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BY SJ PATERSON

ENGINEERING GEOLOGY

OF THE

DEVILS GATE SCHEME, TASMANIA

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(non-member)*

Summary

The geological situation and the foundation and abutment conditions are described. Discussed are the problems arising from the presence of free graphite on bedding and joint planes, the presence of the upstream edge of a large exfoliation shell within part of the right abutment, and the presence of a fault block adjacent to the upper left abutment. The scheme was completed in September, 1969.

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1. INTRODUCTION

The Devils Gate Scheme is part of the Mersey-Forth Hydro-Electric Development in Tasmania, which has been briefly described by Mitchell and Paterson (Ref. 1). The scheme comprises a 275ft. high double curvature arch dam and a 63 MW power station. These were investigated, designed and built by the Hydro-Electric Commission of Tasmania. The dimensions of the scheme are given in Table I.

2. SITUATION

Devils Gate Dam and Power Station (Figure 1) are situated 17 miles from Devonport on the North-West Coast of Tasmania in the gorge tract of the River Forth. At the site the river has cut through the basalt covered coastal plateau and is incised in a sequence of Cambrian chert, argillaceous chert and siliceous argillite. The site lies within the disturbed zone between two major wrench faults.

3. ROCK TYPES

The rocks forming the damsite belong to a Cambrian sedimentary sequence that grades from a pure chert (cryptocrystalline silica, chalcedony) to argillaceous chert to siliceous argillite to argillite as the argillaceous content increases. The right abutment, the foundations and most of the left abutment are formed of chert. Siliceous argillite occurs in a fault block in the thrust block area of the upper left abutment and argillaceous chert occurs in the power station area.

The cherts are thought to be the result of direct precipitation of silica from a sea rich in silica, and the silica is thought to be of magmatic orgin for extensive deposits of volcanic rocks occur throughout the Cambrian rock sequence.

TABLE I

DIMENSIONS DEVILS GATE SCHEME

Type of Dam	Concrete Arch
Maximum Height	275 ft.
Crest Length	440 ft.
Total Fill Volume	40,000 cubic yards
Parapet Level	*SL420
Crest Level	SL400
Tailwater Level	SL175
Maximum Flood Level	SL416
Full Supply Level	SL400
Minimum Drawdown Level	SL387
Storage at Full Supply Level	298 sq. mile ft.
Peak Inflow at Maximum Flood	72,000 cusecs
Type of Spillway	Free Overflow - Stepped
Crest Levels of Spillway	SL400 & 405
Crest Lengths of Spillway	161 & 206
Powerhouse	Surface - Francis
Rated Output	63 MW
Rated Discharge	3 604 cusecs
Live Storage	30 sq. M. ft.
Rated Net Head	220
Conduit	Short Steel Lined Shaft

*SL refers to Standard Level related to Sea Level.

The cherts range from thinly bedded to massive and vary in colour from red to grey to black. The dark grey and light grey cherts are almost pure, as is shown by the chemical analyses given in Table II. These rocks have silica percentages of 93.6% and 95.5% respectively. From the point of view of stability, the most important impurity present in the cherts is graphite. In the black cherts it is disseminated throughout and occurs free on bedding planes and joint surfaces. The graphite content of these cherts ranges up to 25% by volume of the rock.

The cherts at Devils Gate are extremely hard rocks, which because of their composition, being mostly composed of silica, are resistant to weathering. Except along fault zones and major open joints, the effects of weathering are practically non-existant. The argillaceous cherts and siliceous argillites are moderately hard rocks that commonly have a fine fissility. They are weathered to a depth of 5 - 6 ft. from the surface and along fault zones.

4. ROCK PROPERTIES

The density of the chert ranged from 158 to 176 lbs./cu. ft. The values for the Modulus of Elasticity listed in Tables III(a) and III(b) were obtained by carrying out "jack" tests in adit No. 1 and by conducting a seismic survey around the adits using a 3 - component geophone.

In the foundations and the lower parts of both abutments, where free graphite is present on bedding and joint planes, the resistance of the rock mass was subject to close study. Thus direct shear tests were conducted in the laboratory and in the field to determine the shearing resistance along incipient graphitic joints. The laboratory tests were performed on specimens cut from NX (2.844 in.) and 6 in. diameter core. The shearing

TABLE II

CHEMICAL ANALYSIS - CAMBRIAN BARRINGTON CHERT

	DARK GREY CHERT	LIGHT GREY CHERT
SIO_2	93.66%	95.50%
AL_2O_3	1.77	1.25
Fe_2O_3	2.27	0.50
Fe O	0.38	0.26
Mn O	Nil	Nil
TiO_2	0.06	0.08
P_2O_5	0.02	0.03
Ca O	0.52	1.28
Mg O	0.45	0.29
Na_2O	0.07	0.14
K_2O	0.24	0.11
H_2O^-	0.20	Nil
H_2O^+	1.00	0.75

TABLE III (a)

MODULUS OF ELASTICITY

In Situ Values obtained by "JACK" Tests in Adit No. 1.

Range of Stress p.s.i.	Modulus of Elasticity $X10^6$ p.s.i.
40 - 200	2.17
45 - 400	1.04
40 - 800	2.30
40 - 1,200	2.22
40 - 1,600	2.44

TABLE III (b)

MODULUS OF ELASTICITY & POISSONS RATIO

Values from Seismic Velocities

Determinations by the Bureau of Mineral Resources, Geology and Geophysics (Ref. 2)

LOCATION	APPARENT VELOCITY*		TRUE VELOCITY**		POISSONS RATIO		MODULUS OF ELASTICITY X10 ^{6} p.s.i.	
	LONGITUDINAL	TRANSVERSE	LONGITUDINAL	TRANSVERSE	APPARENT VELOCITY	TRUE VELOCITY	APPARENT VELOCITY	TRUE VELOCITY
Outcrop on	7,200	3,800	10,400	6,400	0.24	0.22	1.5	3.4
Right Abutment	8,400	4,800	12,000	7,000	0.25	0.24	2.1	4.3
35ft. Inside Adit No. 2	6,400	3,500	15,500	9,300	0.28	0.24	1.2	7.7
Fault Zone 70ft. Inside Adit No. 2	8,600	4,700	5,300	3,000	0.27	0.27	2.3	0.8

Apparent Velocity* is the average velocity through weathered layer and bedrock.

True Velocity** is bedrock velocity.

resistance along chert - concrete interfaces was also determined in the laboratory and in the field. The laboratory tests were conducted on a prepared chert - concrete specimen and in the field direct shear tests were conducted on concrete blocks poured on the chert floor of two adits (Adits 4 and 5). The results of these tests are given in Table IV.

In interpreting the data obtained consideration was given to the fact that there should be significant cohesion due to interlock and that in several parts of the foundation prestressing should help maintain this interlock. These factors were offset by the effect of a large number of parallel planes of weakness in the chert. It was concluded that $\tan \phi = 0.55$, with zero cohesion, was a reasonable value.

(Design took 100 psi giving F of S = 1.39 at base of crown cantilever F.K.

The unconfined compressive strength of the rock ranged from 2,000 - 6,000 p.s.i.

Because chert is generally subject to adverse reaction with cement alkalis fresh and weathered samples were tested for reactivity with caustic soda in accordance with CRD - C128-55, and the cherts were found to be weakly reactive. Mortar bar tests of 1 year duration were conducted in accordance with CRD - C123-57 using weathered and unweathered chert and normal and low alkali cements. Dolerite aggregate was used for control bars. At the conclusion of the tests those bars made with dolerite showed a slight shrinkage, whereas those made with chert showed slight expansion. The results are given in Table V. It was concluded that it was safe to use chert with either of the cements used in the tests. These conclusions were pertinent to the bond between the dam and its foundations and abutments, but the chert was eliminated as a source of concrete aggregate because, as a result of extremely close jointing, it breaks down under mechanical stresses to small particles with an unsatisfactory size distribution.

TABLE IV

RESIDUAL STRENGTH PARAMETER FROM DIRECT SHEAR TESTS

Shearing Surfaces	Cohesion Intercept (Shear Strength at Zero Normal Stress) lbs/sq. in.	Tangent of Friction Angle	Remarks
Graphitic	120	0.65	Laboratory Test
Chert	22	0.55	Specimens cut from NX Core
	55	0.68	Laboratory Test Specimen cut from 6" dia. Core
Concrete on	0	0.44	Laboratory test on prepared Chert - Concrete specimen
Graphitic Chert	0	0.80	Insitu tests Adits 4 and 5. Concrete Block cast on graphitic chert of adit floor

TABLE V

EXPANSION OF MORTAR BARS AFTER 1 YEAR

CEMENT	AGGREGATE	AVERAGE % EXPANSION
Low Alkali	Dolerite	- 0.0054
	Weathered Chert	- 0.0001
	Unweathered Chert	+ 0.0009
Normal	Dolerite	- 0.0034
	Weathered Chert	+ 0.0030
	Unweathered Chert	+ 0.0047

Aggregate and sand for the project were obtained from washed river gravels from Merseylea on the Mersey River. Dolerite and quartzite fragments form the bulk of this deposit.

5. STRUCTURE

The damsite is located in the intensely deformed area between two major wrench faults (Figure I), which trend N.S. and have strike slip displacement of the order of 8,500 ft. The intensity of the deformation is such that almost all of the rock forming the damsite gorge has been brecciated and recemented. The two major wrench faults control the course of the River Forth upstream and downstream of the damsite, whereas jointing is the controlling influence within the damsite gorge. The fault - line scarp of the upstream fault (Fault I, Figure II) forms the start of the main gorge and is the upstream limit of good foundation and abutment conditions. A crushed zone 90 ft. wide occurs along this fault - line and in it chert, chert breccia and argillaceous chert occur in disorder.

The pattern of subsidiary faulting at Devils Gate is similar to the system of faults recorded by Moody and Hill (Ref. 3) as being associated with the San Andreas Fault in California, a well known wrench fault. At Devils Gate 2nd order faults (Faults II, III, IV and V, Figure III) cross each abutment. Faults II and IV meet in the river bed and thus appear as one fault with a semicircular trace. The weathered zone along these faults is up to 15 in. wide. Some 2 in of graphitic breccia is associated with fault III and this varies from soft to hard. Second and third order faults define a fault block on the upper left abutment, and along these faults the typical plug is 1 - 3 in of rock flour, ground up rock consisting of clay - sized quartz, illite and kaolinite in equal proportions (x-ray analysis). For this material a value of tan $\phi \simeq 0.45$ was used for design purposes. Rarely was it possible to determine the amount of displacement along the faults because of the scarcity of marker information.

Intense micro-fault, joint and incipient fracture patterns exist throughout the rock. The micro-faults have thinly brecciated surfaces and numerous small cavities. On the right abutment major stress relief cracking parallel to the river valley has occurred and large shells of rock (Plate 2) have seperated from the valley walls.

Major faulting commenced in Cambrian time soon after deposition of the chert. Further major disturbances occurred during the Devonian and Tertiary. The main faults probably formed paths for the outpouring of Tertiary basalt, which covers the coastal plateau. There is no evidence of further faulting during historic time.

6. METHOD OF INVESTIGATION

The initial surface mapping was followed by a limited diamond drill core programme, and when this was completed the main structural features of the site were apparent. These features, particular faults I and II, were then investigated further by diamond drilling, adits and trenches. Diamond drilling totalled 2,700 ft., and 8 investigation adits and 2 drainage adits totalled 1,000 ft. in length. The adits were used to obtain in situ rock properties by means of "JACK" tests and seismic (3-component geophone) observations. The left abutment was sluiced clean of debris and the power station area was investigated by a seismic survey and 2 core holes.

At the design stage three dimensional perspex models were made of each abutment showing the structural features. These were kept up to date during construction and proved invaluable, for they enabled the design and construction engineers to fully appreciate the structural interaction of the dam and its foundations. They were also invaluable during the design of the drainage and grouting systems.

During construction all excavations were mapped in detail, and the site was repeatedly critically re-examined. Detailed geology was plotted directly on to photo-theodolite prints in the field and the mapping was completed by the Commission's Photogrammetric Section. A Wild P30 Photo-theodolite was used in conjunction with a Wild A7 Autograph Plotter, and a Wild C120 Stereo-metric Camera was used with a Wild A40 Autograph. Collection of data continued until the dam was completed, thus drain holes from the two drainage adits on the left abutment were drilled to detail the fault complex.

Dam Base

7.. FOUNDATION AREA

base

The dam foundation is situated on a hard bar of fresh, black graphitic chert that lies between Fault I and Fault III (Figure III). The river bed falls away rapidly downstream towards Fault II and a 10 ft. deep pot hole is located where Fault II crosses the river bed. The foundations are crossed by a number of steeply dipping minor faults that have smooth undulating surfaces and are associated with recemented graphitic breccia ranging from $\frac{1}{8}$ - 2 in. in thickness No major slide planes are present.

8. RIGHT ABUTMENT

The lower right abutment is formed by fresh, hard black graphitic chert, and the main structural feature present is Fault II. At river level the river had eroded a cavern along the fault line and this extended beneath the abutment. The cavern was backfilled with concrete and the backfill was stressed into the rock upstream of the abutment. On the surface the fault crossed the abutment at SL187 and dipped steeply (70°) into the abutment. It had a smooth, undulating graphite (1/16 in.) coated surface and a 6 ft. wide zone of recemented breccia. The fault itself presented no major problem, but much baring down of "drummy" rock was necessary as a result of the close jointing and incipient fracture pattern. This problem was not restricted to faulted areas, but was encountered over most of both abutments, and in many areas final "clean up" was completed by workmen equiped with geological hammers.

In the upper part of the abutment fresh, hard grey and fawn chert are dominant, but considerable excavation was necessary between SL200 and SL310 to remove the upstream edge of a large "onion skin" shell of rock (Plate 2 and Figure III) that extended into the abutment area. The shell rests on a base 120 ft. long and is seperated from the valley walls by tension cracks that extend from river bed level at SL175 to SL310. Between SL200 and SL240 the shell has an average thickness of 30 ft. The tension cracks contain infillings of surface material, brown to black plastic clay and rock chips up to 6 in. in thichness. Adits 6 and 7 (Figure IV) were driven along the crack at SL200 and SL240 respectively to define the extent of the shell. These adits were subsequently driven into the abutment to investigate the nature of the country within the abutment. The shell has been attributed (Ref. 4) to stress relief cracking parallel to the valley. Wolters (Ref. 5) has stated that rock deformation due to unloading by natural excavation is far too small to form shells of this size. He explains such phenomena as being the result of temperature changes.

9. LEFT ABUTMENT

The lower part of the left abutment is formed by fresh, hard black graphitic chert that is cut by a number of steeply dipping minor faults. These faults commonly have a smear of graphite on the fault plane and up to 1 in. of recemented breccia. This part of the abutment was intensively studied for slip planes, but it was concluded that none of the faults was of such extent and in such an adverse direction to endanger the dam.

Above SL307 the abutment lies adjacent to a fault block (Plate 3) bounded by Faults V, VI and VII. The fault zones have up to 3 in. of weathered breccia and up to 3 in. of rock flour. The area was the subject of a stability analysis and as a result of this a comprehensive drainage system was designed to improve the stability of this part of the abutment.

At SL390, at thrust block level, the dam crosses Fault V, which is the boundary between chert and siliceous argillite. Up to 2 in. of silica rock flour is present along the fault zone. This chert - argillite boundary was explored at depth during the construction stage, when the drainage holes from the drainage adits were core drilled. The siliceous argillite in the thrust block area is partially weathered and much broken by minor faults. At the level of the upper drainage adit it was fresh and moderately hard, but weathering and rock - flour persisted along the faults. This part of the abutment was treated as an area of low modulus and a valve of 0.36×10^6 p.s.i. was used for design purposes. As a result of the stability analysis the thrust block and its foundations were stabilised by thirty-seven 170 ton stressing cables anchored vertically at depths of 80 - 100 ft.

10. SPILLWAY APRONS

The spillway aprons were pre-stressed to the rock downstream of the dam and this has further assured the security of the dam. A total of three hundred and sixty four 6½" Freyssinet monostrand cables were used. The cables on the right hand apron passed through the "onion" skin shell of rock.

11. DIVERSION TUNNEL AND POWER CONDUIT

Both the diversion tunnel and the power conduit tunnel were driven through sound, hard chert. The diversion tunnel encountered Fault II near the upstream portal and the fault breccia was weathered for 12 in. A number of minor faults were also encountered, but these presented no stability problems. The tunnel, however, was lined for hydraulic reasons.

The power conduit tunnel was also cut by a number of minor faults and small quantities (½ in.) of rock flour were present on the fault planes. No stability problems were present, but the tunnel has a steel liner. Both tunnels provided excellent means of examining the interior of the right abutment.

12. POWER STATION

The power station is sited on hard chert on the foot wall of the major fault that marks the downstream limit of the chert mass that forms the right abutment. The station was sited so that most of the excavation took place in the soft siliceous argillite on the hanging wall of the fault.

13. ACKOWLEDGMENTS

The author is indebted to the Commissioner of the Hydro - Electric Commission, Mr. A.W. Knight, C.M.G., M.E., B.Sc., B.Com., M.I.E. Aust., for permission to publish the information contained in this paper. Mr. G.T. Colebatch, O.B.E., B.E., M.I.E. Aust., is the Chief Civil Engineer of the Commission.

Thanks are due to Mr. G.E.A. Hale, B.Sc., Chief Geologist, to Mr. W.R. Mitchell, B.E., Group Engineer, Dams and Structures, and to Mr. J. Fidler, B.E., Section Engineer Dams I Section of the Commission for helpful discussion, and to Mr. H. Johnson for the preparation of the figures.

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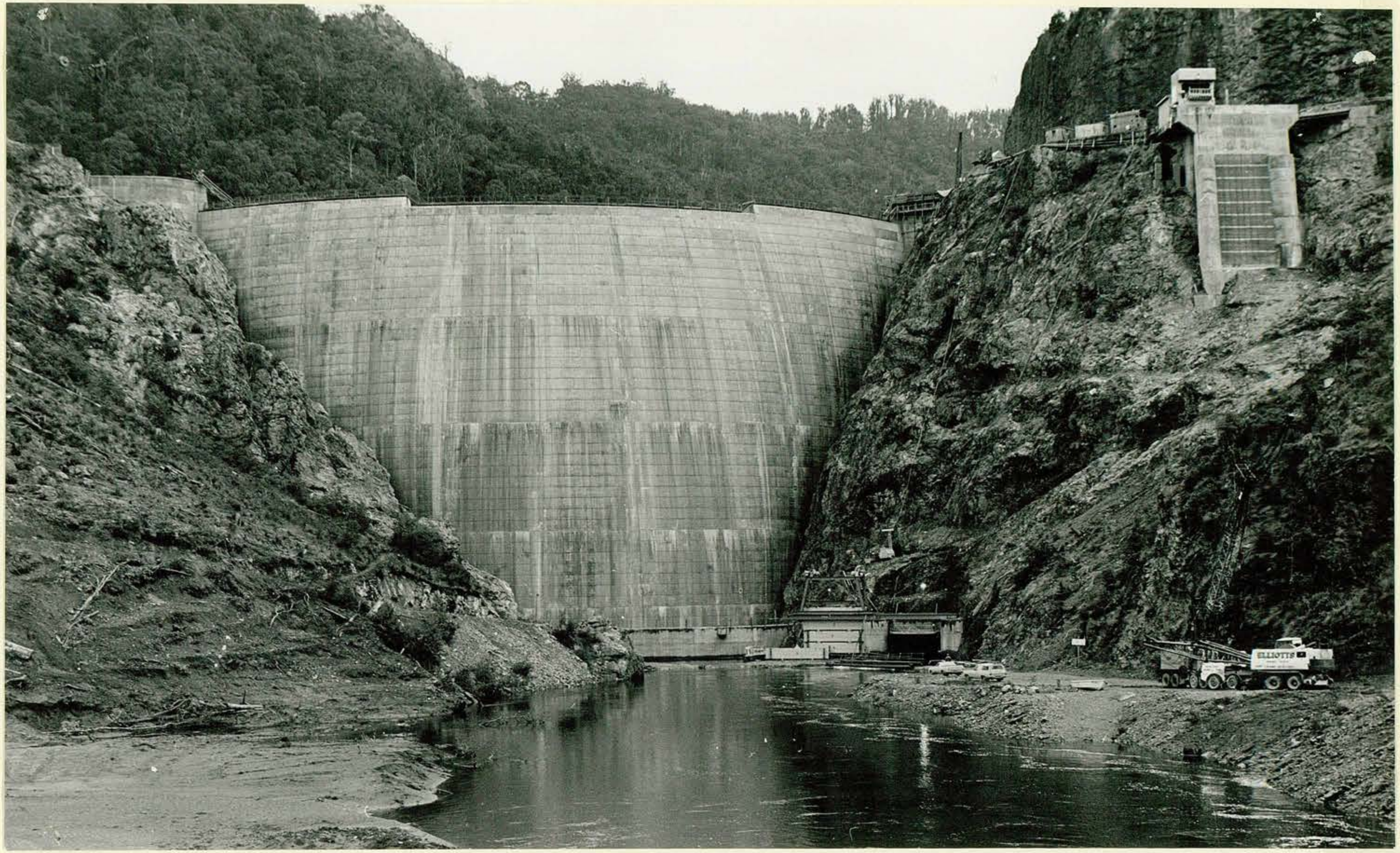

PLATE. 1. Devils Gate Arch Dam, nearing complrtion.

PLATE .2. Part of the right abutment showing the upper limit of the "onion" skin shell of rock immediately downstream of the dam and the slot cut to take the dam behind the shell.

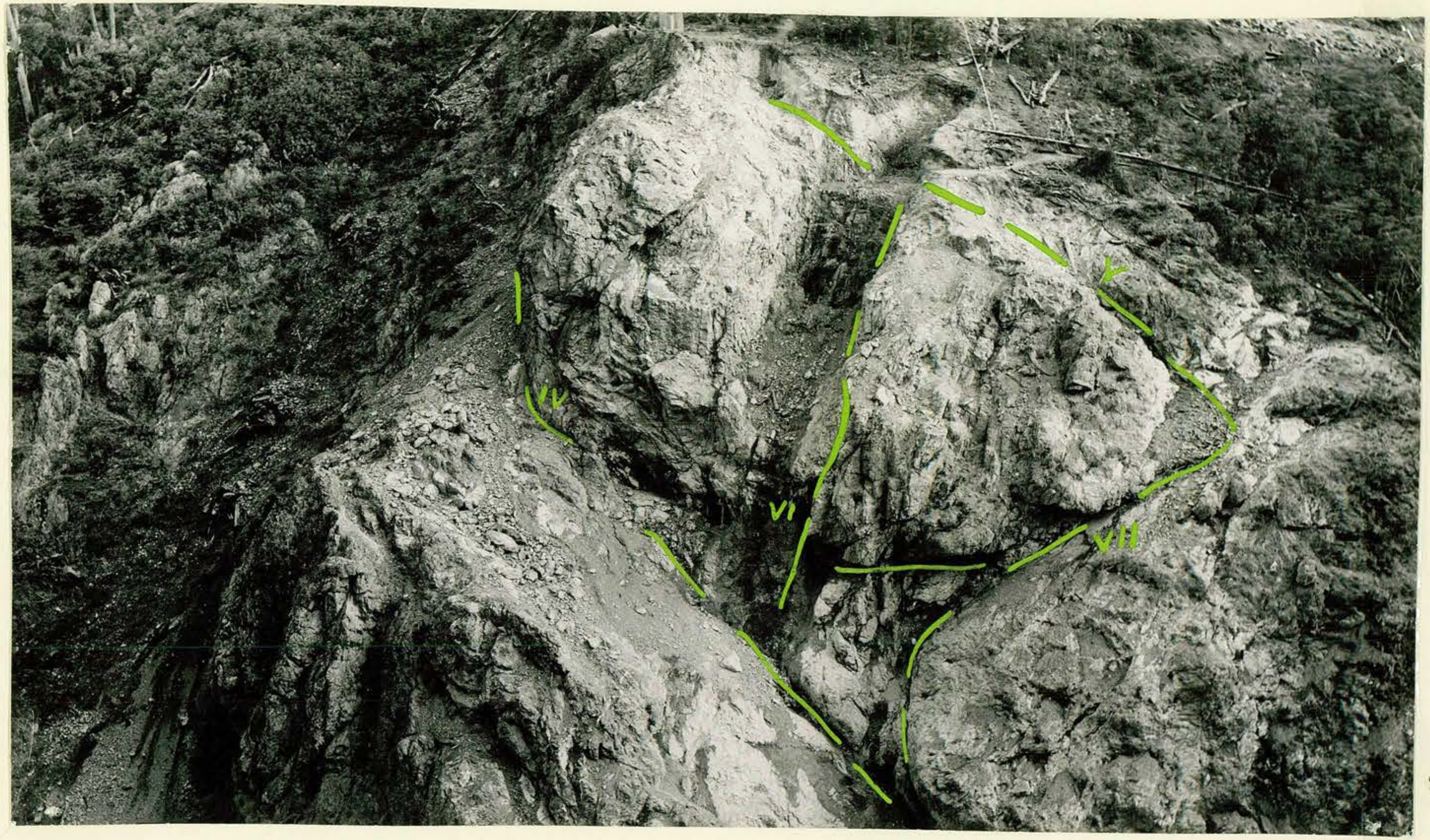

PLATE .3. The upper left abutment during excavation showing the abutment slot and the fault wedge immediately downstream of the abutment.

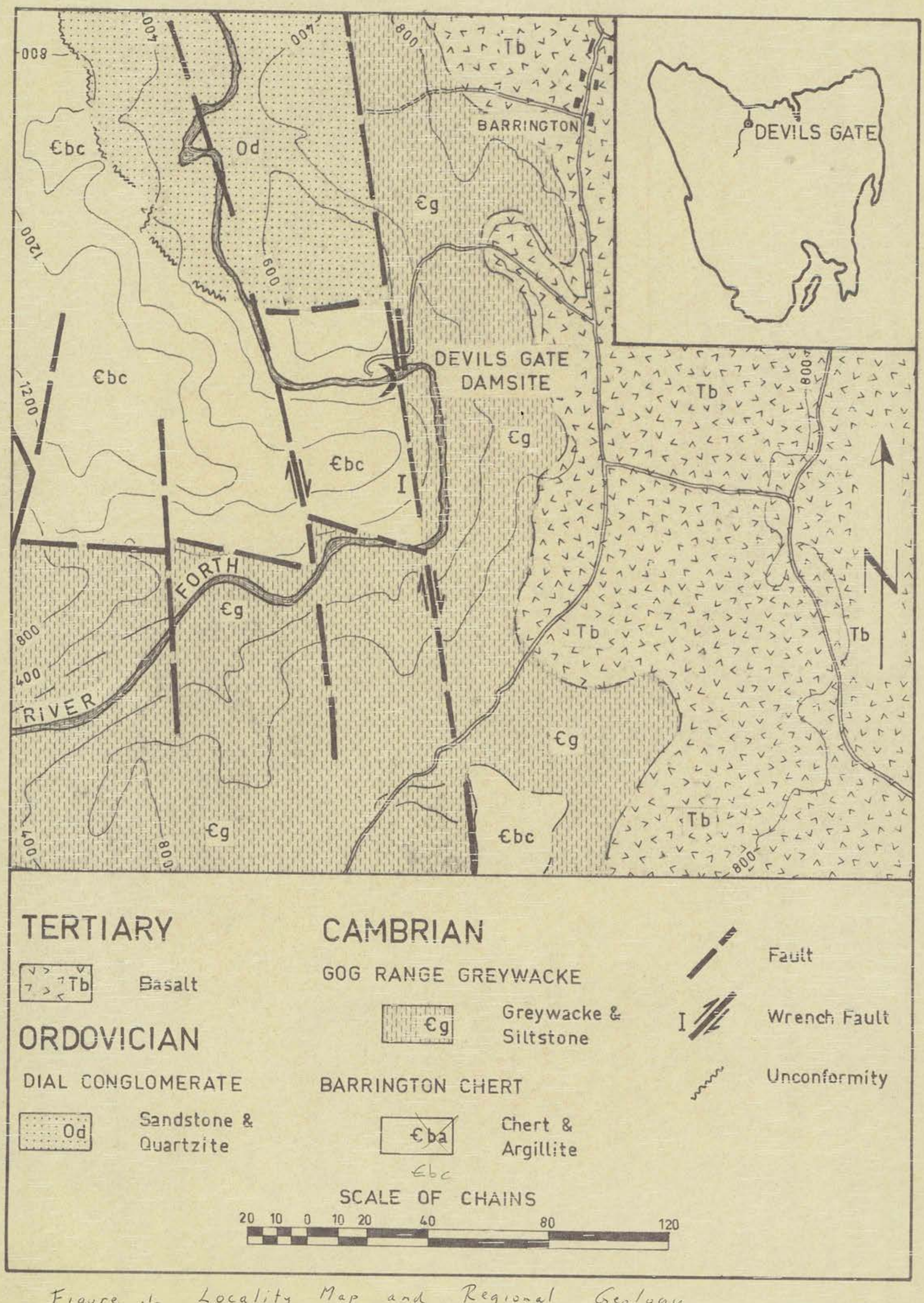

Figure 1. Locality Map and Regional Geology.

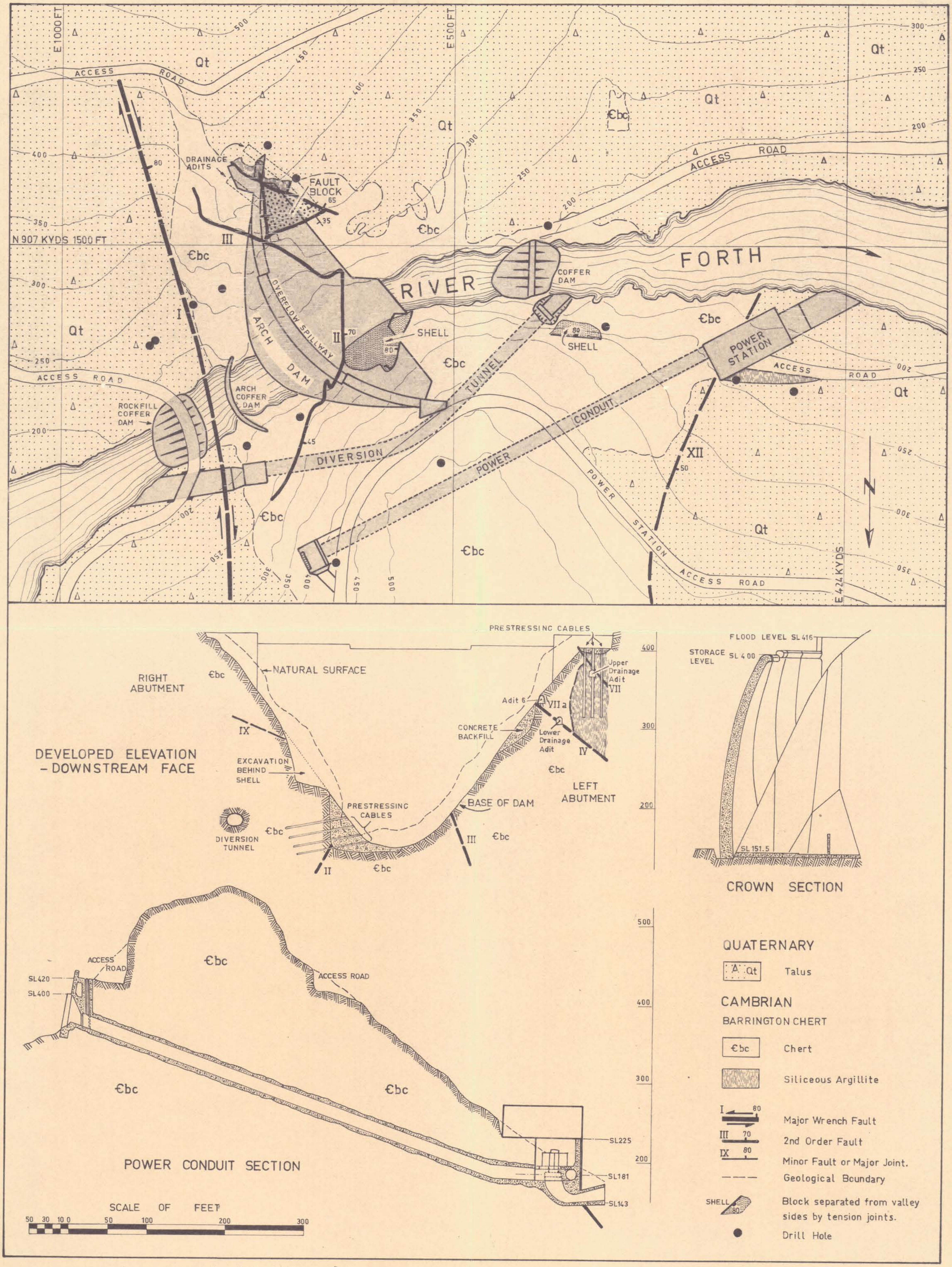

Figure 2. Devils Gate Scheme.

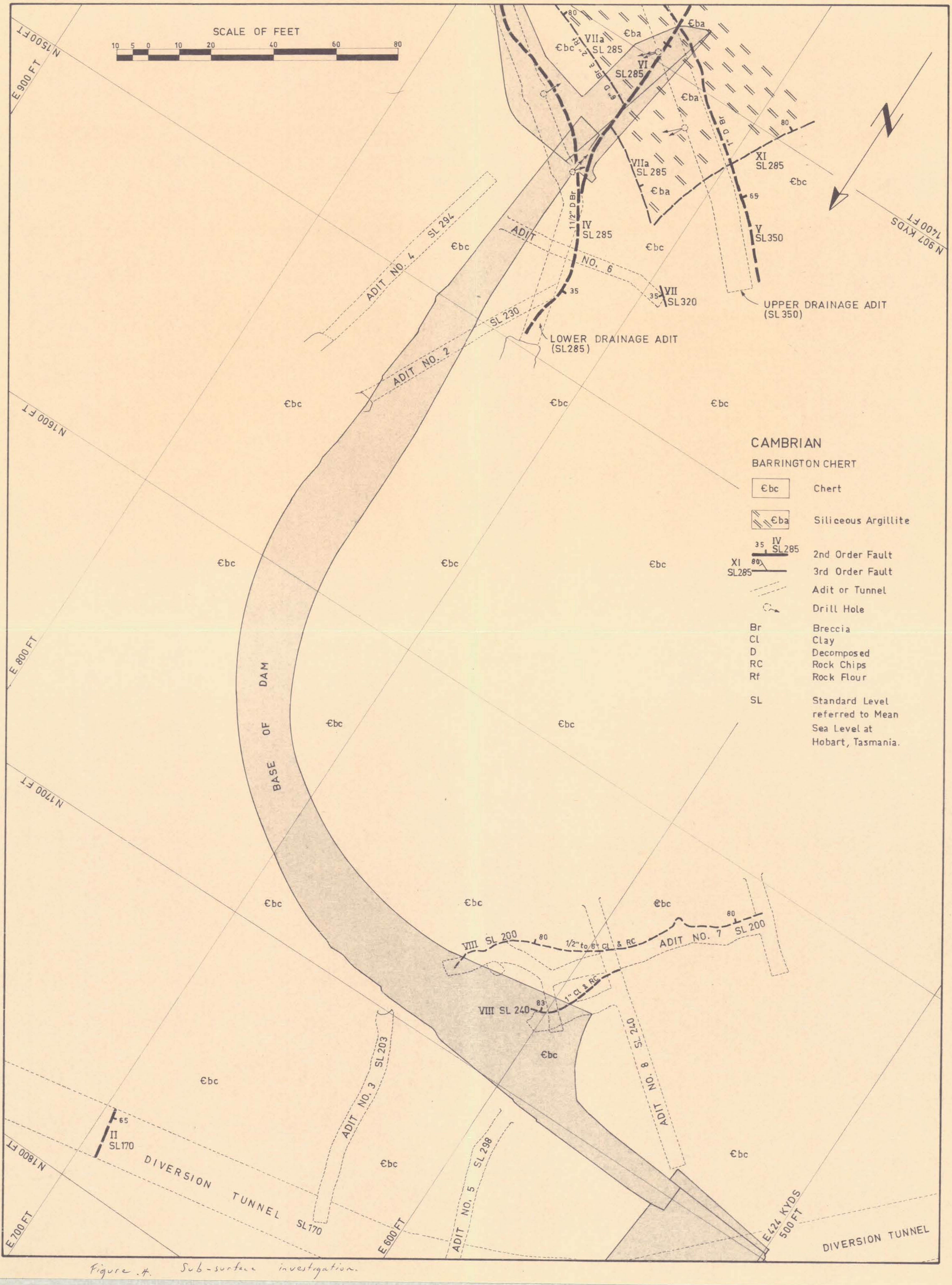

Figure 4. Sub-surface investigation.

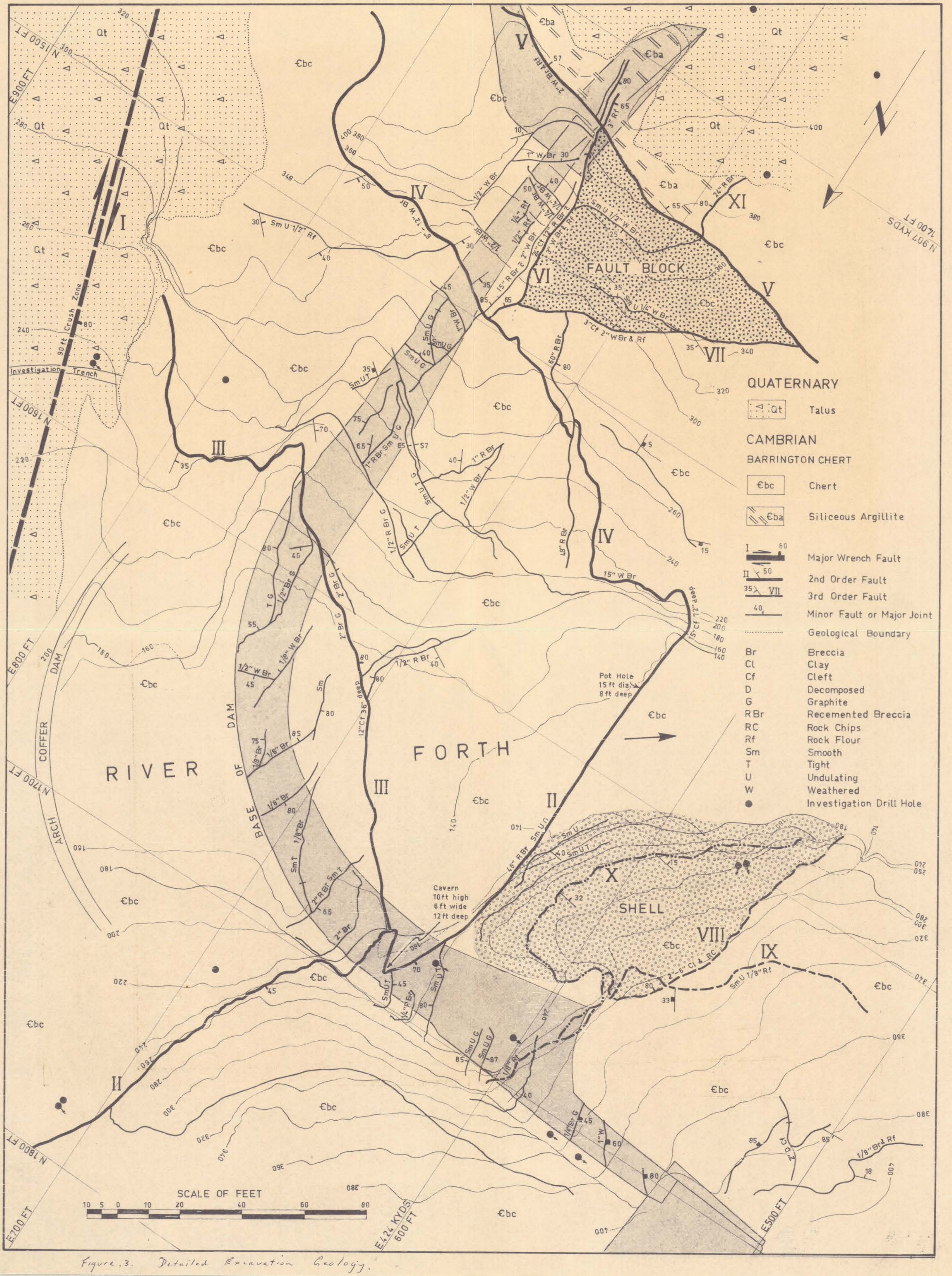

Figure. 3. Detailed Excavation Geology.