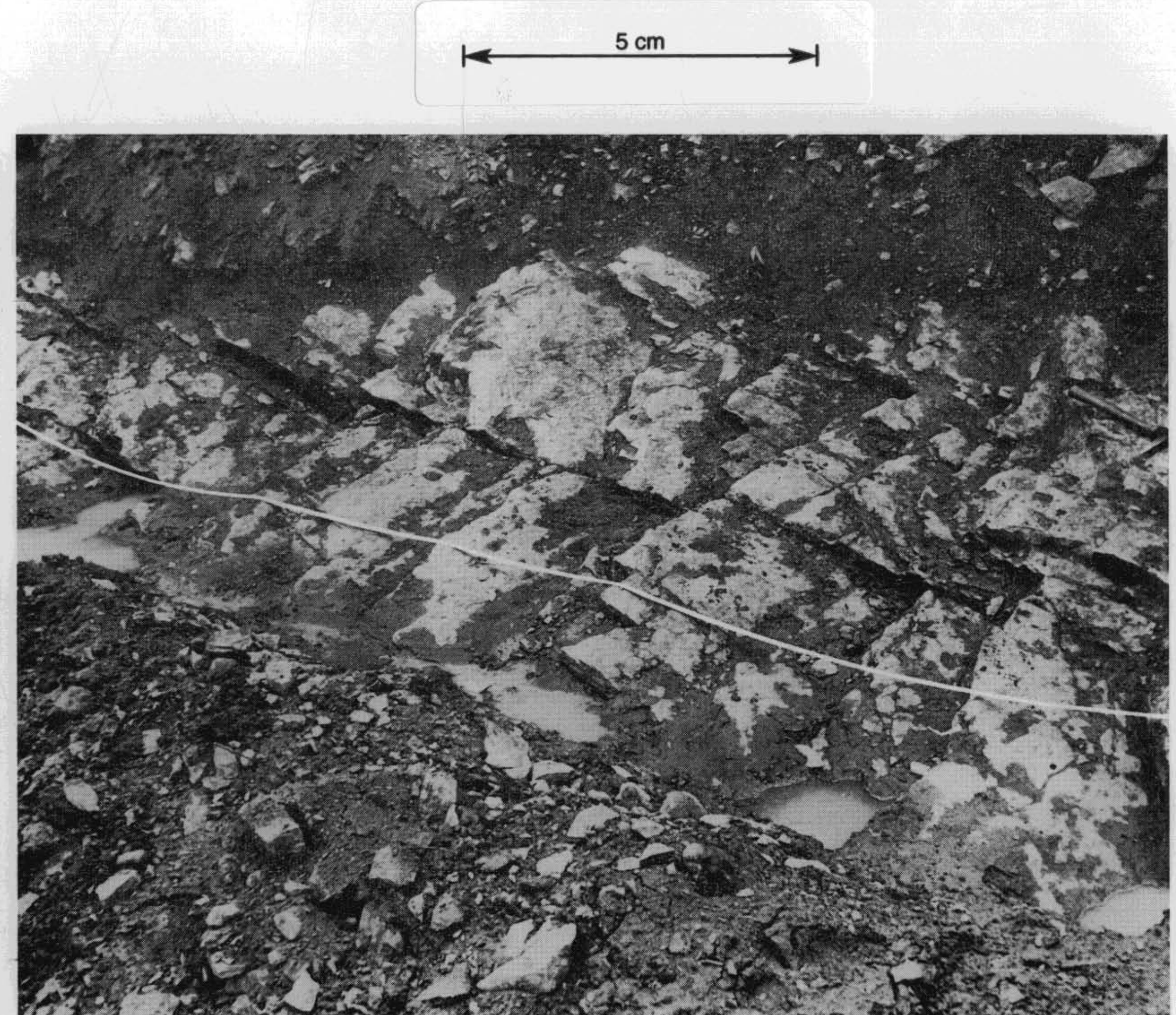

PLATE 2. Open east-west joint, trench Whitewater Creek.

In BH 12 two zones of weathering were encountered from the surface to 39 ft, and from 80-96 ft. No satisfactory explanation for the exceptionally deep weathering at this location or for the presence of two zones has been found. No reflection of this deep weathering and its two zones is apparent in the pump tests for BH 12. Water losses for the holes were low and varied from 2 to 4.5 gal/min for the entire hole.

Drilling of trial grout cell in the cut-off wall position

BH 16 and 17, the two control holes drilled for the grout cell were located in a well-jointed area on the valley floor in a small trench cut across the main trench. BH 16 was drilled for lithological control, BH 17 was drilled subsequently to observe the effects of grouting. The sediments from both cores are well jointed with open and rusted joints occurring to a depth of 100 ft and would be representative of the valley floor jointing as opposed to that of the abutment areas.

Leakage during pump testing in both holes was lower than for BH 2 drilled and tested in 1967. It is suspected that some of the very high water losses experienced in pump testing in 1967 were the result of using the double packer method of testing and using mechanical packers rather than hydraulic packers. Because of the small surface area sealed by a mechanical packer (1 foot thick) it is possible for the water to flow around it through a vertical joint. With a hydraulic packer which covers a 3-foot length of bore hole such a leakage path is less likely.

Soft grey grout was found in many of the joint faces of BH 17 but it was only a veneer and did not cement the core. Only one example of the grout acting as a seal was found where at 81 ft a ⅛-inch band of soft grout sealed a bedding plane joint. From this grout hole it can be concluded that the cement travelled from the grout holes to BH 17 but did not seal off the artesian water which flowed in BH 16 continuously and in BH 17 when drilled.

Lower dam site drilling

In BH 13 a quartz sandstone succession, grading to feldspathic sandstone of a total thickness of 66 ft overlies a succession of thin beds of interbedded sandstone and mudstone to 100 ft. The succession in BH 14 is similar except that the quartz sandstone is thicker and the interbedded mudstone and sandstone was encountered at 83 ft. The total thickness of the sandstone is exposed in the cliffs on the N bank of Whitewater Creek, and in BH 14 is approximately 110 ft; that on the S bank is approximately 75 ft. This difference could be the result of a small E-W fault along the river with a downthrow of 10 ft to the N.

When the two holes were being drilled it was found that the water losses when pump tested were very low at all levels. The highest loss in either hole was in the near-surface layer from 2-12 ft in BH 14. Here 10 gal/min for 10 lb/in^2 pressure was lost, but this declined to 3 gal/min from 12-22 ft and the average loss for the entire hole to 100 ft was only 5 gal/min. In BH 13 the water losses were even lower with a loss of 5 gal/min for 10 lb/in^2 pressure occurring from 12-22 ft. For the remainder of this hole only 2 gal/min was lost.

The permeabilities calculated for these two bore holes (well below 100 ft/year) indicate that the Triassic sediments in Whitewater Creek when unweathered are as impermeable as the Permian siltstone at the upper site.

CONCLUSIONS

Lower site

(1) From the information gained from the two holes drilled at the lower site the permeability of the Triassic sediments is as low as the permeabilities of the Permian sediments at the upper site.

(2) It appears likely that the buried valley found near the southern abutment of the upper site enters the reservoir area of the lower site.

(3) From the experience gained in the investigation of the upper site, it is the writer's opinion that surface mapping alone is not adequate for ascertaining the feasibility of any dam site in the Kingston area. Any feasibility study of the lower site would involve a sub-surface investigation of similar size to that carried out to date on the upper site.

Upper site general geology

(1) The foundations on which the dam would be built (as exposed in the trench in the valley and from the results of drilling at the abutments) are strong competent sediments.

(2) Zones of high leakage associated with close and intense jointing particularly in the finer grade of sediments are confined to the valley area. These zones as exposed in the trench are thought to be relaxation joints which opened due to the removal of the overburden as the valley was eroded.

(3) The trial grouting programme with the techniques used did not stop the leakages even though the cement travelled to the drill holes in the centre of the grout cell.

(4) There is a wide crush zone along the upstream fault between the Permian fossiliferous mudstone and grey sandy siltstone. Leakage on this fault was low when pump-tested.

(5) Leakage was low in the two holes drilled through the Triassic/Permian fault at the S end of the planned centre line.

(6) Some of the high leakage losses encountered in the 1967 drilling programme may partly be explained because the double packer method of pump testing with mechanical packers was used.

(7) In the reservoir area occupied by the orchard and extending S to the saddle area there is a down-faulted block of Triassic sediments.

(8) A deep Tertiary valley, of unknown dimensions and origin, was located in this Triassic block S of the centre line in BH 11 and again in BH 11a and 11b. The valley was filled with clay, gravels and sand interfingered and underlain by basalt and thin sandstone of both Tertiary and Triassic age. The leakages were low in the three holes, with the basalt having the highest value. The valley at this locality was at least 96 ft deep. Close by in Res. BH 6 unconsolidated sand with no basalt was encountered in this valley to a depth of 72 ft. The unconsolidated sand rests on Triassic sandstone. In the saddle area between Doctors Hill and Parks Hill similar sediments were encountered to a depth of 153 ft and here they were resting on Tertiary sediments. No pump tests were possible in the unconsolidated sand but there is no doubt that leakages would be very high.

(9) Basalt occurs on the margins of this valley. The basalt comprises several flows and there is a complex history of erosion, deposition, and lava extrusion during Tertiary times.

(10) The mode of deposition of the unconsolidated sands is unknown.

(11) The western side of the Tertiary valley appears to pass through a line between BH 11a and 11b and Res. BH 5 and 6. Its direction then appears to swing to the W parallel to the road and then S through the saddle.

(12) A tributary valley could join this valley between the holes drilled along the proposed reservoir water line at the 100 ft water level in the orchard but it is more likely to join between the road into the orchard and the dolerite outcrop to the W.

(13) A rock bar of Triassic sediments overlain by Tertiary basalt separates the Tertiary valley and the orchard in the reservoir area. At the 100 ft reservoir water line (300 ft contour) in the orchard, no Tertiary sediments occur in the bore holes W of BH 5.

(14) The contact between Tertiary basalt and Triassic rocks dip to the W towards the presumed position of the Tertiary valley in the orchard area. From the few pump tests conducted this contact does not appear to leak.

(15) Quarry site No. 1a should provide a sufficient amount of suitable dolerite for a rock fill dam.

Engineering geology

(1) The dam wall and its reservoir must be kept clear of the Tertiary valley.

(2) If the dam wall and its reservoir are separated from the Tertiary valley by a continuous rock barrier comprising basalt overlying Triassic sediments, and these rocks in the area to be flooded are known not to leak, the site could be feasible. This could be done by swinging the proposed centre line from BH 4 south-westwards towards Res. BH 5 rather than towards BH 11 as planned.

(3) The water level in the proposed reservoir must be restricted to a 100 ft level because if the water is any higher it will spill over the underground rock bar into the Tertiary valley.

RECOMMENDATIONS

With the information available the upper site cannot be either recommended or rejected. Before such a decision can be made the position and dimensions of the Tertiary valley must be known. Also it must be known with complete certainty that the Triassic/basalt rock bar in the orchard is continuous westwards to the dolerite sill.

To obtain this information a limited drilling and trenching programme and further geophysical work, both magnetometer and seismic, are required.

Detailed geological surface mapping should be extended S towards North West Bay.

These recommendations assume that a successful grouting technique can be evolved to stop the leakages along the valley floor of Whitewater Creek.

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