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JORDAN VALLEY IRRIGATION PROJECT

STAGE II

FEASIBILITY STUDY

VOLUME III

APPENDIX D
CONSTRUCTION MATERIALS

APPENDIX E
GEOLOGY

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REPORT OUTLINE

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Appendix D

CONSTRUCTION MATERIALS

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SUMMARY

This report presents the results of subsurface investigations and laboratory testing programs which were carried out to confirm and supplement the data previously described in the "Soil Mechanics Report", presented as part of a Feasibility Study prepared by Energoprojekt in 1966. All of the available previously obtained geotechnical data was evaluated and considered along with the data obtained during the current investigations to develop the preliminary design parameters presented herein.

These investigations and studies have shown that sufficient quantities of satisfactory construction materials are available near the site to construct a high rockfill embankment for Stage II and ultimate development of the Jordan Valley Irrigation Project.

Materials available near the site which are suitable for construction of the embankment shells include basalt, chalky limestone and river alluvium materials.

Basalt is available from the required spillway excavation and from potential quarries in the high basalt flows on the Syrian side of the river. The basalt from the Syrian side of the river appears to be a promising source of concrete aggregate and it will produce good quality rockfill. The basalt from the required spillway excavation also may be a source of good quality rockfill.

The chalky limestone is exposed on both sides of the valley in thinly to massively bedded units. Laboratory testing of samples obtained from the massive limestone cliff on the right side of the river downstream from the dam site

indicates that this material would produce marginal quality rockfill.

A large quantity of chalky limestone is available from Stage II spillway excavation. It is expected that it will be suitable for placement as random rockfill in the embankment. Additional testing and evaluation of this material is required during design phase investigations to optimize the use of chalky limestone.

The river alluvium materials will vary from free-draining rockfill quality to nearly impervious material. The alluvium will be available from required excavation and from Borrow Areas U and D, (see Exhibit 2).

Impervious materials available at the site include alluvial and residual clays and clayey talus. Borrow Areas B, B1, R1 and R2 contain primarily alluvial clays of medium to high plasticity. These borrow areas are the primary source of impervious clay. They are large enough to work economically and are relatively close to the dam.

Borrow Areas A, A1, J1, J2 and R4 contain residual clays of high plasticity. These borrow areas are considered the secondary source of impervious clay if the quantities in the primary areas are insufficient.

Clayey talus materials are available from the required dam and spillway excavation and overlie a portion of Borrow Areas R1 and R2.

Filter materials can be produced from the basalt in conjunction with concrete aggregate production. The coarse filter might be produced from processing the river alluvium.

Table D-1 summarizes the types and quantities of materials available from required excavations and borrow areas and material requirements for construction to crest eleva-

tions 158, 168 and ultimate development to crest elevation 200.

Additional exploration and testing are required for the final design studies.

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Table D-1

AVAILABLE CONSTRUCTION MATERIALS AND MATERIAL REQUIREMENTS

Zone	Material	Source	CREST EL. 158 RAISABLE		CREST EL. 200 RAISED FROM EL. 158		CREST EL. 168 RAISABLE		CREST EL. 200 RAISED FROM EL.168		Remarks
			Quantity Available $x10^6 M^3$	Quantity Required $x10^6 M^3$	Quantity Available $x10^6 M^3$	Quantity Required $x10^6 M^3$	Quantity Available $x10^6 M^3$	Quantity Required $x10^6 M^3$	Quantity Available $x10^6 M^3$	Quantity Required $x10^6 M^3$	
1	Primary Source Impervious Clay Secondary Source Impervious Clay	Borrow Area B Borrow Area B1 Borrow Area R1 Borrow Area R2 Borrow Areas A, A1, J1, J2 and R4	1.40 0.97 0.76 0.67 2.63	2.56	0.76 0.67 2.63	1.94	1.40 0.97 0.76 0.67 2.63	2.75	0.76 0.67 2.63	0.75	Borrow Areas B and B1 for Stage II development. Borrow Areas R1, R2, A, A1, J1, J2 and R4 for Ultimate development.
2	Impervious Talus	Required Excavation	2.70	1.35	0.87	0.35	2.61	1.43	0.96	0.27	Talus from Foundation Area and clay and talus from Spillway Excavation.
3F	Fine Filter	Quarry QB1	Unlimited	0.30	Unlimited	0.20	Unlimited	0.33	Unlimited	0.17	
3C	Coarse Filter	Quarry QB1	Unlimited	0.26	Unlimited	0.18	Unlimited	0.30	Unlimited	0.14	
4	Random Rockfill	Borrow Area U Borrow Area D Required Excavation Quarry QL2	1.92 - 2.0 3.20	2.83	1.08 1.04	0.00	1.92 - 2.2 3.20	2.83	1.08 .84	0.00	Borrow Area U for Stage II development. Borrow Area D for Ultimate development. Assumed 40% of River Alluvium from Borrow Areas U and D and 70% of Basalt and 100% of limestone from Required Excavation.
5	Alluvium	Borrow Area U Borrow Area D Required Excavation	2.88 - 0.70	3.14	- 1.62 0.10	0.86	2.88 - 0.73	3.49	1.62 0.07	0.51	Borrow Area U for Stage II development. Borrow Area D for Ultimate development. Assumed 60% of River alluvium from Borrow Areas U and D.
6	Basalt Rockfill	Basalt from Required Excavation Quarry QB1	0.23 Unlimited	2.94	0.20 Unlimited	6.26	.24 Unlimited	4.05	0.19 Unlimited	5.15	30% of Basalt from Required Excavation.
7	Random Fill	Required Excavation	1.44	0.94	0.6	0.00	1.2	0.94	0.84	0.00	Marl from Required Excavation
		Embankment Total		14.32		8.79		16.12		6.99	

INTRODUCTION

The Maqarin Project will include a zoned earth and rockfill dam with an impervious core, filters, rockfill and river alluvium shells, and an upstream weighting berm. The upstream cofferdam will be integrated into the dam. The structures requiring concrete aggregates will be the powerhouse, spillway, and diversion and power tunnels.

This section presents the results of subsurface investigations which were carried out to confirm and supplement the data previously described in the "Soil Mechanics Report" presented as part of a Feasibility Study prepared by Energoprojekt in 1966. All of the available previously obtained geotechnical data was evaluated and considered along with the data obtained during the current investigations to arrive at the conclusions presented herein.

Investigations

General

Potential construction material sources were investigated by surface mapping, test pits, shafts, adits, and boreholes. The locations of the potential construction material sources and exploratory holes are presented on Exhibits D-1 and D-2. All of the test pits, shafts, adits, and recovered core were visually examined and logged. The descriptive logs of the test pits, shafts, and adits are included in Annex D-1, Field Logs and Laboratory Tests.

The investigations essentially covered the same area which was investigated during the previous feasibility study. The field work was performed during August, September and October 1976.

Test Pits

A total of seventeen test pits were excavated in Borrow Areas A, B1, R1, R2, R4, N, D, and U as shown on Exhibit 1.

Each test pit was logged and 50 kg bag samples of representative soils were obtained. Jar samples of all fine grained soils were obtained for natural moisture content determinations. Laboratory testing was performed at the National Resources Authority (NRA) and the Bureau of Public Works (BPW) laboratories and included:

- Natural Moisture Content
- Atterberg Limits
- Grain Size Distribution and Hydrometer Analysis
- Specific Gravity
- Standard Compaction

In addition to this testing, certain representative samples were sent to the United States where the following tests were performed:

- Index Tests
- Permeability
- Dispersion
- Triaxial Shear

All laboratory test data and test procedures are presented in Annex D-1, Field Logs and Laboratory Tests.

Shafts and Adits

Five shafts and four adits, (see Exhibit D-2), were excavated in the proposed foundation area of the dam to investigate the talus and the weathered and unweathered marly limestone. These shafts and adits were hand-excavated and supported as required.

Large scale gradation and in-place density tests were performed in the talus deposits. This was done by weighing

and screening all material excavated from a selected section in the shafts and adits. Representative bag samples weighing approximately 50 kg were obtained from the portion of material passing a 3/4" sieve for laboratory analysis. Jar samples were obtained for natural water content determinations.

The following tests were performed at the NRA and BPW laboratories:

Natural Moisture Content
Atterberg Limits
Grain Size Distribution and Hydrometer Analysis
Specific Gravity
Standard Compaction

Undisturbed block samples of weathered marly limestone were obtained and tested in the NRA laboratory and in the United States as described in subsequent sections of this report.

Quarry Investigations

Potential sources of chalky limestone and basalt were investigated to determine their suitability for use as filter, rockfill, riprap and concrete aggregate. These potential sources, shown on Exhibit D-1, were geologically mapped and samples for laboratory testing were obtained from those areas which appeared promising.

Geologic mapping was performed in a potential basalt source, (designated QB1), on the Syrian side of the river and hand samples of surface outcrops of basalt were taken. The following tests were performed in the United States on these samples of basalt:

Petrographic Analysis
Sodium Sulphate Soundness
Specific Gravity and Absorption

Los Angeles Abrasion
Reactivity (Chemical)

Where applicable, all laboratory tests were conducted in accordance with ASTM (American Society for Testing and Materials) Standards.

Quarry QL2, (Exhibit D-1), was investigated as a potential source for limestone rockfill. Geologic mapping was performed and hand samples were obtained for laboratory testing. The following tests were performed at the BPW laboratory and in the United States:

Petrographic Analysis
Wetting and Drying
Specific Gravity and Absorption
Los Angeles Abrasion

Materials Available from Borrow and Quarry Areas

Shell Materials

General. The shell zones of the dam will be constructed using river alluvium deposits from Borrow Areas U and D as well as limestone and basalt rockfill obtained from required excavation and designated quarry areas.

Borrow Area U. This borrow area is located in and adjacent to the river channel upstream from the dam site. It is a combination of Borrow Areas U1, U2, U3, and U4 as designated in the Energoprojekt Report. It extends from elevation 30 to 55 m and the haul distance varies from 200 to 2,000 m. Accessibility to the borrow area is good, except during periods of high river flow.

Two test pits excavated to a maximum depth of 5.5 m, where ground water was encountered, indicate that the

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material generally consists of poorly-graded to well-graded gravels, cobbles and boulders with silty sand lenses. In test pit HU2-1 a thin layer, (0.4m), of silty clay was found at 2.1 meters depth.

The gravel, cobble and boulder sizes generally consist of well-rounded pieces of basalt with a few pieces of limestone. The finer fraction consists primarily of limestone and chert particles with some basalt.

Excavation with high production equipment will mix the sands and silty sands with the coarse particles to produce a granular fill which will be very dense and have excellent shear strength. The drainage characteristics will vary from free draining to semi-pervious depending on the amount of fines in the final product, which in turn depends on the method of excavation, (wet or dry), and the natural distribution of fines in the borrow area. Washing the alluvium to remove fines may be required to make the material usable as fill for the dam shell.

The results of laboratory tests performed on this material are shown on Table D-2.

It is estimated that Borrow Area U will produce approximately 4,800,000m^3 of shell material. This estimate includes the material below the water table and was made by utilizing the total depth of the alluvial material as indicated by the drill holes at the dam site.

Borrow Area D. This borrow area is located in and adjacent to the river channel downstream from the dam site and is a combination of Borrow Areas D1, D2, and D3 as designated in the Energoprojekt Report. It extends from elevation 5 to 25 m and the haul distance varies from 200 to 1500 m. The accessibility to the borrow area is good, except in periods of high river flow.

Table D-2

SUMMARY OF TEST RESULTS
BORROW AREA U

Test** Pit No.	Sample No.	Depth (M)	Grain Size* +#4 %	Grain Size* -#4+#200 %	Grain Size* -#200 %	Atterberg Limits L.L. %	Atterberg Limits P.L. %	Atterberg Limits P.I. %	Insitu Dry Density tons/m3	Natural Moisture Content %	Specific Gravity	Field Permeability K20 cm/sec	Classification USCS
U1-150	1	0.3-1.0	31	24	45	-	-	-	-	-	2.77	-	CL
U1-150	2	1.0-3.9	69	25	6	-	-	-	1.65	4.2	2.81	6.3×10^{-3}	GW
U1-150	3	3.9-4.5	61	37	2	-	-	-	-	-	2.80	-	GP
U2-160	1	0.3-3.6	62	33	5	-	-	-	-	-	2.81	-	GP
U2-160	2	0.3-3.6	77	20	3	-	-	-	-	-	2.84	-	GP
U3-170	1	0.3-3.1	66	12	22	-	-	-	-	-	2.80	-	GP
U3-170	2	3.1-3.5	47	35	18	-	-	-	-	-	2.81	-	GM
U4-180	1	0.4-2.3	84	8	8	-	-	-	-	-	2.81	-	GP-GM
U4-181	1	0.2-2.2	67	28	5	-	-	-	-	-	2.80	-	GW
HU1-1	1	0.3-3.0	57	23	20	-	-	-	-	-	2.58	-	GM
HU1-1	2	3.0-5.0	74	19	7	-	-	-	-	-	2.64	-	GP
HU4-1	1	1.0-2.0	61	20	19	-	-	-	-	-	2.70	-	GM
HU4-1	2	2.0-3.0	79	17	4	-	-	-	-	-	2.78	-	GP

* U.S. STANDARD SIEVE
** U series Test Pits completed in 1965.
H series Test Pits completed in 1976.

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Two test pits, excavated in this area to verify previously reported data, indicate that a 0.3 meter thick layer of sandy loam covers the area. Underlying the loam are heterogeneous deposits of gravel, sand, intermittent clay lenses, clean sandy gravels, and cobbles and basalt boulders in a sandy gravel matrix.

In-place field permeability tests performed by Energoprojekt indicated insitu permeabilities of 2.9×10^{-2} to 2.2×10^{-3} m^3/s.

The results of laboratory tests performed on samples from Borrow Area D are shown in Table D-3.

It is estimated that Borrow Area D will yield 2,700,000 m^3 of alluvial material using the same basis for the estimate as for Borrow Area U.

Quarry Area QL2. This chalky limestone area is located on the right bank downstream of the dam site at an elevation of 25 to 50m where the chalky limestone is exposed as a cliff. The access to this area is good.

The chalky limestone is buff-gray, thickly bedded, compact, non-friable and moderately hard and strong. Some case-hardening of the outcrops appears to be present. Hand samples of this material were selected for laboratory tests to determine its suitability for use as rockfill.

The results of laboratory tests, (Table D-4), indicate that the chalky limestone may be suitable for rockfill. The material has a specific gravity range from 2.53 to 2.63 and a Los Angeles abrasion resistance loss varying from 44 to 50 percent. It has a high absorption, (7 to 10%). Wetting during placement is required to reduce post construction settlement.

Table D-3

SUMMARY OF TEST RESULTS
BORROW AREA D

Test** Pit No.	Sample No.	Depth (M)	Grain Size* +#4 %	-#4+#200 %	-#200 %	Atterberg Limits L.L. %	P.L. %	P.I. %	Insitu Dry Density tons/m^3	Natural Moisture Content %	Specific Gravity	Field Permeability K20 cm/sec	Classification USCS
D1-100	1	0.3-1.2	38	21	41	53.9	23.1	30.8	1.56	10.5	2.73	-	GC
D1-100	2	1.2-3.2	1	18	81	55.5	24.8	30.7	1.54	19.5	2.72	-	CH
D1-100	3	3.2-3.9	64	9	21	53.5	23.0	30.5	-	-	2.73	-	GC
D1-100	4	3.9-6.0	72	10	18	-	-	-	-	-	2.80	-	GC
D1-101	1	0.3-3.5	82	15	3	-	-	-	-	-	2.79	-	GW
D2-110	1	0.3-2.8	4	53	43	34.4	22.6	11.8	1.30	9.0	2.69	2.2×10^{-3}	SC
D2-110	2	2.8-3.0	79	18	3	-	-	-	-	-	2.73	-	GP
D3-120	1	0.5-1.0	39	41	20	-	-	-	-	-	2.80	-	SC
D3-120	2	1.0-4.0	72	21	7	-	-	-	-	-	2.80	-	GP-GM
D3-121	1	0.0-2.0	69	25	6	-	-	-	-	-	2.78	-	GW
D3-121	2	2.0-4.5	68	24	8	-	-	-	-	-	2.79	-	GW
HD1-1	1	1.3-1.8	76	20	6	-	-	-	-	-	-	-	GW
HD1-1	2	2.0-3.0	9	40	51	42.6	24.2	18.4	-	-	-	-	CL
HD1-1	3	3.9-6.3	79	15	5	-	-	-	-	-	-	-	GW
HD3-1	1	0.3-1.8	63	29	8	-	-	-	-	-	2.70	-	GW
HD3-1	2	1.8-3.9	28	49	8	-	-	-	-	-	2.71	-	SC

* U.S. STANDARD SIEVE
** D Series test pits completed in 1965.
H Series test pits completed in 1976.

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Table D-4

SUMMARY OF TEST RESULTS ON LIMESTONE
QUARY QL-2

		ASTM Designation	Sample Number QL2-1	QL2-2	QL2-3
Specific Gravity of Coarse Aggregates		C-127	2.53	2.63	2.63
Absorption of Coarse Aggregates (%)		C-127	7.27	9.70	8.13
Los Angeles Abrasion	% Wear @100 Rev.	C-131	-	14.7	-
(Grading A)	% Wear @500 Rev.	C-131	43.6	50.1	47.8
Soundness of Aggregates by Sodium Sulfate	% Total weighted loss	C-88	-	78.5	-
Wetting and Drying Test	% loss @5 cycles	California	3.8	0.19	3.1
	% loss @10 cycles	Highway wetting and drying test, Method B	-	0.27	-
	% loss @15 cycles		-	0.38	-
	% loss @20 cycles		-	0.47	-

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Quarry Area QL2 will yield an estimated 3,200,000 m^3 of rockfill.

Basalt Quarry QB1. A potential basalt quarry is located in the high basalt flows on the right side of the river approximately 1100 m dowsntream from the dam axis. The basalt is dark grey to black, finely crystalline in massive flows, but vesicular at the top of the flows. The total thickness is approximately 50 meters, consisting of 7 individual flows. The mass has horizontal flow structure with local discontinuous joints parallel to the base of the flows. Thick flows have vertical columnar jointing with joint spacing varying from 0.5 to 2.0 m.

Hand samples of this basalt were obtained from outcrops for laboratory testing to determine its suitability for use as concrete aggregate, filter and rockfill. These tests, summarized on Table D-5, indicate that the basalt will produce good quality rockfill and aggregate. The jointing pattern indicates that adequate size riprap can be obtained from this source.

An unlimited quantity of basalt is available within an economical haul distance of the dam site.

Impervious Material

General. Impervious fill materials are available from the required excavation and Borrow Areas B, B1, R1 and R2. These materials exist in alluvial deposits, often covered with talus which is also impervious. The impervious materials consist of medium to highly plastic clays and clayey gravels. Access to these areas is good.

The natural moisture content averages approximately 11 percent below the optimum moisture content and the materials will require moisture conditioning before compaction in the

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Table D-5

SUMMARY OF AGGREGATE TEST RESULTS ON BASALT
QUARRY QB-1

		ASTM Designation	Basalt No. 1	Basalt No. 2
Specific Gravity of Coarse Aggregates		C-127	2.83	2.90
Absorption of Coarse Aggregates (%)		C-127	1.36	1.06
Potential Reactivity of Aggregates		C-289	Innocuous	Innocuous
Los Angeles Abrasion	% Wear @100 Rev.	C-131	5.1	2.8
(Grading A)	% Wear @500 Rev.	C-131	18.0	16.1
Soundness of Aggregated by Sodium Sulfate	% Total weighted loss	C-88	2.48	0.87

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embankment. Compacted specimens have satisfactory shear strength and compressibility characteristics.

Clayey soils in Borrow Areas A, A1, J1, J2 and R4 are possible sources of impervious fill, if the quantities in the primary borrow areas are insufficient.

Borrow Area B1. Borrow area B1 is located on the right bank upstream from the dam site between elevations 60 to 90 m. The average haul distance is 1300 m and the accessibility is good.

Test pits HB1-1 and HB1-2 confirmed that the material found in the eleven test pits excavated by Energoporjekt will produce a satisfactory impervious fill. A two to eleven meter layer of fat brown clay underlain by river terrance deposits of sand, gravel and cobbles was found.

Laboratory test results show the clayey materials have a liquid limit ranging from 33.0 to 83.1 percent with a plastic limit ranging from 16.1 to 44.4 percent.

The insitu dry unit weights range from 1.31 to 1.57 tons/m^3 with a natural moisture content range from 5.8 to 26.6 percent. Standard compaction tests indicate that the maximum dry unit weights range from 1.26 to 1.51 tons/m^3 with optimum moisture contents ranging from 23.8 to 37.6 percent.

Triaxial shear tests performed on material compacted to maximum standard compaction density show an effective cohesion intercept ranging from 0.01 to 0.32 kg/cm^2 with an effective angle of friction ranging from 22.0 to 26.0 degrees.

The laboratory test results for Borrow Area B1 are presented in Table D-6.

Borrow Area B1 will yield approximately 1,400,000 m^3 of impervious fill.

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Table D-6

SUMMARY OF TEST RESULTS
BORROW AREA B1

Test** Pit No.	Sample No.	Depth (M)	Grain Size* +#4 %	-#4+#200 %	-#200 %	Atterberg Limits L.L. %	P.L. %	P.I. %	Insitu Dry Density tons/m^3	Natural Water Content %	Specific Gravity	Standard Maximum Dry Density tons/m^3	Compaction Optimum Water Content %	Field Permeability K20 cm/sec	Triaxial Shear C' kg/cm^2	Triaxial Shear Ø' deg	Soil Classification USCS	Soil Classification Dispersion
500	1	0.3-1.5	29	9	62	56.2	23.3	32.9	1.39	6.2	2.73	-	-	6.3×10^{-4}	-	-	CH	-
500	2	1.5-4.0	3	12	85	73.8	27.4	46.4	1.50	17.4	2.71	-	-	-	-	-	CH	-
500	3	4.0-5.2	2	12	86	74.2	30.2	44.0	1.54	18.0	2.71	-	-	-	-	-	CH	-
500	4	5.2-5.8	1	18	71	34.1	16.1	18.0	-	-	2.76	-	-	-	-	-	CL	-
500	5	5.8-6.0	75	15	10	-	-	-	-	-	2.79	-	-	-	-	-	GM-GP	-
501	1	0.3-2.5	13	15	72	53.7	24.3	29.4	1.42	15.7	2.73	-	-	-	-	-	CH	-
501	2	2.5-3.2	4	14	82	76.1	21.6	54.5	1.47	16.4	2.74	-	-	-	-	-	CH	-
501	3	3.2-6.0	76	4	20	61.6	28.7	32.9	-	-	2.74	-	-	-	-	-	GM	-
502	1	0.9-6.0	11	15	74	59.3	22.3	37.0	1.31	22.3	2.74	1.40	23.8	-	-	-	CH	-
502	2	0.9-6.0	13	19	68	52.4	21.1	31.3	1.49	15.6	2.74	-	-	-	-	-	CH	-
503	1	0.3-1.5	42	20	38	35.9	19.8	16.1	1.48	5.8	2.71	-	-	6.4×10^{-5}	-	-	CL	-
503	2	1.5-3.0	2	31	67	39.5	18.6	20.9	1.43	14.1	2.72	-	-	-	-	-	CL	-
503	3	3.0-5.0	13	47	40	33.0	18.0	15.0	1.41	13.5	2.72	-	-	-	-	-	SC	-
503	4	5.0-6.0	80	14	6	-	-	-	-	-	2.82	-	-	3.1×10^{-2}	-	-	GP-GM	-
504	1	0.2-2.0	2	13	85	67.2	26.8	40.4	1.35	18.1	2.70	-	-	-	-	-	CH	-
504	2	2.0-5.8	3	15	82	55.2	25.2	30.0	1.40	21.1	2.73	1.35	27.2	-	0.20	25.6	CH	-
504	3	2.0-5.8	4	11	85	66.8	25.5	41.3	1.32	21.0	2.71	-	-	-	0.18	26.0	CH	-
504	4	5.8-6.0	85	6	9	51.8	24.3	27.5	-	-	2.79	-	-	-	-	-	OM-MH	-
505	1	0.3-1.5	74	8	18	51.0	26.2	24.8	1.44	8.9	2.72	-	-	-	-	-	CH	-
505	2	1.5-2.9	59	13	28	55.3	22.3	33.0	1.54	16.5	2.71	-	-	3.3×10^{-4}	-	-	CH	-
505	3	2.9-3.4	77	7	16	54.5	24.8	29.7	-	-	2.73	-	-	-	-	-	GC	-
505	4	3.4-6.0	-	-	-	53.6	22.9	30.7	1.52	19.0	2.73	-	-	-	-	-	GC	-
506	1	0.3-2.0	1	14	85	68.4	26.6	41.8	1.57	18.8	2.73	-	-	-	-	-	CH	-
506	2	2.0-4.0	88	6	6	52.2	27.7	24.5	-	-	2.74	-	-	1.0×10^{-3}	-	-	GP	-
507	1	0.3-1.5	66	7	27	55.3	25.3	30.0	1.48	8.3	2.68	-	-	3.2×10^{-4}	-	-	CH	-
507	2	1.5-4.1	7	14	79	59.2	25.3	33.9	1.45	15.7	2.68	1.42	26.7	-	0.32	22.0	CH	-
507	3	4.1-5.5	5	14	81	72.5	28.5	44.0	1.50	20.8	2.72	-	-	-	-	-	CH	-
507	4	5.5-6.0	86	7	7	-	-	-	-	-	2.76	-	-	-	-	-	GP	-
508	1	0.4-3.2	57	13	30	47.7	22.7	25.0	1.48	6.4	2.72	-	-	-	-	-	CL	-
508	2	3.2-6.0	14	12	64	61.0	27.3	33.7	1.51	15.4	2.72	-	-	-	-	-	CH	-
510	1	0.3-4.0	80	3	17	83.1	26.5	56.6	1.49	20.4	2.73	-	-	-	-	-	CH	-
510	2	4.0-6.0	1	10	89	70.5	24.6	45.9	1.54	16.0	2.74	-	-	-	-	-	CH	-

Table D-6 (Continued)

SUMMARY OF TEST RESULTS
BORROW AREA B1

Test** Pit No.	Sample No.	Depth (M)	Grain Size* +#4 %	Grain Size* -#4+#200 %	Grain Size* -#200 %	Atterberg Limits L.L. %	Atterberg Limits P.L. %	Atterberg Limits P.I. %	Insitu Dry Density tons/m³	Natural Water Content %	Specific Gravity	Standard Maximum Dry Density tons/m³	Compaction Optimum Water Content %	Field Permeability K20 cm/sec	Triaxial Shear C' kg/cm²	Triaxial Shear Ø' deg	Soil Classification USCS	Soil Classification Dispersion
HB1-1	1	0.3-2.5	32	5	63	55.8	36.0	19.8	-	14.0	-	1.40	31.7	-	-	-	MH	-
HB1-1	2	2.5-4.7	17	8	75	61.7	33.8	32.9	-	19.5	2.75	1.32	35.5	-	-	-	CH	-
HB1-1	3	4.7-5.8	4	10	86	51.5	28.3	23.2	-	11.8	-	1.41	31.1	-	-	-	MH	-
HB1-1	4	5.8-8.2	58	28	14	-	-	-	-	-	2.69	-	-	-	-	-	GP	Nondispersive
HB1-1	5	4.7-5.8	3	7	90	57.8	30.6	27.2	-	11.8	2.65	1.51	23.8	-	-	-	MH	-
HB1-2	1	0.3-2.5	6	7	87	68.4	44.4	24.0	-	15.3	-	1.26	37.6	-	-	-	MH	-
HB1-2	2	2.5-11.5	5	8	87	65.6	35.4	30.2	-	26.6	2.63	1.30	36.8	-	-	-	MH	Nondispersive
HB1-2	3	5.0-7.0	9	15	76	61.0	31.2	29.5	-	26.6	2.70	1.49	23.8	-	0.0	25.5*	MH	-

* U.S. STANDARD SIEVE
** H series test pits completed in 1976 all others completed in 1965.

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Borrow Area B. Borrow Area B is located on the left bank upstream from the dam site at an elevation of 79 to 103 m. The average haul distance is 1600 m and accessibility is good. Borrow Area B was not investigated during this study because the area had been mined. However, investigations were carried out by Energoprojekt in 1965, and the results of those investigations have been reviewed.

Ten test pits excavated to a maximum depth of 6 m showed a 2 to 6 m layer of fine grained soils suitable for use as impervious material. These materials consist of brown silty clays with silty sand lenses overlain by a clayey talus. The fine grained soils are underlain by basalt conglomerates and limestone.

Laboratory test results show a liquid limit ranging from 32.8 to 80.1 percent with a plastic limit range of 17.3 to 27.0 percent.

The insitu dry unit weights range from 1.15 to 1.80 tons/m^3 with natural moisture contents ranging from 10.0 to 28.5 percent. Standard Proctor compaction tests show that the maximum dry unit weights range from 1.43 to 1.48 tons/m^3 with optimum moisture contents ranging from 26.9 to 28.3 percent.

Triaxial shear tests show an effective cohesion intercept ranging from 0.20 to 0.50 kg/cm^2 and effective angle of friction of 17.8 to 36.5 degrees.

The laboratory test results for this area are presented in Table D-7.

It is estimated that Borrow Area B will yield 970,000 m^3 of impervious fill.

Borrow Area R1. Borrow Area R1 is located on the right bank of the river downstream from the dam site at elevations

Table D-7

SUMMARY OF TEST RESULTS
BORROW AREA B

Test** Pit No.	Sample No.	Depth (M)	Grain Size* +#4 %	-#4+#200 %	-#200 %	Atterberg Limits L.L. %	P.L. %	P.I. %	Insitu Dry Density tons/m³	Natural Water Content %	Specific Gravity	Standard Maximum Dry Density tons/m³	Compaction Optimum Water Content %	Field Permeability K20 cm/sec	Triaxial Shear C' kg/cm²	Ø' deg	Soil Classification USCS	Dispersion
300	1	0.4-3.5	46	14	40	47.1	19.7	27.4	1.25	17.6	2.73	-	-	3.9×10^{-4}	-	-	CL	-
300	2	3.5-6.0	3	17	80	64.8	27.0	37.8	1.18	20.0	2.74	-	-	-	-	-	CH	-
300	3	3.5-6.0	5	18	77	64.8	21.8	43.0	1.23	18.5	2.74	-	-	-	-	-	CH	-
301	1	0.3-1.0	8	21	71	47.7	16.3	31.4	1.32	24.0	2.72	-	-	-	-	-	CL	-
301	2	1.0-2.3	8	16	76	47.9	18.3	29.6	1.23	18.7	2.73	-	-	-	-	-	CL	-
301	3	2.3-6.0	4	12	84	51.7	22.9	28.8	1.51	18.6	2.73	1.44	26.9	6.4×10^{-6}	0.20	23.2	CH	-
301	4	3.9-6.0	0	13	87	66.0	19.6	46.4	1.34	19.5	2.73	-	-	-	-	-	CH	-
302	1	0.4-1.8	35	25	40	43.2	18.0	25.2	1.34	16.5	2.72	-	-	-	-	-	CL	-
302	2	1.8-3.0	54	17	29	41.2	19.9	21.3	1.30	21.9	2.74	-	-	-	-	-	CL	-
302	3	3.9-6.0	36	17	47	45.7	18.8	26.9	1.44	12.9	2.74	-	-	1.8×10^{-4}	-	-	CL	-
302	4	3.9-6.0	30	16	54	49.6	20.0	29.6	1.55	17.5	2.74	1.48	27.1	-	0.50	17.8	CL	-
303	1	0.3-0.8	6	43	51	39.6	21.2	18.4	1.33	23.7	2.69	-	-	-	-	-	CL	-
303	2	0.8-4.0	64	16	20	48.5	19.7	28.8	1.35	12.0	2.73	-	-	-	-	-	CL	-
303	3	4.0-5.0	22	32	46	42.7	18.9	23.8	1.15	14.2	2.71	-	-	-	-	-	CL	-
303	4	5.0-6.0	34	35	31	44.6	18.8	25.8	1.26	10.0	2.74	-	-	-	-	-	CL	-
304	1	0.3-2.9	31	23	46	40.0	18.8	21.2	1.29	13.2	2.73	-	-	2.6×10^{-4}	-	-	CL	-
304	2	2.9-4.0	44	16	40	45.6	20.3	25.3	1.54	19.4	2.74	-	-	-	-	-	CL	-
304	3	4.0-6.0	2	14	84	80.1	21.8	58.3	1.39	20.0	2.73	-	-	-	-	-	CH	-
305	1	0.3-0.9	21	31	48	40.5	18.7	21.8	1.29	28.5	2.67	-	-	-	-	-	CL	-
305	2	0.9-3.2	29	32	39	37.5	20.2	17.3	1.21	12.6	2.69	-	-	-	-	-	CL	-
305	3	3.2-5.0	44	27	29	35.0	19.8	15.2	1.36	11.9	2.73	-	-	-	-	-	CL	-
305	4	5.0-6.0	48	34	18	33.2	20.2	13.0	1.18	14.8	2.74	-	-	-	-	-	OC-CL	-
306	1	0.3-1.2	5	28	67	41.0	24.5	16.5	1.18	25.5	2.71	-	-	-	-	-	CL	-
306	2	1.2-1.7	10	18	72	43.0	18.5	24.5	1.23	19.7	2.71	-	-	-	-	-	CL	-
306	3	2.3-3.5	42	26	32	55.8	22.1	33.7	1.80	14.7	2.73	-	-	-	-	-	OC	-
306	4	5.0-6.0	8	16	76	71.7	26.5	45.2	1.23	17.1	2.74	-	-	-	-	-	CH	-
307	1	0.3-1.0	16	28	56	36.2	22.0	14.2	1.22	25.5	2.70	-	-	-	-	-	CL	-
307	2	1.5-3.0	13	59	28	32.8	25.6	7.2	1.27	21.7	2.72	1.43	28.3	5.7×10^{-4}	0.25	36.5	SM	-
307	3	3.0-5.0	34	18	48	46.1	22.2	23.9	1.37	13.4	2.73	-	-	-	-	-	OC	-
307	4	5.0-6.0	17	17	66	54.4	22.4	32.0	1.25	17.0	2.75	-	-	-	-	-	CH	-
308	1	0.3-0.5	5	23	72	45.7	17.3	28.4	1.43	23.2	2.73	-	-	-	-	-	CL	-
308	2	0.5-3.0	25	49	26	-	-	-	1.31	14.3	2.71	-	-	-	-	-	SC	-
308	3	0.5-3.0	2	16	82	51.9	21.2	30.7	1.33	25.4	2.74	-	-	7.0×10^{-6}	-	-	CH	-
309	1	0.6-1.7	71	13	16	-	-	-	-	-	2.71	-	-	-	-	-	OC	-

* U.S. STANDARD SIEVE
** All test pits completed in 1965.

of 10 to 85 m. The average haul distance is 1000 m and the accessibility is good.

Test pits HR1-1 and HR1-2 revealed a 4.0 to 8.4 m layer of silty clay.

A layer of decomposed marly limestone underlies the silty clay in test pit HR1-1. Dispersion tests indicate that this decomposed marly limestone may be dispersive and may not be suitable as impervious fill.

In test pit HR1-2 the silty clays are underlain by a minimum of 2.5 m of river terrace deposits consisting of sand, gravel, cobbles, and boulders.

Laboratory test results show that the clay material has a liquid limit ranging from 31.0 to 49.7 percent with a plastic limit range of 13.6 to 29.1 percent.

The natural moisture contents range from 11.8 to 29.8 percent. Laboratory compaction tests indicate maximum dry unit weights ranging from 1.33 to 1.61 tons/m^3 with the optimum moisture contents ranging from 18.8 to 29.0 percent.

Triaxial shear tests performed on 4" diameter compacted specimens of minus 3/4 inch material show no cohesion and an effective angle of friction of 34.0 degrees. The permeability of this material is approximately 10^{-6} cm/sec.

The laboratory test results are presented in Table D-8.

It is estimated Borrow Area R1 will yield 760,000 m^3 of impervious fill.

Borrow Area R2. Borrow Area R2 is located on the right bank downstream from the dam site at an elevation of 55 to 95 m. The average haul distance is 1800 m.

Two test pits, HR2-1 and HR2-2 were excavated in this area to a maximum depth of 12.0 m and the full depth of clay materials was not penetrated.

Table D-8

SUMMARY OF TEST RESULTS
BORROW AREAS R1 AND R2

Test Pit No.	Sample No.	Depth (M)	+#4 %	Grain Size* -#4+#200 %	-#200 %	Atterberg Limits L.L. %	P.L. %	P.I. %	Insitu Dry Density tons/m³	Natural Water Content %	Specific Gravity	Standard Maximum Dry Density tons/m³	Compaction Optimum Water Content %	Field Permeability K20 cm/sec	Triaxial Shear C' kg/cm²	Ø' deg	Soil Classification USCS	Dispersion
HR1-1	1	0.3-2.1	34	19	47	33.7	13.6	20.1	-	11.8	2.74	1.61	18.8	-	-	-	CL	Nondispersive
HR1-1	2	2.1-4.6	22	20	52	31.0	22.4	8.6	-	19.7	2.76	1.57	23.9	-	-	-	CL	-
HR1-1	3	4.6-5.9	22	10	88	36.2	24.2	12.0	-	29.8	2.69	1.33	29.0	-	-	-	CL	Dispersive
HR1-2	1	0.4-3.0	58	8	34	48.4	28.2	20.2	-	12.3	2.66	1.47	26.7	-	-	-	GC-CL	-
HR1-2	2	3.0-5.9	17	16	67	47.2	24.1	23.1	-	16.7	2.79	1.52	25.3	-	-	-	CL	-
HR1-2	3	5.9-8.4	67	10	23	43.0	28.9	14.1	-	19.1	2.74	1.55	23.6	-	-	-	ML	-
HR1-2	4	8.4-10.0	84	13	3	-	-	-	-	-	2.69	-	-	-	-	-	-	-
HR1-2	5	0.4-3.0	34	16	50	49.7	29.1	20.6	-	-	2.65**	1.58***	20.5***	-	0.0	34.0	ML	Nondispersive
HR2-1	1	0.3-3.0	19	5	76	53.0	35.0	18.0	-	23.2	2.64	1.28	39.0	-	-	-	MH	-
HR2-1	2	3.0-5.0	7	5	88	57.4	45.0	12.0	-	20.1	2.77	1.31	35.0	-	-	-	ML	-
HR2-1	3	5.0-12.0	-	-	-	86.8	46.7	40.1	-	25.4	2.65	1.25	38.5	-	-	-	MH	-
HR2-2	1	0.3-2.1	18	12	70	46.0	32.5	13.5	-	17.9	2.66	1.40	28.4	-	-	-	ML	-
HR2-2	2	2.1-5.0	62	13	25	51.0	29.3	22.0	-	15.8	2.68	1.42	29.9	-	-	-	GC-CH	Nondispersive
HR2-2	3	5.0-12.0	-	-	-	48.3	25.4	22.9	-	27.3	2.74	1.49	24.5	-	-	-	CL	-

* U.S. STANDARD SIEVE
** Specific Gravity: 2.65 Passing No. 4 sieve
2.75 retained on No. 4 sieve
*** Maximum unit weight and optimum moisture content of material passing 3/4" sieve

Laboratory test results show the clay material has a liquid limit ranging from 46.0 to 86.8 percent with plastic limit ranging from 25.4 to 45.0 percent.

The natural moisture contents range from 17.9 to 27.3 percent. Standard compaction tests indicate maximum dry unit weights ranging from 1.25 to 1.49 tons/m^3 with optimum moisture contents ranging from 20.5 to 39.0 percent.

The laboratory test results for this area are presented in Table D-8.

It is estimated Borrow Area R2 will yield approximately 670,000 m^3 of impervious fill.

Borrow Areas A, A1, J1, J2, and R4. Borrow Areas A1, J1 and J2 are located on the right bank on high plateaus within 1.5 km of the dam site. Borrow Area A is located high on the left bank within 1.0 km of the dam site. Borrow Area R4 is located on the right bank 3.0 km downstream of the dam site.

The impervious materials encountered in these areas are essentially fat brown clays.

Laboratory test results show the materials have a liquid limit ranging from 34.9 to 100.4 percent with plastic limits ranging from 15.0 to 44.7 percent.

Insitu dry unit weights range from 1.24 to 1.68 tons/m^3 with natural moisture contents of 4.8 to 34.5 percent. Standard compaction tests indicate maximum dry unit weights ranging from 1.27 to 1.40 tons/m^3 with optimum moisture contents ranging from 29.2 to 38.0 percent.

Triaxial shear tests indicate an effective cohesion intercept ranging from 0.07 to 0.65 kg/cm^2 with angles of friction ranging from 13.0 to 21.3 degrees.

Laboratory test results for these areas are summarized on Tables D-9 and D-10.

The estimated quantities of impervious material available from these areas are summarized as follows:

Borrow Area	Volume M^3
A	1,610,000
A1	75,000
J1	135,000
J2	135,000
R4	675,000

Filter Material

The proposed embankment section utilizes thin double stage filters on both upstream and downstream sides of the core to provide a transition between the impervious material and the rockfill. There are no naturally occurring materials within economical hauling of the dam to provide filter material without processing. Materials near the site which could be processed for filter material include the alluvium, basalt and chalky limestone.

Alluvium. The alluvial material in the valley bottom is a heterogenous mixture of cobbles and boulders with the voids filled with sand and gravel and silty sand. Lenses of silty sand and clayey sand up to 1 meter in thickness occur at irregular intervals. A typical large sample might consist of approximately 50 percent cobbles and boulders, 30 percent gravel, 15 percent sand sizes and 5 percent fines.

The sand size particles are primarily limestone, chalk, chert and marly limestone. Much of this material is soft and would degrade during processing, placing and compaction. These characteristics combined with the actual low percentage

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Table D-9

SUMMARY OF TEST RESULTS
BORROW AREAS J2, J1 AND A1

Test** Pit No.	Sample No.	Depth (M)	Grain Size* +#4 %	Grain Size* -#4+#200 %	Grain Size* -#200 %	Atterberg Limits L.L. %	Atterberg Limits P.L. %	Atterberg Limits P.I. %	Insitu Dry Density tons/m³	Natural Water Content %	Specific Gravity	Standard Maximum Dry Density tons/m³	Compaction Optimum Water Content %	Field Permeability K20 cm/sec	Triaxial Shear C' kg/cm²	Triaxial Shear Ø' deg	Soil Classification USCS	Soil Classification Dispersion
J2-600	1	0.3-6.0	0	11	89	81.7	23.4	58.3	1.49	22.8	2.74	-	-	-	-	-	CH	-
J2-600	2	0.3-6.0	53	7	40	81.7	25.6	56.1	1.28	26.6	2.73	-	-	-	-	-	CH	-
J2-601	1	1.5-2.8	1	11	87	74.0	24.9	49.1	1.50	20.8	2.72	-	-	-	-	-	CH	-
J2-601	2	2.8-4.3	72	5	23	80.5	28.9	52.6	1.38	23.0	2.73	1.27	33.0	-	0.20	20.3	CH	-
J1-604	1	0.4-2.1	-	-	-	71.8	28.2	43.6	1.51	20.8	2.72	-	-	-	-	-	CH	-
J1-605	1	0.4-2.8	-	-	-	65.2	22.8	42.6	1.54	19.5	2.72	-	-	-	-	-	CH	-
A1-400	1	0.3-3.2	58	4	38	82.3	28.6	53.7	1.46	25.2	2.70	-	-	-	-	-	CH	-
A1-400	2	3.2-5.7	65	5	30	86.0	29.8	56.2	1.58	16.9	2.75	-	-	-	-	-	CH	-
A1-401	1	0.3-6.0	63	5	32	78.9	26.1	52.8	1.45	24.6	2.72	-	-	-	-	-	CH	-
A1-401	2	0.3-6.0	43	5	52	100.4	30.5	69.9	1.46	24.1	2.74	-	-	-	-	-	CH	-
A1-402	1	0.3-3.0	54	2	44	83.2	28.5	54.7	1.40	23.5	2.73	1.31	32.9	-	0.25	16.7	CH	-
A1-402	2	3.0-6.0	61	4	35	83.9	30.5	53.4	1.41	20.7	2.69	-	-	-	-	-	CH	-
A1-403	1	0.3-6.0	2	7	91	85.8	27.8	50.0	1.35	26.1	2.70	1.31	31.6	-	0.20	21.0	CH	-
A1-403	2	0.3-6.0	2	11	87	84.2	29.4	54.8	1.38	21.4	2.70	1.31	31.6	-	0.65	13.0	CH	-
A1-404	1	1.5-4.0	45	3	52	89.3	27.9	61.4	1.36	24.9	2.73	-	-	-	-	-	CH	-
A1-404	2	4.0-6.0	51	5	44	84.3	29.3	55.0	1.41	21.5	2.73	-	-	-	-	-	CH	-
A1-405	1	0.3-6.0	23	7	90	77.9	26.2	51.7	1.45	24.4	2.71	-	-	-	-	-	CH	-
A1-405	2	0.3-6.0	66	7	27	86.3	29.2	57.1	1.34	21.2	2.73	-	-	-	-	-	CH	-
A1-406	1	0.3-5.0	4	7	89	86.8	27.9	58.9	1.33	23.5	2.72	-	-	-	0.26	18.3	CH	-
A1-406	2	5.0-6.0	13	13	74	90.5	30.0	60.5	1.40	19.5	2.73	-	-	-	-	-	CH	-

* U.S. STANDARD SIEVE SIZE
** All test pits completed in 1965.

Table D-10

SUMMARY OF TEST RESULTS
BORROW AREA A

Test** Pit No.	Sample No.	Depth (M)	Grain Size* +#4 %	Grain Size* -#4+#200 %	Grain Size* -#200 %	Atterberg Limits L.L. %	Atterberg Limits P.L. %	Atterberg Limits P.I. %	Insitu Dry Density tons/m³	Natural Water Content %	Specific Gravity	Standard Maximum Dry Density tons/m³	Compaction Optimum Water Content %	Field Permeability K20 cm/sec	Triaxial Shear C' kg/cm²	Triaxial Shear Ø' deg	Soil Classification USCS	Soil Classification Dispersion
200	1	0.3-1.8	6	10	84	67.4	20.4	47.0	1.31	20.6	2.66	-	-	-	-	-	CH	-
200	2	1.3-3.7	1	10	89	69.8	19.6	50.2	1.43	21.5	2.74	-	-	-	-	-	CH	-
200	3	3.7-6.0	31	26	43	34.9	17.8	17.1	1.39	13.4	2.74	-	-	-	-	-	CL	-
201	1	0.3-2.5	1	4	95	63.0	21.0	42.0	1.24	23.0	2.71	-	-	-	-	-	CH	-
201	2	2.5-6.0	47	18	29	-	-	-	1.44	11.1	2.71	-	-	-	-	-	-	-
201	3	2.5-6.0	47	19	28	-	-	-	1.52	9.1	2.75	-	-	-	-	-	-	-
202	1	0.2-3.8	1	34	65	39.2	23.2	16.0	1.36	23.6	2.69	-	-	-	-	-	CL	-
202	2	0.2-3.8	43	20	37	44.3	15.0	29.3	1.44	22.5	2.76	-	-	-	-	-	CL	-
202	3	3.8-6.0	4	58	38	-	-	-	1.28	15.5	2.74	-	-	-	-	-	SC	-
203	1	0.3-3.0	0	16	84	78.0	18.0	60.0	1.39	22.8	2.69	-	-	-	-	-	CH	-
203	2	3.0-5.0	5	19	76	83.8	20.0	63.2	1.41	22.8	2.72	1.36	29.2	-	0.30	19.3	CH	-
203	3	5.0-6.0	1	22	77	44.8	22.5	25.8	1.34	8.7	2.75	-	-	-	-	-	CL	-
204	1	0.3-3.6	2	6	92	79.0	20.1	58.9	1.47	22.4	2.70	1.39	30.5	-	0.32	19.0	CH	-
204	2	3.6-4.0	1	7	92	67.2	21.7	45.5	1.40	23.4	2.72	-	-	-	-	-	CH	-
204	3	4.0-5.5	-	-	-	-	-	-	1.49	10.1	-	-	-	-	-	-	-	-
205	1	0.3-2.7	0	8	92	76.1	17.5	58.6	1.46	22.3	2.73	-	-	-	-	-	CH	-
205	2	2.7-4.5	0	13	87	50.2	22.0	28.3	1.37	23.0	2.71	-	-	-	-	-	CH	-
205	3	4.5-6.0	12	88	0	-	-	-	1.68	9.0	2.74	-	-	-	-	-	SP	-
206	1	0.3-0.7	4	10	86	65.6	20.5	45.1	1.44	20.6	2.64	-	-	-	-	-	CH	-
206	2	0.7-1.0	-	-	-	-	-	-	1.45	8.4	-	-	-	-	-	-	-	-
207	1	0.2-1.3	0	6	94	67.2	18.0	49.2	1.47	18.0	2.65	-	-	-	-	-	CH	-
208	1	0.2-1.5	1	13	86	63.0	17.5	45.5	1.43	20.2	2.72	-	-	-	-	-	CH	-
208	2	1.5-1.8	1	55	44	-	-	-	1.42	21.2	2.73	-	-	-	-	-	SC	-
209	1	0.3-2.2	0	9	91	71.6	19.0	52.6	1.52	16.6	2.69	-	-	-	-	-	CH	-
209	2	0.3-2.2	0	8	92	68.9	16.9	52.0	1.46	21.2	2.74	-	-	-	-	-	CH	-
209	3	2.2-6.0	0	4	96	69.0	18.9	50.9	1.53	21.4	2.73	1.38	30.5	-	0.07	21.3	CH	-
209	4	2.2-6.0	0	10	90	61.9	22.5	39.4	1.43	19.1	2.72	-	-	-	-	-	CH	-
210	1	0.3-6.0	1	12	87	69.9	17.2	52.7	1.48	16.3	2.73	-	-	-	-	-	CH	-
210	2	0.3-6.0	0	9	91	71.3	21.0	50.3	1.24	24.9	2.70	-	-	-	-	-	CH	-

Table D-10(Continued)

SUMMARY OF TEST RESULTS
BORROW AREA A

Test** Pit No.	Sample No.	Depth (M)	Grain Size* +#4 %	-#4+#200 %	-#200 %	Atterberg Limits L.L. %	P.L. %	P.I. %	Insitu Dry Density tons/m³	Natural Water Content %	Specific Gravity	Standard Maximum Dry Density tons/m³	Compaction Optimum Water Content %	Field Permeability K20 cm/sec	Triaxial Shear C' kg/cm²	Ø' deg	Soil Classification USCS	Dispersion
HA-1	1	1.0-2.5	9	3	88	65.1	44.7	20.5	-	25.5	2.75	1.35	31.0	-	-	-	MH	Nondispersive
HA-1	2	2.5-7.5	4	10	86	73.1	42.6	30.5	-	26.0	2.60	1.33	36.4	-	-	-	MH	-
HA-1	3	7.5-12.0	3	5	92	67.8	39.9	27.9	-	24.4	2.78	1.37	32.6	-	-	-	CH	-
HA-2	1	0.3-2.5	2	5	93	72.4	38.5	33.9	-	29.6	2.66	1.33	33.5	-	-	-	CH	-
HA-2	2	2.5-5.0	5	8	87	48.4	32.0	16.3	-	22.9	2.57	1.40	32.3	-	-	-	ML	-
HA-2	3	9.2-10.5	30	67	3	-	-	-	-	4.8	-	-	-	-	-	-	GP	-
HA-3	1	0.3-2.0	4	8	88	72.5	40.5	31.0	-	34.5	2.47	1.32	35.6	-	-	-	CH	-
HA-3	2	2.0-5.0	2	4	94	76.5	37.2	39.3	-	27.7	2.61	-	-	-	-	-	CH	-
HA-3	3	5.0-6.2	42	5	53	72.0	38.7	33.3	-	30.5	2.51	1.29	38.0	-	-	-	CH	-

* U.S. STANDARD SIEVE SIZE
** H Series test pits completed in 1976. All other test pits completed in 1965.

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of sand in the alluvium indicate that it would not be feasible to utilize the fine fraction of the alluvium for filter.

The gravel sized fraction, (3" - #4), of the alluvium could be processed to produce a coarse filter, however, the waste would exceed 60 percent of the material excavated, unless the oversize were crushed and blended with the gravel sizes. Much of the oversize consists of vesicular basalt boulders and limestone cobbles. Crushing of this type of alluvial material could produce materials with undesirable compaction and drainage properties and would require extensive evaluation and testing.

Chalky Limestone Unit. It might be possible to produce satisfactory filter material from certain beds of the chalky limestone. Because of the relatively soft and porous nature of the limestone, the waste in processing would be high. Additionally, this material would tend to degrade during handling, placement and compaction.

Basalt. The basalt appears to be the most attractive source of concrete aggregates and high-quality rockfill within an economical haul distance of the dam. Satisfactory filter materials can be produced from the basalt in conjunction with the production of concrete aggregates.

Concrete Aggregates

Concrete aggregate sources which have been investigated are:

River alluvium.
Chalky limestone and marly limestone.
Basalt.

River Alluvium. The river alluvium was investigated extensively by Energoprojekt. This material is generally unsatisfactory for use as concrete aggregate because of its

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high silt and clay content, and high percentage of chert and organic matter.

Chalky Limestone and Marly Limestone. These materials, in the vicinity of the damsite, would produce an inferior quality concrete aggregate. The rock is of moderate to low hardness and porous with high absorption, low durability, low specific gravity and contains chert and organic matter. Even with careful selection, there would be considerable waste in the production of aggregates, quality control would be difficult because of the high absorption and fines produced during handling.

Basalt. The basalt from the right side of the river appears to be the most favorable source of concrete aggregates. Hand samples of this material were obtained from outcrops and the following tests were performed:

Petrographic Examination.
Specific Gravity.
Absorption.
Potential Reactivity (Chemical Method).
Los Angeles Abrasion.
Soundness of Aggregates by Sodium Sulfate.

The petrographic examinations indicate that the basalt will not be reactive in the concrete and will produce satisfactory aggregate. The results of the petrographic examinations are in Annex D-1, Field Logs and Laboratory Tests.

The laboratory tests are summarized on Table D-5 and indicate that the basalt is innocuous to cement, hard and will produce durable concrete.

Materials Available from Required Excavation

General

The embankment section, (see Exhibit D-3), was designed to utilize suitable materials from required excavation. Some of the required excavation materials will not be suitable for the interior zones of a dam of this height and will be wasted or placed as a weighting berm. Additional detail on the testing and properties of those materials suitable for placement in the dam has been given previously.

Tunnels and Portals

The required portal excavation will consist primarily of clayey talus and river alluvium, both of which are suitable for use in the dam section. The quantities, however, are very small and construction scheduling will require double handling of these materials. This excavation can be used in construction of the cofferdams or Contractors' haul roads.

The tunnels will be in the Bituminous Marl Unit. The quantities are small and the material is expected to break into small fragments during excavation and handling. It will be wasted or utilized by the Contractor for temporary construction.

Dam Foundation

The dam foundation excavation will include removal of the following estimated quantities.

Embankment Crest

Material Type	El.158 Raisable	El.168 Raisable	El.200 Raised from El.158
Talus	1,677,000 m^3	1,799,000 m^3	263,000 m^3
Alluvium	697,000 m^3	730,000 m^3	98,000 m^3
Marly Limestone	625,000 m^3	625,000 m^3	-0- m^3
Chalky Limestone	155,000 m^3	162,000 m^3	20,000 m^3

The talus consists primarily of weathered angular limestone gravel and cobbles with the voids loosely filled with dry marly clay. This material was explored by shafts S-1, 2, 3 and 5 and the portal excavation for Adits 2, 3 and 4. Laboratory tests performed on samples of the talus material are given in Annex D-1 and are summarized on Table D-11. The laboratory test results indicate that the clayey talus will have good shear strength and compressibility characteristics and will be relatively impervious. This material will be utilized in Zone 2 of the embankment and will form the downstream supporting zone of the impervious portion of the dam. Construction scheduling will probably require double handling of this material, however, it is quite dry of the optimum moisture content and the double handling operation provides a convenient process for moisture conditioning.

The river alluvium is similar to that found in Borrow Areas U and D. Most of this material will be suitable for placement in embankment Zones 4 and 5.

The decomposed and highly weathered marly limestone will be removed from beneath the entire enbankment section except under the river alluvium in the upstream cofferdam and weighting berm. This material is not suitable for embankment fill, however, it is suitable for placement in the upstream weighting berm.

Additional excavation will be required in the core trench. This material is not suitable for embankment fill, however, it is suitable for placement in the upstream weighting berm or may be used by the Contractor for temporary construction.

The chalky limestone excavation in the dam foundation will consist of the removal of highly broken rock from beneath the impervious zones. This material will be suitable for placement in Zone 4 of the embankment.

Table D-11

SUMMARY OF TEST RESULTS
FOUNDATION AREA

Hole* No.	Sample No.	Depth (M)	Grain Size +#4 %	Grain Size -#4+#200 %	Grain Size -#200 %	Atterberg Limits L.L. %	Atterberg Limits P.L. %	Atterberg Limits P.I. %	Insitu Dry Density tons/m³	Natural Water Content %	Specific Gravity	Standard Compaction Dry Unit Weight tons/m³	Standard Compaction Optimum Moisture Content %	Insitu Permeability K20 cm/sec	Triaxial Shear C' kg/cm²	Triaxial Shear Ø' deg.	Soil Classification USCS	REMARKS
FD1	1	0.3-1.0	6	23	71	34.9	20.0	14.9	-	-	2.74	-	-	-	-	-	CL	Right Abutment Talus
	2	1.0-4.0	82	11	7	32.1	19.5	12.6	-	-	2.80	-	-	-	-	-	CL	" " "
	3	4.0-6.0	68	10	22	31.4	19.1	12.3	-	-	2.80	-	-	-	-	-	CL	" " "
FD2	1	0.3-3.5	61	19	20	-	-	-	1.37	8.3	2.71	-	-	-	-	-	-	" " "
FD3	1	0.3-6.0	77	8	15	31.5	19.0	12.5	-	-	2.75	1.67	19.4	-	-	-	CL	" " "
	2	0.3-6.0	65	16	19	30.4	15.6	14.8	-	-	2.76	-	-	-	-	-	CL	" " "
FD4	1	0.4-1.0	2	21	77	43.8	31.7	12.1	-	-	2.65	-	-	-	-	-	ML	Bottom of Right Abutment Talus
	2	1.0-3.0	84	9	7	-	-	-	1.48	9.9	2.72	-	-	7.3×10^{-4}	-	-	-	
	3	5.3-5.8	0	13	87	33.7	16.2	17.5	-	-	2.70	-	-	-	-	-	CL	" " "
FD5	1	0.3-4.2	72	13	15	-	-	-	1.59	9.5	2.74	-	-	3.3×10^{-4}	-	-	-	" " "
	2	0.3-4.2	51	20	29	30.1	16.8	13.3	-	-	2.74	-	-	-	-	-	-	" " "
FD6	1	0.7-1.2	63	12	25	43.2	26.0	17.2	-	-	2.66	-	-	-	-	-	CL	" " "
	2	1.2-2.5	2	20	78	34.3	17.3	17.0	1.49	18.7	2.73	-	-	9.0×10^{-5}	0.1	35.0	CL	" " "
	3	2.5-3.0	61	17	22	31.2	16.8	14.4	-	-	2.74	-	-	-	-	-	CL	" " "
FD7	1	0.2-3.5	69	6	25	-	-	-	-	-	2.70	-	-	-	-	-	-	" " "
	2	3.5-5.5	83	4	13	-	-	-	1.36	11.1	2.78	-	-	-	-	-	-	" " "
FD8	1	0.0-1.0	58	14	28	35.2	20.1	15.1	-	-	2.72	-	-	-	-	-	CL	" " "
	2	1.0-3.5	0	14	86	36.3	18.6	17.7	1.46	19.0	2.75	-	-	-	-	-	CL	" " "
FD9	1	0.4-2.0	70	17	19	-	-	-	1.36	8.5	2.71	-	-	1.1×10^{-2}	-	-	-	Left Abutment Talus
	2	2.0-6.0	85	8	7	-	-	-	-	-	2.70	-	-	-	-	-	-	" " "
FD10	1	0.5-6.0	0	11	89	-	-	-	-	-	2.72	-	-	-	-	-	-	" " "
	2	0.5-6.0	0	11	89	-	-	-	1.48	11.6	2.72	-	-	2.5×10^{-7}	-	-	-	" " "
Shaft 2	1**	0.3-2.0	56	17	27	36.9	19.7	16.2	-	5.9	2.71	-	-	-	-	-	GC	Right Abutment Talus
	2	2.0-4.0	-	-	-	58.0	34.8	23.2	-	-	2.86	-	-	-	-	-	GC	" " "
	3	10.0-10.3	73	13	14	-	-	-	-	-	-	-	-	-	-	-	GC	" " "
Shaft 5	1	2.0-3.0	73	11	16	36.9	26.3	10.6	1.93	2.4	2.81	1.74	15.4	-	-	-	GC	" " "
Adit 2	1	portal	48	18	34	34.6	20.3	14.3	1.73	6.3	2.67	1.68	18.4	-	-	-	GC	" " "

* FD series test pits completed in 1965. All others completed in 1976.
** Clay dispersion tests indicate this material is nondispersive.

Spillway

The spillway excavation will require removal of the following estimated quantities.

Material Type	Embankment Crest El. 158 Raisable	Embankment Crest El. 168 Raisable	Embankment Crest El. 200 Raised from El. 158
Talus and Clay	1,020,100 m^3	812,000 m^3	607,000 m^3
Basalt	757,000 m^3	804,000 m^3	686,000 m^3
Marly Limestone	812,000 m^3	581,000 m^3	586,000 m^3
Chalky Limestone	1,351,000 m^3	1,487,000 m^3	545,000 m^3

The clayey materials will consist of fat brown clay similar to those found in Borrow Area A. This material can be placed in the impervious portions of the cofferdams or in Zone 1 of the main embankment.

The talus materials are similar to those which will be excavated in the dam foundation area and are suitable for the impervious Zone 2 of the embankment.

The baslat, as indicated in drill hole HQ-2 and HQ-3 varies from sound, unweathered material to broken, weathered, vesicular basalt with clay seams and layers. Recent investigations indicate that a zone of sound unweathered basalt suitable for production of good quality rockfill or riprap may be found in this required excavation. Most of the required basalt excavation will be placed in random rockfill portion, (Zone 4), of the embankment. The better quality material will be suitable for Zone 6.

The chalky limestone excavated from the spillway will, in general, be of better quality than the limestone to be excavated from the dam foundation. It is expected that it will be suitable for placement in Zone 4, (random rockfill), of the embankment. Additional testing and evaluation of this material is required during the design phase of the studies.

The marly limestone from the spillway will be suitable for placement in the upstream weighting berm (Zone 7).

Development of Design Parameters

Foundation Materials

General. The naturally occurring materials at the dam site which must be evaluated as foundation materials include the following:

- River alluvium
- Cemented alluvium
- Marly Limestone, varying from decomposed to fresh
- Chalky limestone

The design parameters for these materials summarized on Table D-12 and the development of these parameters is discussed in the following sections.

River Alluvium. The river alluvium will be removed under the core, downstream shell and a portion of the upstream shell of the embankment to expose the foundation rock and allow treatment of geological defects in the foundation and to remove the decomposed and weathered marly limestone under the shells and core of the dam. The river alluvium will be left in place under the upstream cofferdam.

The alluvium is very heterogeneous and contains lenses and layers of silty and sandy clay. The average shear

Table D-12

PRELIMINARY DESIGN PARAMETERS

Zone	Material	Unit Weight Dry	Unit Weight Moist	Unit Weight Saturated	Effective Shear Strength		Construction Pore Pressure Ratio	Assumed Permeability k
		γd T/m^3	γm T/m^3	γs T/m^3	C' kg/cm^2	Q' Degrees	R_u	cm/sec
1	Impervious	1.41	1.83	1.89	0 2.0	23.5[1] 10.0[2]	0.5 - 0.8	10^{-7}
2	Impervious	1.55	1.92	1.98	0	34.0	0.5	10^{-6}
3	Filter	-	-	-	-	-	0	10^{-3}
4	Random Rockfill	1.9	2.0	2.2	0	36.0	0	10^{-4}
5	Select Alluvium	1.98	2.06	2.26	0	38.0	0	10^{-3}
6	Basalt Rockfill	2.06	2.10	2.34	0	43.0[1] 40.0[2]	0	Free-draining
7	Random Fill	-	1.85	2.02	0	30.0	0	10^{-4}

1) Effective Normal Stress < 7 kg/cm^2

2) Effective Normal Stress <F 7 kg/cm^2

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strength of this material will be a combination of the shear strength of the silty and sandy clay and the gravel, cobble, boulder mixture. An effective internal friction angle of 34 degrees with no cohesion was assumed for the stability analyses. The unit weights for the stability analyses were obtained from data in the Energoprojekt report, (reproduced as Table D-13).

Cemented Alluvium. For preliminary design purposes the cemented alluvium was assumed to have the same characteristics as the river alluvium.

Bituminous Marly Unit. The decomposed and highly weathered marly limestone will be excavated from the foundation of the embankment.

The hard weathered marly limestone was sampled in Adit 2 and tested in the NRA laboratory in Jordan and in Chicago. Testing included density and moisture determination, direct shear and triaxial shear. These test results are included in Annex D-1 and are summarized on Exhibit D-4. The shear strength for the triaxial tests is shown for the peak deviator stress and is represented by $\emptyset'=28°$, $C'=6.0$ kg/cm^2 in the range of normal stresses for embankment loading.

The direct shear tests were performed on specimens which were cut with a saw to produce a residual shear plane. These tests indicate residual shear strength varying from 32.0 to 36.5 degrees.

Tests performed by Energoprojekt on a remolded slurry of altered marly limestone from the Mukheibeh Dam Site showed the following results:

Triaxial test	$\emptyset'=28.7°$	$C'=0$
Direct shear	$\emptyset=27.0°$	$C=0.2$ kg/cm^2
Direct shear (residual)	$\emptyset=22.3°$	$C=0.3$ kg/cm^2

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Table D-13

SPECIFIC GRAVITY AND UNIT WEIGHT OF ALLUVIAL GRAVELS*

Test Pit No.	Unit Weight		Specific Gravity				Porosity	
			coarse aggreg.		fine aggreg.			
	Comp. tons/m^3	Loose tons/m^3	bulk	apparent	bulk	apparent	Comp. %	Loose %
MP-1	1.980	1.760	2.69	2.75	2.64	2.79	25.60	34.00
MP-2	1.975	1.770	2.65	2.74	2.70	3.01	26.10	33.80
MP-3	1.987	1.80	2.50	2.60	2.70	2.76	23.90	30.70
MP-4	1.950	1.765	2.53	2.64	2.65	2.85	24.00	32.00
MP-5/1	1.933	1.687	2.53	2.67	2.63	2.78	25.00	34.50
MP-5/2	1.646	1.451	2.58	2.66	-	2.62	31.30	33.70
MP-6	1.510	1.299	2.56	2.78	-	2.67	-	-
MP-7	1.259	1.103	-	-	-	2.65	-	-
MP-8/1	1.858	1.679	2.63	2.72	2.67	2.87	29.80	-
MP-8/2	1.660	1.400	-	-	2.65	2.81	37.30	44.10
MP-9	1.732	1.472	2.76	2.89	2.43	2.71	33.30	43.20
MP-10	1.758	1.526	2.74	2.84	2.57	2.83	33.80	42.60

* Data obtained from "Final Report on Mineralogical - Petrographic Analysis" by Energoprojekt, 1966.

37

The fresh marly limestone was sampled in Shaft 3 and drill hole HS-1 for laboratory shear testing. Direct shear tests on specimens cut with a hand saw to produce a residual shear plane were performed at the NRA laboratory in Amman. These tests, summarized on Exhibit D-4, indicate a residual angle of friction of 35.5 degrees. Triaxial shear tests on core samples were performed in Chicago. These tests indicate an angle of friction of approximately 39° with cohesion of 36 kg/cm^2. Unconfined compressive strength tests on samples of fresh marly limestone from hole HV-1 show unconfined compressive strengths varying from approximately 45 kg/cm^2 to 321 kg/cm^2.

The drill holes, adits and shafts have all indicated that the marly limestone is massive without distinct bedding planes. Slickensided joints have been found in some of the drill cores, however, they are vertical or steeply dipping and should have no adverse affect on embankment stability. Therefore, there does not appear to be any valid reason to use the residual shear strengths to evaluate the stability of the embankment. However, the residual strengths represent the lower bound of the foundation shear strength and as such assist in the selection of the design parameters. The shear strengths used in the stability analysis are as follows:

Weathered marly limestone	$\phi' = 28.0°$	$C' = 0$
Unweathered marly limestone	$\phi' = 34.0°$	$C' = 5.0$ kg/cm^2

<u>Chalky Limestone</u>. The chalky limestone has much greater strength than any of the embankment materials and is located in the upper portions of the abutments where the loading is smaller. This geologic unit was not used in the stability analysis.

Embankment Materials

Impervious Clay-Zone 1. This zone will be constructed from the medium to highly plastic clays in Borrow Areas B, B1, R1 and R2. These materials are of relatively low shear strength as shown on Exhibit D-5. Consolidated-undrained triaxial shear tests were performed on this material and confirm the shear strength values reported by Energoprojekt up to effective normal stress values of approximately 7.0 kg/cm^2, which was the testing limit at that time. Above 7.0 kg/cm^2 the effective strength appears to be less than that developed from a straight line projection of the strengths at lower stress. The shear strength used for the stability analyses was $\emptyset'=23.5°$, $C'=0$ up to 7.0 kg/cm^2 effective normal stress and $\emptyset'=10°$, $C'=2.0$ kg/cm^2 above an effective normal stress of 7.0 kg/cm^2.

Unit weight and other properties of this material were computed directly from laboratory test results. For the end of construction stability case, the pore pressure in Zone 1 was varied from 60 to 80 percent of the total vertical stress.

Impervious Talus-Zone 2. The material for this zone will consist of the clayey gravel talus from the required excavation and Borrow Areas R1, R2 and B1. These materials have good shear strength and are relatively impervious. One triaxial shear test was performed on this material and confirmed the data previously reported (see Exhibit D-5). The shear strength used for the stability analyses was $\emptyset'=34°$ with no cohesion.

Unit weight and other properties of the material were computed from the laboratory test results. It was assumed that the pore pressures in Zone 2 for the stability analysis for the end of construction case would be 50 percent of the total vertical stress.

39

Filters-Zones 3F and 3C. The shear strengths and unit weights of these materials are similar to those of the rockfill. These narrow zones were not considered separately in the stability analysis.

Random Rockfill and Alluvium-Zone 4. This material will consist of dirty rockfill from required spillway and dam excavation or from borrow. River Alluvium from borrow and dam excavation might also be used, if suitable. This zone may contain hard weathered rock, however, the fines content will be limited so that the zone will be well-compacted and dense. Triaxial tests were not performed on this material and a shear strength of $\phi'=36°$ with no cohesion was used for the stability analysis. The compacted unit weight was assumed to be 2.0 tons/m^3 with a porosity of 30 percent.

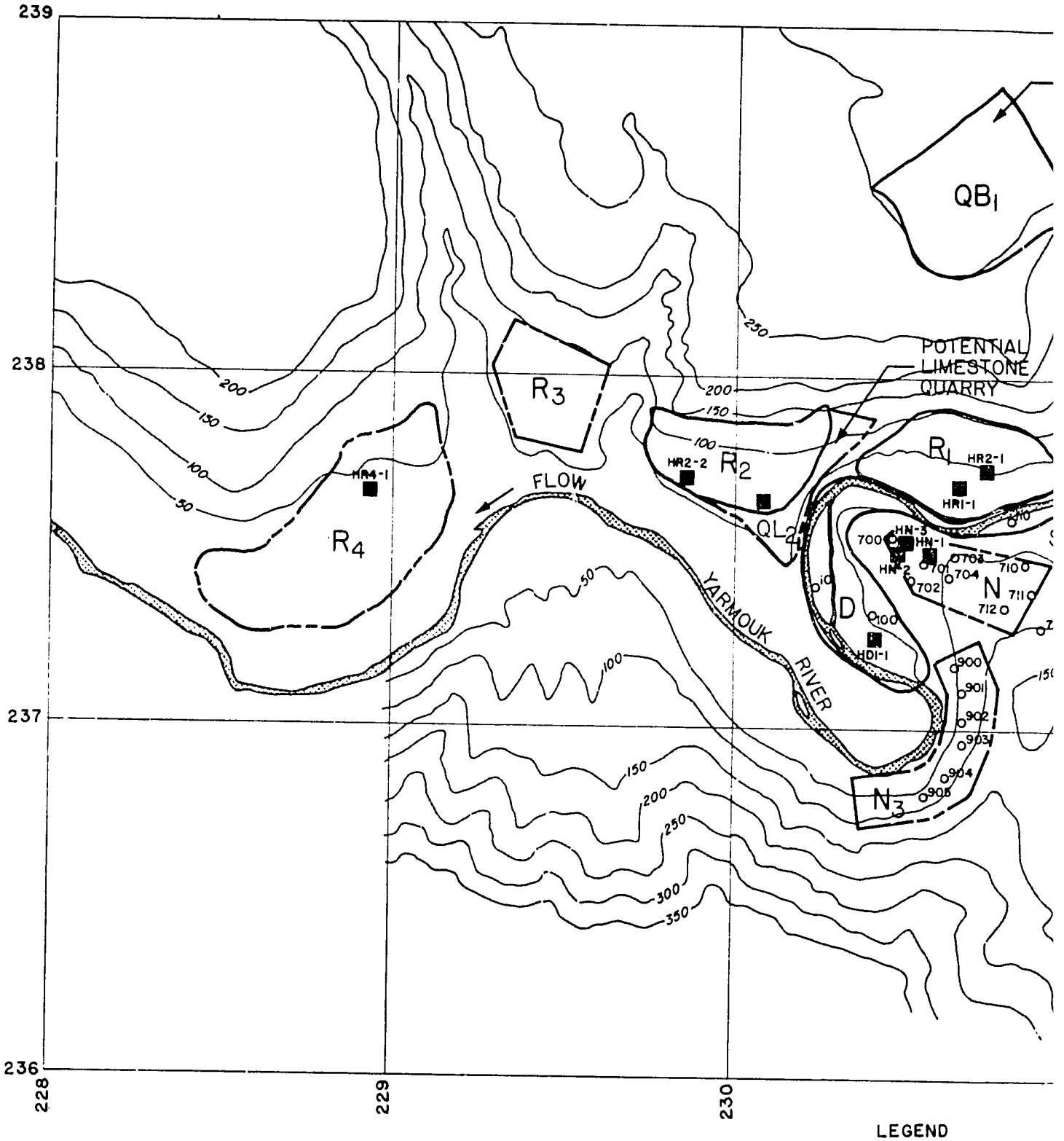
Alluvium-Zone 5. This zone will be composed of river sand, gravel, and cobbles. The material will be washed, if necessary, to remove fines. It will resemble rockfill and be pervious to free draining. A shear strength of $\phi'=38°$ with no cohesion was assumed for the preliminary design. The compacted unit weight was assumed to be 2.06 tons/m^3 with a porosity of 28 percent.

Basalt Rockfill-Zone 6. The basalt rockfill will consist of fresh to slightly weathered rock placed in 1 meter lifts and compacted with vibratory rollers. This zone will have low compressibility and be free-draining. The basalt fragments will be hard, durable and angular. It was assumed that the shear strength of this material would be $\phi'=43°$ with no cohesion for effective normal stresses of 7.0 kg/cm^2 and less, and $\phi'=40°$ with zero cohesion for effective normal stresses greater than 7.0 kg/cm^2. The compacted unit

weight was assumed to be 2.1 percent.

Upstream Weighting Berm consist of required excavati placement in the interior zo be placed in 50 cm, lifts an placing equipment. A shear cohesion was assumed for the pacted unit weight was assum

41



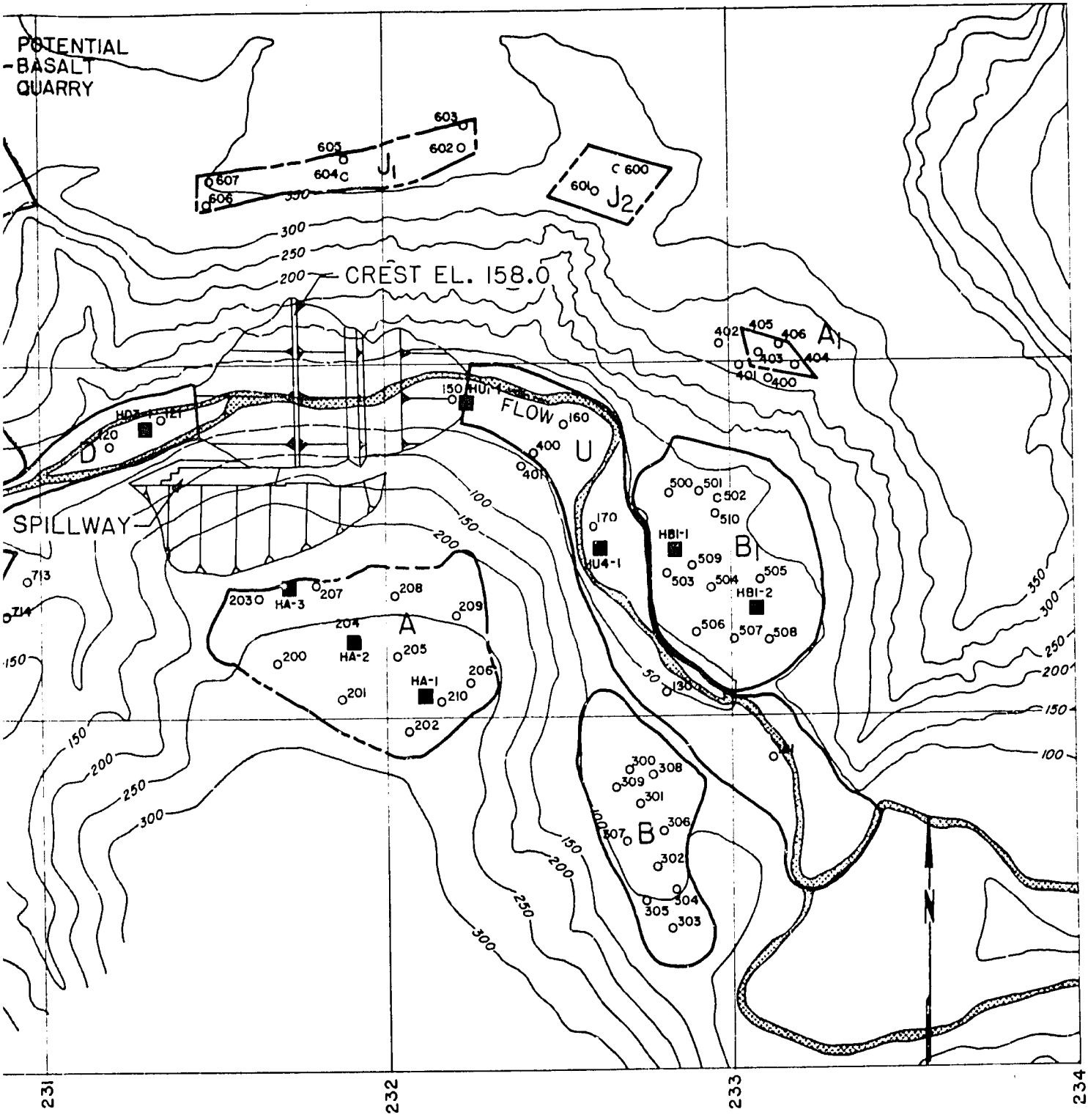
LEGEND

■ LOCATION C

○ LOCATION C

LIMIT OF PF

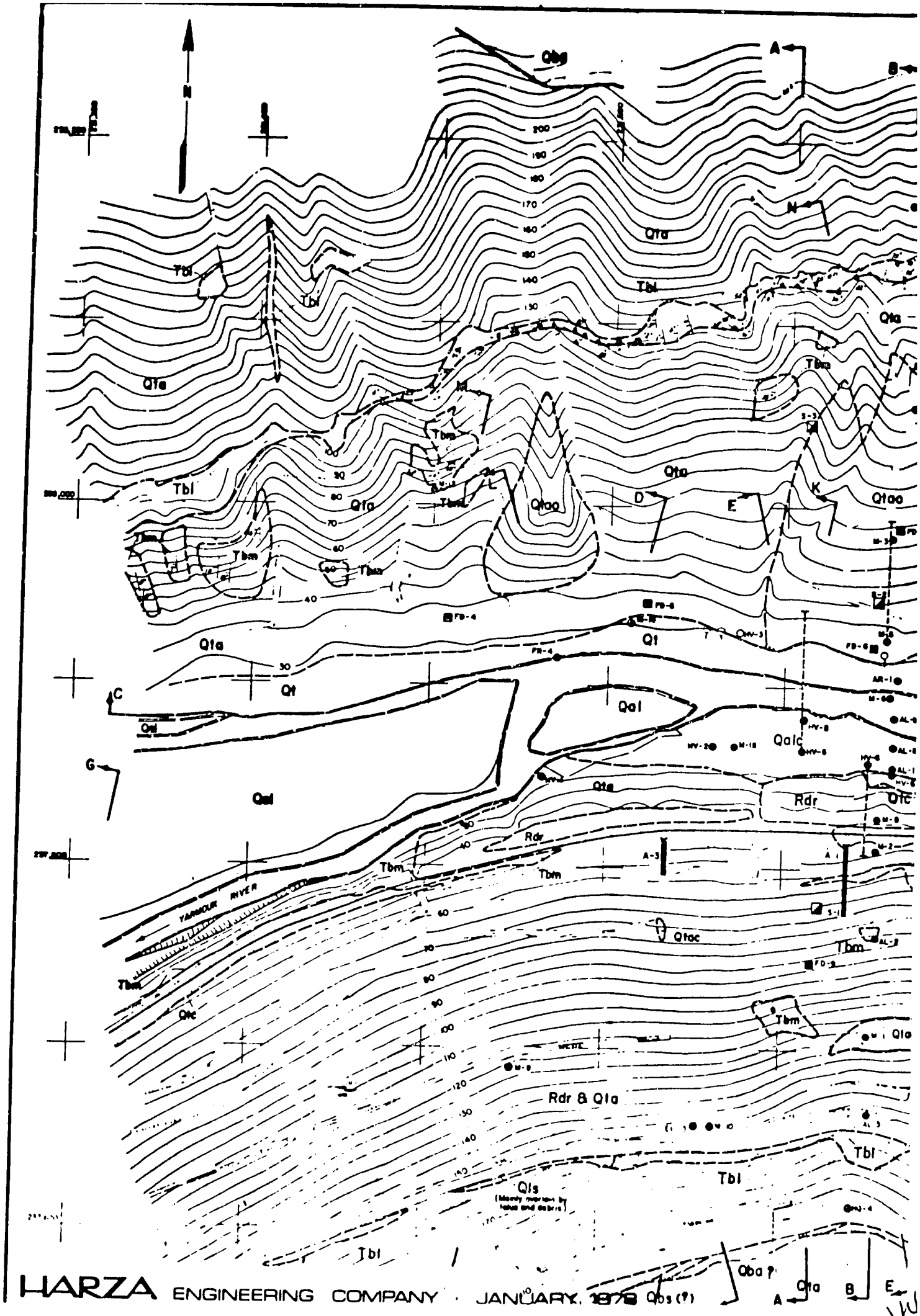
LIMIT OF PF



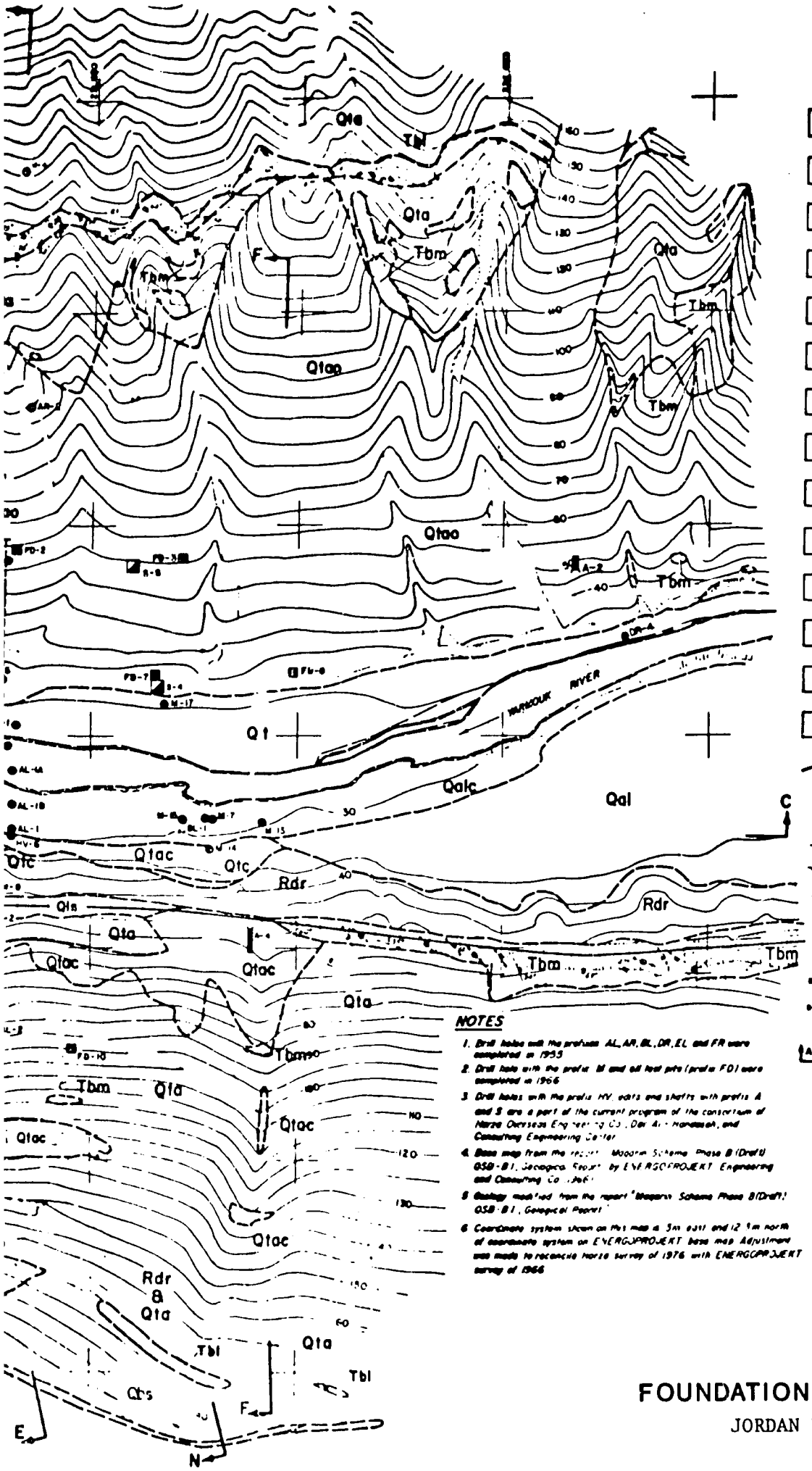
SCALE 0 1 KILOMETER

N OF TEST PIT BY HARZA
N OF TEST PIT BY ENERGOPROJEKT
: PROPOSED PRIMARY BORROW AREA
: PROPOSED SECONDARY BORROW AREA

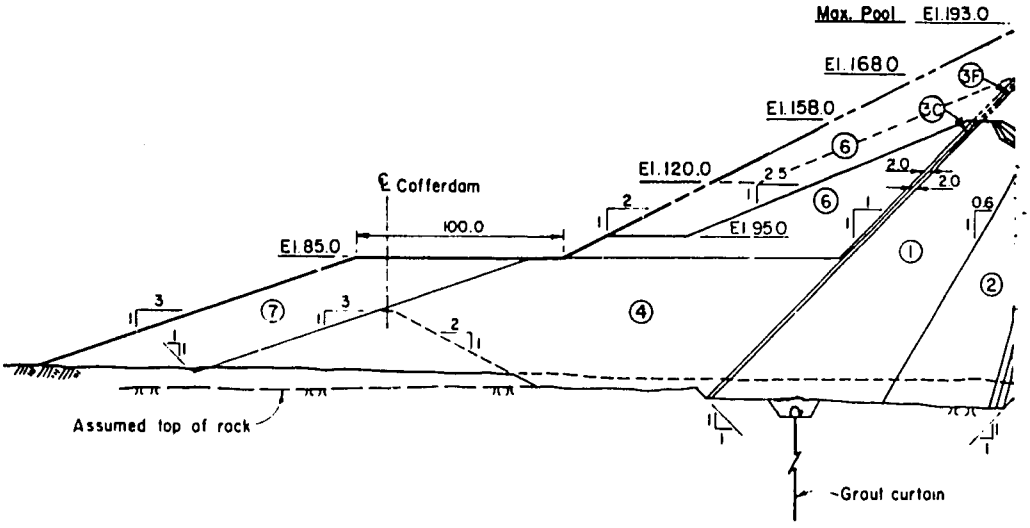
MAQARIN DAM
CONSTRUCTION MATERIALS EXPLORATION
JORDAN VALLEY IRRIGATION PROJECT
STAGE II



HARZA ENGINEERING COMPANY · JANUARY, 1978

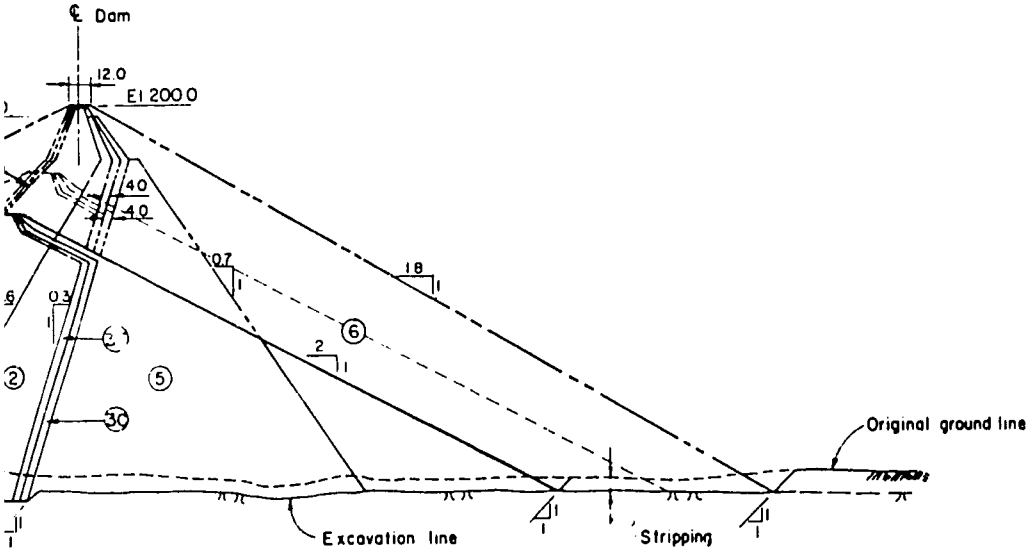


MAQARIN DAM
FOUNDATION AREA EXPLORATION
JORDAN VALLEY IRRIGATION PROJECT
STAGE II



Sta. 0

1	Impervious clay	4	Rockfill from required excavation
2	Impervious talus	5	Alluvium
3F	Fine filter	6	Basalt Rockfill
3C	Coarse filter	7	Random fill



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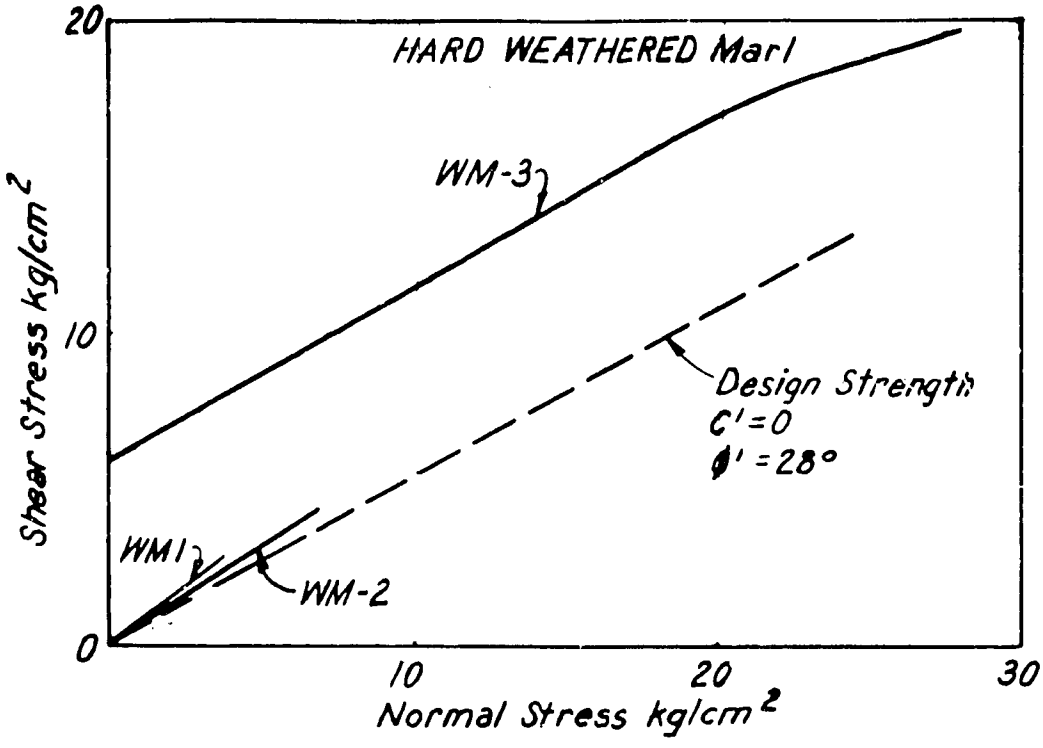
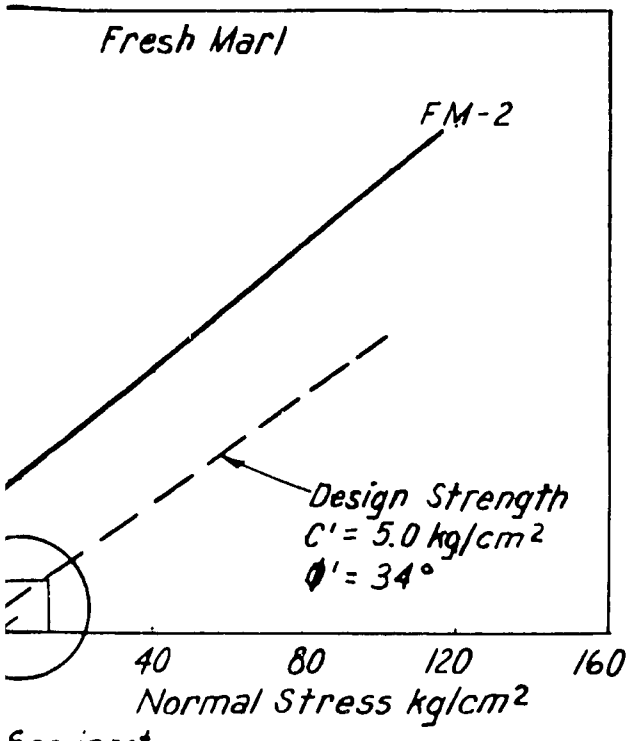
Scale 0 50 100 Meters

MAQARIN DAM
MAXIMUM EMBANKMENT SECTION
JORDAN VALLEY IRRIGATION PROJECT
STAGE II

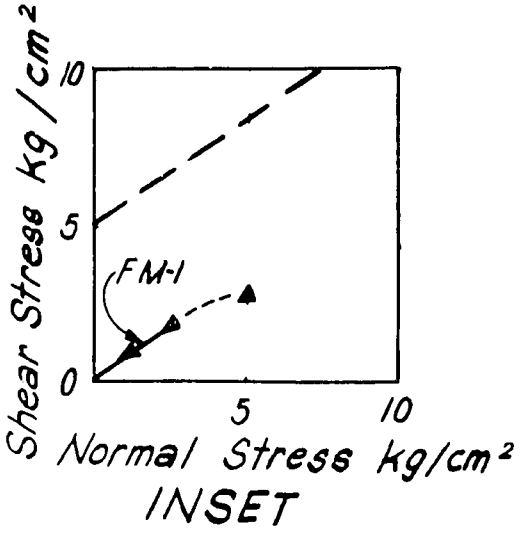


Sample No.	Type of Test	Dry Unit Wt. T/m³
WM-1	Direct Shear Residual	—
WM-2	Direct Shear Residual	1.59
WM 3 See Note 1	Triaxial Peak Strength	1.56
FM-1	Direct Shear Residual	—
FM-2	Triaxial Peak Strength	1.60

Note 1 - C = 6.0 φ = 28.0 for σ_n < 15.0 kg/cm²

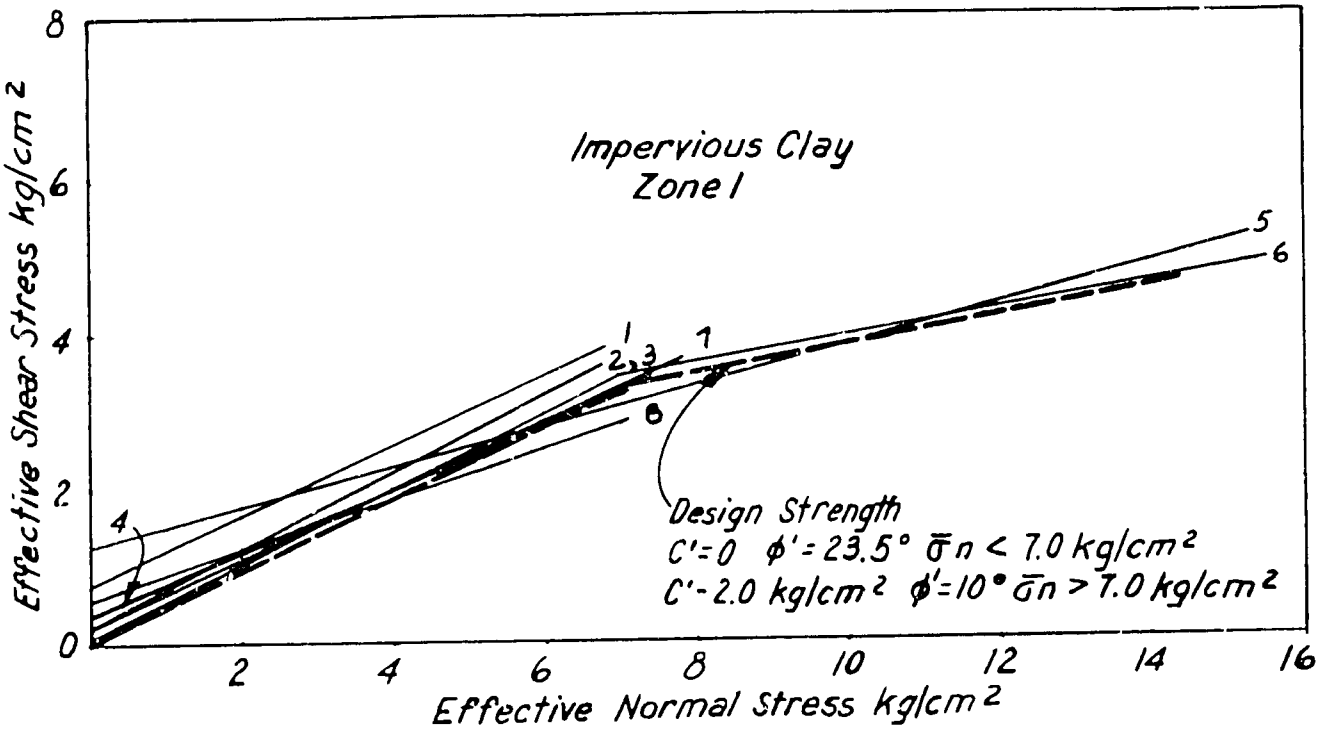


See inset



isture ntent %	C kg/cm²	Ø°
—	0	36.5
3.5	0	32.0
9.5	6.0	28.0
--	0	35.5
0.3	36.3	39.0

MAQARIN DAM DESIGN
PARAMETERS FOUNDATION MARLS
JORDAN VALLEY IRRIGATION PROJECT
STAGE II



Test No.	Test Pit No.	Sample Preparation	Dry Unit weight T/m³
1	BI-502	See Note 1	1.56
2	BI-504	" " "	1.44
3	BI-504	See Note 2	1.33
4	BI-507	" " "	1.22
5	HBI-1	See Note 1	1.51
6*	HBI-2	" " "	1.45
7	B-301	See Note 2	1.27
8	B-302	See Note 1	
9	FD-6	See Note 2	1.56
10	FD-8	See Note 3	1.52
11	FD-6	" " "	1.64
12	HRI-2	See Note 4	1.57

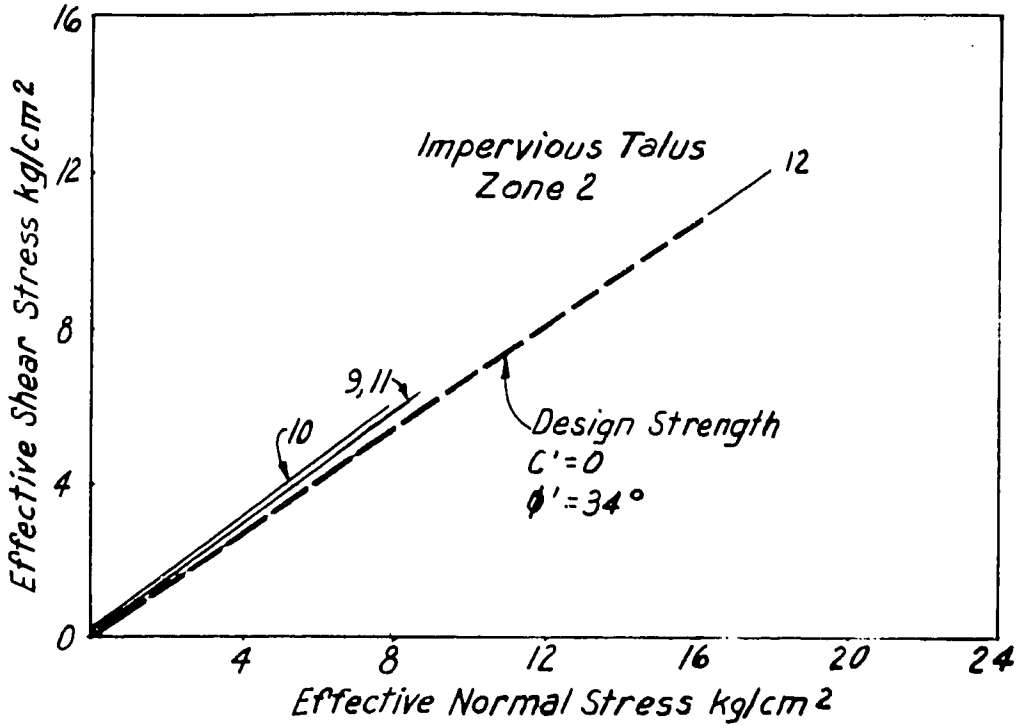
*C'=0, φ'=25.5 σ̄n < 7.0 kg/cm² C'=2.0 kg/cm² φ'=10.0

Note 1 - Compacted to standard maximum dry unit weig

Note 2 - Slurry consolidated at 1.0 kg/cm²

Note 3 - Compacted to insitu density and moisture conte

Note 4 - Compacted to maximum dry unit weight and opt
representative of the portion of material passing



3	Initial Moisture Content %	C' kg/cm2	ϕ'°
	25.0	0.07	24.0
	27.7	0.20	25.6
	47.3	0.18	26.0
	43.4	0.32	22.0
	23.5	1.20	14.0
	23.5	0.0	25.5
		2.0	10.0
	40.9	0.20	23.2
	26.9	0.50	17.8
	26.1	0.10	35.0
	27.5	0.10	36.3
	21.9	0.10	35.0
	20.4	0.0	34.0

7° $\bar{\sigma}_n$ > 7.0 kg/cm²
ght and optimum water content

ent:
otimum water content
the 3/4" standard sieve

MAQARIN DAM DESIGN PARAMETER
IMPERVIOUS EMBANKMENT MATERIALS
JORDAN VALLEY IRRIGATION PROJECT
STAGE II

Appendix E

GEOLOGY

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Appendix E

GEOLOGY

Summary and Recommendations

Project Area Geology and Seismicity

The Maqarin Dam and Reservoir and all of the proposed irrigation water conveyance routes from the dam to the East Ghor Main canal would be located in the highland area east of the Jordan Valley. This highland area is a moderately high (el. 300 m to 500 m), plateau which has been dissected by wadis, (or streams), flowing in steep-sided valleys and draining into the Jordan Valley.

Rocks of the plateau consist of very gently northerly dipping Mesozoic and Tertiary marine chalks, limestones, bituminous limestones and marls of the Belqa Series. These beds are locally overlain in the plateau area by Quaternary basalt flows and soils, and in the valleys and on valley sides by talus, alluvium and local basalt flows. Landslides have occurred on the sides of the valleys in some places.

The Jordan Valley is a rift valley separated from the highlands to the east and to the west by large regional faults. Exposed sediments in the Jordan Valley consists of Quarternary and Late Tertiary continental and lacustrine deposits.

Seismic activity appears to be associated with the rift valley faults. This seismic activity has caused destructive earthquakes which have been recorded in the Project area. Project structures, hence, are to be designed for heavy earthquakes.

Geology of the Maqarin Damsite

The Maqarin Damsite is located in a narrow, steep-sided portion of the Yarmouk River Valley, approximately 50 km upstream of its confluence with the Jordan River.

The damsite is underlain by a series of thick-bedded, gentle northwesterly (downstream) dipping beds of moderately hard bituminous marly limestone (Bituminous Marl Unit) conformably overlain by thick-bedded chalky limestones (Chalky Limestone Unit). These calcareous strata are overlain on the right side of the valley by a thick sequence of basaltic lava flows and on the left side of the valley by an isolated remnant of a flow. The Bituminous Marl Unit extends up both valley walls to about 100 m above the valley bottom and extends below the valley bottom to an unknown depth of possibly 300 meters or more. The Chalky Limestone has a stratgraphic thickness of 170 m on the right side of the valley and about 50 m on the left side.

Talus, shallow landslides, generally now stable, and a sizable slump block overlie bedrock on parts of the valley sides. In some places the talus has slumped and in other places, large (up to 3 m^3) voids are found. Alluvium overlies bedrock in the valley bottom. Parts of the talus and alluvium are cemented and parts uncemented and loose. This variation in cementation, presence of local voids and of slumping results in large variations in the physical characteristics of the talus.

The chalky limestones and marly limestones have relatively low primary permeabilities; however, jointing and effects of weathering near the surface and local open jointing and cavities at depth result in modest to locally high permeabilities. The basaltic units are highly jointed and highly pervious.

Evidence of shearing has been found in drill holes which cross below the river channel and block faulting has been observed in outcrop on the left abutment. The Chalky Limestone and Bituminous Marl units are intersected by steeply dipping joint sets which are more consistently developed in the chalky limestones than in the marly limestones. Relief joints oriented approximately parallel to the valley walls are found in the near-surface zone of the Marl Unit. Surficial weathering extends to a depth of about 10 m in the Marl Unit and within this zone there occur networks of thin gypsum seams. Only sparse data has been obtained concerning depth of significant weathering in the Chalky Limestone. For planning it has been assumed that the Chalky Limestone is weathered to 20 m depth.

Within the Bituminous Marl Unit beneath the river, exploratory drilling has encountered a number of small cavities and a large alluvium-filled hole extending about 50 m into rock beneath the bedrock channel which in an earlier report was called a "pothole". Also in the Marl Unit beneath the river there have been found some clay zones, which apparently are local and at different stratigraphic positions. One of these beneath the presently proposed dam axis is reported to be about 30 m thick. Artesian conditions of warm water are found in several drill holes in the valley bottom and also in the large "pothole".

Engineering Geologic Evaluation of the Maqarin Damsite

The features described above-namely the clay zones, cavities and artesian conditions-must be more thoroughly explored before the location of the dam embankment can be

decided upon. The extent of occurrence and the distribution of these features and also their interrelationships and geologic origins must be adequately understood before a final evaluation of the foundation rock beneath the river can be made. The objective will be to locate a dam embankment axis where potential foundation problems are absent or minimal along the reach of the Yarmouk River between the Wadi Shallala and the Wadi Sidiin.

This will require an intensive and extensive exploration program over a reach of the river several hundred meters in length. It is essential to complete this exploration for embankment location before performing any exploration for the other elements of the project, therefore, it must be started soon and pursued intensively. The exploration for axis location will require several months and it must be performed with modern equipment and run by competent personnel.

The arrangement of other features, such as the spillway and division tunnel will require little modification from their present concepts once the dam axis location is fixed.

The following general conditions for foundation preparation and treatment are directly related to the site geology and will be applicable to any location selected for the embankment. Examination of the bedrock foundation will be essential, hence it will be necessary that all alluvium be removed from the embankment area. The need to excavate all highly weathered marly limestone and gypsiferous marly limestone from the core and shell foundation areas will require stripping all talus from valley sides as well as the alluvium from the river channel. The hard slightly weathered chalky limestone and marly limestone bedrock possess adequate strength to support the embankment.

A deep grout curtain backed up by a drainage curtain, both extending well into the abutments, must be provided for control of seepage and seepage pressures, and thereby insuring the long term stability of the rock masses forming the abutments.

The spillway gate and weir structure for the initial project would be founded on the Bituminous Marl Unit, while for the raised dam these would be on the Chalky Limestone Unit. All rock will be removed from the foundation area. The gentle downstream dip of bedding will be considered in the design of this structure.

The spillway bucket and most of the chute for both initial and future spillways would be founded on the Bituminous Marl Unit. Design and construction of these structures, as for other elements of the spillway, will insure that the foundation consists of sound unweathered rock. Rock anchorage may be required to insure the stability of the rock foundation beneath both the chute and bucket.

The diversion tunnel would be driven through the Bituminous Marl Unit. This rock is considered to have characteristics favorable for tunnelling and can be supported where necessary by a conventional support system. Tunnel portals should be designed so that a thickness of two diameters of bedrock are above the tunnel crown at the portal.

Evaluation of Maqarin Reservoir Geology

The Maqarin Reservoir would be mainly in valleys eroded into gently dipping beds of the Chalky Limestone Unit, capped in places by basalt flows. The contact between the basalt and the limestone, except in the left abutment of the damsite has generally been found to he higher than elevation

195 m which is the highest of the planned reservoir levels. However, the overlying basalt flows are expected to be permeable and in places the contact zone may be permeable. If places where the contact is lower than the reservoir level are found during the on-going investigation, remedial measures to prevent reservoir leakage may be required. Springs are known to occur at the contact between the basalt and the limestone indicating that the limestone-basalt contact zone is relatively impermeable as compared to the overlying basalts.

Relatively steep-sided valleys have been eroded into the nearly flat lying beds which form the reservoir. The steep-sided aspect of the valleys may be conducive to the formation of small slides however the nearly flat-lying beds are not conducive to massive landslides which could damage the project.

Evaluation of the Maqarin Powerplant Scheme

The proposed Maqarin Powerplant would be constructed on the Bituminous Marl Unit. These beds, generally have adequate strength to support this structure.

The power tunnels would be constructed in the Bituminous Marl Unit. Tunnelling by conventional means should be possible and conventional support systems should suffice.

The gate shaft would be placed partly in the Bituminous Marl Unit and partly in the Chalky Limestone Unit. No unusual difficulties should be anticipated in the construction of this feature.

Evaluation of Channel of the Yarmouk River as a Conveyance to the East Gohr Main Canal

One of the schemes for conveying water to East Ghor Main Canal would be to release water from the Maqarin Dam

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into the Yarmouk River Channel. The flows of released water would be similar in most respects to the present flows in the Yarmouk River. Thus, no changes in the stability of valley sides or other geologic considerations should occur by using the stream channel as a conveyance route.

Evaluation of the Wadi Khalid Damsite

The ultimate development of the water resource of the Yarmouk River will require a high (reservoir el. 195 m) Maqarin Dam and the construction of a dam on the Yarmouk River downstream of the Wadi Raggad. This dam downstream of the Wadi Raggad would be at the Wadi Khalid Damsite. No investigations were performed at this site during this study; however, earlier studies by Harza (Harza-Baker in 1955) reported that the site is favorable for the construction of a dam.

In this earlier study, bedrock is reported to be the Chalky Limestone Unit. This limestone on the left or Jordanian side of the valley is, in places, overlain by talus deposits. On the right side of the valley a nearly horizontal series of alluvial conglomerates, basalt flows, alluvial chalk-limestone conglomerate, and residual and transported soils overlie the Chalky Limestone Unit. The alluvial conglomerate the basalt flows are reported to be permeable. As these two units may be difficult to remove from the right abutment, additional studies will be required to develop methods to make this abutment watertight.

The weathered chalky limestone bedrock is permeable and the fresh bedrock may also be permeable. Foundation treatment consisting of excavating highly weathered bedrock from the core trench and constructing a grout curtain and a drainage curtain should be anticipated as means of seepage control for the site.

Evaluation of the Wadi Khalid Powerplant

Geological conditions reported at this damsite indicate that it would be feasible to construct a powerplant and attendant structures in the area.

Evaluation of the Yarmouk Diversion to the East Gohr Main Canal Site

Recommended Stage II development of the Yarmouk River water resource would require the construction of a low dike, approximately 5.5 m high, to divert river water into a tunnel leading to the East Ghor Main Canal. This would be located immediately downstream from the present river diversion. Preliminary field studies of the site indicate that the site is suitable for the construction of the dike envisioned.

Evaluation of the Tunnel from Maqarin Damsite to Wadi Arab

The 20 km long tunnel between the Maqarin Damsite and the Wadi Arab would be constructed partly in the Chalky Limestone Unit and partly in the Bituminous Marl Unit. These beds dip gently to the northeast are jointed and are probably also block faulted.

Both units are considered to have lithologies favorable for tunnelling. The tunnels should generally be supported by conventional support systems.

Some inflows of ground water along joints and faults could be troublesome and inflows of warm mineral water could be encountered.

Explosive gasses could be encounterd in parts of the tunnel, especially in reaches of the tunnel that are in the Bituminous Marl Unit.

Evaluation of the Penstock and Powerplant at Wadi Arab

The powerplant being considered for the Wadi Arab would have its location selected to accomodate the proposed el. -110.5 m

dam to be constructed by the Japan International Cooperation Agency. This scheme envisions a maximum normal reservoir level of -115 m.

The powerplant would probably be founded on the Bituminous Marl Unit which possess a strength adequate for this structure. Penstocks would be constructed on the stable scarp (antidip) slope.

Evaluations of Side-Wadi Diversion Sites

Three side-wadis, the Wadi Yaris, Wadi Kufrinja and Wadi Rajib are being considered for diversion to the EGMC. Preliminary field studies indicate that the proposed diversion structures which are small (less than 6 m high) can be constructed at the proposed sites in these wadis.

Evaluation of the King Talal Dam Powerplant

The construction of a powerplant is proposed for the King Talal Dam. This structure will be near the downstream outlet of the diversion tunnel and founded on bedrock similar to that encountered in the tunnel. It is anticipated that this bedrock will possess adequate strength to support this proposed structure.

Introduction

Purpose

The purpose of this Appendix of the Jordan Valley Irrigation Project Stage II Report is to present the results of the geological studies that are relevant to Project elements. These studies were performed during this and preceding phases of the Project's development. Conclusions derived from these studies and geologically controlled criteria to be followed in designing Project features to be built in Stage II will also be presented.

Scope

The scope of this Geology Appdndix is a presentation of the data obtained from the studies of the geology of the Maqarin Damsite and reservoir, and of the schemes for conveying irrigation water from the Maqarin Reservoir to the East Ghor Main Canal.

Briefly summarized these schemes are:

(1) By channel flow in the Yarmouk River Valley to the diversion to the East Ghor Main Canal. This scheme would include a dam of a structural height of 170 m (crest el. 158 m, reservoir el. 150 m); a powerplant at the Maqarin Damsite and an improved irrigation intake at the tunnel leading to the East Ghor Main Canal. The ultimate stage of development of the water resource will require construction of a high dam (crest el. 200 m, reservoir el. 193 m) at the Maqarin Damsite and a dam and powerplant at the Wadi Khalid Damsite, approximately 20 km downstream of Maqarin.

Stream flow from three side-wadis will also be diverted to the EGMC by the construction of small diversion weirs.

(2) By tunnel from the Maqarin Damsite to the Wadi Arab. A powerplant would be located in the Wadi Arab.

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Each of these schemes is described more fully in the appropriate section of the Appendix and in detail in the Main Report.

Extensive geological studies have been made of the Maqarin Damsite, Powerplant and Reservoir and are continuing. Appraisal studies have been made of the conveyance schemes between the Maqarin site and the East Ghor Main Canal including the Wadi Khalid Damsite in the Yarmouk River Valley downstream of the Maqarin site. A geological comparison of the Mekheibe and the Wadi Khalid damsites has also been made.

Appraisal level studies have also been made of the proposed powerplant at King Talal Dam and the proposed diversion structures for the side-wadis Yabis, Kufrinja and Rajib.

Studies of the geology have included: a review of published literature and reports prepared by other organizations concerning various parts of the project; conducting subsurface explorations at the Maqarin Damsite; interpreting the subsurface exploration performed at the other damsites; and conducting surface geological surveys of the Maqarin Damsite, of the Maqarin Reservoirs area, of the sites of the various diversion structures, and of the various water conveyance schemes. These studies are described in detail in the section on Investigations.

Location

The Project area is in the northern part of Jordan and the southwestern part of Syria ("Regional Location Map", Exhibit E-1). Specifically this area includes the eastern side of the Jordan River Valley, the highlands to east of the Jordan Valley, the Yarmouk River Valley, and the Wadi Arab, ("Locations of Project Features", Exhibit E-2). The

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boundary between Syria and Jordan lies in the Yarmouk River Valley, thus parts of the proposed dams and reservoirs in this valley will be in Syria.
boundary between Syria and Jordan lies in the Yarmouk River Valley, thus parts of the proposed dams and reservoirs in this valley will be in Syria.

Access

The Jordan River Valley is reached by the main highway leaving Amman toward the west and is approximately 30 km distant. A road near the eastern side of the valley traverses the valley in a north-south direction. The Yarmouk River diversion to the EGMC and Side-Wadis are near this north-south highway.

The Maqarin Damsite is approximately 75 km north of Amman and reached by a paved road. It takes approximately 2 hours to reach the Maqarin site by auto.

Access to the Wadi Khalid Damsite is by trail or by the Hijaz Railway roadbed in the Yarmouk River Valley.

The King Talal Dam is approximately 30 km northwest of Amman and reached by a paved road.

Investigations

Previous Investigations

Published Reports. Several published articles and maps have been used in preparing this Appendix, but generally these articles are not specifically referred to. Several agencies of the Jordanian government were also consulted and information supplied by them has been used as applicable.

Some of the regional maps in this Appendix have been adapted from published sources with only minor modifications. In these cases the source is identified.

These various published articles and maps pertinent to this appendix are listed in the Bibliography.

Unpublished Reports and Previous Investigations. Several studies have been prepared about one or more of the various elements of the Project. All have generally concluded that element of the Project described was technically feasible to construct. The various studies that apply and their general conclusions are listed below in chronological order:

Burdon, David V. (1952) Report to the Government of the Hashemite Kingdom of Jordan of the Geological Features of the Yarmouk Valley Scheme.

This report conclued that a reservoir formed by a dam at Maqarin site would be watertight and that reservoir slopes would be stable with respect to "huge" landslides.

Baker, Jr., Michael Inc. and Harza Engineering Company (1955) The Jordan Valley Project, Master Plan Report.

Geological and geotechnical studies by Harza Engineering Co. and Michael Baker Jr., Inc. in 1955 consisted of the following exploration and geotechnical testing for Maqarin Damsite:

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1. Eleven drill holes with a total meterage of 926 m. The drill holes were pressure tested for permeability.

2. Unconfined compressive strength tests of samples of drill core.

3. Geological mapping of the site.

4. Areas where pervious and impervious borrow could be obtained for dam construction. Samples of these borrow materials were tested.

Potential sources of riprap and concrete aggregate were also examined and tested.

Drill hole locations of the 1955 exploration at the Maqarin Damsite are shown on the "Geology of the Maqarin Embankment Area", (Exhibit E-9) and logs of these drill holes are in Annex E-1.

This report concluded that the Maqarin Damsite was favorable for the construction of a low dam and that the reservoir formed by such a dam would be watertight.

Subsurface exploration was also performed at the Wadi Khalid Damsite, approximately 20 km downstream of the Maqarin Site. At this site 25 drill holes totaling 1690 m were drilled. Location of the Wadi Khalid Damsite is shown on the "Geology of the Yarmouk River" (Exhibit E-28B) and locations of drill holes are shown on the "Geology of the Wadi Khalid Damsite" (Exhibit E-29).

Subsurface exploration was also performed at the Yarmouk Diversion Damsite, approximately 35 km downstream from the Maqarin site. Location of the Yarmouk Diversion Damsite is shown on the "Geology of the Yarmouk River" (Exhibit E-28C).

Geologic mapping was performed in all reservoirs.

Wassemann, Gerd and Adullatif, A. (1963) Geology of the Yarmouk Area, North Jordan, Final Report.

The area between the Yarmouk River and the Wadi Arab was geologically mapped and the formations were described. Predictions of the formations that would be encountered in a tunnel between the Maqarin Reservoir and the Wadi Arab were also made.

From the geological mapping of the Maqarin Reservoir it was concluded that rocks of the reservoir are essentially impermeable and that the reservoir would be watertight.

ENERGOPROJEKT (1966) Yarmouk Project Geological Report - Maqarin Scheme, Phase B (Draft).

This report, which was based on surface and subsurface investigations, concluded that:

1. The bedrock at the site is relatively impermeable and firm to hard.

2. No large faults were found and none were inferred to be present.

3. The site is suitable for the construction of a 130 m high embankment dam with a crest elevation of 157 m.

4. The report further concluded that the reservoir formed by this dam would be watertight and impounding of reservoir waters would not result in large landslides.

The exploration and geotechnical testing performed for the Maqarin Damsite were as follows:

1. Eighteen drill holes with a total meterage of 921 m. Some of the drill holes were pressure tested for permeability. Piezometers were installed in 3 of the drill holes.

2. Ten test pits in the foundation area.

3. Eighty-one test pits in borrow areas. Classification and physical properties tests were also performed on samples from these test pits.

4. Geologic mapping of the reservoir and along three tunnel alignments to proposed powerhouses in the Yarmouk River Valley was also performed.

This report also recommended that an additional exploration phase for the Maqarin Damsite be completed during the design stage.

Locations of 1966 drill holes in the damsite area are shown on the "Geology of the Maqarin Embankment Site" (Exhibit E-9). Logs of these drill holes are in Annex E-1.

ENERGOPROJEKT (1967) Yarmouk Project Khalid Bin Al Walid - Wadi Arab Scheme, Volume II, MSB-B1 Geological Report

This is a report on a scheme with a dam at the Khalid Bin Al Walid (Mekheibe) Damsite (approximately 26.5 km downstream of the Maqarin Damsite) and on a tunnel to Wadi Arab with an underground powerplant near the wadi.

Twelve drill holes totaling about 1400 m were drilled in and near the Wadi Arab. Some permeability tests were performed in the drill holes and a few strength tests were performed on samples of drill core. A part of this exploration was useful in evaluating the geological conditions of the proposed Maqarin Damsite to the Wadi Arab conveyance scheme.

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Sixty-five drill holes totaling 4970 m were drilled in the vicinity of the Khalid Bin Al Walid Dam. The axis of the proposed dam is shown on the map "Geology of the Yarmouk River" (Exhibit E-28C).

Japan International Cooperation Agency (November 1976) Feasibility Report on Wadi Arab Dam and Irrigation Project - Main Report - Annex II, Geology.

This report has a short summary of the geology of the proposed Wadi Arab Dam. The Geology Annex of this report was reviewed with reference to the proposed Wadi Arab powerplant.

Present Investigations

General. The geological and construction materials investigation programs at the Maqarin Damsite have been carefully planned to augment and compliment the Harza-Baker and ENERGOPROJEKT studies which are described in the preceding subsection.

Other geologically related elements for the Project were also examined to permit an appraisal of their feasibility. These appraisals have relied heavily upon existing studies. The various geological exploration programs for the Maqarin Damsite and Powerplant for the other parts of the Project are summarized below.

Maqarin Damsite and Powerplant Foundation Investigations

i. Surface Mapping: Geologic maps of the site are a part of both the ENERGOPROJEKT and Harza-Baker reports. These maps were verified and the data on the maps has been augmented for this report. The mapped area, which is contained in this Appendix as the "Geology of the Maqarin Damsite" (Exhibit E-8), was extended from earlier mapping to

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higher elevations to portray surface geology for spillway cut-slopes. Data from drill holes have been used to verify surface mapping. Some surveys of contacts between formations were also made.

ii. Drill Holes: The current drilling program has resulted in the drilling of an additional 15 drill holes in the damsite area totaling 1030 m as shown on Exhibits E-8 and E-9. This includes 3 drill holes totaling 93 m which were used to evaluate basaltic rock for dam fill material, concrete aggregate and riprap, and one drill hole near the proposed powerplant. Most drill holes in the damsite area were pressure tested for permeability.

During this exploration program and the preceding programs, a total of 44 drill holes totaling 2877 m, have been drilled at the site.

iii. Adits: Four adits totaling 96 m have been excavated to examine the talus covering damsite slopes and to explore the underlying bedrock.

iv. Shafts: Five shafts totaling 50 m have been excavated to examine bedrock and overburden.

Logs of the adits, drill holes, and shafts are contained in Annex E-1.

Maqarin Damsite Materials Investigations

i. Impervious Borrow Investigations: Sixteen test pits have been excavated in potential impervious borrow areas. Samples have been collected from many of these pits. Logs of these pits and results of tests are in Appendix D.

ii. Investigations of Quarry Sites in Basalt Rock: Three drill holes have been drilled to evaluate the suitability of the basalt on the south side of the valley as a source of quarry rock for rockfill or riprap for the dam or as a

source of concrete aggregate. Logs of these drill holes are in Annex E-1.

Other areas of basalt flows have also been investigated. The results of these investigations are contained in Appendix D.

iii. Investigation of Quarry Sites in Chalky Limestone: Hand samples have been collected to evaluate the suitability of the Chalky Limestone of the damsite area as a source of rockfill for the dam. Results of these tests are contained in Appendix D.

Maqarin Reservoir Studies. Mapping of the reservoir, contained in the Harza-Baker and ENERGOPROJEKT reports, was confirmed and augmented during this stage of project investigation. The map of this area is titled "Geology of the Maqarin Reservoir", (Exhibits E-24A, E-24B).

Studies of Conveyance Schemes in the Yarmouk River Valley. Reconnaissance geologic mapping and verification of existing mapping has been made for the scheme for conveying irrigation waters down the Yarmouk River Valley to the East Gonr Main Canal.

Wadi Khalid Damsite Studies. Studies of this site were confined to a reappraisal of the Harza-Baker Report of 1955. Political and military conditions hampered on-site verification of the earlier study.

Yarmouk Diversion to EGMC Studies. Studies of the Diversion site consisted of reconnaissance level geologic mapping of the area. This study was hampered by political and military conditions.

Studies of the Maqarin Damsite to Wadi Arab Tunnel. Reconnaissance geological mapping was perfomed along this proposed tunnel route to verify the Wassemann-Adullatif

report of 1963. This is presented on the "Geologic Map and Section of the Maqarin Damsite to Wadi Arab Tunnel" (Exhibits E-33A and E-33B).

Greater control of the stratigraphy, which would be encountered in tunneling, was also obtained by measuring stratigraphic sections in the Wadi Arab. ("Stratigraphic Column of the Project Area", Exhibit E-7).

Wadi Arab Powerplant Studies. A reconnaissance geologic map has been prepared at the proposed Wadi Arab Powerplant. Applicable data from the ENERGOPROJEKT Report of 1967 and from the Japan International Cooperation Agency Report of 1976 have also been used.

Side-Wadi Diversion Sites. On-site reconnaissance of the three Wadi Diversion sites scheduled to be constructed have been made.

King Talal Dam Powerplant Studies. Studies for the King Talal Powerplant have consisted of the review of the "as built" drawings of the King Talal Dam Diversion Tunnel outlet portal. As the proposed powerplant is near the outlet portal, it was assumed that many of the geological situations encountered during the driving of this tunnel will also be encountered during the construction of the powerplant.

Mukheibeh (Khalid Bir Al Walid) Damsite Studies. Studies of this site were confined to a reconnaissance of the site and an appraisal of the ENERGOPROJEKT report of 1967.

Regional Geology

Geographic Description

The Jordan River Valley, in which the irrigation service area of the Project will be built occupies, along with the Dead Sea and Lake Tiberias, a low depression ("Physiographic Provinces", Exhibit E-3). This depression is between highlands lying to the west, which are in Israel and occupied Jordan, and highlands in Transjordan to the east. The Jordon River flows from Lake Tiberias, which is 209 m below sea level, to the Dead Sea, 395 m below sea level.

The topography of the Jordan Valley is dominated by two topographic forms: the zor or the alluvial covered flood plain of the Jordan River, and the ghor or the dissected alluvial and lacustrine terraces which border the flood plain. The ghor is generally 10 m to 50 m higher than the zor.

The highlands east of the Jordan River Valley rise abruptly to elevations as high as 500 m and commonly are above elevation 300 m. In general, this highland area is the western margin of the plateau region which comprises the most of Transjordan. The western margin of this area is the eastern steeply sloping side of the Jordan River Valley. The irrigation water conveyance in the Yarmouk River Valley and the proposed tunnel between the Maqarin Damsite and the Wadi Arab would pass through or into the formations of the highlands east of the Jordan Valley.

The steeply sloping east side of the Jordan River Valley is transversed by the Yarmouk and Zarqa Rivers, the Wadi Arab, and many lesser streams and wadis. All of these streams drain into the Jordan River. The Maqarin Damsite is located in the Yarmouk River Valley ("Locations of Project Features", Exhibit E-2).

The Maqarin Dam, which will provide water storage for irrigation, is located approximately 40 km upstream of its confluence with the Jordan River and near the Maqarin Railway Station of the Hijaz Railway. The Yarmouk River, the main tributary of the Jordan River, drains an area of approximately 6800 km^2. Approximately 90% or nearly 6000 km^2 of the drainage area of the Yarmouk River is upstream of the Maqarin Damsite. Nearly all of the drainage area is upstream of the Wadi Khalid Damsite.

Geologic Setting

The geology of Jordan has been influenced by its position at the boundary between the continually subsiding (during the Palezoic, Mesozoic and early Tertiary) Tethys Sea and the stable African-Arabian Shield (Exhibit E-1). The shield area is composed of PreCambrain plutonic and metamorphic rocks. In Jordan and to the north, the shield area is overlapped by continental and marine sediments of Paleozoic, Mesozoic and early Tertiary age. The marine sediments are transitional to those deposited in the Tethys Sea.

This broad geological framework has had superimposed on it the large scale rifting, which has resulted in the formation of the Jordan Valley-Gulf of Aqaba Rift and by the large outpourings of basalt lavas, which form plateaus in the northern part of the country. Regional orogenic movements have also caused a northward tilting of the lands east of the Rift. More local orogenic movements have resulted in swells and basins and in local anticlines, monoclines, and synclines.

Physiography

Most of Jordan has been emergent since the Eocene and much of the area has been eroded into mature topographic

forms. These mature topographic forms were in places, covered by large outpourings of basalt. Differential movements of the Earth's surface, which has influenced stream direction and rates of erosion, has also modified the topographic forms. The result has been the formation of areas or regions with similar topographic forms which are considered to be physiographic provinces. These are shown on the map "Physoigraphic Provinces" (Exhibit E-3) and are listed below:

1. Highlands East of the Rift Valley
2. Jordan Valley - Gulf of Aqaba Rift
3. Central Plateau
4. Northern Basalt Plateau
5. Northeastern Plateau
6. Southern Mountainous Desert
7. Highlands West of the Rift Valley

The Project area lies in the northern part of the Highlands East of the Rift Valley and in the Jordan Valley portion of the Jordan Valley - Gulf of Aqaba Rift. These two physiographic provinces will be described in greater detail below. A description of the other provinces is in the book Geology of Jordan by Friedrich Bender (Reference 1, Bibliography).

The Highlands East of the Rift Valley province stretches north-northeast from the Gulf of Aqaba to Lake Tiberias. The higher areas and the eastern part of the province generally slope gently to the east in response to regional tilting of the earth's crust. These higher areas generally have a low relief reflecting the long period of erosion since regional emergence in the Eocene.

There is evidence at the Maqarin Damsite that rocks of the highlands were deeply and severly weathered during this period of emergence and erosion.

The western margin of the province slopes steeply westward into the Jordan Valley-Gulf of Aqaba Rift. Because the elevation of the Jordan Valley is much lower than that the Northern Highlands, westward flowing streams are deeply incised. These streams commonly show a youthful form with steep-sided valleys indicating a rapid downcutting. This downcutting is in response to the continuing subsidence of the Jordan Valley. The Maqarin Damsite, the Wadi Khalid Damsite, the Yarmouk Diversion to the EGMC, the proposed Wadi Arab Dam, and the proposed water conveyance tunnel to the Wadi Arab Damsite are located in the northern part of the Highlands East of the Rift Valley physiographic province. To the east, this province merges into the gently rolling mature topography of the Central Plateau province.

The Northern Basalt Plateaus form the northern and northeastern boundary of the Highlands East of the Rift Valley Province. These basalt flows have covered and filled-in older drainage systems. Their greater resistance to erosion (relative to the limestones) has apparently caused the Yarmouk River to erode its valley near the boundary between the Northern Basalt Plateau and the Highlands East of the Rift provinces.

The Jordan Valley - Gulf of Aqaba Rift is a narrow deep depression extending from the Gulf of Aqaba northward to the Dead Sea and from there to Lake Tiberias. South of the Dead Sea, the floor of the Rift Valley is composed of terrestrial deposits, such as talus and alluvial fans, alluvial gravel outwash and sand dunes. The Jordan River Valley lies north

of the Dead Sea and continues to Lake Tiberias. The valley is between 5 km and 20 km wide and slopes gently southward from Lake Tiberias to the Dead Sea. The Jordan River generally flows in the center of the valley meandering in a floodplain approximately 100 m wide which is known as the zor. This floodplain is incised to a depth of between 10 m and 50 m below the dissected terrestial, alluvial and lacustrine deposits known as the ghor. Irrigation works will be located on the ghor.

Regional Stratigraphy

Older (pre-Oligocene) deposits in the Project Area show the influence of both the stable African-Arabian Shield and the ancient Tethys Sea which at various times trangressed over the shield, (Exhibit E-1). The interaction of the Tethys Sea and shield has at the margins of the shield, resulted in the deposition of continental sediments in the south which grade northward into sequences of marine beds.

Emergence at the close of the Eocene has resulted in deposition of continental or lacustrine sediments during the Middle and Upper Tertiary and Quaternary periods. In some places, basalts of various types have also flowed over this emerged terraine.

Description of the formations found in the project area of western Jordan (west of 37°E longitude and north of the Dead Sea) are summarized below in ascending order and summarized in the "Stratigraphic Column" (Exhibit E-5). Only those formations that are relevant to the project are in this summary. Other formations are described in the several publications listed in the Bibliography. Formational names and general descriptions are from the Handbook of the Geology of Jordan by D. J. Burdon (Reference 4, Bibliography). The

descriptions have been modified by those given in the Geology of Jordan by F. Bender (Reference 2, Bibliography) and by observations of outcrops. Thicknesses have also been modified by applicable field data.

Triassic and Jurassic Periods	Zarqa Group: Fossiliferous sandy limestone, varicolored shales and coarse-grained sandstones. These beds range up to 400 m thick.
	Unconformity
Lower Cenomanian Stage of the Cretaceous Period	Kurnub Sandstone: Varicolored sandstone with hard glauconitic sandstone and shales at the base. These beds vary between approximately 50 m and 250 m thick.
	Unconformity
Cenomanian Stage of the Cretaceous Period	Ajlun Series: Alternating beds of limestone, dolomitic limestone, marl, glauconitic shale and locally some gypsum. Thickness varies between approximately 100 m and 300 m.
Cenomanian Stage of the Cretaceous Period to the Eocene Epoch of the Tertiary Period.	Belqa Series: Thick and thin-bedded limestones, marly limestones, marls, bituminous marls, bituminous limestones and chalks. Thickness varies from

	approximately 250 m to over 850 m. The Maqarin Dam and water conveyance systems to the East Ghor Main Canal will be founded on rocks of this series.
	Unconformity
Miocene Stage of the Tertiary Period and the Pleistocene Stage of the Quaternary Period	Plateau Basalts: Basalt flows with the composition of a normal plateau basalt. Six separate flow episodes have been identified. Aggregate thickness is approximately 200 m.
Late Pleistocene Stage of the Quaternary Period	Lisan Marls: Fossiliferous shale and marl with some gypsum and native sulfur. Approximately 100 m of these beds are exposed, in the Gulf of Aqaba-Jordan Valley, however, the formation is probably considerably thicker as its base is not exposed.

The formations that outcrop in the Project area within the Highlands East of the Rift, namely the upper part of the Belqa Series and the Plateau Basalts, will be described in greater detail in other sections of this Appendix.

Regional Structure

The geologic structure of Jordan is dominated by the Jordan Valley - Gulf of Aqaba Rift and the structures formed by the regional orogenic movements of the areas bordering the Rift Valley. Orogenic movement has resulted in a prevailing gentle dip to northeast of the strata of the Highlands East of the Rift and the Central Plateau (Exhibits E-3 and E-4). Several lesser regional structural elements, consisting of broad upwarps and downwarps, have been superimposed on these major features in these areas. Large fault zones, secondary to the Rift zone, are also present. Many of these features are generally not germane to the project and will not be discussed further although they are identified on the "Regional Geologic Map" (Exhibit E-4).

Regional features, generally those north of the Dead Sea within the Highlands East of the Rift physiographic province, are described below.

Folding. The major Ajlun Arch dominates the structure of the highlands area immediately east of the Rift Valley. This structure trends north-northeasterly and plunges gently northerly. It apparently trends obliquely into the Rift.

Other smaller folds of local development trend in the same direction as the Ajlun Arch.

Faulting. Major faults, except for those of the Rift Valley, are absent in the Project Area. A few faults, however, are present and may locally affect Project features. There generally trend in either a northerly direction and parallel to the Rift or in an easterly direction and nearly at right angles to the Rift. Faults will be described in greater detail as they may effect Project features.

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Seismicity

General

Seismic activity, which has included occasional severe earthquakes, has been noted intermittently throughout the recorded history of the area. While early records do not include modern earthquake parameters, they nevertheless show that settlements in the area were severly damaged.

Modern records, which are instrumentally recorded earthquakes, indicate that earthquakes within the region of Jordan generally have their epicenters near the Jordan Valley - Gulf of Aqaba Rift (Exhibit E-6). This suggests that the tectonism, which caused the rift to form, is still active.

Instrumentally recorded earthquakes range in magnitude to 6.25 (Richter scale). The focal depth of the earthquake has been noted in only three of these records and in these three cases focal depths were classified as shallow (33 km or less).

Records from the earthquake of July 1927, which occurred in the Jordan Valley west of Amman (Exhibit E-6), indicate that the earthquake had an intensity varying between IX and X (Mercalli Scale) in the Project area.

Selection of Design Earthquake

On the basis of this data and of the data from the July 1927 earthquake, structures are to be designed to withstand strong earthquake forces. The seismic coefficient and method of analysis is described in Appendix J.

Geology of the Maqarin Damsite

Physical Description

The Maqarin Damsite is located in a narrow part of the Yarmouk River Valley. This part of the valley is generally set off by a sharp bend leading to the Wadi Shallala in the upstream area and the Wadi Sidiin to the downstream. Both of these features are on the Jordanian side of the river and, in effect, they form a ridge for the left abutment. This is shown on the "Geology of Maqarin Damsite Area", (Exhibit E-8). The right side of the river valley is relatively featureless with only small shallow drainages. The length of the narrow part of the valley is approximately 3/4 km and the bottom of this part of the valley is at an elevation of 30 m.

The bottom of the valley in the vicinity of the axis of the dam is approximately 100 m wide but widens both upstream and downstream. Sides of the valley slope approximately 32° from the horizontal on the Jordanian or south side of the river and approximately 36° on the Syrian side. This is shown on the "Geology of the Maqarin Damsite Area", (Exhibit E-8). The valley walls rise to an elevation of approximately 230 m on the Jordanian side and to approximately 350 m on the Syrian side. This 230 m elevation effectively limits the height of the proposed dam and reservoir.

Weathering of the bedrock on the plateaus or ridges above the valley may be severe and may also place a constraint on the height of the dam. The nature and distribution of this weathering has not been established.

Bedrock Stratigraphy

General. Bedrock at the damsite consists of marine beds of chalky limestone, and bituminous marly (argillaceous)

limestones belonging to the Belqa Series. These beds overly the Ajlun Series, Kurnub Sandstone and the Zarqa Group, as has been generally described in the section on Regional Stratigraphy. Only the upper part of the Belqa Series outcrop at the damsite. These rocks are divisible into two units, a Bituminous Marl Unit and a Chalky Limestone Unit. These are described in detail below and their stratigraphy is illustrated on the "Stratigraphic Column of the Project Area" (Exhibit E-7). Other formations are also generally described with reference to their possible effect on the Project.

Basalts unconformably overlie the Chalky Limestone Unit in the damsite area.

Geological considerations pertaining to construction uses of bedrock materials are contained in the Engineering Geology Section.

Pervious Formations Below the Bedrock of the Maqarin Damsite. Sandstone beds in the Zarqa Group and the Kurnub Sandstone may be deep acquifers. These sandstones are believed to have been encountered at depths between 1300 m and 2190 m in the Ramtha Well S-90 which was drilled 20 km to the east of Irbid and 30 km southeast of the site. The Ramtha Well S-90 was a stratigraphic test well drilled by the Natural Resources Authority. The well is believed to have started in the lower part of the Belga Series. Regional dip of beds indicates that these sandstone acquifers are deeper at the damsite than in the Ramtha Well S-90.

Limestones of the Ajlun Series are also deep aquifers in the area and furnish well water at Mafraq. These limestones are believed to have been encountered at a depth of 490 m in the Ramtha Well S-90. Due to the regional dip they should be at least that deep at the Maqarin Damsite.

Some formations in the Belqa Series form aquifers. The more important of these are generally below the Bituminous Marl Unit. The aquifers are commonly chalks associated with chert. The beds of the lower Belga Series are not believed to have been reached by drill holes at the site.

Bituminous Marl Unit-Belqa Series. The Bituminous Marl Unit is the bedrock in the valley bottom and the lower parts of the valley sides at the damsite. Previous reports have identified beds of this unit as marl. More recent petrographic analyses, as described in a following subsection and as summarized in Tables E-5 and E-6, identify these beds as (argillaceous) limestone.

This unit has been referred to as a marl in much of the literature and in previous reports. Thus to avoid the introduction of new terminology, which could be confusing, the term marl or marly limestone will be used when referring to beds of the Bituminous Marl Unit.

Visual examination of hand samples of the unweathered beds of the Bituminous Marl Unit obtained from drill holes, shafts and adits show that they are grey to dark-grey, massive, compact, non-friable, slightly soft to moderately hard, moderately strong, generally non-crystalline, argillaceous bituminous limestones. The bituminous content is variable. Bedding partings are rarely observed in the unweathered marly limestone. The fabric of the rock, which is commonly indistinct, consists of small pods, lenses (1 cm x 3 cm) and laminae of a medium grey limestone in a groundmass of dark grey limestone. Small amounts of finely crystalline pyrite are disseminated throughout the marly limestone. Petrographic analyses are described in a subsection that follows and results of these analyses are summarized in Table E-5.

Zones or intervals of clay and uncemented sand have been encountered in bedrock in several of the drill holes in the channel area. These occurrences are summarized below.

1. A zone in the Bituminous Marl Unit, which is variably silty and sandy and which is in part a plastic clay, was reported in drill holes AL-1, AL-1A, AL-1B, M-6 and AR-1 in the channel area, (Exhibit E-11). This zone varies in thickness from 20 m to 40 m and its length parallel to the dam axis is at least 60 meters and may be as much as 100 meters. The top of the zone is at about elevation - 25 m, which is about 40 meters below the bedrock surface in the river channel. A smaller and shallower zone of soft and moderately hard bituminous marl was encountered in drill holes M-6 and AL-1A. This zone is approximately 10 m below the bedrock surface.

2. Drill hole HV-5 (inclined 45°) of the current program (Exhibit E-10), beginning at a vertical depth of 12.8 m, encountered a 6.1 m zone of stiff gray silty clay of moderate plasticity and a 3.1 m zone fine silty sand and clay separated by 3.9 m of bituminous marl.

3. HV-5A, the replacement of HV-5 and 2 m west of HV-5, encountered intermittent clay zones between vertical depths of 13 m and 25 m.

4. A short interval of compact gray clay of low plasticity was encountered in drill hole HV-6 (inclined 30°, Exhibit E-11). This interval was 1.7 m thick and was found at a depth of 43.8 m.

5. HV-7, an inclined hole, (Exhibit E-10) encountered sandy and silty clays between vertical depths of 461. m and 49.0 m, 53.9 m and 55.4 m and between 83.5 m and 91.2 m.

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Cavities up to 1.5 m in vertical dimension were reported from some borings of the earlier site investigations, but none were encountered in drill holes in the Bituminous Marl Unit in the present program.

The relationships and possible interconnections between the cavities and clayey or sandy zones occuring within the Bituminous Marl Unit have not been determined and they must be thoroughly investigated during future exploration.

Beds of the Bituminous Marl Unit generally weather to a light-brown to white, soft, friable, porous chalk-like limestone of low density. In the weathered state the material often develops platy to shaley partings and has a susceptibility to surface hill creeping or shallow slumping. In some road cuts made for the Hijaz Railway, weathering appears to be associated with calcite veins.

Gypsum, both in crystalline form and in a microcrystalline powder form, occurs as irregular randomly oriented veinlets in the weathered parts of the Bituminous Marl Unit. These veinlets may be as thick as 1 cm, although they are commonly less.

Many calcite veins ranging from a fraction of a centimeter to 20 cm thick are found in the Bituminous Marl Unit at the site. These generally strike northwesterly and have a nearly vertical dip. Commonly they are bordered by a bleached or altered zone a few centimeters thick and often have small lenses of limestone derived from the Marl Unit entrained in the vein material. They were apparently implaced by a replacement phenomena. The veins are also described in the subsections on Structure and Petrographic Analyses.

The unconfined compressive strength of unweathered drill core samples from beds of the Marl Unit varied between 45 kg/cm^2 and 403 kg/cm^2 and averages 275 kg/cm^2 as is described in a following subsection.

Chalky Limestone Unit - Belqa Series. The Chalky Limestone Unit is the bedrock in the upper parts of the valley sides. Beds of the unit conformably overlie the Bituminous Marl Unit, outcropping at an elevation of approximately 115 m on the Syrian side of the river. On the Jordanian side of the river, outcrops of the Chalky Limestone also occur at approximately 115 m elevation although they are largely concealed by talus. The unit generally dips downstream as is shown on the map of the "Geology of the Maqarin Damsite Area", (Exhibit E-8).

A relatively erosion resistant 10 m thick bed in the Chalky Limestone Unit in many places forms cliffs on the valley sides and serves as a marker bed for locating the Chalky Limestone - Bituminous Marl contact. This bed, which is persistent in outcrop, has been mapped as the contact. The contact is difficult to identify in drill holes. This is apparently due to its gradational nature and the tendency of beds that are typical of the Bituminous Marl Unit to be found in the Chalky Limestone Unit well above the contact

and for beds of chalky limestone to occur well down in the Bituminous Marl.

The Chalky Limestone Unit is typically composed of thick to very thick beds of interbedded light-brown to white, compact, firm, non-friable, porous, moderately hard, moderately strong, generally non-crystalline, chalky limestone. Some beds of the unit contain nodular chert.

In a weathered condition the Chalky Limestone is soft and friable, and in some places (drill holes AL-3, HP-1, HQ-1, HQ-4 and HQ-5) the limestone weatheres to clay. Some cavities up to 0.5 m in vertical dimension (in drill holes and AL-3) are found in the weathered Chalky Limestone. A case-hardening phenomena, which causes exposed surfaces of the limestone to become dense and hard, is also observed.

Chalky Limestone outcrops occur in some places on the Jordanian side of the valley covered with crusts of tufa and travertine. Some solution erosion of the limestone outcrops is generally apparent in these areas. This phenomena is best represented on east side of the lower part of the Wadi Sidiin.

Samples of the Chalky Limestone Unit have been examined petrographically. These are described in a following section and are summarized in Table E-5.

Unweathered beds of this unit may be stronger than those of the Bituminous Marl Unit although they have not been tested for strength.

Basalt Flows. Basalt flows are present near the site on both sides of the valley and unconformably overlie the Chalky Limestone. This relationship is shown on the "Geology of the Maqarin Damsite Area" (Exhibit E-8).

The basalts on the Syrian side of the valley are a part of the sequence of flows that form the extensive plateau in the southern part of that country. The elevation of the base of this series of flows in the damsite area varies from approximately el. 350 m upstream of the site to el. 190 m downstream of the site. This series of flows apparently filled in valleys and other depressions in the region prior to the formation of the present Yarmouk River Valley.

The basalt flow on the Jordanian side of the valley is believed to a remnant of flows that entered the Yarmouk River Valley during an early stage of its development. Other areas in which similar flow remnants can be observed are found both upstream and downstream from the site. At places they can be seen to have been fed by steeply inclined surface flows which originated on basalt plateau on the northern side of the Yarmouk Valley.

Basalts of the area are classed as olivine dolerite, (basalt), and are dark-grey to black, generally finely crystalline, and hard. The basalt is often vesicular at the top and at the base of individual flows. Thicker flows commonly exhibit columnar jointing.

The unconformity between the basalt and Chalky Limestone Unit is generally irregular and commonly has a pre-basalt soil of variable thickness.

The flows on both the Syrian and Jordanian side of the Yarmouk River have been investigated and tested as a possible source of concrete aggregate. Results and evaluations of the basalts as potential construction materials are the section on Engineering Geology and in Appendix D of this Report.

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Overburden Stratigraphy

General. Debris from road construction, talus, cemented talus, alluvium, cemented alluvium, slump blocks, and landslides overlie bedrock. The distribution of these deposits is shown on the "Geology of the Maqarin Embankment Area" (Exhibit E-9) and the nature of the deposits are described below.

Much of the dam embankment will be constructed from overburden materials. Tests to determine uses of these materials and zones in the dam embankment in which they will be used are described in Appendix D. Geological considerations pertaining to construction uses of overburden materials are in the section on Engineering Geology.

Talus Deposits. Most of the right side of the valley and a part of the left side is mantled with unconsolidated to poorly consolidated talus deposits. These deposits generally consist of fragments of chalky limestone, marly limestone and basalt. The size of individual fragments commonly range to 20 cm although some blocks of basalt range up to 2 m in diameter. The space between rock fragments is generally filled with silt and clay, although in shaft S-5, a void of approximately 3 m^3 was encountered.

Deposits on the right side of the valley have been separated into older, thicker talus deposits, which range to a thickness of 25 m, and into younger, thinner talus deposits, which generally are only a few meters thick. The older deposits have, in part, been undercut by the river so that low steep banks are formed at their toes.

The left side of the valley is mantled in part with hard cemented talus and in part with loose talus deposits. The thickness of these deposits ranges to 10 m. No attempt

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has been made to separate the talus on the left side of the valley into older and younger deposits.

Shafts S-2, S-3, S-4 and S-5, drill holes M-3 and AR-2, and adit A-2 have penetrated the talus deposits on the right side of the valley and on the left side of the valley, drill holes AL-3, M-2, AL-2, M-9, M-10 and EC-3 and adits A-1 and A-3.

Cemented Talus Deposits. Deposits of talus, which in places are cemented with tufa and travertine, overlie the Bituminous Marl Unit on the left side of the valley. In outcrop and in shaft S-1, this material consists of material from the Bituminous Marl Unit with a few fragments of chalky limestone and basalt. These have been cemented into a sedimentary breccia by tufa and travertine. Drill holes AL-2, AL-3, M-1, M-2 and M-6; and shaft S-1 have penetrated this cemented talus. In these drill holes and in the shaft, the deposit ranges to 8 m thick.

A large detached block (slump block) of material from the Bituminous Marl Unit, appears to have overidden a thick deposit of talus-like material. This is seen in adit A-1. In this adit the talus-like material is cemented and in places in the adit masses of crystalline calcite ranging to 30 cm on a side are also found in the material. The talus-like material consists of a mixture of rounded boulders of basalt and large (over 2 m on a side) angular blocks of material from the Bituminous Marl. The origin of the assumed slump block and talus-like material will be determined by future exploration.

Alluvium. Alluvium deposited during the current cycle of river erosion and aggradation is exposed in the river channel and on the flood plain. These deposits are unconsoli-

dated and consist of cobbles, boulders and gravel with variable amounts of sand and clay. Particle sizes range to 80 cm or more in diameter.

Drill holes HV-3, HV-7, M-5, M-17, M-6, AL-1B and AR-1 have penetrated these deposits.

Cemented Alluvium. Cemented alluvial gravel occurs on the left bank of the river. In outcrop this deposit extends along the river from about 1000 m upstream of the proposed dam axis to about 200 m downstream of the dam axis. In drill core, the cemented alluvium varies between a well cemented conglomerate and a poorly cemented alluvial gravel.

It has been observed in drill holes AL-1, AL-1A, BL-1, M-7, HV-1, HV-2, HV-5 and HV-8. The alluvium ranges to a thickness of 9 m in these holes.

"Pothole" Filling. A pothole-like feature has been located near the left bank approximately 200 m upstream from the proposed dam axis (Exhibit E-12). Drill hole information infers that this feature has a conical shape with its bottom (comparable to the apex of the cone) at least 56 m below ground level. This substantical depth and conical shape indicates that the feature is not a "pothole" in the classical sense of being formed by stream erosion. Moreover the "pothole's" depth suggests that the feature was formed by spring activity.

Drill holes BL-1, M-7, M-13, M-14, and M-15, penetrated this feature. From cores obtained from these drill holes it was found that material in this pothole-like feature consists of layers of gravel, sand, silt, clay and material from the Bituminous Marl Unit. Some of this material consists of basalt pebbles characteristic of the river alluvium.

Landslides. Adit A-1 and drill hole M-6 on the left side of (identified as landslide on the map "Geology of the Maqarin Dam Embankment Area," Exhibit E-9) the valley encountered a block of weathered material from the Bituminous Marl Unit that is underlain by and isolated from the bedrock of the valley side by cemented talus This block is considered to have slumped to its present position when the river had cut its channel to near its lowest level.

A landslide involving talus and chalky limestone (Exhibit E-9) has been observed along the access road and penetrated in drill holes M-9 and HQ-5. The depth to bedrock in HQ-5 and M-9 is approximately 20 m suggesting that this is a shallow slide.

Landslides are also found near the damsite in the Wadi Sidiin. These apparently formed when the base level of the Yarmouk River was at a higher level and are now inactive. They are shown on the "Maqarin Reservoir Geologic Map", (Exhibit E-24B).

Debris. Loose debris, consisting primarily of weathered material from the Bituminous Marl Unit, excavated during the construction of the Hijaz Railway in 1906, covers some the lower part of the left abutment. Higher parts of the left abutment are partly covered by debris consisting of material from Chalky Limestone Unit and basalt fragments. This material was excavated during the construction of the site access road.

Structure

Folding. The Maqarin Damsite is located on the northwest limb of a small northeasterly trending anticline as shown on the map of the "Maqarin Reservoir Geologic Map", (Exhibit E-24B).

At the site area beds strike approximately N35E and dip 5° NW. The angle of dip tends to locally steepen in the downstream direction. In the upstream direction the dip tends to flatten as the crest of the anticline is neared.

Faulting. Block faulting has been recognized near the Wadi Sidiin in the damsite area. The orientation (dip and strike) of this faulting, which bounds a graben, will be determined by future exploration. Faulting, or shedring has also been found in drill holes HV-5A and HV-7 which cross below the river channel.

Jointing. Two sets of prominently developed joints are present in the bedrock. These are a generally northwesterly striking steeply dipping joint set, which is commonly marked by calcite veins, and an east-west striking steeply dipping set. The more prominent of these joints are shown on the "Geology of the Embankment Area" (Exhibit E-9).

The calcite veins in the northwesterly striking joint set are a common feature of the Bituminous Marl Unit but tend to become less prevelant in the Chalky Limestone. Horizontally trending slickensides are also a common feature of these veins and brecciation of veins and of the material adjacent to veins has been observed. These joints (or veins) are generally spaced about 1/2 m apart although this spacing varies to over a meter.

The east-west striking joint set has been mainly observed in the Chalky Limestone Unit on the right side of the valley but is assumed to also be present on the left. Spacing of these joints is 1 m to 2 m.

Short cross-joints have variable dips and strikes. One of the more common sets of cross-joints strikes northeasterly and dips steeply to the southwest.

Relief joints striking, generally parallel to the valley and dipping toward the river, are found in the Bituminous Marl Unit on the left side of the valley. These relief joints are also observed on the right side of the valley but appear to be discontinuous and less prevalent.

Specifically these joint sets are:

Joint Set	Range in Strike	Range in Dip
Northwesterly	N 20 W to N 70 W	60 N to 60 S
Relief (left abut.)	N 35 E to N 75 W	25 N to 50 N
East-West	N 70 E to East-West	65 S to 80 N

Some random joints are also present. These generally are short and discontinous.

Weathering

Surficial weathering generally extends to shallow depths (2 m to 3 m) in the Bituminous Marl Unit, although it ranges to 11 m (as in shaft S-5). In outcrops and on valley sides weathering causes the beds of the Marl Unit to be generally light-brown, soft, friable, and chalk-like. Veins and seams of gypsum, which range to a thickness of 2 cm, as exposed in shafts S-1 and S-5, are common in this weathered zone. In extremely weathered areas, gypsum is estimated to constitute up to 10% of the rock volume, generally, however, the volume of gypsum is much smaller and appears to rarely exceed 1%. In some zones in the river bottom, weathering or alteration reduces parts of the Bituminous Marl Unit to a plastic clay.

The Chalky Limestone Unit is often deeply weathered as observed in drill hole HQ-4 where the depth of weathered rock is approximately 85 m. Drill hole HQ-4 is a vertical hole located on a talus covered slope, thus the thickness of the zone of weathered rock as measured normal to the surface

is considerably less. The weathered limestone is generally soft and friable, however, "case-hardening" often causes exposed surfaces of the limestone to become dense and hard as are seen in exposures along the road from the plateau to the camp.

Permeability of Foundation Rock

Relatively high permeabilities have been measured in portions of many of the drill holes. These high permeabilities generally are related to the near surface zone of open jointing and permeability generally decreases with depth.

Solutions cavities or channels, apparently related to faulting and/or jointing, have also been observed in some drill holes. Permeabilities are high in the intervals with solution cavities. Cavities have been observed at depths as great as 90 m in AR-1 and may occur at greater depths. Depth of cavity occurence will be determined during future exploration. This is a preface to statements made on p 54.

Ground Water

Level of Water in Joints and Fractures. The level of water in joints and fractures is low on the valley sides as indicated by the failure of drill holes HQ-4, M-1 and M-4 to reach this level. M-1 and M-4 are 80 m deep and HQ-4 is 98 m deep.

Perched water, however, may be present as indicated by water inflows into adit A-1.

Artesian Water Flows. Some drill holes, specifically M-6, M-7, AL-1, AR-1, BL-1, HV-1 HV-2, HV-3, HV-5, HV-5A, HV-6, HV-7 and HV-8, have encountered flows of artesian water. These holes are all located in or near the valley bottom. In drill holes AR-1, AL-1, HV-6 and HV-7, flows of

artesian water increase with depth. In drill holes M-6, M-7, HV-2, HV-5A, HV-6 and HV-7, artesian water was warm (up to 29°C). The increase in artesian flow with depth and it's warmth implies that joints or faults encountered in these drill holes may extend downward into water-bearing zones or aquifers as described in the section on stratigraphy.

Part, if not all, of the artesian flow, in drill holes BL-1, HV-8, HV-3 and HV-5 may be attributed to confinement in previous zones in the cemented alluvium.

Springs. Several small springs are located near river level on the right side of the valley. These springs are generally located near the contact between the talus and alluvium. Water issuing from these springs is moderately sulfurous suggesting that the spring water has played a role in the oxidation of the pyrite (ferric sulfide) contained the Bituminous Marl Unit.

Small intermittant springs were found at the contact of the cemented talus and Bituminous Marl Unit along the Hijaz Railway on the left side of the valley. These springs are responsive to rainfall and represent bank storage in the talus.

Sampling and Testing of Foundation Rocks

Tests consisting of unconfined compressive strength tests, petrographic examination, and chemical analyses have been performed on samples of foundation rocks from drill holes. A summary of the results of these tests, which include those performed during this investigation and preceding investigations, follows. The summary data has been tabulated on Tables E-4, E-5, E-6 and E-7.

Unconfined Compressive Strength. Fourteen unconfined compressive strength tests have been performed on drill core

samples from the Bituminous Marl Unit. (Table E-4). The strength varied between 45 kg/cm^2 and 403 kg/cm^2 and averaged 245 kg/cm^2. Five of these samples (S-prefix) were examined petrographically.

Triaxial Compresssive Strength. One triaxial compressive strength test was performed on a sample of weathered material from the Bituminous Marl Unit. This test gave an angle of friction (Ø') equal to 28° and a cohesion (C') equal to 6 kg/cm^2. Description of the test is in Appendix D.

Petrographic Examinations

i. Bituminous Marl Unit. Twenty-nine samples from the Bituminous Marl Unit marly (argillaceous) bituminous limestone) have been examined petrographically. This number includes four samples of material from clay zones, six samples with calcite veins, and four samples of weathered material.

The unweathered bituminous marly limestone is generally very fine-grained, grey or brown, pyritic, non-crystalline, argillaceous, bituminous limestone. The bituminous matter occurs as a prevailing stain. The samples contained abundant tests of pelagic foraminifera. Very fine-grains of quartz were reported in three of the samples. While the sample is generally non-crystalline, a few rhombs of calcite or dolomite have been observed in some of the samples.

The weathered marly limestone is fine-grained, light-grey to white, fiable, chalk-like limestone.

The material in the clay zone in HV-5 is a dark-grey, plastic clay, (Plastic Limit 30%, Liquid Limit 86%).

The clay fraction in samples of clay from drill hole HV-7 was 34-44% and the silt fraction 10-30%. Clay minerals included kaolinite, chlorite and montmorillonite.

ii. Chalky Limestone Unit. Three samples of the Chalky Limestone Unit were petrographically examined.

The unweathered Chalky Limestone consists of greyish-white, microgranular, non-crystalline to cryptocrystalline, slightly argillaceous, non-friable, porous chalky limestone. The sample contained pelagic foramininfera and radiolaria.

Chemical Analyses

i. Bituminous Marl Unit. Fifteen samples from the Bituminous Marl Unit were chemically analyzed. This includes a sample of clay.

The $CaCO_3$ content of the unweathered material from the Bituminous Marl Unit varied between 26% and 79%. In two of the samples, loss on ignition of the insoluble fraction, which is mainly organic matter, was 16% and 20%. The residue is mainly clay.

A sample from the clay zone in drill hole M-6 contained 5% $CaCO_3$. The remaining material was considered to be mainly clay.

Engineering Geology of the Maqarin Dam

General

The conceptual design for the initial project (Stage II, dam crest El. 158 m) consists of a zoned embankment dam with an inclined impervious core and a free-draining downstream shell; a grout curtain and drainage curtain arrangement to control underseepage and abutment seepage; and a gated spillway on the left abutment to control reservoir levels. River diversion during construction is provided by a diversion tunnel through the left abutment and appropriate cofferdams. The relationship of the proposed structures to the site geology is shown in plan on Exhibit E-8A and on various geologic sections. This initial dam will be designed to permit its raising to a high level (el. 200 m) at a later time.

The design for the raised dam with crest elevation 200 m, consists of zoned embankment and impervious core carried to the higher elevation; and with appropriate extensions of the grout and drainage curtains. A new spillway would be provided on the left bank. River control during construction while no spillway is operative will be by releases through the low level outlet and powerplant. The relationship of the proposed high dam structures to the site geology is shown in plan on Exhibit E-8B and on various geologic sections.

The discussion which follows first describes the general geologic considerations which must be applied to design and layout of both the initial and the raised projects, and then describes separately the specific engineering geologic conditions for the two phases of the project development.

General Geologic Considerations for Design and Layout of Structures

Positioning of Civil Structures. The layout of civil structures for the initial (Stage II) project is well adapted to the topographic conditions. The dam axis is located along a reach of the valley that is locally constricted by the broad left side nose. Positioning the spillway on the left side results in greatly reduced excavation as compared to a right side location. The positioning of the power structures takes advantage of the river configuration to place the proposed powerplant well downstream of the dam thus maximizing the available head at the damsite. The length of the power tunnel for the selected arrangement is only slightly longer than required for a powerplant location close-coupled to the dam.

The positioning of the embankment, and the positioning of the impervious core in particular, is under careful study in relation to defects (e.g. the pothole-like feature, clay zones, cavities, etc.) known to exist in the foundation rock beneath the river alluvium. Subsurface exploration has yielded substantial information on the general nature of these defects within the foundation area as are discussed in later sections of this report. However, additional exploration is required to examine possible interrelationships between these features and to more completely define their occurrence and distribution.

Future exploration will be used in selecting a geologically acceptable dam axis which will be relatively free from foundation defects. The exploration will also guide in the selection of the most practical methods for any required remedial foundation treatment. It also will guide in adjust-

ments in the location of the embankment so as to optimize foundation conditions for the core trench.

Foundation Characteristics and Foundation Treatment. Geological considerations for spillway line and grade are that all components should be founded on sound, unweathered bedrock.

The unweathered beds of Bituminous Marl Unit upon which the spillway weirs, retaining wall, chute and flip bucket will be founded, is adequate to support these structures.

Local areas of open joining that may be encountered in the foundations for spillway structures will be strengthened by consolidation grouting.

Possible adverse effects of relief joints (parallel to the slope) may require a system of rock anchors to insure stability of foundation.

Uplift pressures on the weir and on the retaining wall downstream of the grout curtain may require relief by drainage.

Hard weathered to fresh bedrock will form the foundation for the core. Foundation preparation will include excavation of all alluvium, talus, weathered or slabby rock, and gypsiferous rock from the core trench. Concentrated seepage will be prevented from occurring at the core-bedrock contact zone by slush grouting, dental treatment and by area or consolidation grouting. A deep grout curtain will be used to reduce seepage beneath the core and through the abutments. Extensive drainage curtains will be provided in both abutments downstream of the grout curtain to control seepage pressures.

The foundation bedrock, upon which the shells of the embankment will be founed, should be stripped of all talus, alluvium, significantly weathered and gypsiferous rock, and

slabby rock. This would permit inspection and treatment of the bedrock foundation as required.

Stability of Excavated Slopes. Relief joints, which are subparallel the slope, are common in the Bituminous Marl Unit in tne left abtument. These joints, dip as gently as 35¼ from the horizontal. The feasibility estimate has assumed that slopes will be excavated at 1.5H:1V. Further study of the stability of cut-slopes will be made during design.

The dip of the more prominent is generally steep and these joints will rarely be a factor in cut-slope design.

Underground Openings. Tunnel portals should be made so that the thickness of sound bedrock above the portal crown is equal to at least two tunnel diameter.

Cover over the tunnel will be greater than the two diameter thickness of bedrock designated for the tunnel portals.

Seismicity. The embankment and civil structure should be designed to withstand strong earthquakes. This is discussed in greater detail in Appendix J.

Initial (Stage II) Project - Dam El. 158 m

Main Dam and Cofferdams. The dam (el. 158 m) which may be raised to el. 200 m will be a zoned embankment. The el. 158 m dam will extend toe to toe for a distance of approximately 800 m and will have a crest length of approximately 500 m. The upper 40 m of the dam on the left side of the valley will abut into a retaining wall adjacent to the spillway approach channel and which forms a part of the gate structure and chute. These relationships are shown on the "Gelogy of the Maqarin Damsite" (Exhibit E-8A) and the "Section Along Crest of Dam - El. 158 m Dam" (Exhibit E-10) and the "Section Transverse to the Axis of the Dam" (Exhibit E-12).

The upstream cofferdam, which will be an approximately 30 m high embankment, is planned to be incorporated into a weight berm at the toe of the main dam. The dowmstream cofferdam, a 10 m high embankment, will be a separate structure.

i. Core Trench. The core trench will be excavated to hard weathered to fresh bedrock. This depth should be sufficient to reach the zone where joints related to surface weathering and relief phenomena are relatively closed and are free from fillings of surficial origin. Gypsum fillings in these joints will also be absent, or merely thin coatings. Overhangs and sharp irregularities in the excavation should be removed from the core trench excavation.

The surficial zone of weathered rock in the Bituminous Marl Unit ranges to a thickness of greater than 11 m (in shaft S-5) and may be locally thicker. However, it is anticipated that an average core trench depth of 15 m, as reckoned from the base of the talus, will be adequate to remove most of these weathered materials. Local more deeply weathered areas, shear zones and other foundation defects will be treated by deeper excavation and special dental treatment.

The slump block at the base of the left abutment (Exhibits E-9, and E-11) should be removed. Some shaping of the core trench may be required in this area to obtain a surface satisfactory for the placement of core material.

The Chalky Limestone Unit, into which the upper part of the core trench will be excavated, is generally more deeply weathered than the underlying marly limestone unit and often with open joints. In a road cut in the chalky limestone on the left side of the valley, only moderate weathering is observed at depths of about 5 m below the rock surface. Contrasting with this there is evidence of rather severe

weathering extending to substantial depths as described in the subsection of weathering. An average core trench depth of 20 m in chalky limestone has been selected for the feasibility studies. This depth must be verified and/or adjusted by future exploration.

Core trench side-slopes, which would be of a temporary nature, are expected to be generally stable a 1H:1V. However, as the core trench is deep, areas of unstable side-slopes may occur.

ii. Embankment Shells. The embankment shells will be constructed in an area that is underlain by the Bituminous Marl Unit bedrock in the valley bottom and lower slopes. This bedrock is overlain by talus and cemented talus on the valley slopes and by alluvium in the valley bottom. Bedrock forming the higher parts of the slopes consists of beds of the Chalky Limestone Unit. The Chalky Limestone either outcrops as cliffs or is covered by thin talus deposits. These relationships are shown on several of the geologic sections (Exhibits E-10, E-11, E-12, E-14, E-15, E-21, and E-22).

The talus varies considerably in its density and other physical characteristics, as is described in the section on "Geology of the Maqarin Damsite" and in Appendix D. These variations of physical properties are considered to be one reason for removing all talus from the shell foundation area and placing the shells on hard weathered bedrock.

Exploration in the channel area has shown that local clay zones and a pothole-like feature are in the foundation bedrock. The need to locate and examine these and other similar features which may exist is considered to be the primary reason for removing the alluvium and other materials which cover the bedrock. These materials will be removed from both the upstream and downstream shell areas.

iii. Cofferdams. The need to examine the bedrock beneath the shell of main dam makes it more practical to construct the cofferdams as separate structures. This is due to the difficulty that would be encountered in removing the alluvium in the river channel from the foundation areas of the cofferdams, a requirement if they are a part of the main dam.

Removing talus from the valley sides and nominal stripping of alluvium from the valley will, however, be required in preparing the foundations for these structures.

The upstream cofferdam will be incorporated into a weight berm.

Seepage Control and Drainage.

i. Grout Curtain Cutoff. An extensive grout curtain will be required to reduce the permeability of the foundation below the base of the core trench and within the abutments. For feasibility planning the grout curtain is shown to be 150 m deep beneath the valley bottom and lower valley slopes and 100 m deep in the higher slopes. The greater depth of the grout curtain in the valley bottom will be a part of the preparation of the foundation for the higher dam (el. 200 m). A grouting gallery beneath the core will permit grouting during construction or at a later time. Grouting galleries will also be excavated into the abutments.

The grout curtain is also shown to continue well beyond the end of the spillway weir on the left abutment and beyond the end of the dam on the right abutment. A preliminary layout of the grout curtain and grouting galleries is shown on "Geologic Section Along the Grout Curtain", (Exhibit E-17). However, because of the deep and poorly known effects of solution of the chalky and marly limestones, additional exploration will be required prior to the final design of the grout curtain.

ii. Consolidation Grouting. The primary permeability of bedrock is generally low. Permeability tests performed at depths below the surficially weathered zone generally yielded moderate to low permeabilities indicating that joints are surficial and closed at depth. It is however, anticipated that some open joints will extend into the core trench. Local consolidation or area grouting will be required to close these joints.

iii. Drainage Galleries and Drain Holes. Protection from seepage forces for the downstream parts of both abutments and the spillway will be needed. The feasibility layouts provide two levels of drainage galleries from which drainage curtains will be constructed. The preliminary arrangement of the drainage galleries and drain holes is shown on "Section Along Drainage Curtain (Exhibit E-16).

The free-draining chracteristics of the downstream shell (or of elements of the downstream shall) should provide additional protection from seepage forces.

Spillway

The spillway will consist of an unlined approach channel, a gated weir approximately 50 m wide with three 12.5 m by 15 m gates and two separate chutes. The dam will abut into a retaining wall on the spillway gate structure and approach channel. The arrangment is shown on the "Geology of the Maqarin Damsite", (Exhibit E-8A) and the "Section Along Right Wall of right Spillway", (Exhibit E-18) and other geologic sections. The spillway is described in the Preliminary Design Report, Appendix I.

i. Approach Channel. The approach channel will be excavated into the Basalt Flows, the Chalky Limestone Unit

and the Bituminous Marl Unit. The Bituminous Marl Unit will form the floor for the approach channel and provide the foundation for the retaining wall on the right side of the approach channel.

The three units into which the approach channel will be excavated are intersected by steeply dipping joint sets. Some faults may also be present. Relief joints dipping as flatly as 35° may also be present, therefore, side-slopes for the approach channel are designed at 1.5H:1V as has been described in the subsection on "General Geologic Considerations".

ii. Retaining Wall. The large retaining wall, into which the upper part of the left side of the dam will abut, forms the right side of the approach channel. In effect, this wall will be the abutment for the uppermost 40 m of the dam embankment. The wall extends for 100 m along the dam embankment and also forms one side of the spillway gate structure and of the spillway chute. This structure is shown on the "Section Along the Right Wall of the Spillway", (Exhibit E-19) and "Section Along Crest of Dam" (Exhibit E-10).

The foundation for the approach channel wall will be the Bituminous Marl Unit. Unconfined compressive strength tests indicate that the unweathered beds of the Marl Unit have sufficient strength to support the wall. Future exploration will be required to determine the depth to unweathered Marl beds.

Relief joints which dip toward the river may be present in the foundation. The butressing action of the dam on the slope below the wall will, in general, counter this adverse element. However, local anchoring the wall with grouted anchors may be required. The design of the system of anchors will follow additional subsurface exploration for this structure.

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iii. Gate and Weir Structure. The Bituminous Marl Unit will be the foundation rock for the spillway weir (see "Section Along Crest of Dam," Exhibit E-10) as has been previously described. Unweathered beds of this unit have strength adequate to support this structure.

Bituminous Marl Unit beds dip gently (5°) downstream. This unit in an unweathered condition has a massive appearance with bedding planes widely spaced and with adjacent beds apparently strongly bonded. While bedding partings have not been observed, it is considered to be premature to discount their presence. The spillway chute, which begins its steep incline near the weir, will undercut the gently dipping bedding. Any bedding partings that may exist could cause potential instability of the structure. To counter this type of situation rock anchors have been included in feasibility estimates.

Relief joints, which dip toward the river, may be present in the foundation area. The adverse effects of these joints should be largely countered by buttressing of the dam embankment. The more prominent joints are generally steep and are not expected to be a factor contributing to instability of the weir. Some faulting may also be present. This will have an adverse effect on foundation strength which will require attention and possibly treatment during construction.

Excavated slopes for the weir are continuations of the approach channel slopes and are expected to be stable at 1.5H:IV.

iv. Spillway Chute. The spillway chute (See Sections K and L; Exhibits E-20 and E-21) will be constructed on unweathered Bituminous Marl Unit beds. The location of the spillway near the valley side may be where relief joints,

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which dip toward the river, could adversely affect the chute's stability. To counter these conditions system of rock anchors may be locally needed to stablize chute walls and floors. The chute will also cross several faults which, at least locally, could reduce foundation strength.

Cut-slopes for the chutes are continuous with the slopes for the approach channel and for the gate and weir structure. As with the other slopes, these slopes are expected to be stable at 1.5H:IV.

v. Spillway Bucket. Foundations for the bucket will be on beds of the Bituminous Marl Unit. (See Section D, Exhibit E-13) Beds of the unit have adequate strength to support these structures. Grouted rock anchors have been included in the feasibility layouts. These anchors will provide protection as needed against potential sliding due to the combination of horizontal forces and the gentle dip of bedding.

The area below the buckets will be paved with anchored concrete slabs to prevent erosion during periods of low spillway discharge.

vi. Plunge Pool. The plunge pool must not form so as to undermine the deflector bucket or the downstream toe of the dam. Its approximate location on is shown in the geologic sections "Transverse to the Axis of the Dam", (Exhibit E-12) and "Along Right Wall of Spillway" (Exhibit E-19).

It is considered unlikely that the gently dip of bedding will be a significant factor in the errosive action which will determine the size of the plunge pool.

Diversion Tunnel

The diversion tunnel, which will be concrete lined throughout its length, will be in the Bituminous Marl Unit ("Section Along the Diversion Tunnel", Exhibit E-23). As

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has previously been described, this rock is soft to moderately hard, very thickly bedded, and moderately strong. It dips gently (5°) to the southwest. While it is moderately jointed, joints are generally closed at depth.

These factors (strength, dip of bedding, bed thickness, etc.), result in the unit possessing favorable tunnelling and support charactertstics. These favorable characterstics have been demonstrated in the exploration adits.

Ground water, because of the generally tight joints, will probably not be a serious problem. Joints in some places, however, may be open and cavities have been reported in some drill holes. Thus there could be local troublesome inflows of water accompanied by instability of some portions of the tunnel.

For feasibility studies it is estimated that approximately 20% of the tunnel length may require steel supports. These are expected to be concentrated near the portals and in local areas of close jointing coupled with water inflows.

Future Foundation Exploration

Future exploration at the Maqarin site will initially focus on locating a dam axis that is acceptably free of foundation defects. The known defects, consisting of a deep pothole-like feature, clay zones, cavities in the foundation rock, and flows of warm artesian water, have been found in the channel area. Exploration to date, however, has been inadequate to definitely determine origin, possible interrelationships and distribution of these defects. On-going exploration will be to locate these defects and to determine methods of treating them. Location of the dam axis will follow the determination of the above factors and will be selected in an area where potential foundation defects are absent or minimal.

Approximately 4 lines of deep drill holes located near the valley bottom and oriented transverse to the direction of the river will be required to locate foundation defects permitting final selection of the dam axis. Additional drilling will be required on the valley sides to confirm the acceptability of the selected axis.

The thick soils, the basalt flow, presence of faults and the underlying beds of the weathered Chalky Limestone Unit of the left abutment ridge may cause the abutment to be permeable and may require special treatment to reduce reservoir seepage. Exploration will be required to determine geologic conditions in this area. A line of deep drill holes will be required for this purpose.

Foundation characteristics, stripping depths and data for foundation treatment needed for the design of dam embankment and attendant structures will be determined following positioning of the dam axis. Extensive exploration consisting of drill holes, adits and shafts will be required for these structures.

Construction Materials

General. Most of the dam embankment will be constructed of materials obtained from deposits of overburden and bedrock. Concrete will be made using aggregates manufactured from locally quarried rock. Continuity and composition of these deposits are controlled by factors of origin. Hardness and strength of materials obtained from these deposits are controlled by origin and effects of weathering.

The various units of overburden and bedrock, as they are found in the area, have been described in the section "Geology of the Maqarin Damsite". Results of laboratory tests performed on samples of these bedrock and overburden

units as they pertain to their use as construction materials are contained and described in Appendix D.

Factors of origin and effects of weathering as they relate to the usefulness in construction of materials obtained from the various deposits are described below. Distribution of these formation are shown on the "Geology of Maqarin Damsite Area", (Exhibit E-8).

Formations

i. Bituminous Marl Unit. Samples of material from the Bituminous Marl Unit indicate that the unweathered material would generally be moderately strong. The material, however, weathers fairly rapidly to a relatively weak material and tends to exhibit shaly partings.

A large volume of the weathered and weaker material from the Bituminous Marl Unit will be excavated for founding the dam embankment and spillway chutes. The relatively weak condition of the weathered material generally excludes it from use in those parts of the dam embankment that require materials of high shear strength. Its tendency to weather rapidly probably excludes the use of the unweathered material for the dam embankment and most other construction purposes.

ii. Chalky Limestone Unit. Material obtained from the Chalky Limestone Unit may be harder and stronger than that obtained from the Bituminous Marl. The Chalky Limestone, however, generally is not as hard and as strong as the basalts.

Chalky Limestone has been used locally as concrete aggregate. It, however, is generally absorbent and may be too soft and too weak to make a satisfactory concrete.

iii. Basalt. The extensive basalt flows on the right side of the valley have resulted in the formation of a thick

deposit of hard strong basalt rock. Horizons of softer material have formed at the contacts between individual flows. These softer materials are due to weathering of the upper surface of older flows, and to concentrations of vesicles at the tops and bottoms of flows. Flow are jointed and some weathering has occurred along joints.

In general, the basalts of the right side of the valley are hard and strong. An as yet undetermined volume of basalt is also located on the left side of the valley. Core holes in this basalt, which have consisted of HQ-2 and HQ-3, indicate that parts of the basalt are soft and weathered.

Petrographic Analysis have been made of samples of the basalts from both sides of the valley. These analyses, which are summarized in Table E-5, indicate that satisfactory concrete can be made using aggregate manufactured from the basalts.

iv. Alluvium. Recent alluvial deposits of the Maqarin Valley are composed of silty sands and gravels. In general the larger clasts are hard rounded pieces of basalt with a few pieces of limestone. The finer or sand fraction, which constitutes approximately 24% of the alluvium, consists of grains of basalt, chert and chalky limestone. In samples tested it has a high (approximately 17%) silt content.

The chert in the sand fraction of the alluvium may be reactive with cement, thus making this fraction of the alluvium unattractive as a concrete aggregate. Compacted alluvium, however, may be suitable for constructing the embankment.

v. Talus. Thick (up to 20 m) accumulations of talus mantle parts of the valley side. In general, the talus is a poorly sorted (but well-graded) deposit of silty, clayey and sandy gravel. The clasts consist of weathered limestone and

basalt. Some boulder sized blocks of basalt are also present. The poor sorting of the deposits and the relatively high percentages of fine materials make the talus a potential source of impervious fill. The larger pieces of limestone will probably break down during excavation and handling.

vi. Alluvial Terraces. Terrace deposits of alluvial origin occupy benches bordering the Yarmouk River. In general, these deposits are similar in composition and in size of constituent particles to the deposits of Recent Alluvium in the valley bottom. They, however, are older alluvial deposits and as a result tend to be more weathered. This generally causes these deposits to have higher percentage of fine-grained materials than Recent Alluvium.

Alluvial terrace materials have been tested and are being considered as sources of impervious borrow.

vii. Residual Soils. Soils cover the higher terrace levels and the plateaus above the Yarmouk Valley. In general, they are residual but have a component of aeolian material.

These soils are brick red and consist of silty clays which may make them suitable for impervious borrow.

Ultimate Project - Dam Elevation 200 m.

General. Raising the Maqarin Dam has been anticipated in the design of the dam embankment, of the grout curtain and of the drainage curtain.

Construction scheduling for the dam raising will provide for the lowering of the reservoir to el. 85 m and then adding to the embankment and constructing a new spillway.

In general, the arrangement of structures for the el. 200 m dam is similar to the arrangement for the el. 158 m dam. This is shown on the "Geology of the Proposed Maqarin Dam with Crest El. 200 m", (Exhibit E-8B).

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Design details and construction procedures for the raising will be determined in part from experience gained during construction of the el. 158 m dam.

Main Dam Embankment. The raised embankment (See Section C, Exhibit E-12) will be a relatively simple modifications of the Stage II (el. 158 m) embankment and generally should encounter conditions that are similar to those encountered in construction of the lower dam.

The core trench on the right abutment (See Section P, Exhibit E-22) will be a continuation of the core trench for the low dam. Criteria developed during design and construction of this feature for the low dam (el. 158 m) will apply. The core trench on the left abutment will pass over the approach channel for the low dam (el. 158 m) and end below the retaining wall for the el. 200 m spillway approach channel. Most of the excavation for this continuation of the core trench will have been made for construction of the low dam approach channel.

Construction of upstream and downstream shells on the right abutment will generally follow procedures and criteria developed during design and construction of the low (el. 158 m) dam. These shells on the left abutment will cover the el. 158 m. dam spillway and cut-slopes made for this structure.

Seepage Control and Drainage. The grout curtain for the el. 200 m. dam will be a continuation of the existing (El. 158 m) dam's curtain (Exhibit E-17). It is anticipated that higher part of the curtain will be constructed from adits excavated on both sides of the valley. Existing adits (for the El. 158 m dam) in the left abutment should be continued for a substantial additional distance for the

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el. 200 m dam. This arrangement is shown on Geologic Sections G and H, (Exhibits E-16 and E-17).

Two additional drainage galleries will be constructed for the raised dam (Exhibit E-16). The arrangement of drain holes will generally be similar to that previously described for the el. 158 m dam.

Spillway. Criteria used to set line and grade for the spillway for the el. 158 m. dam should also apply to the high dam spillway. Anchoring of the retaining wall, weir, chute and bucket should be similar to that used for the low dam spillway.

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Geology of the Maqarin Reservoir

General

The reservoir, which will be formed by the Maqarin Dam, will inundate, in addition to a part of the Yarmouk River Valley, the lower reaches of the Wadi Shallala, the Wadi Ehrer and the Nahr Allane.

Current project studies have considiered a range of maximum normal reservoir levels varying from elevation 150 m to 195 m. In either of these cases, the reservoir level will fluctuate approximately 15 m.

Distances the reservoir will extend up the Yarmouk River will vary between 5.0 km and 6.5 km for the lowest and highest reservoirs studied. Distances up the different side wadis will also vary correspondingly. These relationships are shown on the "Maqarin Reservoir Geologic Map", (Exhibits E-24A and E-24B).

Stratigraphy

The entire reservoir, except for small areas of the Bituminous Marl Unit near the damsite, will be in the Chalky Limestone Unit or overburden. Both of these bedrock units are described in the section on the "Geology of the Damsite". The overburden units are also generally similar to those described for the site, with the exception of the landslides. Landslides will be described in the section on Stability of Reservoir Slopes.

Structure

Strata of the bedrock series are generally nearly flat lying or generally dip gently northeasterly.

No major faults have been observed, however, some faulting should be expected.

Joint patterns generally are similar to those observed at the damsite. Through-going joints generally are widely

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spaced (over 1 m) and steeply dipping to vertical. Joints as observed in cliff faces, generally appear to become closed with depth.

Stability of Reservoir Slopes

Existing Landslides. A few small landslides have occurred on the slopes of the Yarmouk River and wadis forming the reservoir. These have been delineated on the "Geology of the Maqarin Reservoir" (Exhibits E-24A and E-24B). In general, these slides are rotational across bedding. Their total volume is small.

Stability of Existing Slopes. Slopes in several areas bordering the reservoir are moderately steep and often rise to elevations considerably higher than reservoir level. Currently these slopes are stable. However, changes caused by reservoir filling could in combination with adverse geologic conditions (low rock strength, unfavorable bedding dip direction and/or joint dip direction) result in landslides. Three areas, which are considered to be potentially most hazardous and one other area are analyzed and discussed below. These areas were considered to require separate discussion because of their proximity to the proposed dam, however, none appear to be hazardous to the project.

i. Confluence of the Wadi Ehrer and the Yarmouk River: This area, which is approximately 2 km upstream of the dam axis, consists of a topographically isolated ridge (Exhibit E-24A). The ridge consists of the Chalky Limestone Unit overlying the Bituminous Marl Unit as shown on Section K (Exhibit E-26). The area of interest lies on the southeastern limb of the anticline near the damsite with beds striking N30°E and dipping approximately 10°SE. While this area possesses some of the elements that could create instability,

the relatively small volume of material (maximum estimated to be 4,000,000 m^3) that could be involved, with respect to the volume of the reservoir would have an insignificant effect on the Project. Moreover, the possibility of such a slide occurring as a single, sudden failure is remote.

ii. Confluences of the Wadi Shallala and the Yarmouk River: This area, which is approximately 2-1/2 km upstream of the dam axis, is a reach of the Wadi Shallala where the strike of bedding trends parallel to the wadi, and bedding planes, in effect, have been undercut. The slopes of the wadi in the area are steep, and rise to moderate heights (El. 400 m) above the reservoir level (Section I, Exhibit E-25). Beds strike approximately parallel to the wadi and dip 50°SE. The wadi is entirely in the thick to very thick-bedded relatively strong Chalky Limestone. The relatively high strength of the limestone and the gentle dip of bedding make if unlikely that a large slide will occur in this area.

iii. Confluence of the Nahr Allane and the Wadi Ehrer: In the reach of the Nahr Allane near its confluence with the Wadi Ehrer (Section H, Exhibit E-25) high steep slopes border the nahr. Bedding is nearly flat. Through-going joints could result in small slides, however, there is little possiblity of a large landslide occurring.

iv. Narrow Ridge Between the Wadi Ehrer and the Yarmouk River: Much of this ridge (Section L, Exhibit E-26) will be submerged by the planned reservoir and presents no slope stability problems for the proposed reservoir. The area near the two tunnels on the Hijaz Railway (Section C, Exhibit E-25) rises to a moderate height above the planned reservoir. Bedding dips, however, are gentle (less than 5°) a situation which is not conducive to the development of landsliding.

v. Other Potential Areas of Large Landsliding: Other reaches of the proposed reservoir may have some potential for developing large slides. These areas, however, are generally remote from the dam and will be only slightly influenced by the reservoir.

From the above analysis it is considered that no significant damage to the project will result from slides in the reservoir.

Watertightness of the Reservoir

While much of the reservoir is in the Chalky Limestone Unit, the down-cutting of the Yarmouk River and its tributaries has been rapid and no extensive subterranian drainage system appears to have formed.

Springs in the Chalky Limestone Unit are generally related to jointing and are small.

Large springs in the reservoir areas are generally located at the contact between the Chalky Limestone and the Basalt Flows and apparently are related to fracture permeability of the basalt and the decrease in permeability at the Basalt-Chalky Limestone Unit contact zone. Exposures of this contact, except in the left abutment ridge at the damsite, have been found to be generally higher than the planned reservoir level. However, if the contact, which would expose permeable basalts to reservoir waters, is found during the on-going investigation to be lower than the reservoir level, remedial measures to prevent reservoir leakage may be required.

Potential seepage through the left abutment ridge of the damsite will be controlled by grout curtain and drainage curtain of the dam.

Geology and Evaluation of the Maqarin Powerplant

General

The powerplant for the Maqarin Dam would be located approximately 1.5 km downstream from the dam axis. This power development (Exhibits E-27A and E-27B), would consist of a 3.2 m (finished) diameter concrete lined power penstock tunnel approximately 1,900 m long, a concrete lined approximately 150 m deep and a powerplant. The mechanical details of this arrangement and description of these structures is contained in the Main Report. Summary geological data, based on an extrapolation of the subsurface exploration performed at the damsite and geological mapping, is presented below.

Power Intake

Talus, possibly on the order of 20 m thick, covers the area in which the power intake will be located. This material overlies the Bituminous Marl Unit. It is anticipated that the talus will be removed from the intake area so that the structure will be founed on the unweathered Bituminous Marl. Talus will be also removed from slopes above the intake.

Power Tunnel

The power tunnel will be driven through the gently dipping beds of the Bituminous Marl Unit. These beds are expected to be similar to those observed at the damsite. As such, they are expected to have characteristics generally favorable for tunneling.

Only minor faulting has been observed in the site. However, as outcrops are poor, some additional faulting may exist that was not observed. If faulting is encountered, it would hamper the tunnel's construction.

The tunnel is expected to be generally lower than the level of ground water occurrence. This is not expected to

be a particularly adverse situation, although, some water inflows along open joints and/or faults may hamper mining operations. The bituminous nature of the rock being excavated could also result in hazardous conditions due to hydrocarbon gasses.

Some support will be required for the tunnel, however, the Bituminous Marl Unit appears to possess good natural support characteristics so support requirements are not expected to be excessive.

Gate Shaft

The gate shaft will be excavated partly in the Bituminous Marl Unit and partly in the Chalky Limestone Unit (Exhibit C-27B.) No unusual support or excavation problems are anticipated as based upon data from the exploration at the damsite. However, subsurface exploration will be needed to determine excavation and support characteristics for design purposes.

Powerplant

The powerplant will be constructed in the river bed at the base of a moderately steep slope (Exhibit C-27B). Much of this slope, which slopes approximately 30°, is covered by what appears to be a thin (less than 5 m thick) deposit of talus. This will be removed from above the powerplant. The bedrock material, upon which the powerplant will be founded is a part of the Bituminous Marl Unit. In general, these beds possess adequate strength to support this structure. However, subsurface exploration will be needed in the design stage to confirm this assumption of strength.

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Geology and Evaluation of Conveyance in the Yarmouk River Channel

General

A scheme for conveying water to the East Ghor Main Canal is by an uncontrolled flow in the natural channel of the Yarmouk River to the diversion to the Canal, (Exhibits E-28A, E-28B and E-28C). For Stage II development, this diversion will require a low (5 m high) Diversion Weir at the current Yarmouk Diversion Site near Adasiye.

The ultimate development of the water resources will require raising the Maqarin Dam and the construction of a dam and powerplant near the Wadi Khalid Damsite (or Khalid Storage Site).

Appraisal level studies of the diversion structure at the Yarmouk Diversion Site and of the Khalid Railway Station Damsite and Powerplant Site have been made ane are described in sections that follow.

Conveyance in the Natural Stream Channel

Flow conditions in River channel caused by construction of the Maqarin Dam will be a change in the velocity of the water and a reduction of sediment load. These changes are expected to have a negligible effect on the effectiveness of the river channel as a conveyance route.

Construction of a dam at the Wadi Kahlid Site will result in a reservoir in the Yarmouk River Valley extending to the Maqarin Damsite and an additional reduction in the velocity of the water and sediment load. This additional reduction in water velocity and sediment load would have insignificant effects.

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Geology and Evaluation of the Khalid Damsite

General

The Wadi Khalid Damsite, (Exhibit E-28B), is approximately 20 km downstream of the Maqarin Damsite and below the confluence of the Wadi Raqqad with the Yarmouk River. It was investigated by the Harza Engineering Company - Michael Baker Inc. consortium in 1955 as has been described in the subsection on Previous Investigations. According to the Harza-Baker Report, this site is favorable for the construction of a dam. The damsite has been studied at an appraisal level during this investigation and the descriptions that follow are largely from the Harza-Baker Report. The conceptual layout at the project and the geology of the site are shown on the "Geology of the Wadi Khalid Damsite" (Exhibit E-29).

The site is in a narrow (200 m wide) portion of the Yarmouk River. The Jordanian side of the river valley is a steep slope disected by small drainage channels. This slope lies midway between the large Wadi Khalid (upstream) and another sizeable drainage (downstream) as is shown on the "Geology of the Yarmouk River", (Exhibit E-28B). The Jordanian side would be the left abutment for the proposed dam. The powerplant and diversion tunnel would be located on this side of the river.

The Syrian side of the valley at the site has several prominent terraces. The lowest of these terraces, into which the right end of the dam would abut, is about 115 m above river level and represents an episode of valley widening followed by river aggradation. The spillway would be excavated in and founded on the formations forming this terrace.

Geology of the Damsite

Bedrock at the site is a part of the Chalky Limestone Unit as described in the section on "Geology of the Maqarin Damsite."

At the Wadi Kahlid Damsite, this unit is white to light grey, bedded, dense, firm to hard, slightly to highly bituminous chalk (Chalky Limestone Unit). The unconfined compressive strength, based on 102 drill core samples varied from 75 kg/cm^2 to 634 kg/cm^2 and averaged 288 kg/cm^2. The limestone apparently has a relatively low primary permeability. The weathered limestone, which is found on valley sides, apparently has a high permeability. Open joints or possibly small solution channels result in local moderate to high permeability in the valley bottom. The limestone as shown on the map of "Geology of the Yarmouk Valley" (Exhibit E-28B) dips gently to the northwest.

On the right side of the river the bedrock is overlain by a nearly flat lying alluvial terrace (Pre-Basalt Conglomerate of the Harza-Baker Report) that varies to 18 m thick. This alluvial terrace consists of pebbles and cobbles of basalt, limestone, and chert in a matrix of coarse to medium sand. In places the deposit is moderately to well cemented with calcite and iron oxide. The alluvial terrace is generally permeable.

A series of basalt flows (Second Valley Flow of the Harza-Baker Report) overlies either the alluvial terrace or the Chalky Limestone on the right side of the river. The flows, while nearly horizontal, dip of 2° to 3° in a downstream direction. Basalt forming the flows is dark grey, massive, dense, and varies from slightly to highly vesicular. Cavities and other voids usually are found along the contacts between individual flows and at the contacts with the alluvial

terrace and with the Chalky Limestone. Columnar jointing has developed in some of the flows. In some cases, the joints are filled or partly filled with clay. Individual flows vary from 2 m to 5 m thick and the series varies to a 40 m thickness. The series is generally permeable with the permeability being attributed to open joints and contacts between flows.

An alluvial terrace deposit located on the right side of the river, consisting principally of debris from the Chalky Limestone Unit (Chalky Limestone Conglomerate of the Harza-Baker Report), overlies the series of basalt flows. The deposit, which is nearly horizontally layered, varies between 27 m and 36 m thick, consists of white, poorly sorted, fragments of chalky limestone and chert in a fine-grained matrix of chalky limestone. Permeability tests in drill holes at the site indicate that this deposit is permeable.

Basalt flows (First Valley Flow of the Harza-Baker Report) outcrop on the right side of the valley at elevations above the crest (el. 5 m) of the proposed dam. These underlie and form a terrace which is approximately 150 m above the river. This basalt flow is a part of an older flow that partly filled the Yarmouk River Valley when it was in an early stage of formation.

Talus consisting of detritus from underlying and topographically higher deposits, covers parts of the slopes on both sides of the valley. The talus is described as consisting of fragments of basalt or chalky limestone in a matrix of silt and clay. In the right abutment area talus ranges to 20 m thick and in left abutment area, to 15 m thick.

Soil, (stoney, clayey soil of the Harza-Baker Report) residual and transported, overlies the alluvial terrace of

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chalky limestone debris and the basalt flows. The soil is a fat clay with pebbles and cobbles of basalt and chalky limestone scattered in the clay. The deposit varies from 1 m to 3 m thick.

Engineering Geology of the Damsite

The dam envisioned at this site would be a zoned embankment approximately 90 m high, (Exhibt E-30). The dam's spillway would have a gated weir and would be located on the right abutment. River diversion would be through a lined 5 m diameter (finished) tunnel on the left side of the river. This tunnel would also serve as the power tunnel for the powerhouse and to release irrigation waters.

Main Dam. The main dam, (Exhibit E-30), would have beds of the Chalky Limestone as its foundation material on the left side of the river and in the valley bottom; and beds of the Chalky Limestone Unit, alluvial terraces and basalt flows on the right of the valley. This is shown on "Section Along the Axis of the Dam", Exhibit E-30).

It is anticipated that talus would be removed from the valley sides in the embankment area. Loose and slabby material and material affected by near surface open jointing would also be removed from the core area to form a core trench. Cut-off for the dam in the valley bottom would be in a core trench in the Chalky Limestone bedrock. The shell in the valley bottom would be constructed on alluvium. This is shown on the "Section Transverse to the Axis of the Dam", (Exhibit E-30).

A grout curtain would be required to reduce the permeability of the bedrock and formations forming the foundation for the dam. The Chalky Limestone is considered to be amenable to sealing by a conventional grout curtain. However,

the alluvial terrace materials and the series of basalt flows are permeable. As these units are extensive on the right side of the valley they may be difficult to remove. Additional studies will be required to develop methods for making this abutment watertight.

It is anticipated that project design will include drainage adits in the abutments to control seepage pressures.

Spillway. The anticipated spillway would have a gated weir, concrete lined chute and a deflector bucket. These relationships are shown on the "Section Along the Spillway Centerline", (Exhibit E-31).

The spillway approach channel would be excavated partly in the alluvial terrace derived from the Chalky Limestone Unit and partly in the series of basalt flows. Subsurface exploration will be required to evaluate the excavation characteristics and to determine cut-slope design in the formations.

The gate and weir structure would be founded on the series of basalt flows. While no foundation defects in the basalt flows that are impossible to correct are anticipated, exploration to determine foundation characteristics of the formation, to develop means of controlling uplift pressure on the weir, and to design a stable structure will be required.

The spillway chute would be founded on the series of basalt flows, on the alluvial terrace and on beds of the Chalky Limestone Unit. While it is anticipated that foundation defects in these rocks can be corrected to permit construction of the chute, subsurface exploration will be required to determine design parameters.

The deflector buckets would be constructed on the Chalky Limestone Unit. The Chalky Limestone will probably

be sufficiently strong to support this structure. Subsurface exploration will be required to evaluate formation strength at the bucket's location and to determine design parameters.

Diversion Tunnel. The diversion tunnel, (Exhibit E-31), which would also be designed to permit irrigation releases and to serve as a power tunnel, would be located in the left abutment. This is shown on the "Section Along the Diversion Tunnel", (Section W, Exhibit E-33). The approach and exit channels, for the tunnel would be in talus and alluvium and the tunnel's portals which would be Chalky Limestone. Susurface exploration to determine the contact between the talus and Chalky Limestone will be required to locate the portals.

The Chalky Limestone is generally considered to have favorable tunnelling characteristics and to require only conventional tunnel support systems. Exploration, however, will be required to confirm tunnelling characteristics and support requirements.

Powerplant. The powerplant would be founded on the Chalky Limestone, (Exhibit E-32). The Chalky Limestone is considered to possess strenght adequate to support the powerplant. Subsurface exploration will be required to confirm this and to determine configuration of the sound bedrock surface.

Geology of the Reservoir

The Yarmouk River has, throughout the reservoir area of the Wadi Khalid Damsite, eroded a steep sided valley into gently dipping strata of the Chalky Limestone Unit and into the overlying basalt flows. In some places basalt have flowed down the valley when the river was at a higher elevation. There basalt flows are frequently underlain and/or

overlain by partly cemented terrace deposits. Talus covers parts of some valley slopes and the valley bottom is filled with alluvium. These relationships are shown on the "Geology of the Yarmouk River", (Exhibits E-28A and E-28B). Some small slides may occur on steep valley sides, however, the gentle dip of bedding indicates that massive slides are unlikely in the reservoir.

Springs, generally occur at the contact between the Basalt and the underlying Chalky Limestone Unit, or high on the valley sides in the Chalky Limestone. This indicates that the Chalky Limestone-basalt contact zone apparently acts as a relatively impermeable barrier in contrast to the permeable basalt. As previously described for the damsite, the series of basalt flows and the terrace gravels which underlie and overlie the basalt flows, are permeable. The Chalky Limestone may also be permeable due to open joints and solution cavities. However, as the valley at the damsite is deep, leakage from the reservoir is unlikely, except for water percolating through formations forming the damite.

Geology and Evaluation of the Yarmouk Diversion Site at Adasiye

General

As improved intake structure to the East Ghor Main Canal for the Stage II development will be located at the present Adasiye intake (Exhibit C-28C). This intake will consist of a low (5.5 m high) dike and a turn out to the tunnel leading to the EGMC.

Geology of the Site

The center and left side of the weir would probably be founded on alluvial gravels, and the right side on beds of the chalky Limestone Unit. The chalky limestone beds appear to be highly fractured, however, they should possess adequate strength to support the weir. The alluvial gravels are also generally strong enough to support this structure. Exploration, however, should be performed during design studies to insure that the design is satisfactory for any defects that may be present in the foundation.

Geology and Evaluation of the Conveyance Tunnel to the Wadi Arab

General

One of the schemes of conveying water from Maqarin Dam to the East Ghor Main Canal will be by a 27 km tunnel from the Maqarin Reservoir to the Wadi Arab. This tunnel will terminate at a penstock for a powerplant that will use the reservoir of the Wadi Arab Dam (studied by the Japan International Cooperation Agency) as its tailwater pool. This plan is diagrammatically shown on the "Geologic Map and Section of Maqarin Dam to Wadi Arab Conveyance Tunnel", (Exhibits E-33A and E-33B), and is described in the Main Report.

Conveyance Tunnel

The tunnel is expected to be driven through the same stratigraphic units as are present at the Maqarin Damsite, specifically the Chalky Limestone Unit and the Bituminous Marl Unit. These have been described in the subsection on Stratigraphy in the "Geology of the Maqarin Damsite Section". The rock types and geologic structural features, such as folding, jointing and faulting, are not expected to present unusual constraints. Cover over the tunnel is not excessive, varying between 80 m and 300 m. No exceptional difficulties are anticipated in constructing the relatively small 2.2 m (finished) diameter tunnel.

Between the Maqarin Damsite and the Wadi Arab, the units of the Belqa Series have a gentle north to northwesterly regional dip. Superimposed on the regional dip are broad gentle folds with axes trending northerly to northeasterly and attendant very gentle dips to the north and northeast. Faults of regional significance are sparse. However, the geologic history of the region suggests that faults of less

than regional significance could be common. This appears to be particularily true of the area near the Wadi Arab.

The Bituminous Marl Unit is considered to possess favorable characteristics for tunnel excavation. The rock is expected to have good natural support characteristics limiting the need for steel supports to local zones of close jointing or shearing. Substantial tunnel portions in this unit may require protective covering soon after excavation as the more argillaceous strata may deteriorate on exposure. It is anticipated that approximately 85% of the tunnel will be in the Bituminous Marl Unit.

Tunnel excavation within the Chalky Limestone Unit likely will be slower than within the Bituminous Marl owing to the variation in lithology and hardness of the chalky limestone strata. The chalky limestone is expected to have good natural support characteristics limiting the need for steel supports to zones of close jointing or shearing. The well developed jointing and occasional thinly bedded characteristic of parts of the Chalky Limestone Unit indicate a probable requirement for a substantial amount of rock bolting. It is anticipated that approximately 15% of the tunnel will be in the Chalky Limestone Unit.

Groundwater of meteoric origin is not expected to create tunnelling problems. The Bituminous Marl generally has a low permeability. Local flows could occur in zones of close jointing or shearing or along solution channels. The more highly jointed nature of the Chalky Limestone Unit generally appears to favor storage and movement of meteoric water.

Thermal springs exist along the Yarmouk Valley and water with artesian head has been encountered in core

borings at the Maqarin Damsite and along the lower reaches of the Wadi Arab. These springs and upstream flows are all located in the Bituminous Marl Unit. Planning for tunnels in the Bituminous Marl Unit should therefore anticipate that flows of thermal water may be encountered.

Encountering toxic and explosive hydrocarbon gas is considered to be a potential hazard in tunnelling through bitumen bearing rocks. Therefore, appropriate warning devices to signal the presence of gas would be mandatory during tunnel construction in the Bituminous Marl. Such precautions should also be observed in other parts of the tunnel.

Wadi Arab Powerplant and Penstock

Elevation of the tailwater for the powerplant will be dependent upon the elevation of the Wadi Arab Dam. The elevation of the dam has tentatively been selected at -111 m, which will place the powerplant at an elevation of approximately -140 m. This elevation implies that the powerplant's foundation would be on the Bituminous Marl Unit. Considerable faulting exists in the area, so care will be required in selecting the powerplant location.

The penstock leading to the powerplant will pass mainly over intensely fractured Chalky Limestone that dips gently in a northerly direction. Some faulting is also likely to be present. The fractured condition of the limestone implies that care must be taken in selecting the location of the penstock, however, as the penstock will pass across the antidip slope, stability problems will probably be nominal.

Geology and Evaluations of the Side Wadi Diversion Structure

General

A portion of the flows in three wadis draining into the Jordan Valley will be diverted into the EGMC. Two of these wadis, Wadi Kufrinjia and Wadi Rajib, will require new construction of new diversion facilities and a third, Wadi Yabis, will require rehabilitation of an existing weir and canal. All three sites were inspected, and evaluated. The results of this inspection are given in the following paragraphs.

Wadi Yabis Diversion

The existing weir is apparently constructed on the alluvium that forms the floor of the wadi. Cemented alluvium forms the abutment for the weir.

Wadi Kufrinja Diversion

The geology of the Wadi Kufrinja near the proposed diversion weir consists of limestone overlain by alluvium in the wadi bottom and by alluvial terraces on the lower parts of the wadi sides. The limestone dips moderately. The central portions of the weir will probably be constructed on alluvium, and the ends of the weir should abut into alluvial terrace deposits. Both deposits should have strength adequate to support the proposed structure.

Wadi Rajib Diversion

The Wadi Rajib at the proposed weir location is incised into an old alluvial fan deposit. The bottom of the wadi is composed of Recent alluvium and the sides of older alluvial fan deposits. The central portion of the weir will probably be constructed on alluvium and its ends should abut into the older alluvial fan deposits. Both deposits should have strength adequate to support the proposed structure.

Geology and Evaluation of the Powerplant at the King Talal Dam

General

A pit type powerplant is proposed for the King Talal Dam. The location will be immediately downstream of the diversion tunnel. The diversion tunnel will be used for the plant's power tunnel and its outlet portal is very near the powerplant location.

Geology and Geologic Evaluation

The geology of the area, as exposed in the diversion tunnel and in the drill holes near the tunnel, consist of a series of thin beds of limestone, sandy and clayey marl, sandy limestone of the Triassic Zarqa Formation. Bedding generally strikes easterly and dips approximately 10° southerly. A few steep open joints striking north easterly were observed in the diversion tunnel. Some drips of water were also observed in the tunnel and an artesian zone has been encountered in drill holes. These conditions, however, did not result in unusual geological problems during the excavation of the tunnel.

The relatively trouble-free excavation of the diversion tunnel which has revealed much of the geology of the area implies that unusual geological problems should not be expected in the construction of the powerplant. A nominal amount of drilling, however, should be planned prior to construction of the powerplant.

Geological Comparison Between the Khalid and Mukheibeh (Khalid Bin Al Walid) Damsite

General

Appraisal level studies were made of the Wadi Khalid and the Mukheibeh (Khalid Bin Al Walid) damsites to determine which is the more favorable.

The locations of both sites are shown on the map of the "Geology of the Yarmouk River" (Exhibits E-28B and E-28C). The geology of the Khalid Damsite was described in a preceeding section.

Comparison of Sites

The rock which would form foundations for the shells of either of the dams has similarities and is considered to be of adequate strength.

The shell of a dam at the Khalid Site would rest on beds of the Paleocene Chalky LiMestone Unit of the Belqa Series on the left side of the valley and in the valley bottom. On the right side of the valley, the shell would be founded on Pleistocene basalt flows, pre-basalt soils and a river terrace composed of chalky limestone debris.

The shell of a dam at the Mukheibeh site would be founded on beds of the Paleocene Bituminous Marl Unit of the Belga Series, on Pleistocene Basalt flows and on pre-basalt soils on the right side of the valley. On the left side of the valley, the shell would be founded on beds of the Bituminous Marl Unit, older river terrace deposits, pre-basalt soils and basalt flows. The shell would be founded on beds of the Bituminous Marl Unit in the valley bottom.

A medium height dam would cause the upstream shell on the left side of the valley to encroach on an extensive landslide area which could present serious stability problems and would probably have to be removed from beneath the shell.

Core trench foundation rocks for both sites are also generally similar and are considered to possess adequate strength.

The core trench for a dam at the Wadi Khalid site would be founded on the Chalky Limestone Unit bedrock on the left side of the valley and the valley bottom and on pre-basalt soils and basalt on the right side of the valley.

The core trench for a dam at the Mekheibe site would be founded on beds of the Bituminous Marl Unit, basalt flows and pre-basalt soil on both right and left sides of the valley, and on beds of the Bituminous Marl in the valley bottom.

The basalt flows and pre-basalt soils are expected to require extensive foundation treatment in the core trench. Presence of basalts and pre-basalt soils on both sides of the valley at Mukheibeh (versus on the right side of the valley only at the Khalid Site) could cause foundation treatment costs to be higher at Mukheibeh.

Grout curtain cut-off for both damsites would probably be made partly through basalt flows, pre-basalt soils and into bedrock. Basalts of the region generally are jointed and have some small caverns which cause them to be permeable. Pre-basalt soils are also considered to be permeable. Cut-off for both sites could be expensive. However, as basalts are found in the core trench on both sides of the valley at the Mekheibe Site (versus on the right side of the valley

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only at the Khalid Site) costs for a grout curtain cut-off should be greater at this site.

The left end of a dam at the Mukheibeh Site should also abut into a relatively thin ridge of talus covered beds of the Bituminous Marl Unit which is bounded by a deep gully downstream of proposed dam axis. This topography could cause difficulties in constructing an effective grout curtain for a dam impounding a reservoir of elevation 0 m. at the Mukheibeh Site. Construction of an effective grout curtain in this ridge to from a reservoir of a lower elevation (-46 m) could also be a problem. No similar topographic conditions are present at the Khalid Site.

Extensive landslides are presenr in a reservoir that would be formed by a dam at the Mekheibe Site. One of these, the Mayabir Landslide, is near the proposed site. Impounding water at the Mukheibeh could reactivate these slides. No extensive landslides are known to exist in the reservoir area of the Khalid Site, and valley sides within the area are considered to be generally stable except for possible small slides which may occur during reservoir operation.

Summary

The above geological comparison of the Khalid and Mukheibeh damsites leads to the conclusion that the Khalid is better. The thin left abutment ridge at the Mukheibeh Site, which could cause troublesome grout curtain cut-off problems, and the extensive landslides near the upstream toe of the dam embankment, which could cause shell foundation problems and could be reactivated with reservoir empoundment, make the Mukheibeh Site geologically inferior to the Khalid Site.

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Table E-1

MAQARIN DAMSITE
DRILL HOLE LOCATION DATA

Drill Hole Number	Co-ordinates North	Co-ordinates East	Eleva-tion	Bearing	Dip
HV-1	237,850	231,564	27.96		90°
HV-2	237,868	231,661	30.67		90°
HV-3	237,930	231,675	33.00		90°
HV-5	237,856	231,711	31.36	N	45°
HV-5A	237,856	231,709	31.4	N	45°
HV-6	237,858	231,748	30.91	S	60°
HV-7	237,924	231,715	31.51	S	45°
HV-8	237,881	231,711	30.13		90°
HS-1	237,654	231,201	39.93		90°
HQ-1	237,117	231,535	248.72		90°
HQ-2	237,469	232,065	248.64		90°
HQ-3	237,479	231,704	243.82		90°
HQ-4	237,613	231,743	195,43		90°
HQ-5	237,645	231,585	157.00 (approx)		90°
HP-1	237,170	230,719	95.34		90°

Notes

Location from Palestine Grid Co-ordinates System Elevation in meters from mean sea level dip in degrees from the Horizontal.

Table E-2

MAQARIN DAMSITE
ADIT LOCATION DATA

Adit Number	Co-ordinates North	Co-ordinates East	Elevation-Bearing	
No. 1	237,815	231,738	46.66	S
No. 2	237,979	232,035	49.01	N
No. 3	237,816	231,634	45.33	S
No. 4	237,813	231,861	48.83	S

Notes

Surveyed point is centerline of invert at portal of the adit.

Location from Palestine Grid Co-ordinates System Elevation in meters from mean sea level.

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Table E-3

MAQARIN DAMSITE
SHAFT LOCATION DATA

Shaft Number	Co-ordinates North	East	Elevation
SH-1	237,779	237,721	72.57
SH-2	237,949	231,753	43.52
SH-3	238,046	231,711	79.43
SH-4	237,950	231,835 (approx)	35 (approx)
SH-5	237,981	231,821	56.87

Notes

Location from Palestine Grid Co-ordinates System Elevation in meters from mean sea level.

Table E-4

MAQARIN DAMSITE
UNCONFINED COMPRESSIVE STRENGTHS
BITUMINOUS MARL UNIT - BELQA FORMATION

Sample	Hole Number	Depth (meters)	s Max (Kg/cm^2)	Type of Rock
UC-1	AR-1	15.90	262.50	bituminous chalk
UC-2	AR-1	16.80	150.85	bituminous chalk
UC-3	AR-1	20.20	295.75	bituminous chalk
UC-4	AR-1	21.10	265.30	bituminous chalk
UC-5	AR-1	24.99	357.00	bituminous chalk
UC-1	AL-1	5.07	110.95	bituminous chalk
UC-2	AL-2	16.54	365.75	bituminous chalk
UC-3	AL-3	19.44	403.20	bituminous chalk
UC-4	AL-2	21.84	266.00	bituminous chalk
S-1	HV-1	7.15	138.52	marly limestone
S-2	HV-1	18.42	45.31	marly limestone
S-3	HV-1	36.00	181.88	marly limestone
S-4	HV-1	42.85	321.40	marly limestone
S-6	HV-1	86.34	262.75	marly limestone

Notes

Test of samples with a "UC" prefix are from the Harza-Baker Study in 1955. The study is described in the subsection "Previous Investigations".

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Table E-5

Jordan Valley Irrigation Project - Stage II

Maqarin Damsite

Petrographic Examination

Chalky Limestone and Bituminous Marl Units - Belqa Formation

Sample No.	Location	Depth (Meters)	Formation	Rock Type	% $CaCO_3$	Microscopic Examination
S-1	Drill Hole HV-1	7.2	Bituminous Marl	Argillaceous bituminous limestone	63%	Brown, very fine-grained carbonate ground mass. Bedding shown as streak-like distribution of organic material and oriented platy or needle-shaped carbonate particles. Several per cent of foraminiferal shells and up to 1% pyrite. Approximately 20% organic matter and 17% clay.
S-2	Drill Hole HV-1	18.4	Bituminous Marl	Argillaceous bituminous limestone		Light grey, faintly brown, very fine-grained, carbonate ground mass. Scattered shells and shell fragments of formanitera and small mollus shells. No visible bedding. Scattered grains and irregular aggregates of pyrite.
S-3	Drill Hole HV-1	36.0	Bituminous Marl	Argillaceous bituminous limestone		Light grey, faintly brownish, very fine-grained groundmass with 15% to 20% square grains (possibly dolomite). Scattered formanifera shells and many fine shell fragments. Scattered pyrite.
S-4	Drill Hole HV-1	42.9	Bituminous Marl	Argillaceous bituminous limestone	70%	Medium to dark orange brown, very fine-grained carbonate matrix. Texture obscured by brown organic stain. Approximately 10% of rock is foraminiferal shells. Chambers of shells filled with calcite. Has disseminated pyrite grains. Approximately 16% organic matter and 14% clay.
S-6	Drill Hole HV-1	86.3	Bituminous Marl	Argillaceous bituminous limestone		Dark to light brown, very fine-grained carbonate matrix. Laminated fabric results from oriented and uniformly distributed shell fragments. Disseminated pyrite and rare silt-sized quartz grains.

Note: Descriptions of samples with the prefix Y are from "Final Report on Mineralogical-Petrographical Analyses" Yarmouk Project Site Investigation Program, By Geoistrazivanja, Zagreb, Yugoslavia. April 1965.

S-10	Drill Hole HV-5	20.0	Bituminous Marl	Fine-grained grey sand	53%	Poorly sorted, very fine-grained (ranging from clay size to fine-grained) sand. Contains fragments of bituminous limestone, foraminiferal shells, quartz, feldspar, magnetite. Of the insoluble grains: 75% quartz, 8% feldspar, 6% largely magnetite, 17% heavy minerals, and 5%-10% clay.
S-11	Drill Hole HV-5	33.0	Bituminous Marl	Dark grey moderately plastic clay		Dark grey, silty (20%-25%) clay. Silt sized particles are mainly quartz with 20% feldspar, grains of bituminous limestone, hornblende and colorless silicates. Tentatively concluded to be a sedimentary layer.
S-12	Drill Hole HQ-4	95.6	Bituminous Marl	Argillaceous limestone	72%	Grey, cloudy, very fine-grained limestone. Contains interstitial calcite grains and silt-sized grains of quartz. Contains scattered gypsum crystals. The fraction that isn't calcite is approximately 5% gypsum and 13% clay.
A-2	Adit A-1	34.5	Bituminous Marl	Argillaceous bituminous limestone with calcite veins		Light-grey, very fine-grained calcite veins and veinlets. Veinlets cut by breccia. Breccia consists of very fine-grained cloudy carbonate containing scattered foraminiferal shells.
A-4	Adit A-1	34.5	Bituminous Marl	Argillaceous bituminous limestone with calcite veins		Pinkish, cloudy, very fine-grained carbonate groundmass. Probably contains clay. Has scattered foraminiferal shells and shell fragments filled with calcite crystals. Has carbonate veinlets with interlocking calcite crystals.
A-7	Adit	34.5	Bituminous Marl	Limestone		Cloudy, grey, very fine-grained. Has scattered foraminiferal shells and shell fragments. Has veins of calcite containing a few masses of pyrite parallel to vein wall. Cloudy banding near walls suggests replacement of limestone by calcite.
H-2	Shaft S-5	21.0	Bituminous Marl	Severely weathered argillaceous bituminous limestone		Grey, cloudy, very fine-grained. Carbonate groundmass containing evenly distributed grains and irregular groups of dark minerals. Dark minerals may be clay minerals coated with iron oxide. Scattered foraminifera shells, shell fragments and waxy organic material.

H-3	Shaft S-5	21.0	Bituminous Marl	Severely weathered argillaceous bituminous limestone		Cloudy, light brown, very fine-grained carbonate. Contains scattered foraminiferal shells. Many thin shell fragments oriented parallel to bedding. Contains orange brown organic particles and a little pyrite and calcite veins.
G-1	Hand Sample	Rail-way cut	Bituminous Marl	Calcite vein in weathered argillaceous bituminous limestone		Coarsely crystalline calcite. Cloudy zone parallel to vein wall suggests replacement of limestone by calcite.
G-2	Hand Sample	Rail-way cut	Bituminous Marl	Calcite vein in weathered argillaceous bituminous limestone		Calcite vein with fragments of limestone and brown isotropic organic matter. Wall rock is brownish-grey, very fine-grained, fossiliferous limestone with brown organic stain.
Y-2	Drill Hole M-6	66.7	Bituminous Marl	"Marl" Argillaceous bituminous limestone	66.7	Brown, cryptocrystalline groundmass, slightly schistous texture; recrystallized microscopic fossils are small foraminifera.
Y-3	Drill Hole M-7	69.0	Bituminous Marl	Bituminous marl	42.8	Grey-brown homogeneous micro crystalline groundmass with oriented minute flakes of clay minerals; very fine quartz grains, and pyritized microscopic fossils.
Y-6	Drill Hole M-6	38.3	Bituminous Marl	Slightly dolomitic "marl" Argillaceous bituminous dolomitic limestone	62.6	Light-grey micro cryptocrystalline groundmass; scattered dolomite grains, very few quartz grains, and very fine calcareous grains microscopic fossils

Y-7	Drill Hole M-3	33.8	Bituminous Marl	"Marl" Argillaceous bituminous limestone	64.7	Grey-brown cryptocrystalline grumous groundmass; recrystallized microscopic fossils, small foraminifera, and ostracoda fragments.
Y-8	Drill Hole M-5	108.2	Bituminous Marl	Bituminous marl	49.7	Dull grey brown homogeneous microcrystalline groundmass with oriented minute flakes of clay minerals; partial recrystallization of microscopic fossils; very fine quartz grains.
Y-9	Drill Hole M-1	15.4	Bituminous Marl	"Marl" Argillaceous bituminous limestone with calcite and gypsum veinlets	66.0	Dull grey brown cryptocrystalline groundmass with grain size below 0.01 mm; pelagic foraminifera with pronounced parallel orientation; partial recrystallization of microscopic fossils.
Y-10	Drill Hole M-2	10.7	Bituminous Marl	"Marl" Argillaceous bituminous limestone with calcite and gypsum veinlets	63.7	Grey-brown, peletic, bituminous groundmass with scattered pyritized foraminifera.
Y-1	Drill Hole M-6	72.5	Bituminous Marl	Dark grey, friable, earthy clay	5.27	No thin section was obtained due to friability and softness of the sample.
Y-4	Drill Hole M-4	10.3	Chalky Limestone	Weathered argillaceous chalky limestone	78.7	Yellowish-white finely porous, micro-cryptocrystalline groundmass; brown limonite patches, small pelagic foraminifera, and other very small micro-organisms.
Y-5	Drill Hole M-4	21.45	Chalky Limestone	"Marly Limestone" Argillaceous chalky limestone	78.4	Greyish-white microgranular and cryptocrystalline mass; recrystallized microscopic fossils, and foraminifera.

Note: Descriptions of samples with the prefix Y are from "Final Report on Mineralogical-Petrographical Analyses", Yarmouk Project Site Investigation Program, By Geoistrazivanja, Zagreb, Yugoslavia. April 1965

Sample No.	Location	Depth (Meters)	Formation	Rock Type	% $CaCO_3$	Microscopic Examination
S-21	Drill Hole HV-7	119.0	Bituminous Marl	Calcareous claystone or siltstone (Marl)	49%	Dark brown, smooth surface, crumbly, bituminous and microfossiliferous 40% clay, 10% silt, insoluble silt-sized minerals are quartz, feldspar, hornblende, pyrite,; clay minerals include chlorite and several other varities.
S-22	Drill Hole HV-7	122.0	Bituminous Marl	Calcareous claystone or siltstone (Marl)	26%	Ligh brown, slightly friable, finely bedded, bituminous and microfossiliferous 44% clay, 30 % silt. Insoluble silt-sized minerals are quarts, feldspar, pyrite. Clay minerals include chlorite and several other varities.
S-23	Drill Hole HV-7	127.5	Bituminous Marl	Calcareous claystone or siltstone (Marl)	34%	Light brown, friable, bituminous microfossiliferous, 40% clay, 26% silt. Insoluble silt-sized minerals are quartz and chert. Clay minerals include chlorite and possibly montomorillonite and several other varities.
S-24	Drill Hole HV-7	116.0	Bituminous Marl	Argillaceous bituminous limestone	61%	Brown, blocky with concloidal fracture, very fine grained, bituminous and microfossiliferous, 34% clay, 15% silt. Insoluble silt-sized minerals are quartz.
S-25	Drill Hole HV-7	129.0	Bituminous Marl	Argillaceous bituminous limestone	70%	Dark brown, blocky fracture, fine-grained, bituminous and microfossiliferous, 25% clay, 5% silt. Insoluble silt-sized minerals are quartz, clay minerals include chlorite and possibly kaolinite.
S-26	Drill Hole HV-7	125.0	Bituminous Marl	Argillaceous bituminous limestone	69%	Dark brown, blocky fracture, finely bedded bituminous, and microfossiliferous, 26% clay, 5% silt. Insoluble silt-sized minerals are quartz.
S-27	Drill Hole HV-7	127.0	Bituminous Marl	Calcareous claystone (Marl)	40%	Light brown, silty, friable, bituminous, microfossiliferous. 42% clay, 18% silt. Insoluble silt-sized minerals are quartz and plagioclase.
QL-2	Hand Sample	Approximate 237,500 N 230,150 E	Chalky Limestone	Weathered Chalky Limestone	90%	Light brown, massive, very fine-grained, porous. 10% foraminifera, tests that are often recrystallized in a very fine-grained carbonate (limestone) matrix. Has a few percent of dolomite.

Sample No.	Location	Depth (Meters)	Formation	Rock Type	Microscopic Examination
QB-1	Hand Sample	Approximate 238,500 N 230,950 E (Syrian side of Yarmouk River)	Basalt	Microporphyritic olivine basalt	Grain size, except for olivine and pyroxene, less than 0.6 mm.; feature of ground mass interstitial with plagri-clase, pyroxene, and devitrified glass; devitrified glass consists of chlorite, magnetite; olivine grains altered with rims of serpentine patches of calcite. Should make unreactive concrete aggregate.
QB-1A	Hand Sample	Approximate 238,500 N 230,950 E (Syrian side of Yarmouk River)	Basalt	Microporphyritic olivine basalt	Similar to QB-1
QB-2	Hand Sample	238,500 N 230,950 E (Syrian side of Yarmouk River)	Basalt	Microporphyritic olivine basalt	Similar to QB-1
QB-2A	Hand Sample	238,500 N 230,950 E (Syrian side of Yarmouk River)	Basalt	Microporphyritic olivine basalt	Similar to QB-1
QB-3	Hand Sample	238,500 N 230,950 E (Syrian side of Yarmouk River)	Basalt	Microporphyritic olivine basalt	Similar to QB-1

Sample No.	Location	Depth (Meters)	Formation	Rock Type	Microscopic Examination
HQ-3-B1	Drill Hole HQ-3 (Jordanian side of Yarmouk River)	18.5	Basalt	Microporphyritic olivine basalt	Grain size, except for olivine and pyroxene, less than 0.6 mm; texture of groundness interstitial with plagroclose, pyroxene and devitrified glass; devitrified glass is chlorite and magnetite; olivine grains altered with rims of serpentine; several percent of fibrous zeolite; patches of calcite. Should make unreactive concrete aggregate.
YMTC-1	Hand Sample	Right Bank (Syrian side of Yarmouk River)	Basalt	Olivine dolerite	Contains a pretty high precentage of devitrified volcanic glass; zeolites present. Additional testing should be performed before acceptance as concrete aggregate.
YMTC-2	Hand Sample	Right Bank (Syrian side of Yarmouk River)	Basalt	Olivine dolerite	Contains a pretty high percentage of devitrified volcanic glass. Should make an acceptable concrete aggregate.
YMTC-3	Hand sample	Left Bank (Jordanian side of Yarmouk River)	Basalt	Olivine dolerite	Contains a pretty high percentage of devitrifeid volcanic glass. Should make an acceptable concrete aggregate.
YMTC-4	Hand Sample	Left Bank (Jordanian side of Yarmouk River)	Basalt	Olivine dolerite	Contains a pretty high percentage of devitrified volcanic glass. Should make an acceptable concrete aggregate.

TABLE E - 6

JORDAN VALLEY IRRIGATION PROJECT - STAGE II
MAQARIN DAMSITE
CHEMICAL ANALYSES

Hole Number	Sample Number	Sample Depth	Field Description	Carbonate %	Insoluble Residue(%)	Ignition Losses (%)	Specific Gravity
M-1	9	15.40	Bituminous Marl	66.0			
M-2	10	10.70	Bituminous Marl	63.7			
M-3	7	33.80	Bituminous Marl	64.7			
M-4	4	10.30	Chalky Limestone	78.7			
M-4	5	21.45	Marly Chalky Limestone	78.4			
M-4	6	38.3	Bituminous Marl	62.6			
M-5	8	108.20	Marl	49.7			
M-6	1	72.50	Clay	5.27			
M-6	2	41.00	Marl	42.8			
M-7	3	69.00	Marl	66.7			
HV-1	1	7.15	Marl	66	34	20	2.0
HV-1	4	42.85	Bituminous Marl	70	30	16	1.8
HV-5	S-10	18.50	Fine-Grained Sand	53	47		
HQ-4	S-12	92.72	Chalk	82	18		
						Clay (%)	Silt (%)
HV-7	S-21	119	Siltstone	49		41	10
HV-7	S-22	122	Siltstone	26		44	30
HV-7	S-23	127.5	Siltstone	34		40	26
HV-7	S-24	115	Bituminous Marl	61		34	5
HV-7	S-25	129	Bituminous Marl	70		25	5
HV-7	S-26	125	Bituminous Marl	69		26	5
HV-7	S-27	127	Siltstone	40		42	18

Notes

Ignition losses consist of chiefly organic matter with about 1% attributed to dehydration of clays, and sulphur from pyrite. The residue after ignition consists of ash, dehydrated clays, iron-oxide, silt, clay and sand size quartz grains.

Table E-7

MAQARIN DAMSITE
MISCELLANEOUS TESTS

Belga Formation - Bituminous Marl unit. Sample of bituminous marly limestone altered to clay. Sample from a depth of 24.4 m in drill hole HV-5.

Natural water content	78.6%
Atterberg limits	
Liquid limit	85.8%
Plastic limit	30.4%
Grain size analysis	
Sand	3%
Silt	39%
Clay	58%

Note: Material smaller than 0.0039 mm classed as clay.

Sample of gypsum from vein in weathered bituminous marly limestone at a depth of 10 m in shaft S-1. Described as: white powdery material and identified as gypsum by petrographic examination.

16

REGIONAL LOCATION MAP

0 100 200 400 600 800 1000 km

0 50 100 200 300 400 500 600 miles

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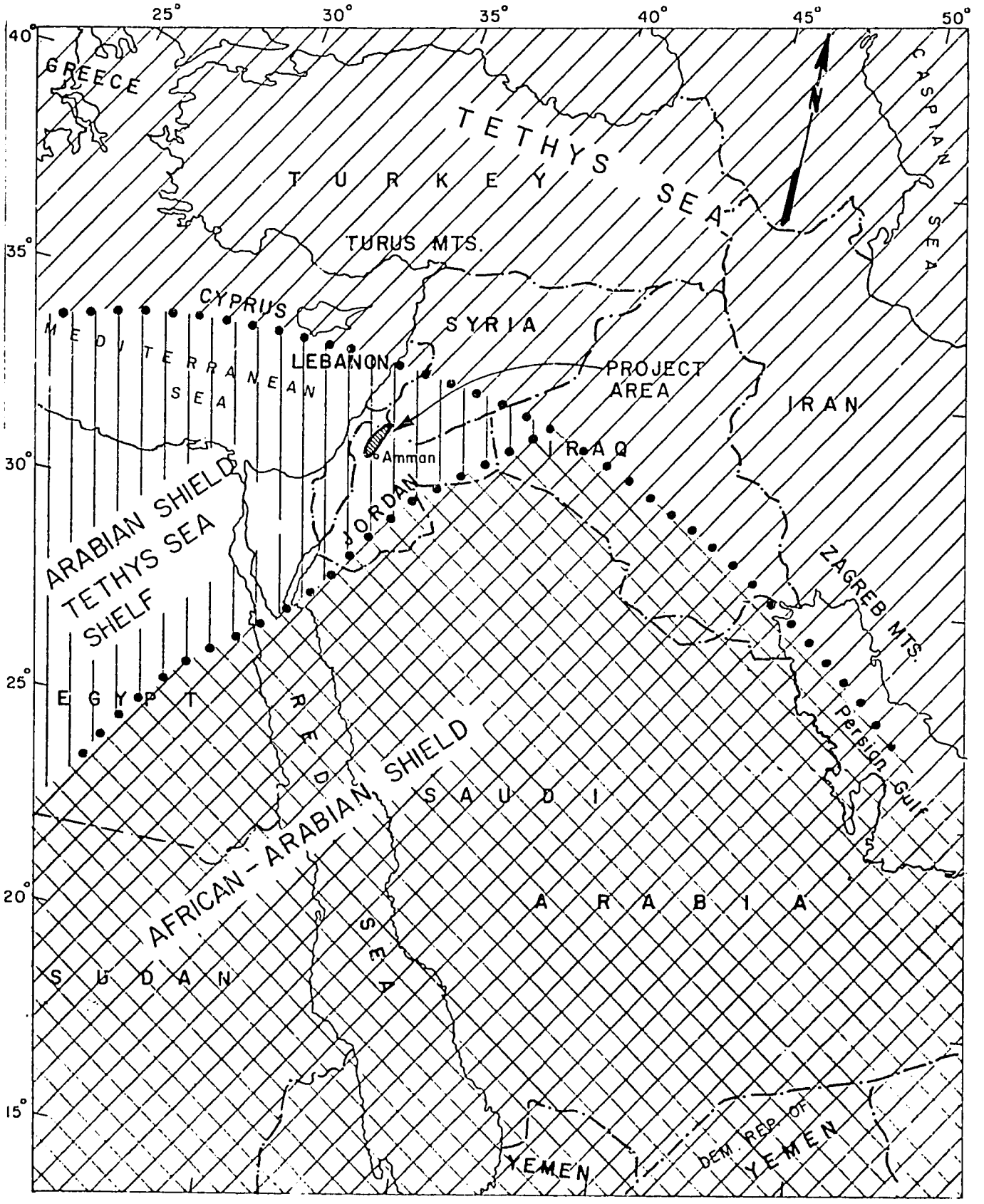
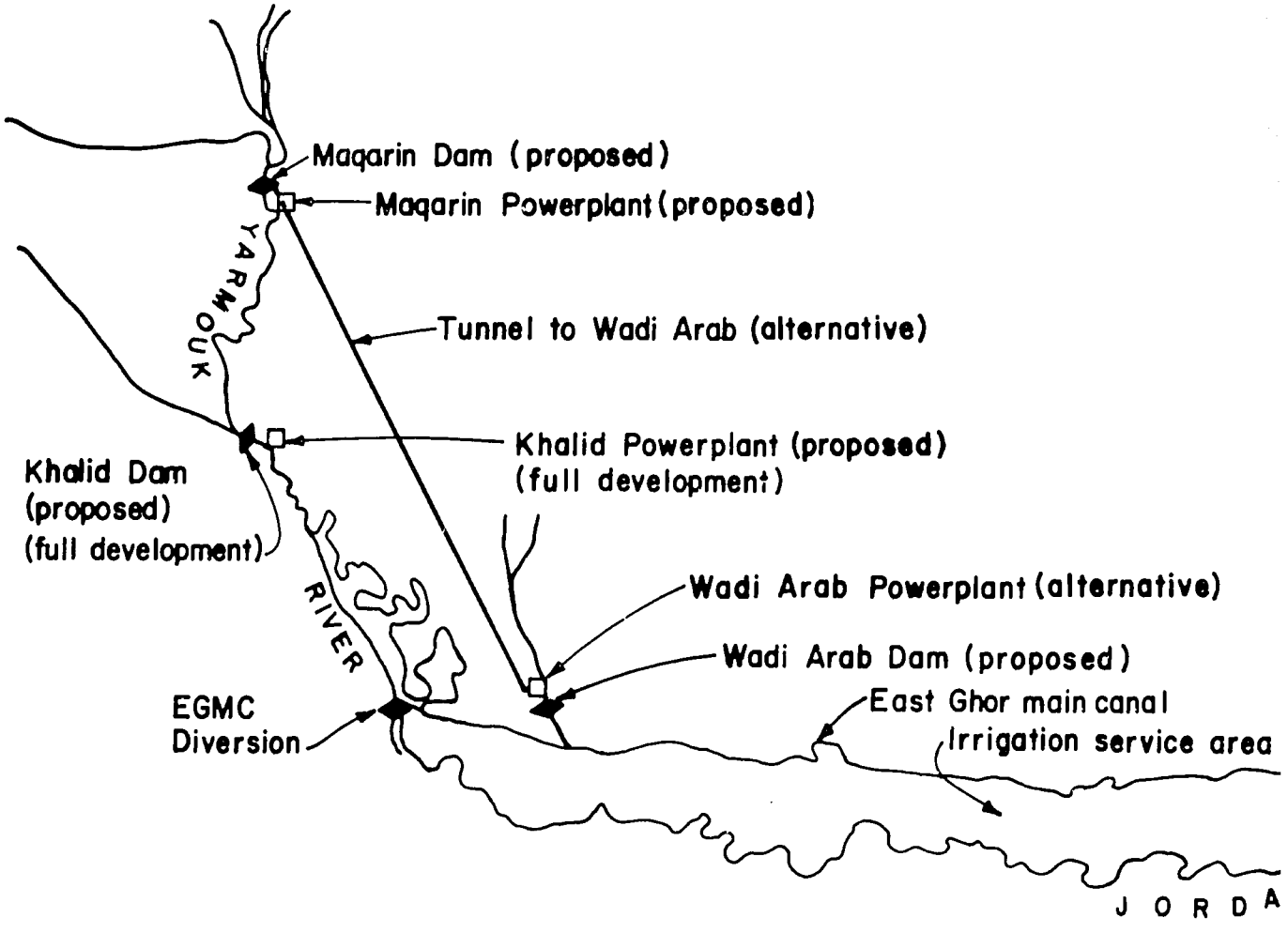
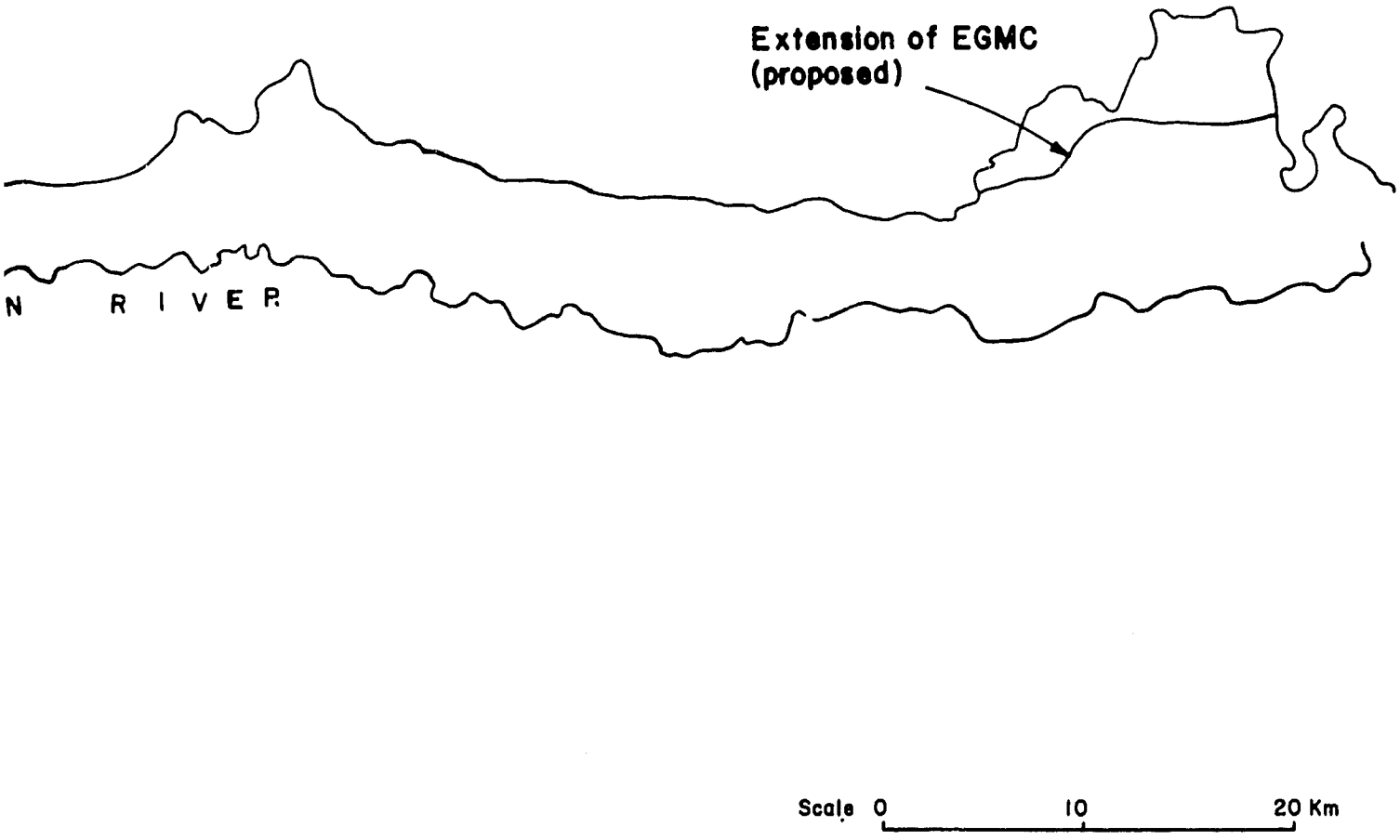


PALEOGEOGRAPHY OF THE EARLY TERTIARY

SCALE 0 200 600 1000 km
0 100 200 400 600 miles

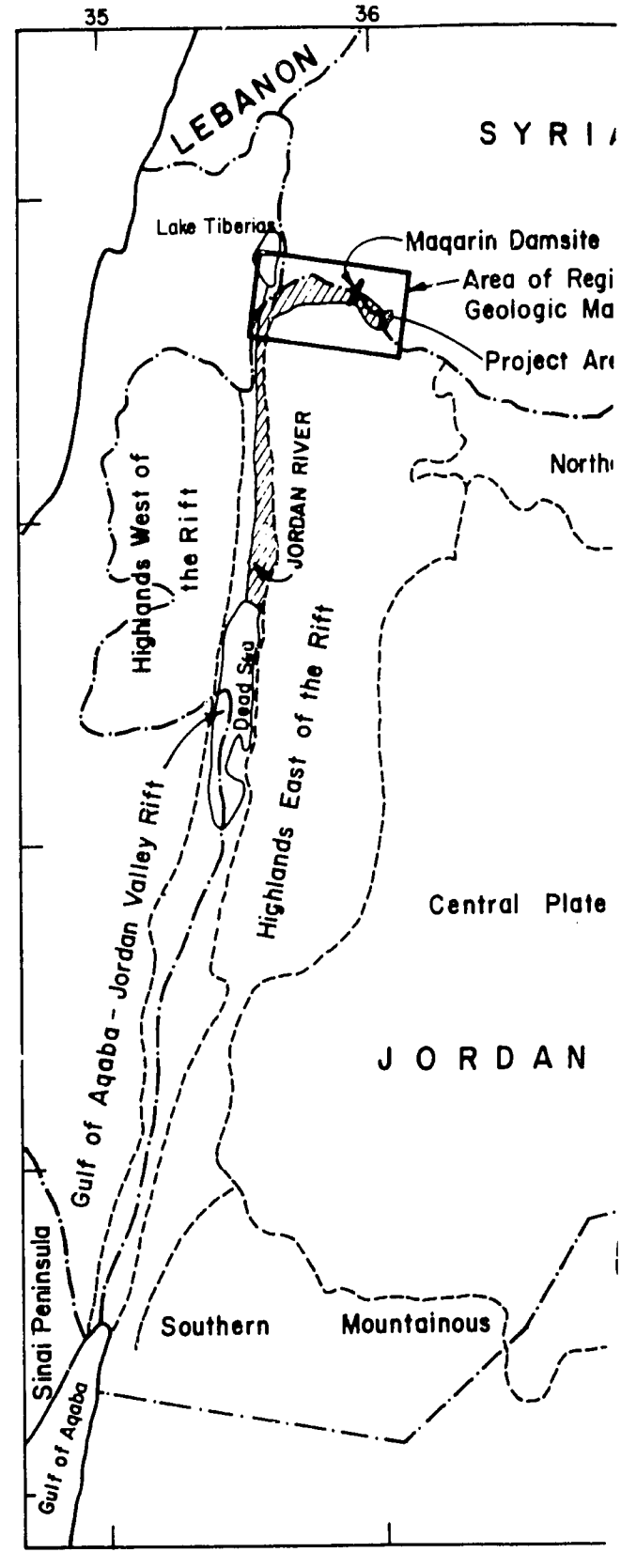
REGIONAL LOCATION MAP
JORDAN VALLEY IRRIGATION PROJECT
STAGE II


Maqarin Dam (proposed)
Maqarin Powerplant (proposed)
YARMOUK
Tunnel to Wadi Arab (alternative)
Khalid Powerplant (proposed)
(full development)
Khalid Dam
(proposed)
(full development)
RIVER
Wadi Arab Powerplant (alternative)
Wadi Arab Dam (proposed)
EGMC
Diversion
East Ghor main canal
Irrigation service area
J O R D A



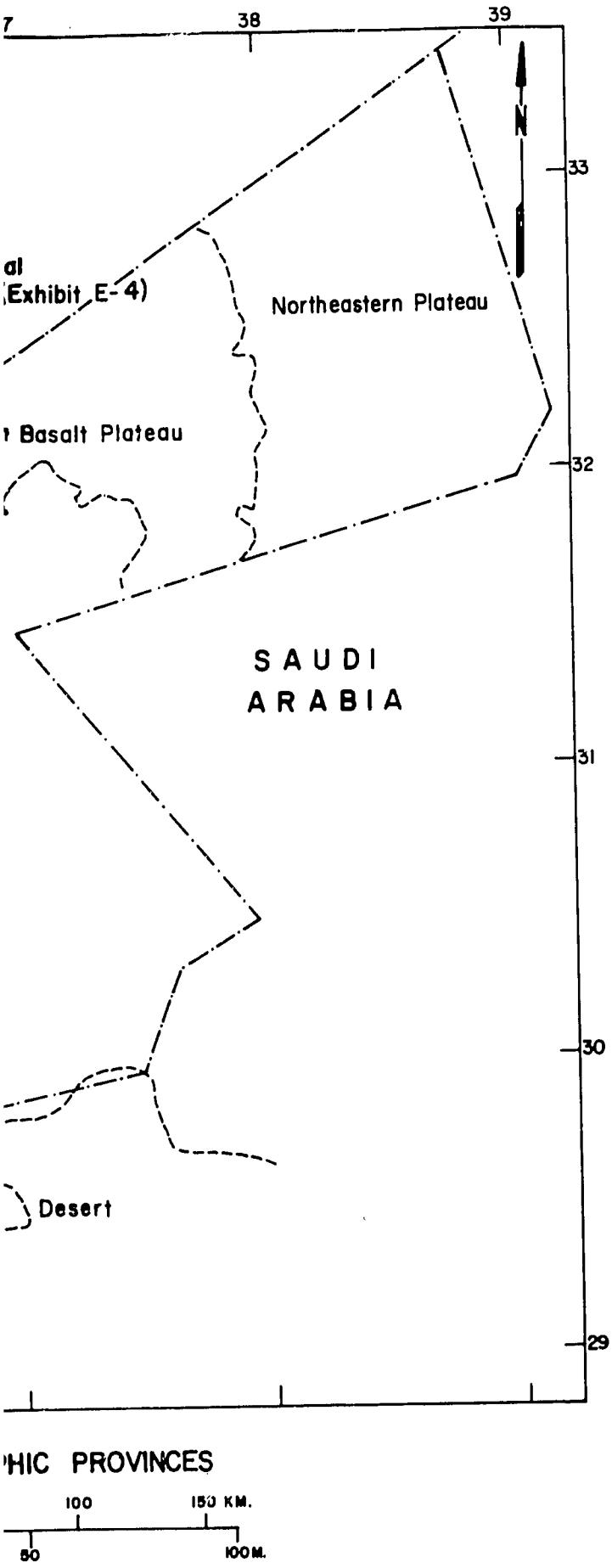
LOCATION OF PROJECT FEATURES

JORDAN VALLEY IRRIGATION PROJECT
STAGE II



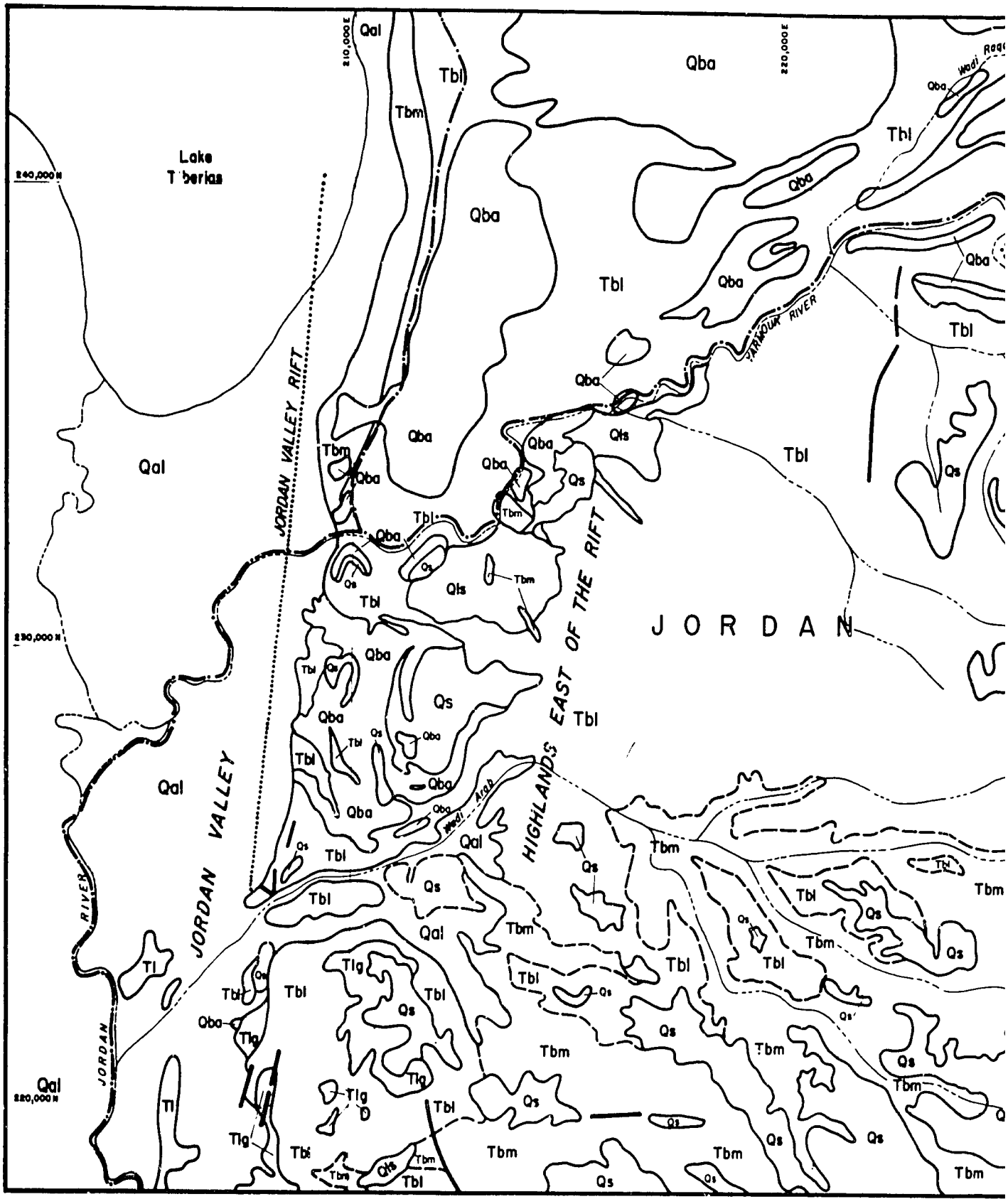
PHYSIOGRA

0 50
0



PHYSIOGRAPHIC PROVINCES

JORDAN VALLEY IRRIGATION PROJECT
STAGE II



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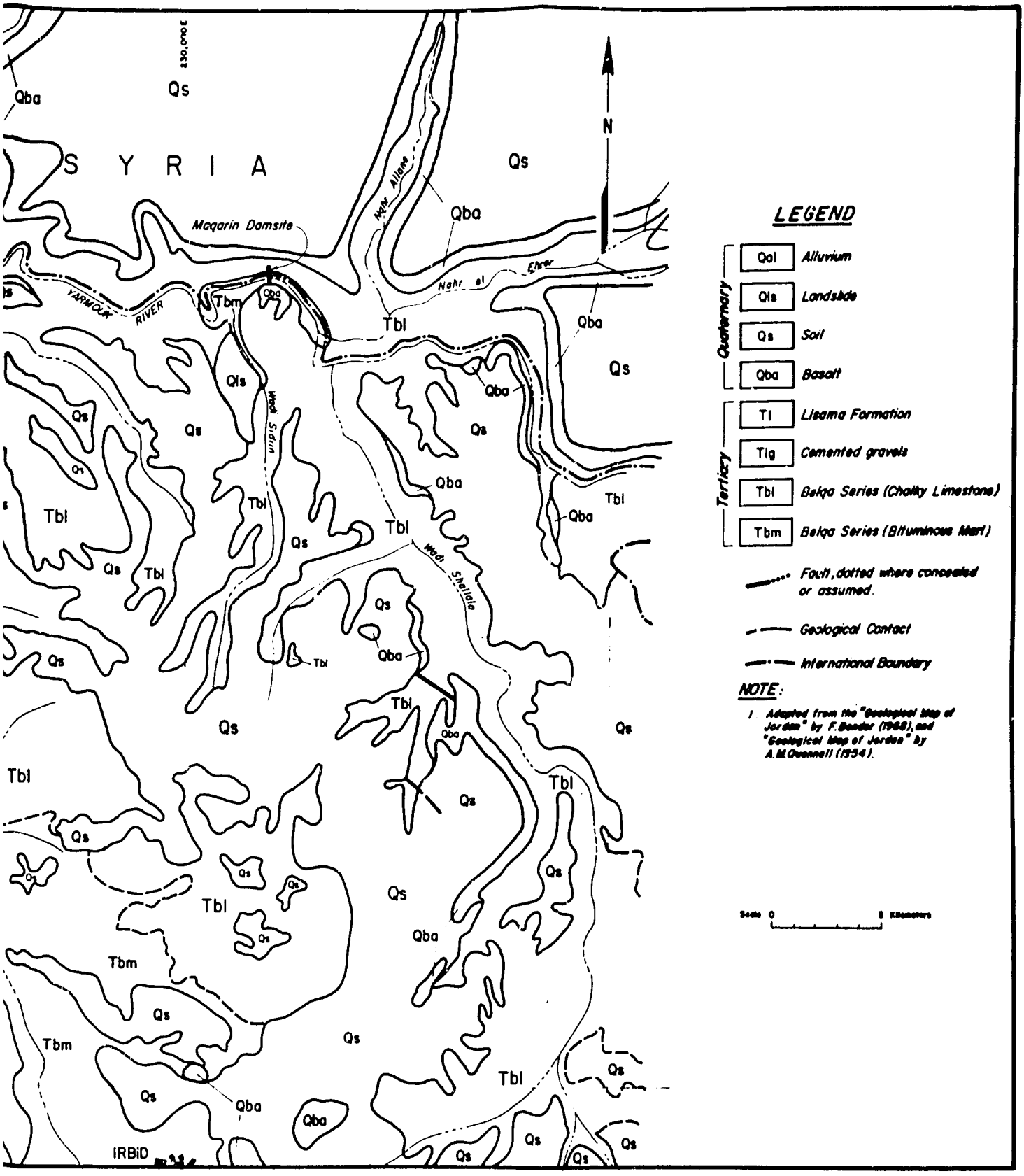
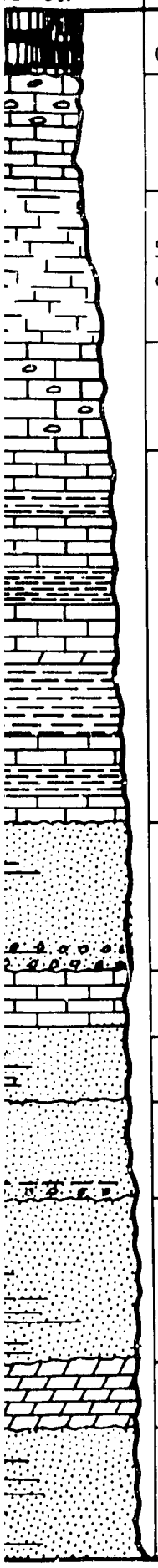


REGIONAL GEOLOGIC MAP
JORDAN VALLEY IRRIGATION PROJECT
STAGE II

SYSTEM	GEOLOGIC UNIT	SECTI
TERTIARY	VOLCANICS	
	BELQA SERIES	
UPPER CRETACEOUS		
	AJLUN SERIES	
LOWER CRETACEOUS	KURNUB SANDSTONE	
JURASSIC & TRIASSIC	ZARQA GROUP	
UPPER PALEOZOIC		
LOWER PALEOZOIC	QUWEIRA SERIES	

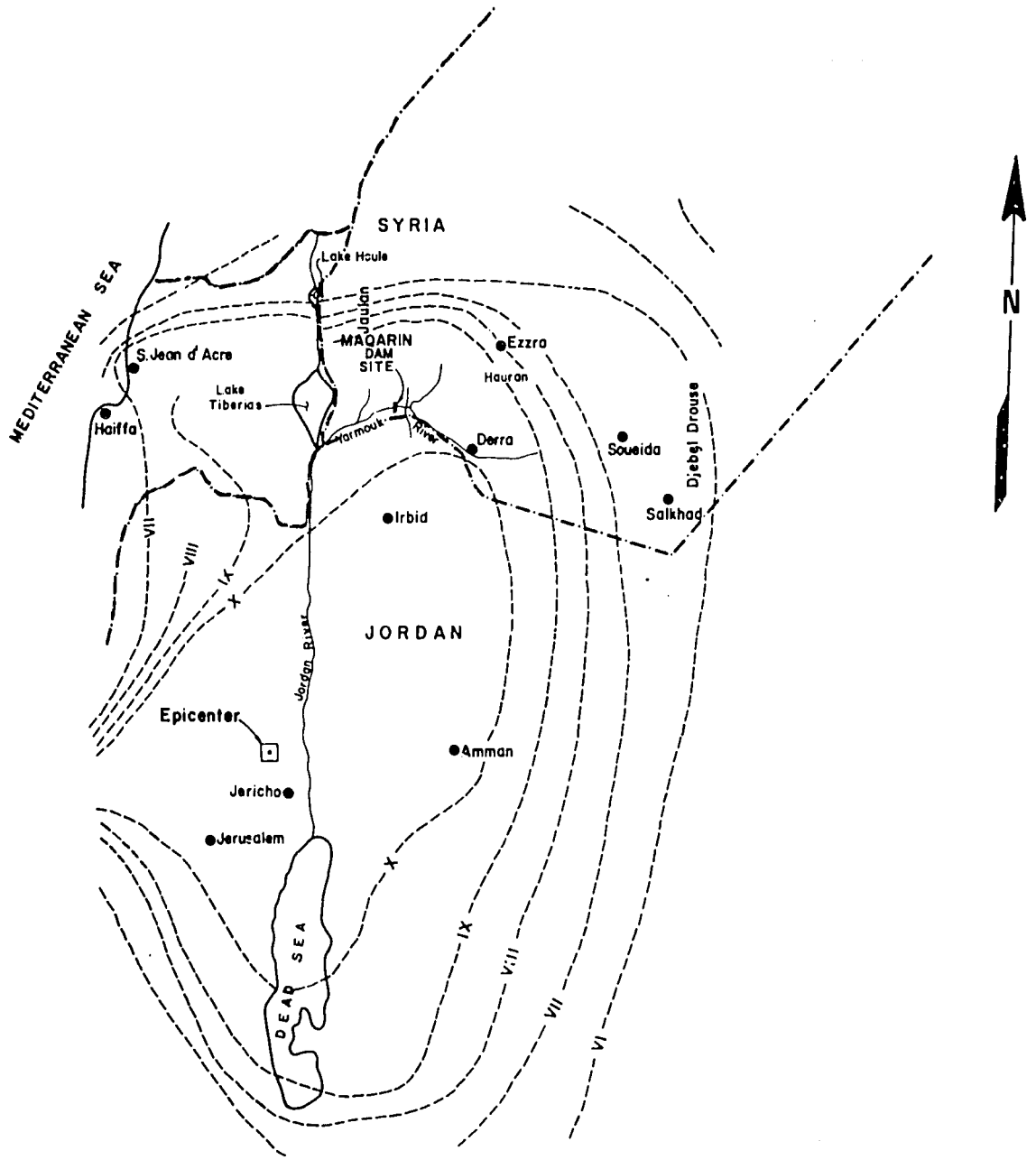


TION	THICK-NESS	CHARACTER
	0-25m	Plateau Basalt
	50-230m	Chalky limestone with some chert nodules.
	50-over 450m	Bituminous marl and bituminous linestone with some limestone beds.
	40-180m	Limestone with some chert.
	100-300m	Limestone, dolomite marl and shale.
	50-250m	Varicolored Sandstone with shale.
	0-120m	Limestone
	0-120m	Shales and sandstone
	0-160m	Sandstone
	140-300m	Sandstone and shales.
	80-130m	Dolomite
	~200m	Sandstone

STRATIGRAPHIC COLUMN OF THE PROJECT AREA

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



ISOSEISMIC CURVES FOR THE EARTHQUAKE OF 11 JULY, 1927

Scale 0 10 20 30 40 50 Miles
0 20 40 60 80 Kilometers

NOTES:

1. Intensities are in modified mercali scale.

2. Information supplied by Ksara, Lebanon observatory.

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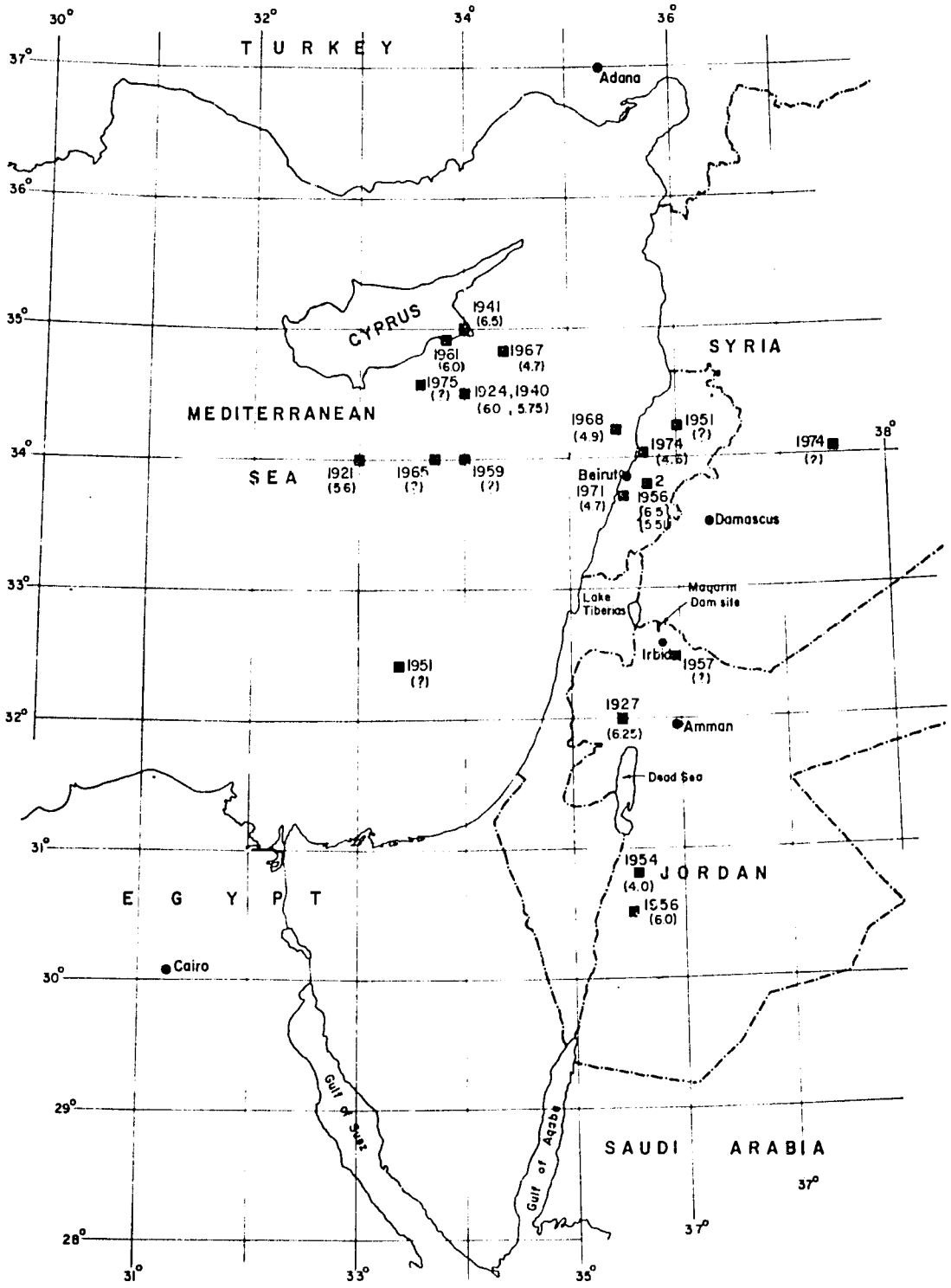


EARTHQUAKE EPICENTERS
WITHIN 250 KILOMETERS OF
MAQARIN DAM SITE

Scale 0 20 40 60 80 100 Miles
0 40 80 120 160 Kilometers

NOTE:

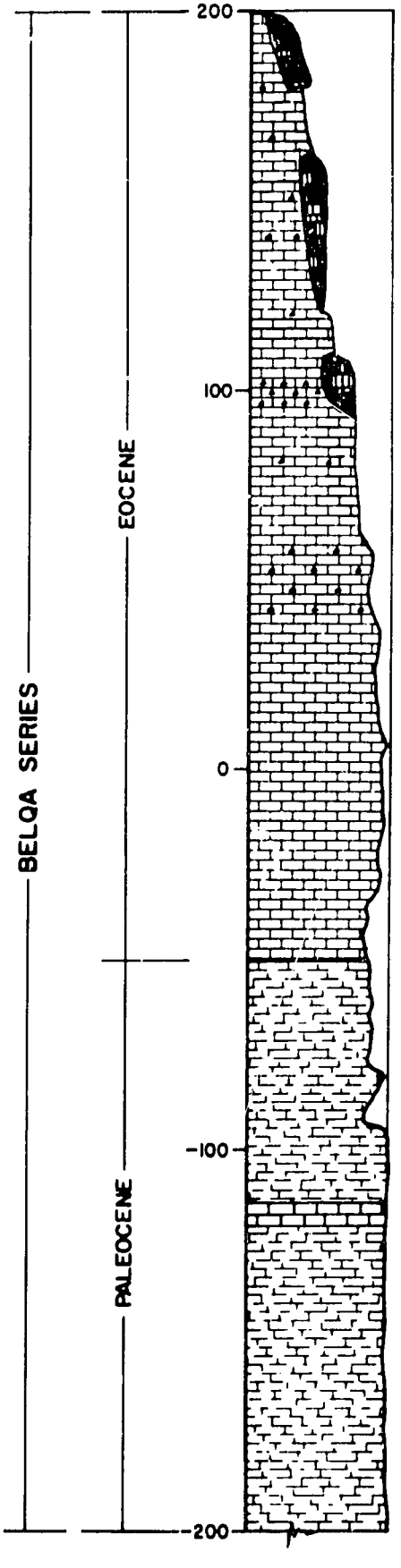
1. Earthquake epicenter (■) shown with date and Richter scale magnitude.

LOCATIONS OF EARTHQUAKE EPICENTERS

JORDAN VALLEY IRRIGATION PROJECT

STAGE II

STRATIGRAPHIC SECTION AT WADI ARAB



BASALT FLOW (Qba) *(Pleistocene)*

Three Basalt flows observed along the sectio. Vesicular to dense, phenocrysts of plagioclase olivine and calcite observed in places. Basalt flo are discontinuous , Limestone beds daylight in eroded depressions.

CHALKY LIMESTONE (Transitional):

Light cream to light brownish gray, medium ba (average thickness 1.0 meters) chalky limestone. bonds and nodules upto 20cm are common.

CHALKY LIMESTONE (Tbl)

Light brownish gray, medium to thin bedded, chalky limestone.

BITUMINOUS MARL (Tbm)

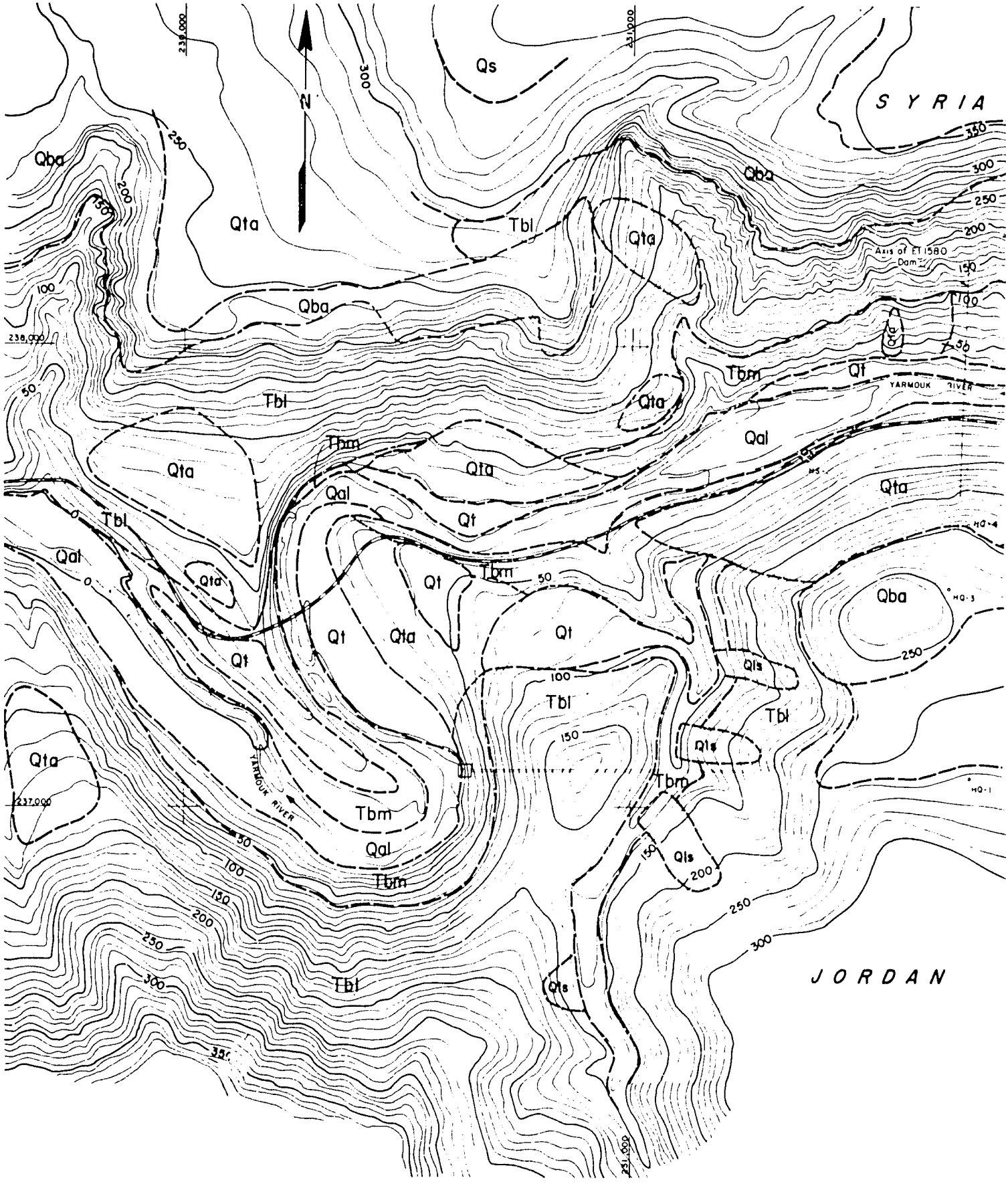
Medium to dark gray, massive, occasional zones and lenses of black highly bituminous marly limestone. Few thin beds 1/4 - 2 meters of and rarely crystalline limestone.

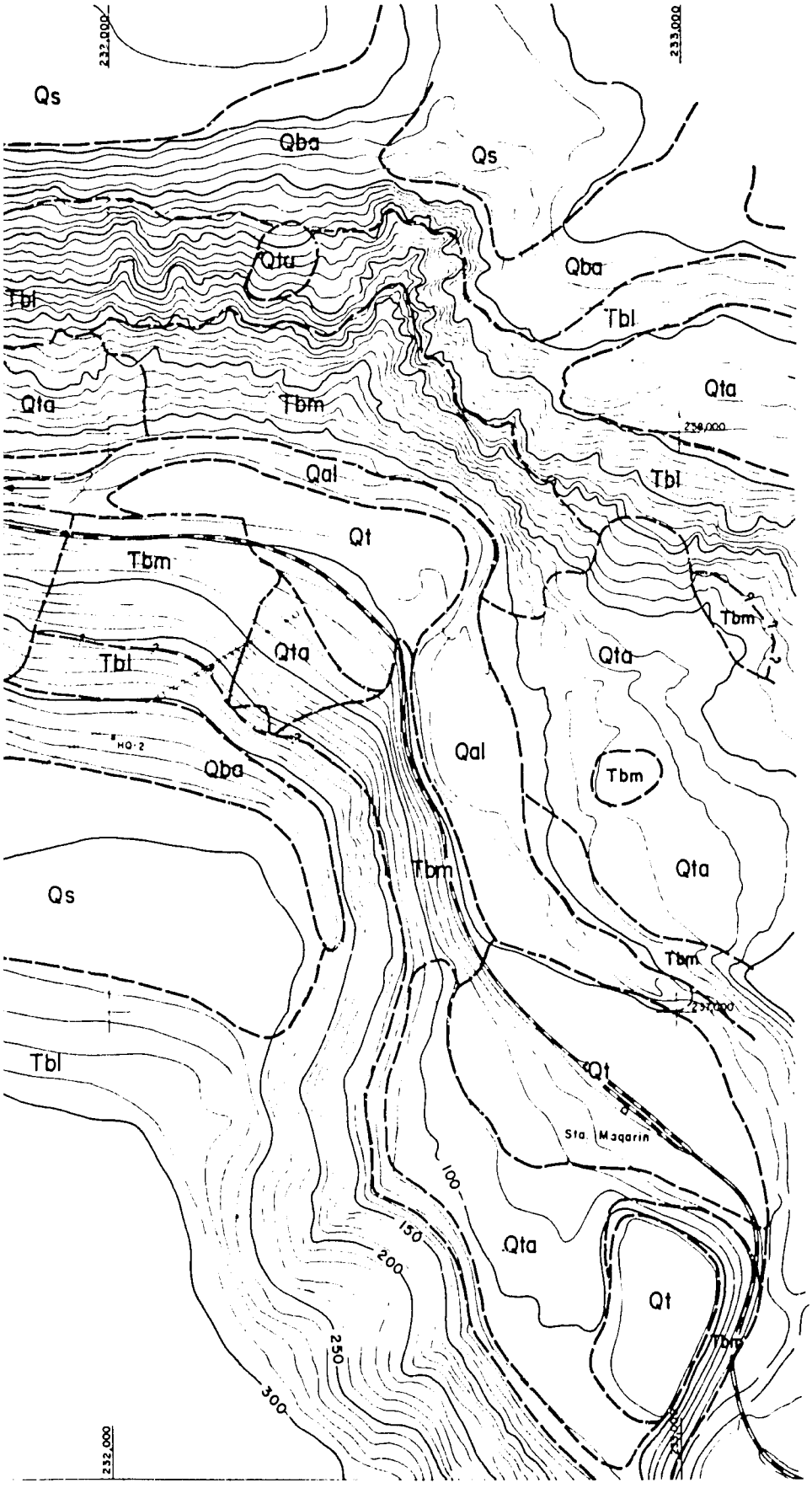
LEGEND

- Basalt
- Chalky limestone.
- Chalky limestone with chert.
- Bituminous M'-ly limestone.

STRATIGRAPHIC COLUMNS OF THE PROJECT AREA

JORDAN VALLEY IRRIGATION PROJECT
STAGE II


SYRIA
JORDAN
N
Qs
Qba
Qta
Tbl
Tbm
Qt
Qal
Qls
YARMOUK RIVER
Axis of El 1580 Dam
238,000
237,000
239,000
231,000
HQ-1
HQ-3
HQ-4
HQ-5



LEGEND

Qal	*Alluvium*
Qt	*Alluvial Terrace*
Qta	*Talus*
Qls	*Landslide*
Qs	*Soil*
Qba	*Basalt Flows*
Tbl	*Chalky Limestone (Belqa Series).*
Tbm	*Bituminous Marl (Belqa Series).*

Geologic Contact

NOTE

1. *For details of the geology and location of exploration in the Maqarin Damsite area see "Geology of Embankment Area" (Exhibit E-9).*
2. *Base map is from the "Republique Syrienne – Plan Coté de la Région du Yarmouk" by Royal Dutch Airlines for the Bureau d'Etudes Neerlandais (1953) and "The Hashemite Kingdom of the Jordan–Yarmouk Valley" by Hunting Aerosurveys Ltd (1951)*

Scale 0 — 300 Meters

GEOLOGY OF MAQARIN DAMSITE AREA

JORDAN VALLEY IRRIGATION PROJECT

STAGE II

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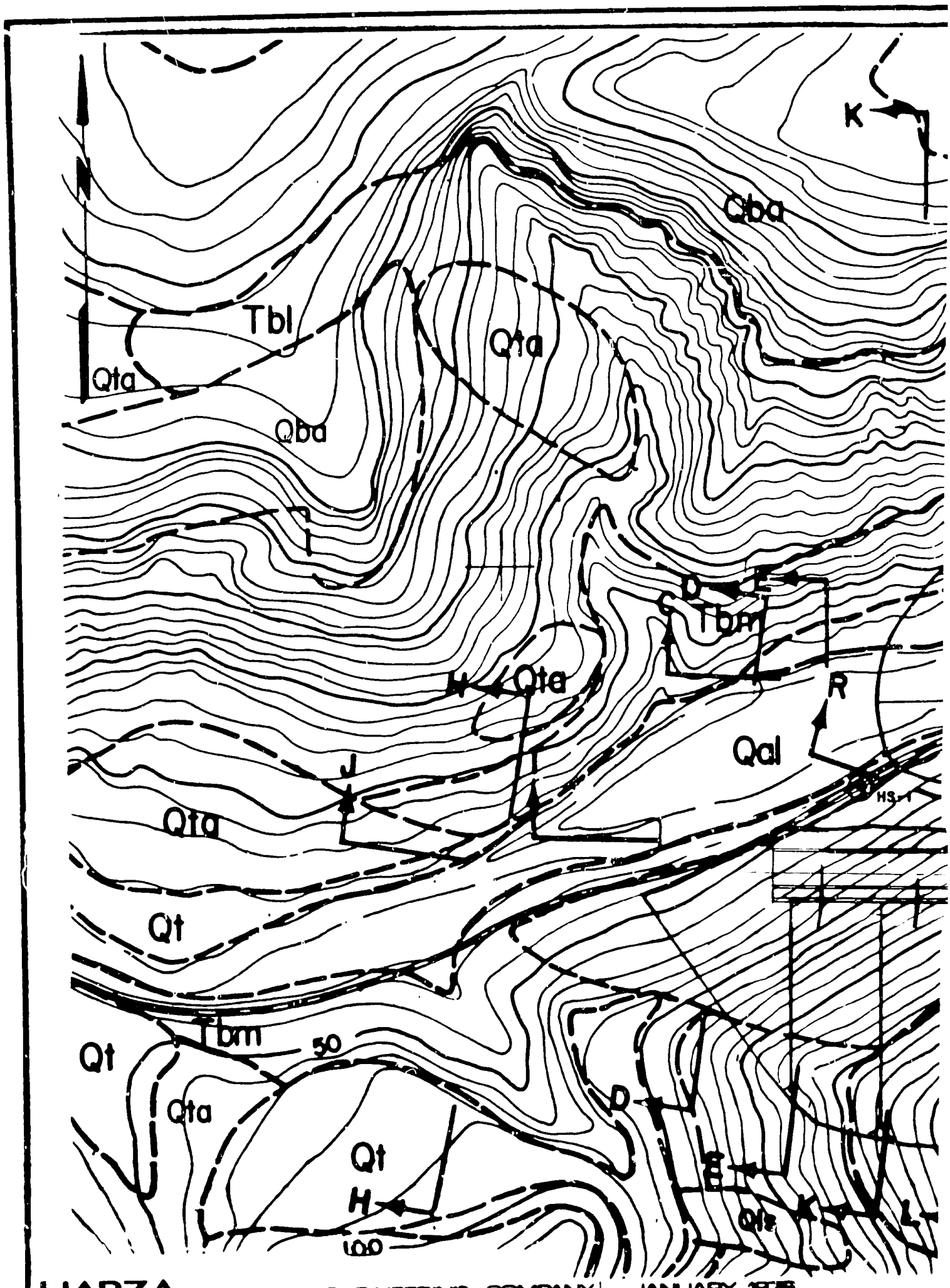
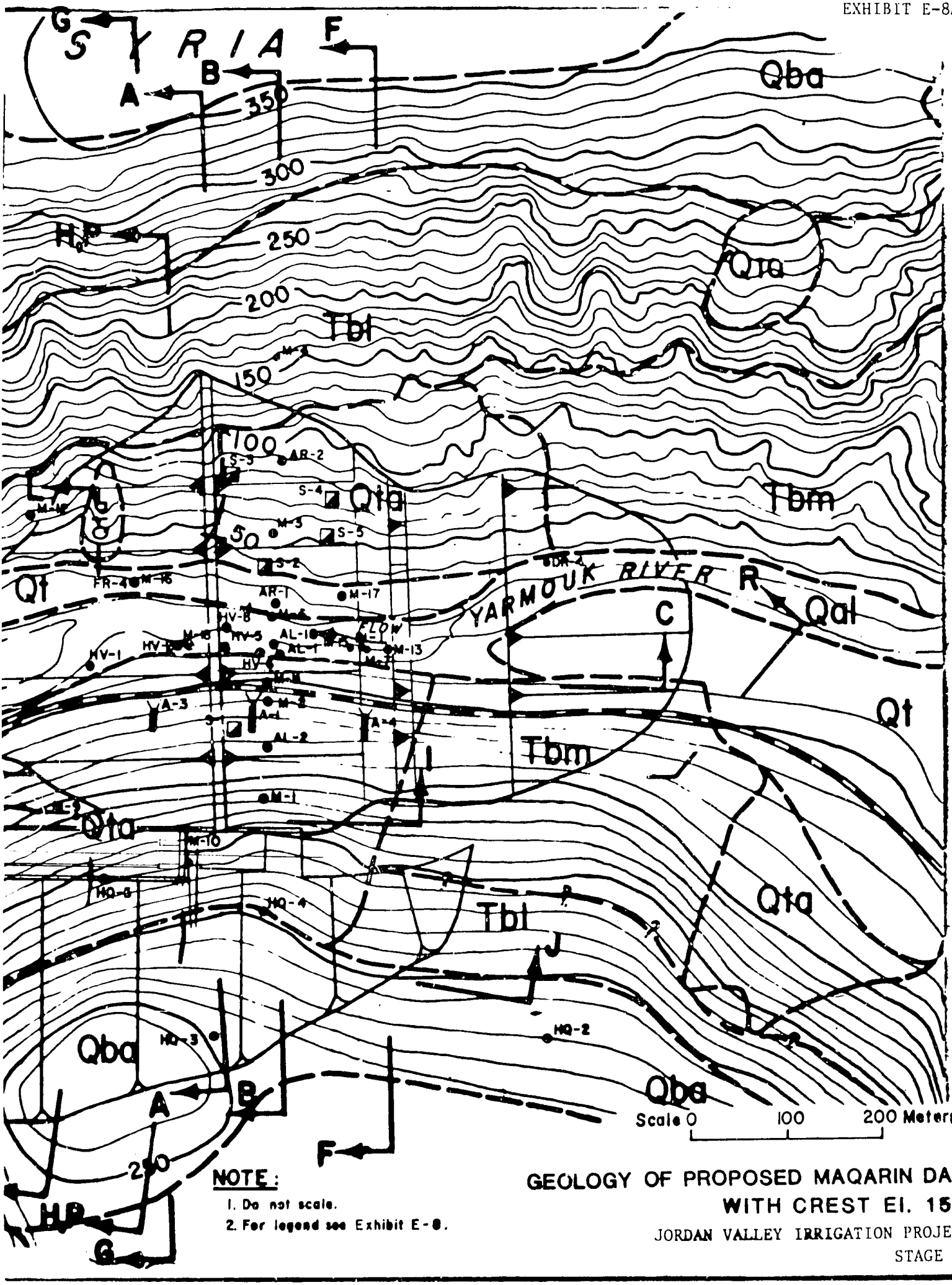


HARZA OVERSEAS ENGINEERING COMPANY JANUARY 1976

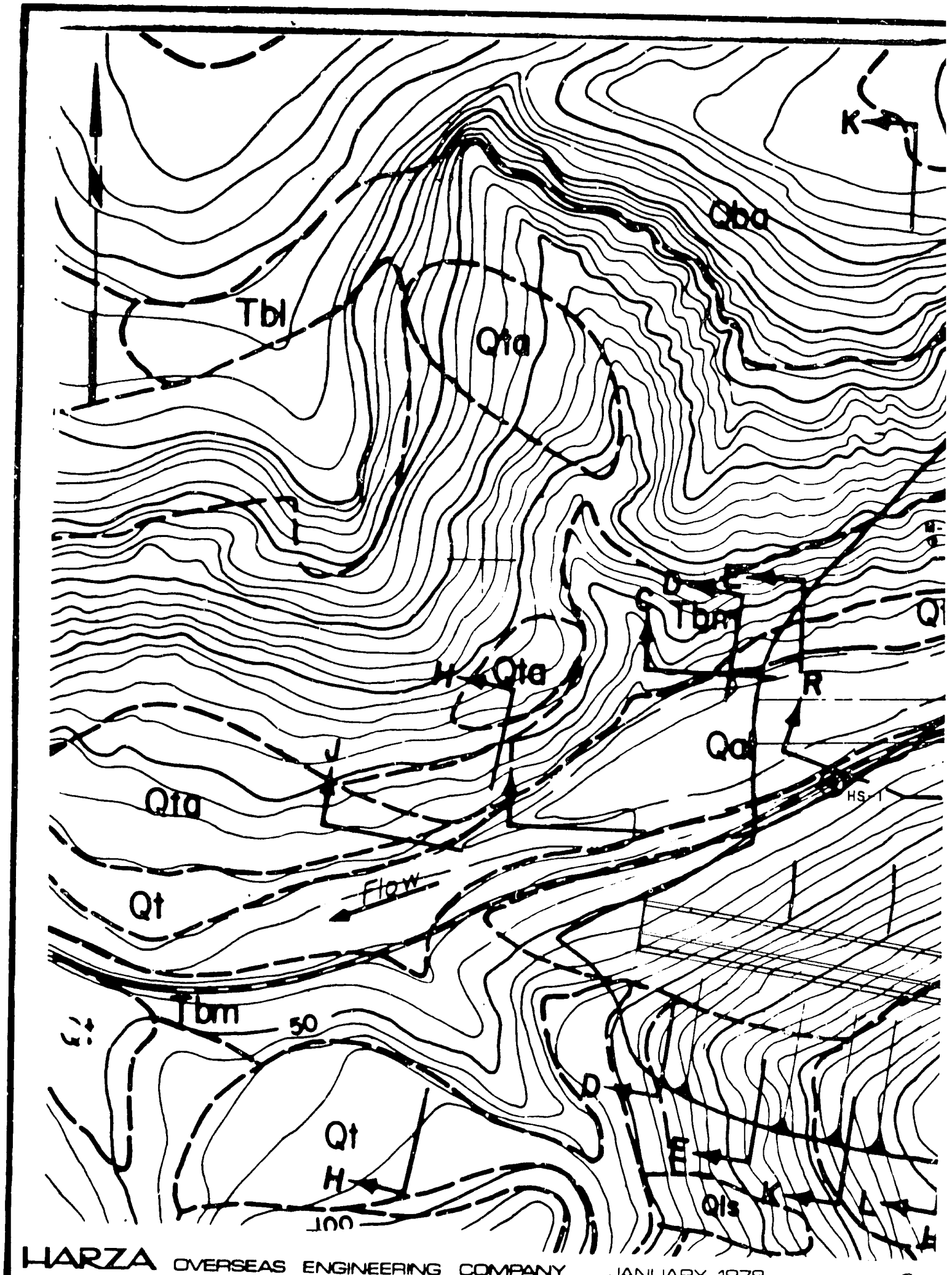


NOTE:

1. Do not scale.
2. For legend see Exhibit E-8.

GEOLOGY OF PROPOSED MAQARIN DAM
WITH CREST El. 158.

JORDAN VALLEY IRRIGATION PROJECT
STAGE II



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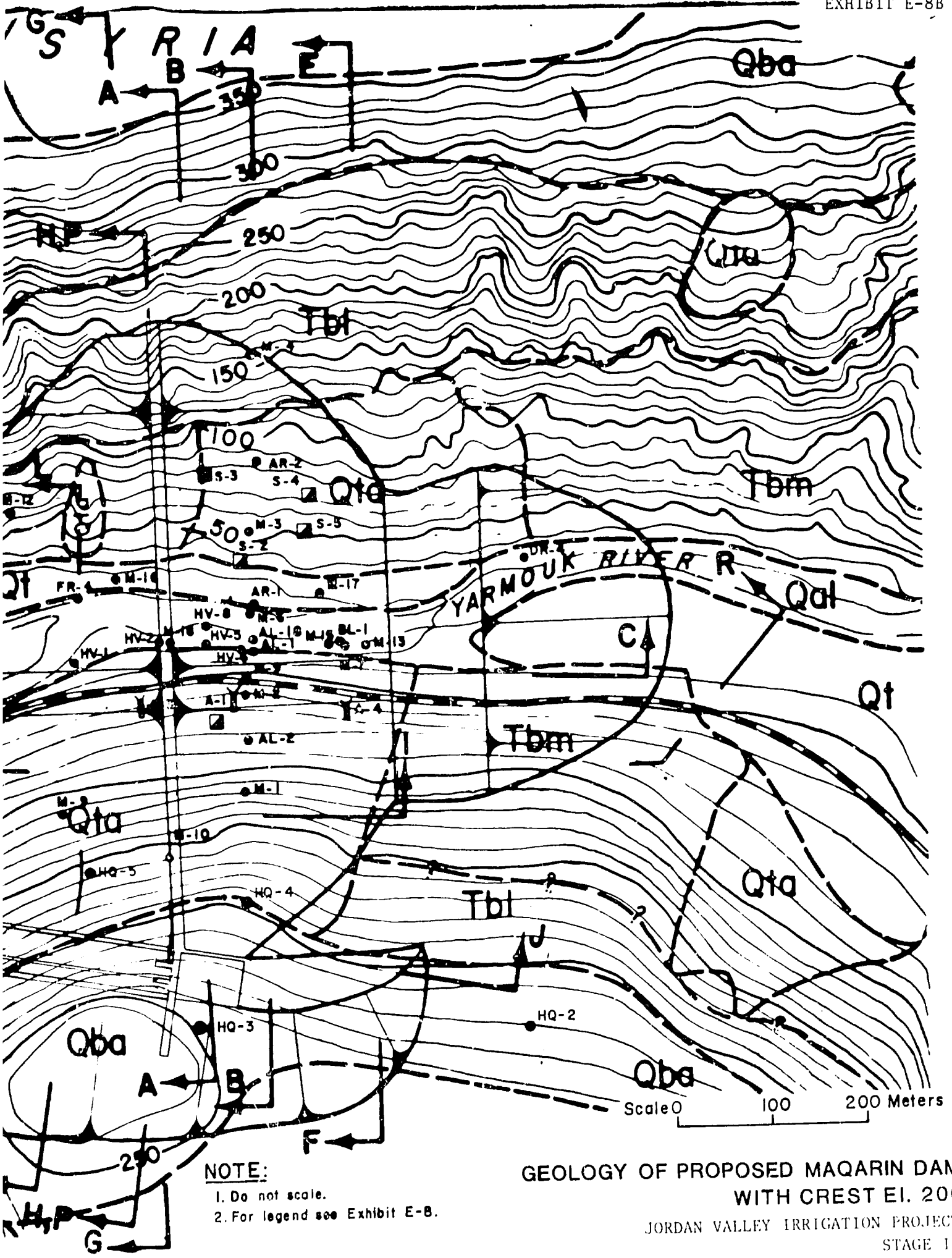
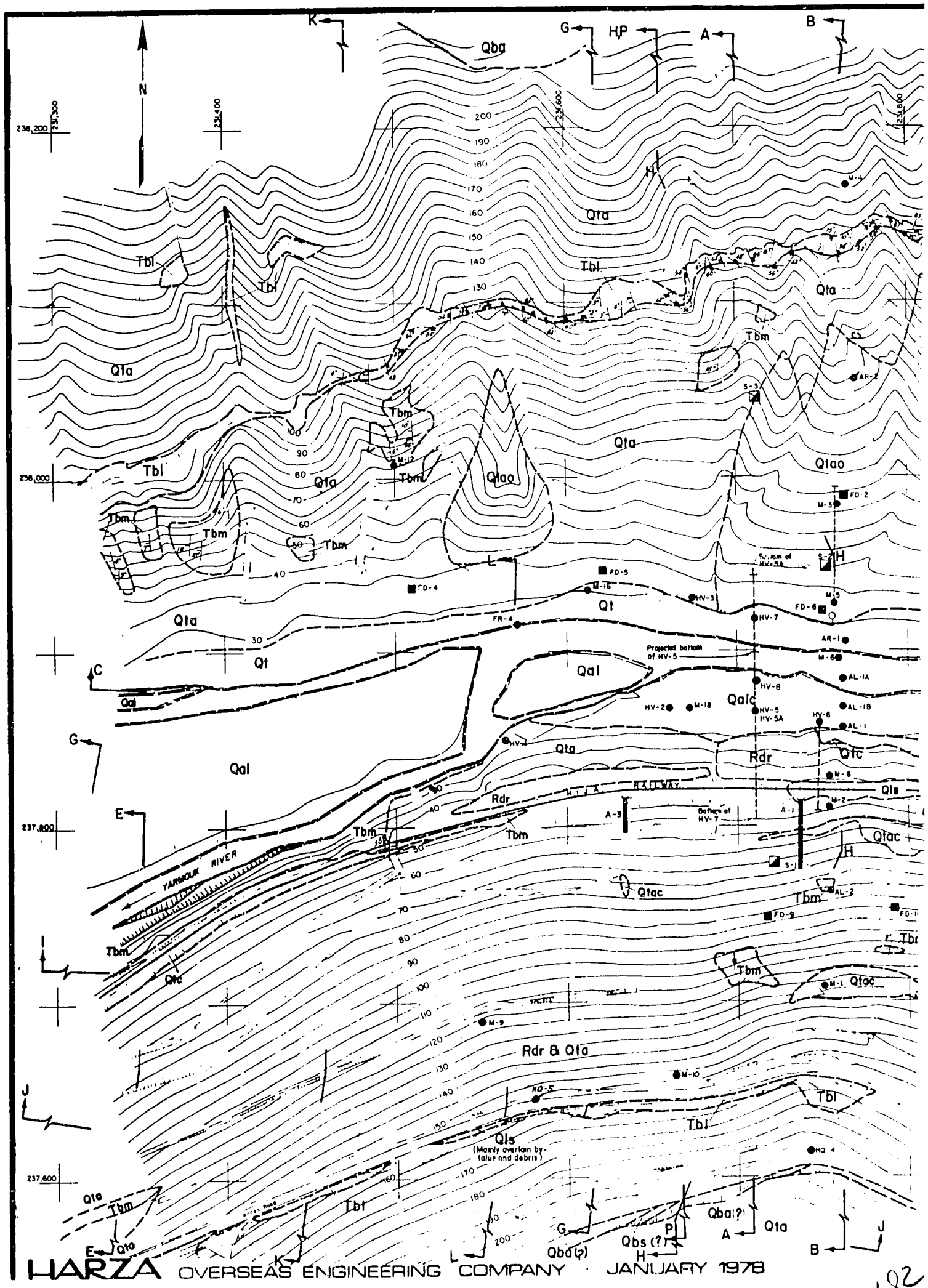


NOTE:

1. Do not scale.
2. For legend see Exhibit E-8.

GEOLOGY OF PROPOSED MAQARIN DAM
WITH CREST El. 200

JORDAN VALLEY IRRIGATION PROJECT
STAGE II


N
236,200
236,300
236,400
236,500
236,600
236,000
237,800
237,600
Qba
Qta
Tbl
Tbm
Qtao
Qt
Qal
Qalc
Qtc
Qtac
Rdr
Qls
Rdr & Qta
Qba(?)
Qbs (?)
YARMOUK RIVER
HIJAZ RAILWAY
Projected bottom of HV-5
Bottom of HV-7
Qls
(Mainly overlain by talus and debris)
HARZA OVERSEAS ENGINEERING COMPANY JANUARY 1978

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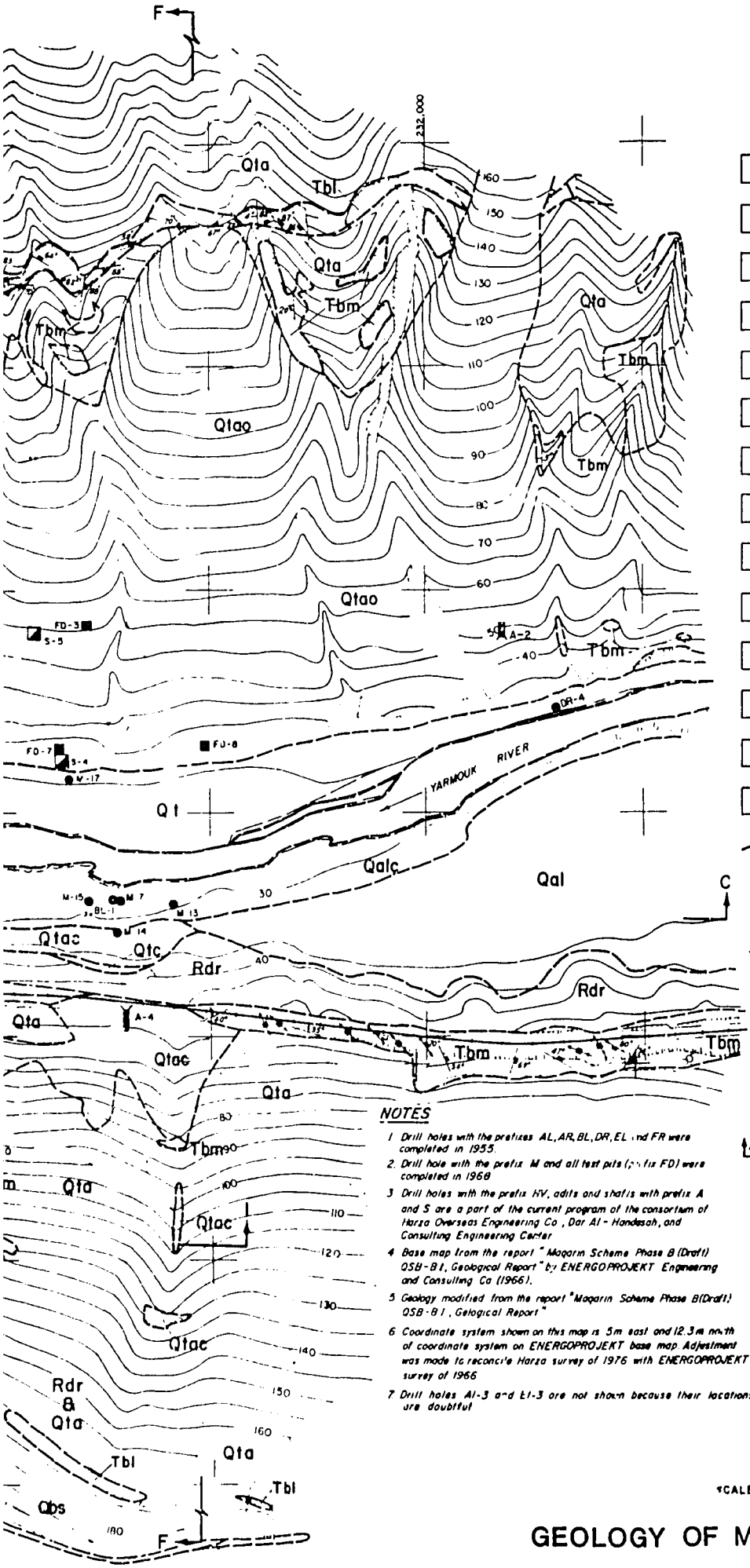


LEGEND

Rdr	**Debris**: Rock and soil wasted during access road and railroad construction
Qal	**Alluvium**: Silt, Sand and Gravel at the river channel
Qalc	**Cemented Alluvium.**
Qt	**Alluvial Terrace.**
Qtc	**Cemented Alluvial Terrace.**
Qs	**Soil**: Fine-grained residual soil
Qta	**Talus**: Loose deposit of clay, silt, sand and angular fragments of rock
Qtao	**Older Talus**: Poorly consolidated, moderately thick accumulations of talus
Qtac	**Cemented Talus.**
Qls	**Landslide**: Dislocated masses of bedrock materials of moderate size
Qba	**Basalt Flow**: Plateau type olivine basalt
Qbs	**Pre-Basalt Soil**: Soil zone developed between Basalt Flows or basalt flows and chalky limestone
Tbl	**Chalky Limestone** (Belqa Series): Thick-bedded marine chalky limestone. Contains occassional nodules of chert
Tbm	**Bituminous Marl** (Belqa Series); Thick-bedded to massive marine bituminous marl.

Geologic Contact; Solid where surveyed, dashed where approximate.

20° Strike and dip of bedding.

70° Strike and dip of joints

Strike of vertical joints.

40° Strike and dip of zone of closely spaced joints

60° Strike and dip of gypsum veins.

Spring

M-3 Drill hole

A-1 Adit

S-2 Shaft

FD-3 Test Pit

A A Location of Section.

NOTES

1. Drill holes with the prefixes AL, AR, BL, DR, EL and FR were completed in 1955.
2. Drill hole with the prefix M and all test pits (prefix FD) were completed in 1968
3. Drill holes with the prefix HV, adits and shafts with prefix A and S are a part of the current program of the consortium of Harza Overseas Engineering Co., Dar Al-Handesah, and Consulting Engineering Center
4. Base map from the report "Maqarin Scheme Phase B (Draft) OSB-B1, Geological Report" by ENERGOPROJEKT Engineering and Consulting Co (1966).
5. Geology modified from the report "Maqarin Scheme Phase B(Draft) OSB-B1, Geological Report"
6. Coordinate system shown on this map is 5m east and 12.3m north of coordinate system on ENERGOPROJEKT base map. Adjustment was made to reconcile Harza survey of 1976 with ENERGOPROJEKT survey of 1966
7. Drill holes AL-3 and EL-3 are not shown because their locations are doubtful

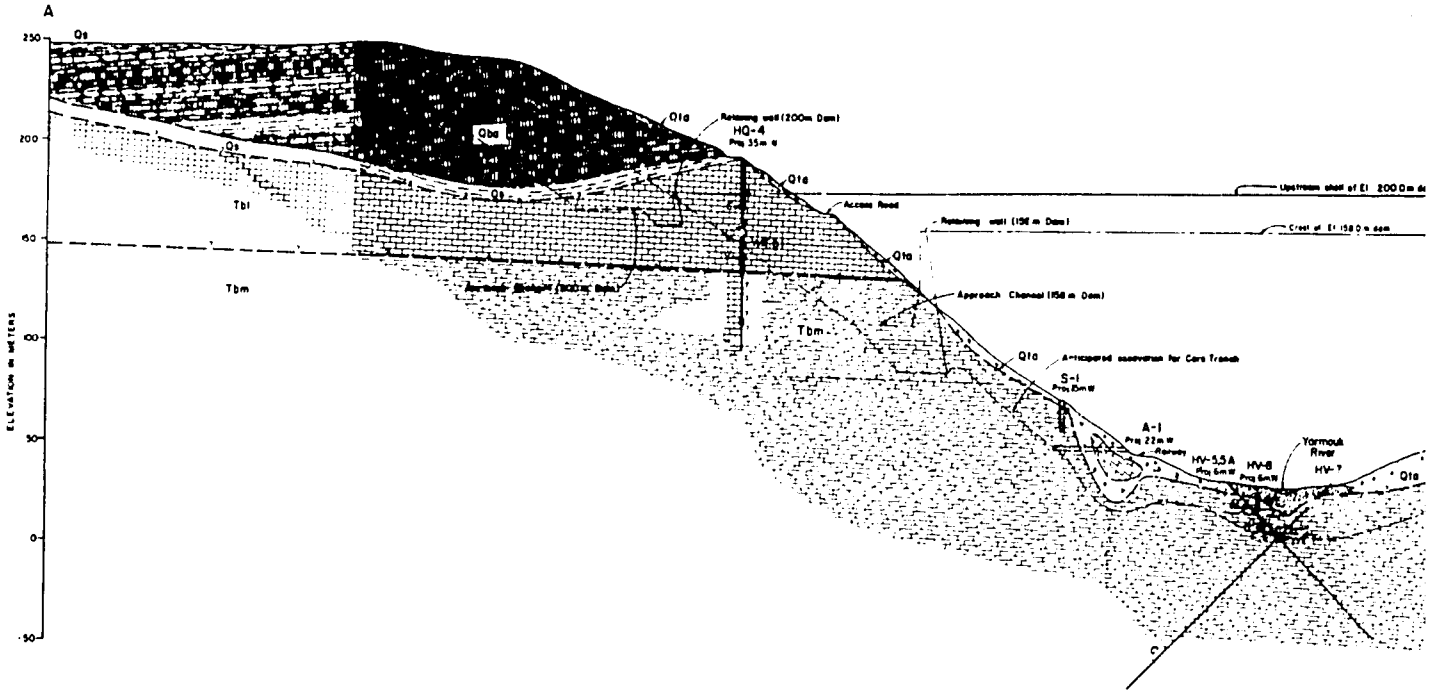
SCALE 0 50 100 METERS

GEOLOGY OF MAQARIN DAM EMBANKMENT AREA

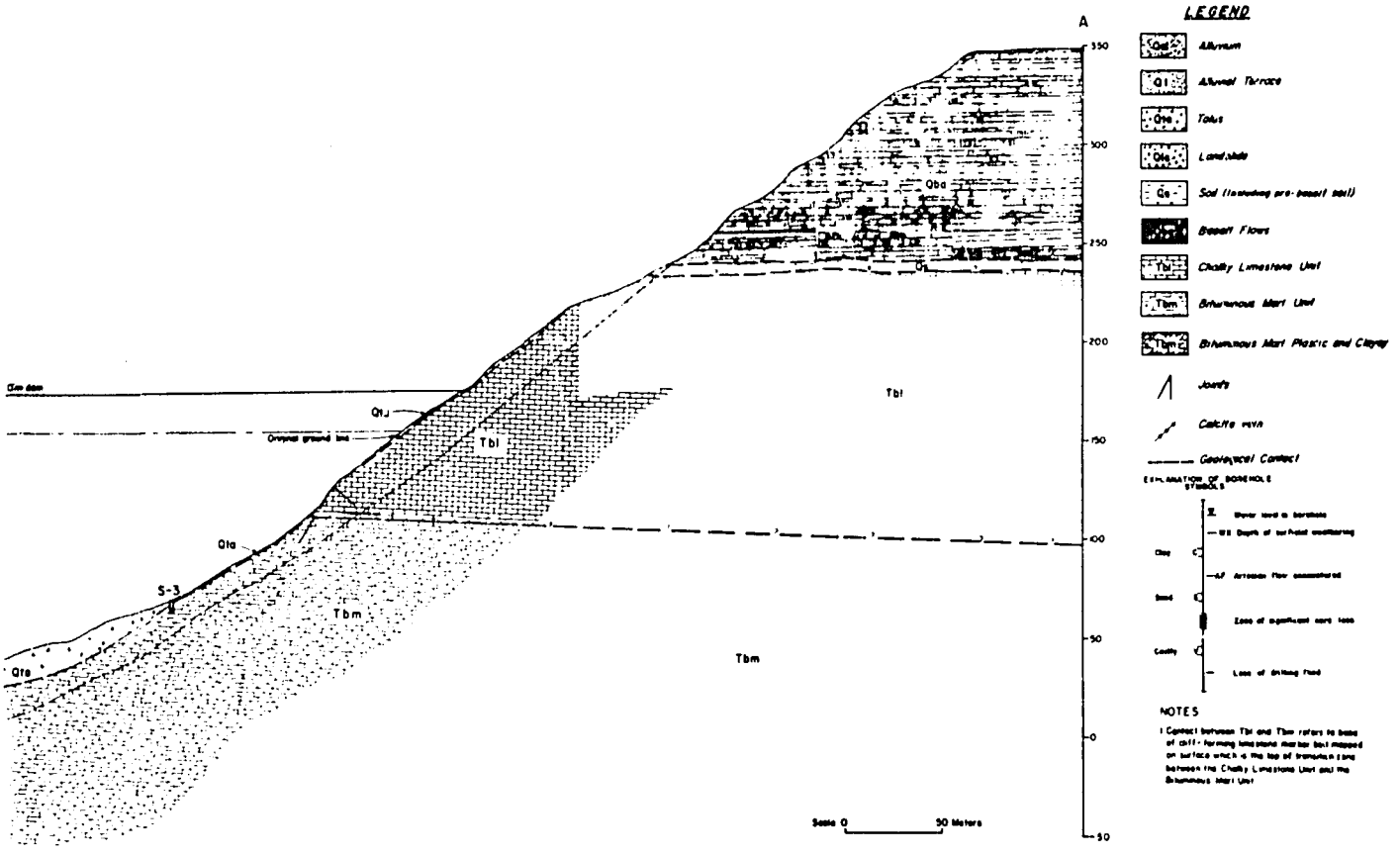
JORDAN VALLEY IRRIGATION PROJECT

STAGE II

182



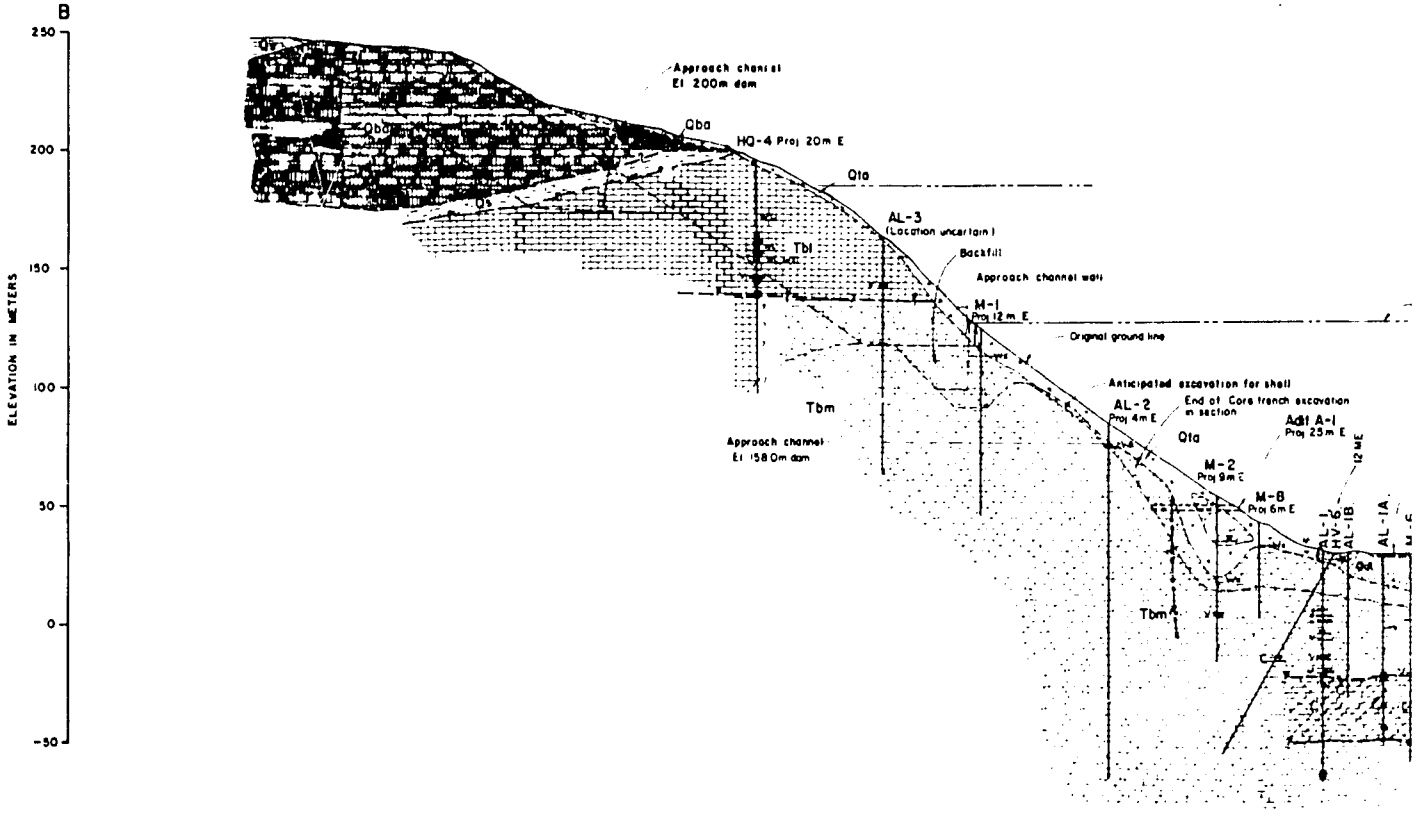
SECTION ACROSS CREST OF DAM - EL. 15



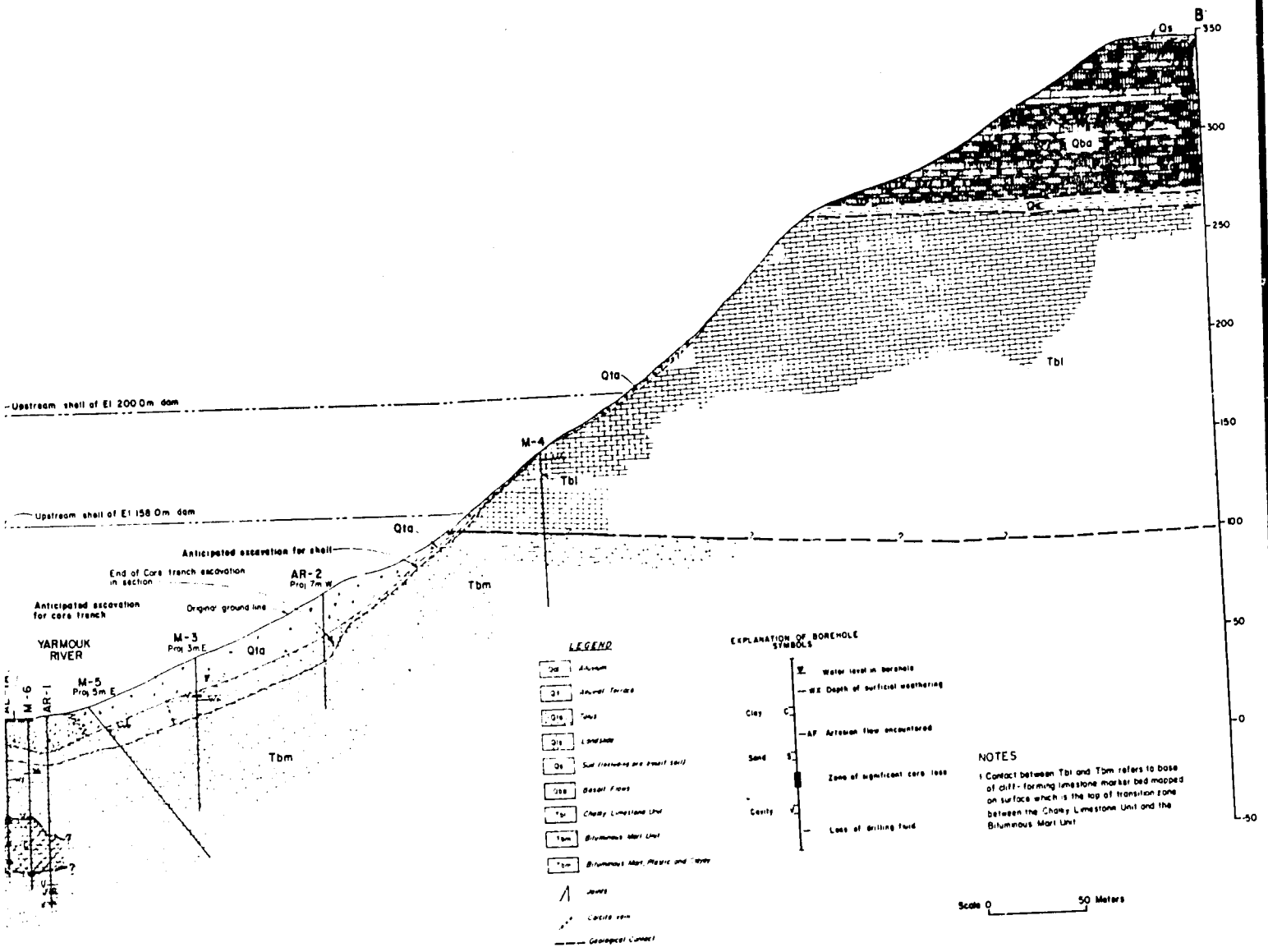
GEOLOGIC SECTION A

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



SECTION ALONG ℄ OF CORE TRENCH IN VAL

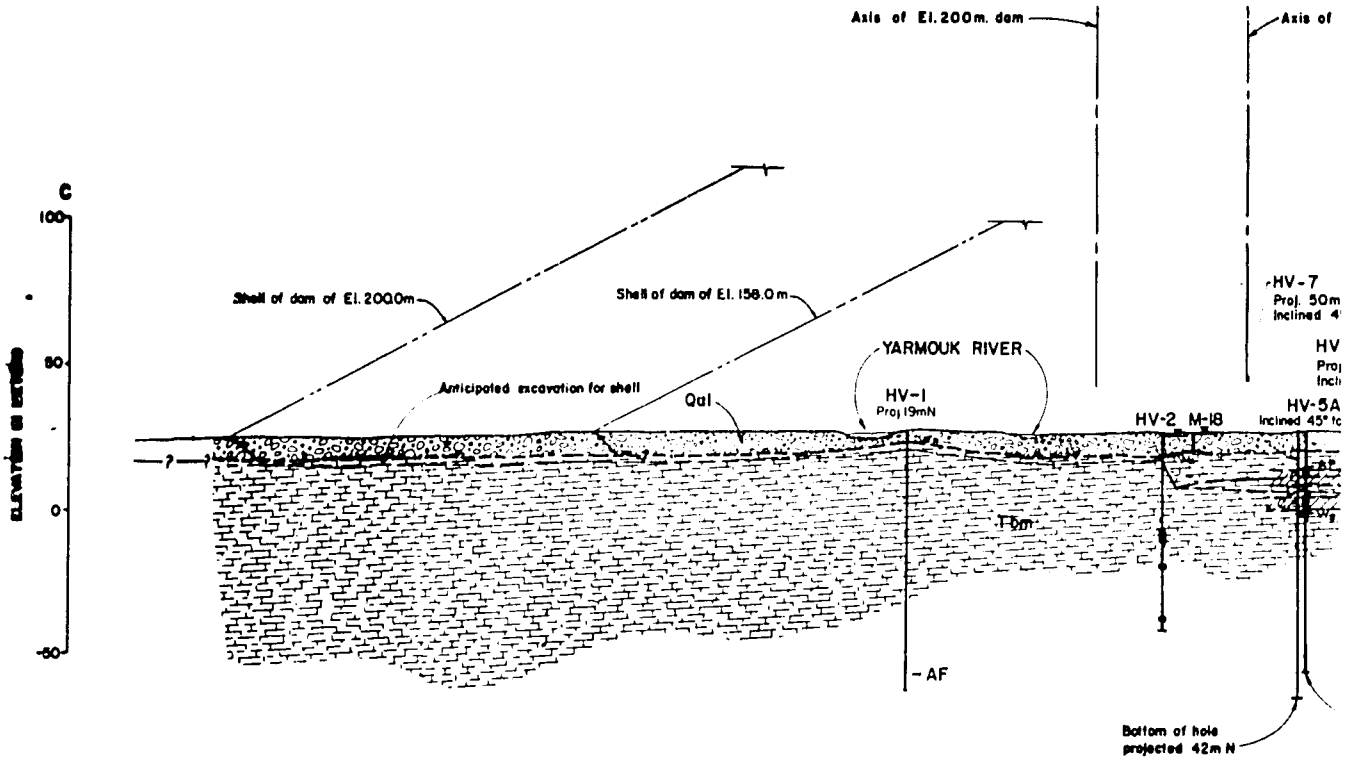


VALLEY BOTTOM

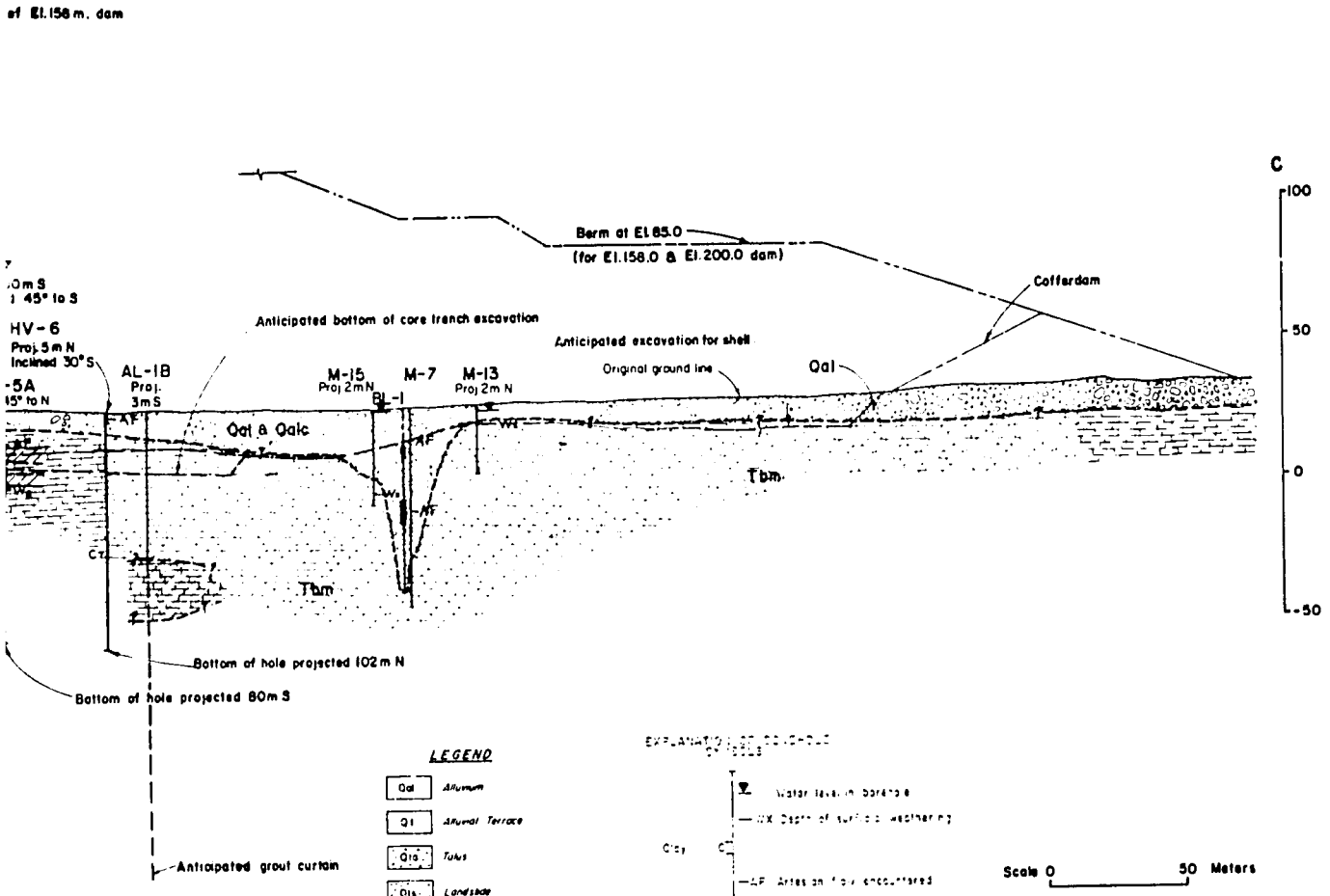
GEOLOGIC SECTION B

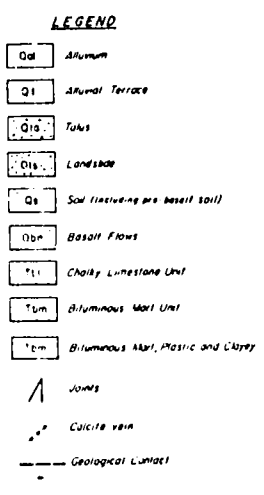
JORDAN VALLEY IRRIGATION PROJECT

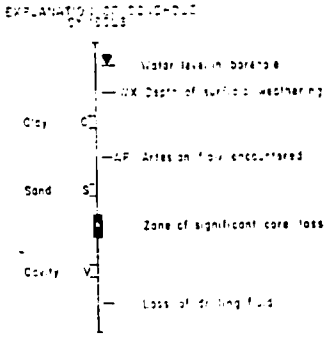
STAGE II



SECTION TRANSVERS







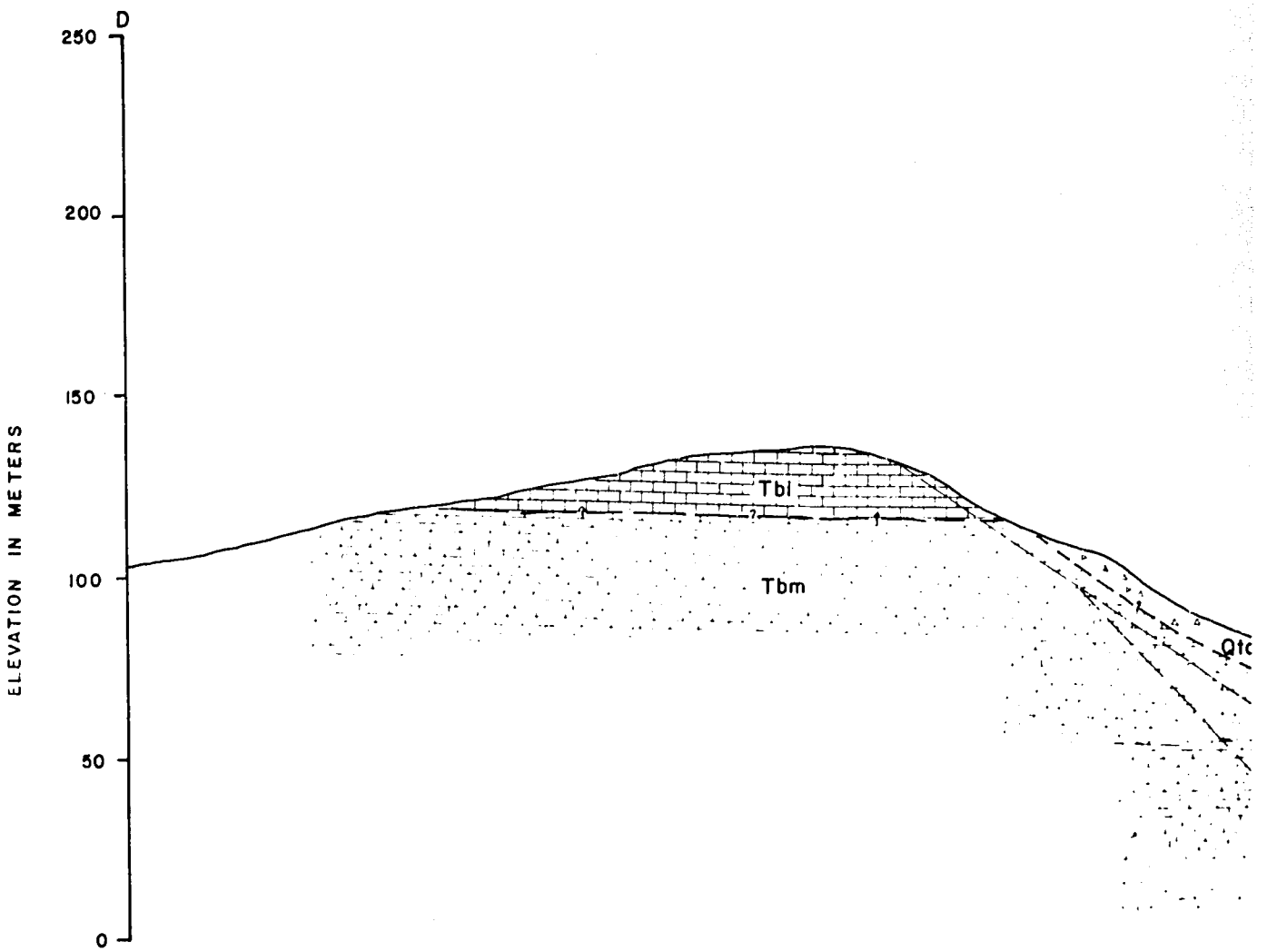
NOTES

1 Contact between Tbl and Tbm refers to base of cliff-forming limestone marker bed mapped on surface which is the top of transition zone between the Chalky Limestone Unit and the Bitumiinous Marl Unit

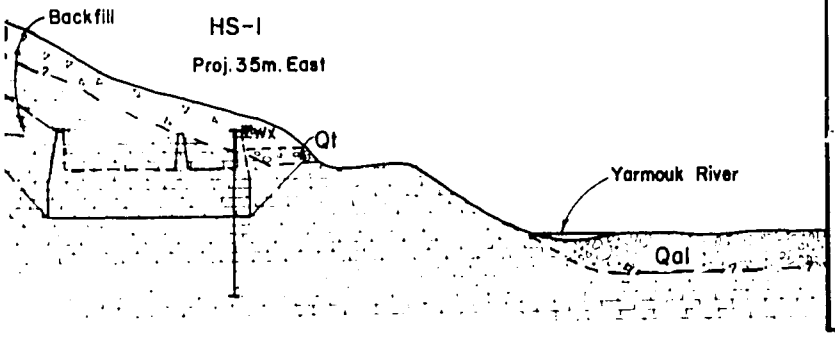
GEOLOGIC SECTION C

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



SECTION ACROSS BUCKET - E



EL. 200m DAM

LEGEND

- Qal — Alluvium
- Qt — Alluvial Terrace
- Qta — Talus
- Qls — Landslide
- Qs — Soil (Including pre-basalt soil)
- Qba — Basalt Flows
- Tbl — Chalky Limestone Unit
- Tbm — Bituminous Marl Unit
- Tbm — Bituminous Marl, Plastic and Clayey.
- Joints
- Calcite vein.
- Geological Contact.

EXPLANATION OF BOREHOLE SYMBOLS

- Water level in borehole
- WX Depth of surficial weathering
- Clay C
- AF Artesian flow encountered
- Sand S
- Zone of significant core loss
- Cavity V
- Loss of drilling fluid

NOTES

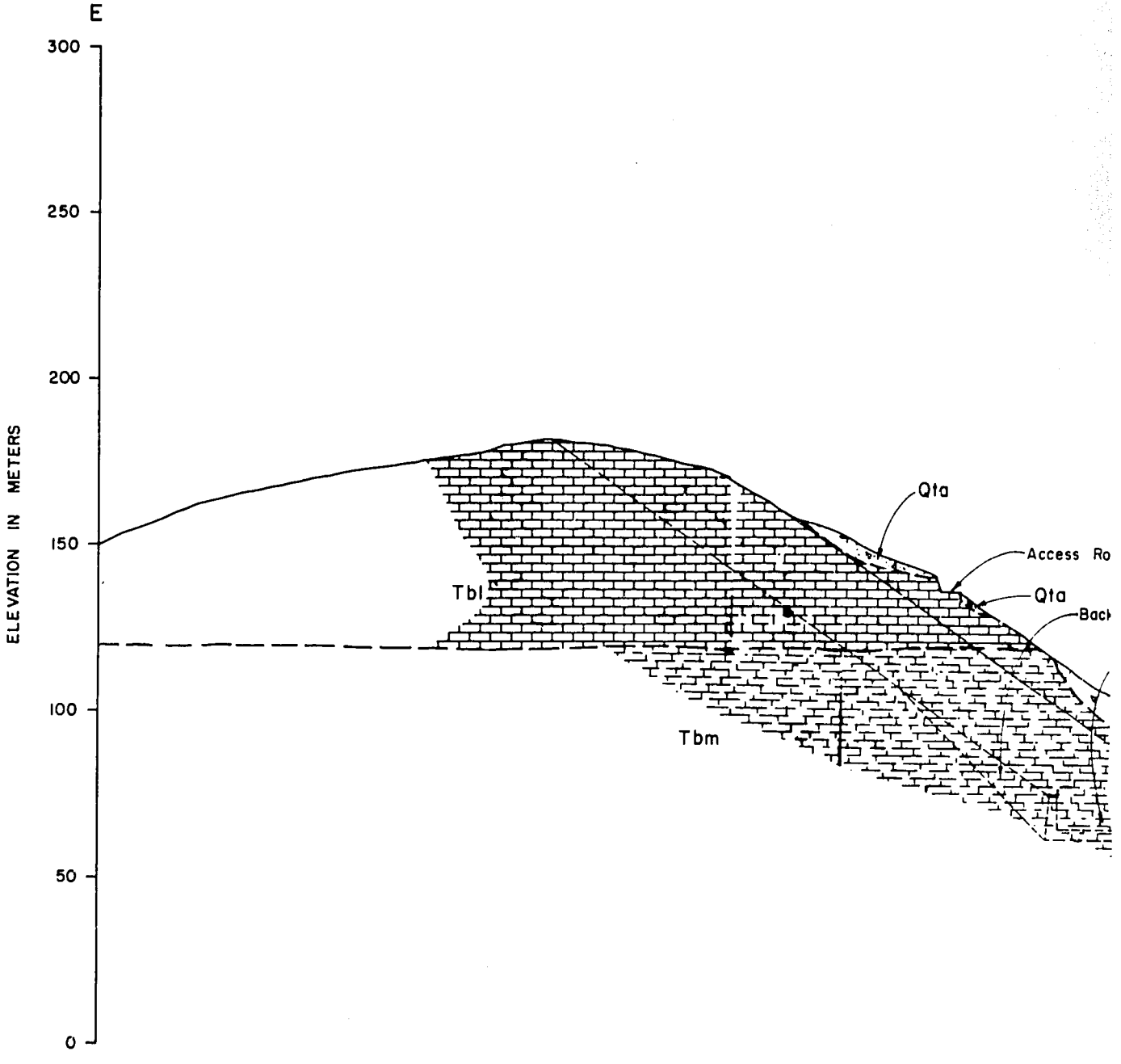
1. Contact between Tbl and Tbm refers to base of cliff-forming limestone marker bed mapped on surface which is the top of transition zone between the Chalky Limestone Unit and the Bituminous Marl Unit.

Scale 0 50 Meters

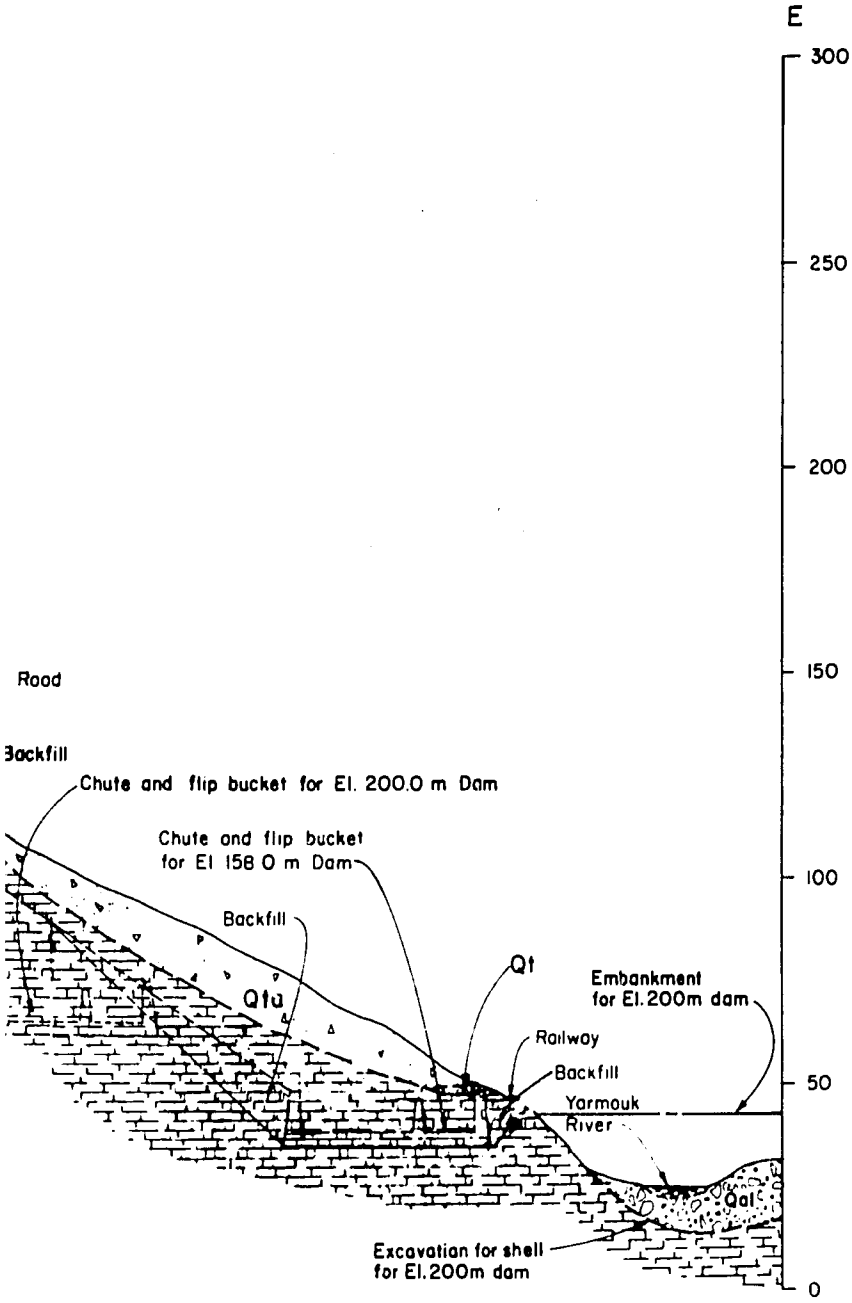
GEOLOGIC SECTION D

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



SECTION ACROSS SPILLWAY



LEGEND

- Qal — *Alluvium*
- Qt — *Alluvial Terrace*
- Qtc — *Talus*
- Qls — *Landslide*
- Qs — *Soil (Including pre-basalt soil)*
- Qba — *Basalt Flows*
- Tbl — *Chalky Limestone Unit*
- Tbm — *Bituminous Marl Unit*
- Tbm — *Bituminous Marl, Plastic and Clayey.*
- *Joints*
- *Calcite vein.*
- *Geological Contact.*

EXPLANATION OF BOREHOLE SYMBOLS

- Water level in borehole
- WX Depth of surficial weathering
- Clay C
- AF Artesian flow encountered
- Sand S
- Zone of significant core loss
- Cavity V
- Loss of drilling fluid

SCALE 0 25 50 METERS

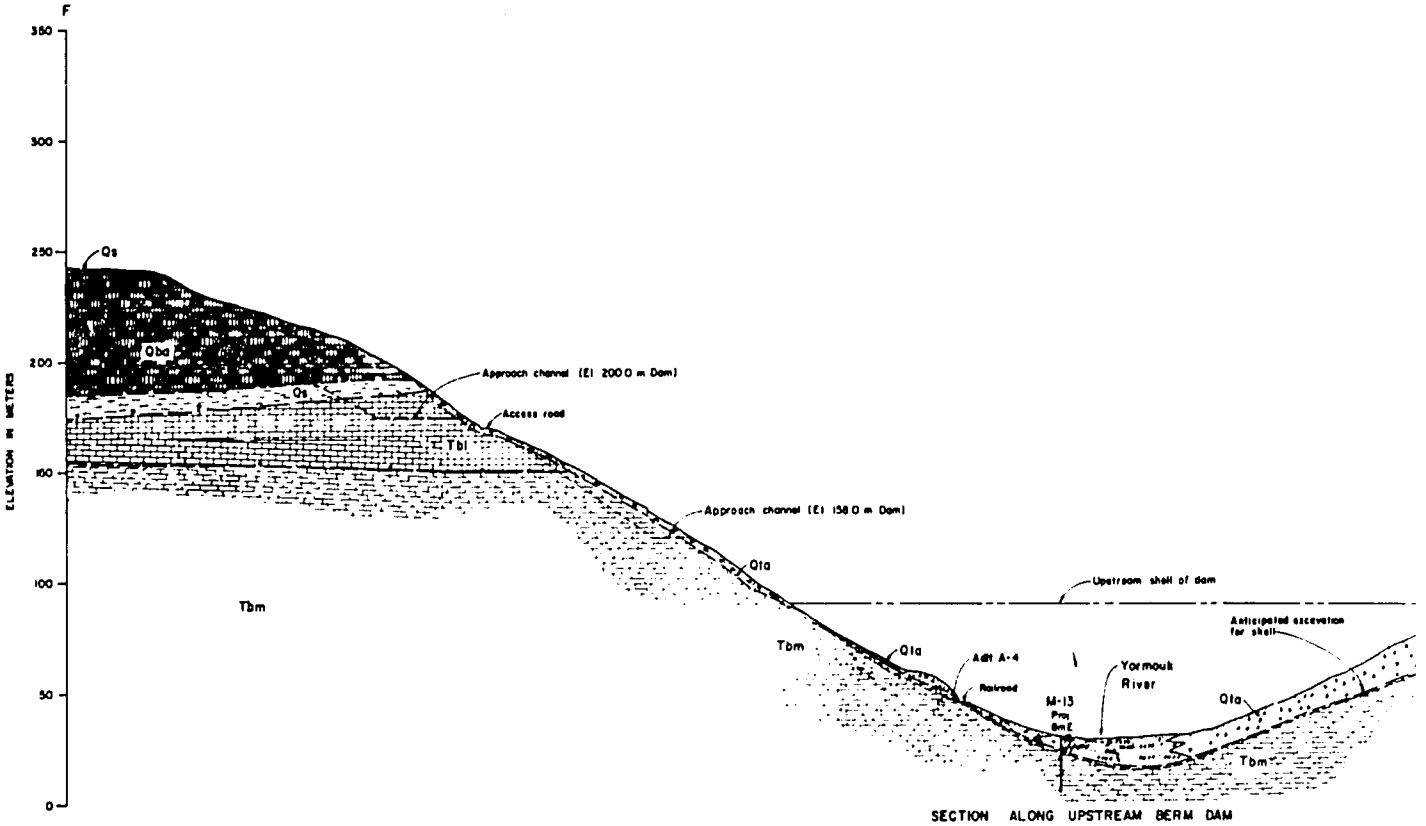
NOTES

1. Contact between Tbl and Tbm refers to base of cliff-forming limestone marker bed mapped on surface which is the top of transition zone between the Chalky Limestone Unit and the Bituminous Marl Unit

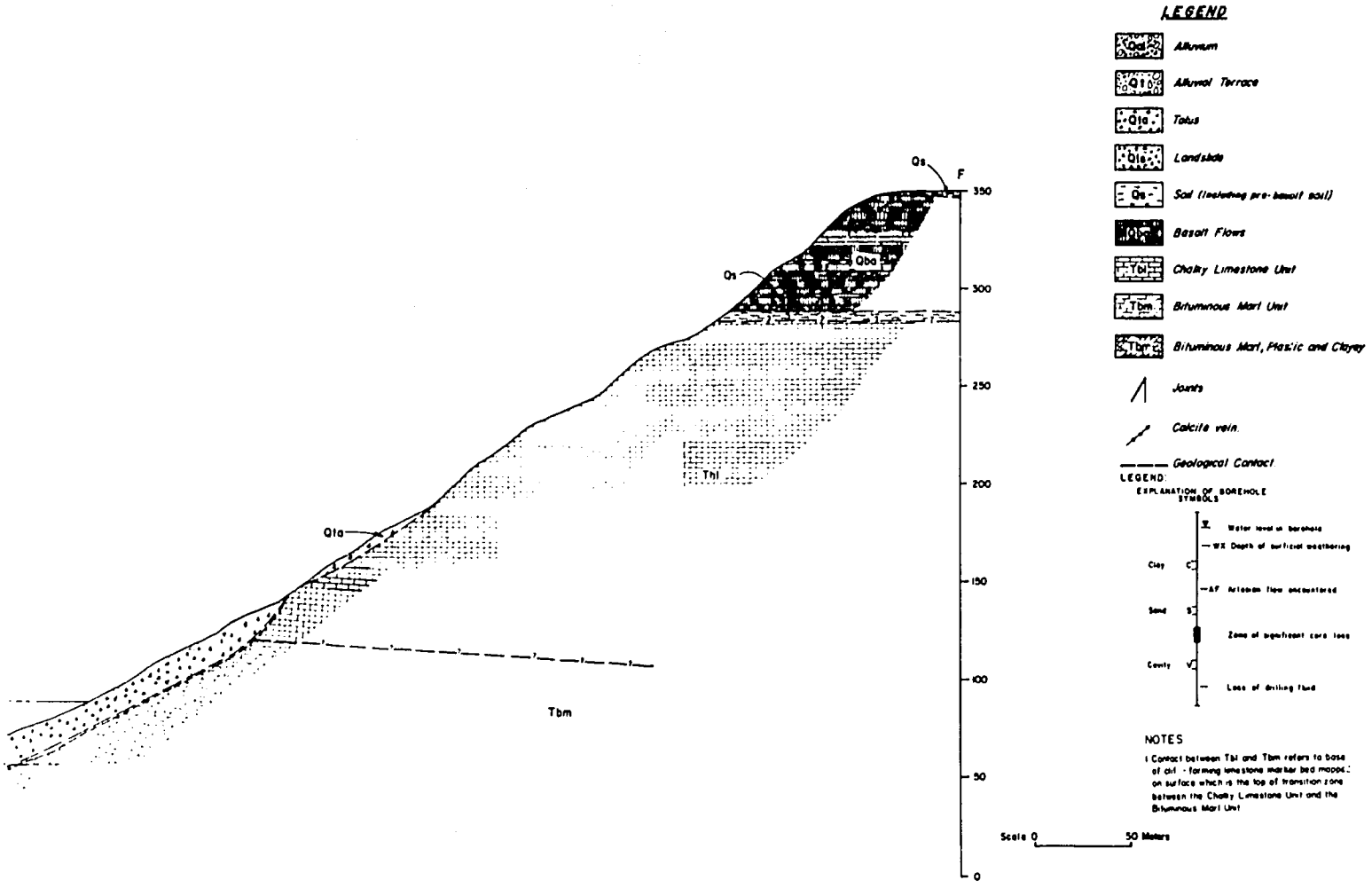
GEOLOGIC SECTION E

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



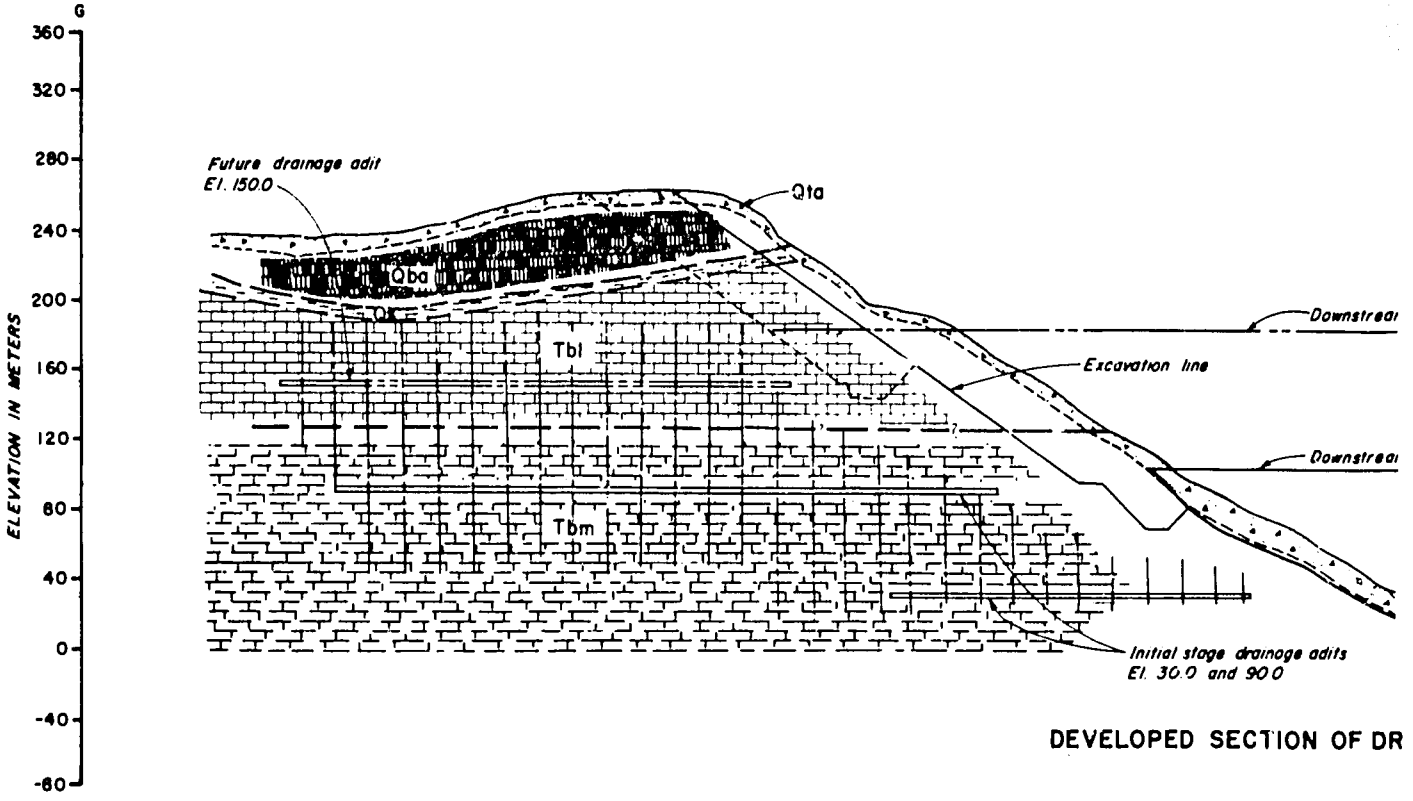
SECTION ALONG UPSTREAM BERM DAM



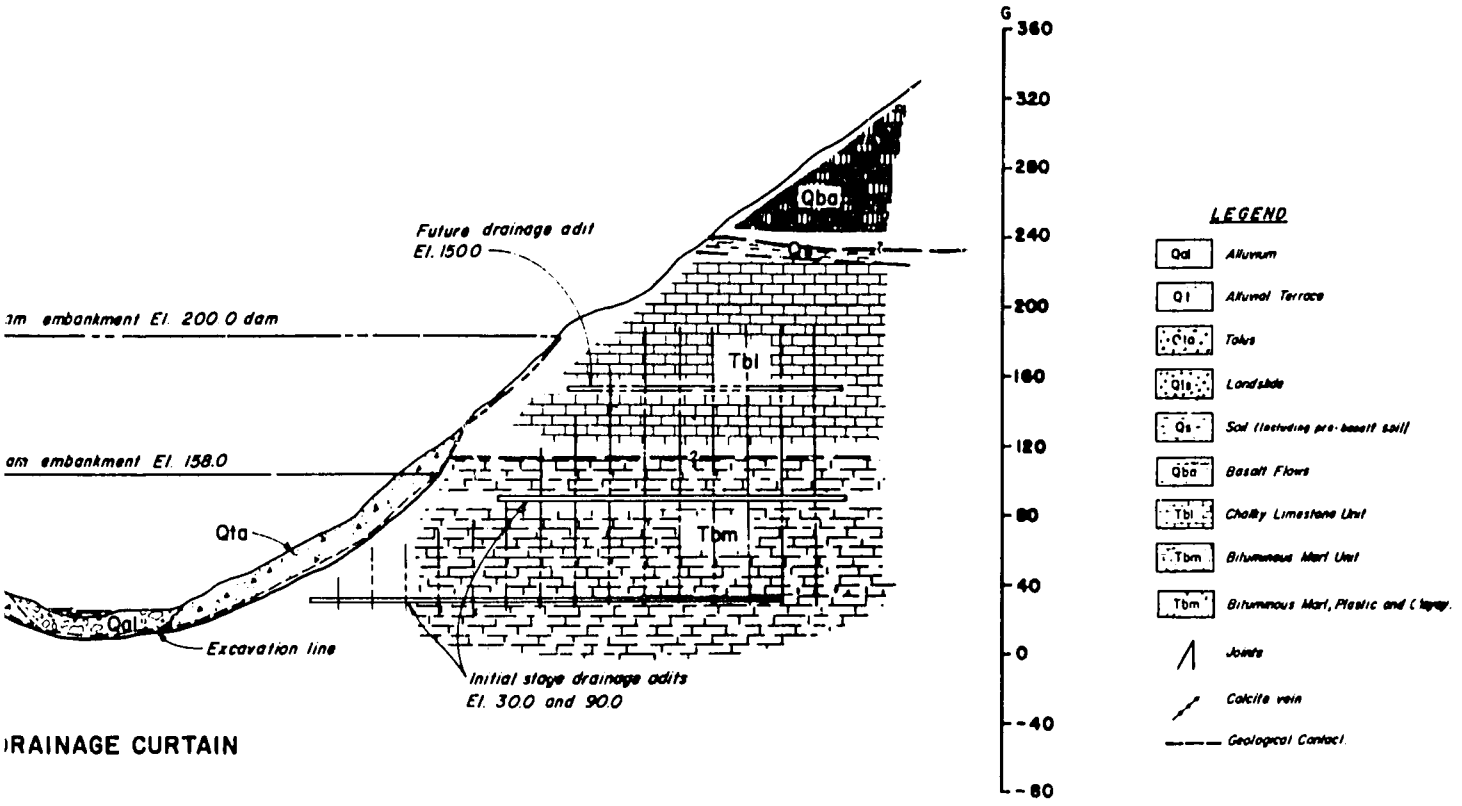
GEOLOGIC SECTION F

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



DEVELOPED SECTION OF DR



DRAINAGE CURTAIN

NOTES

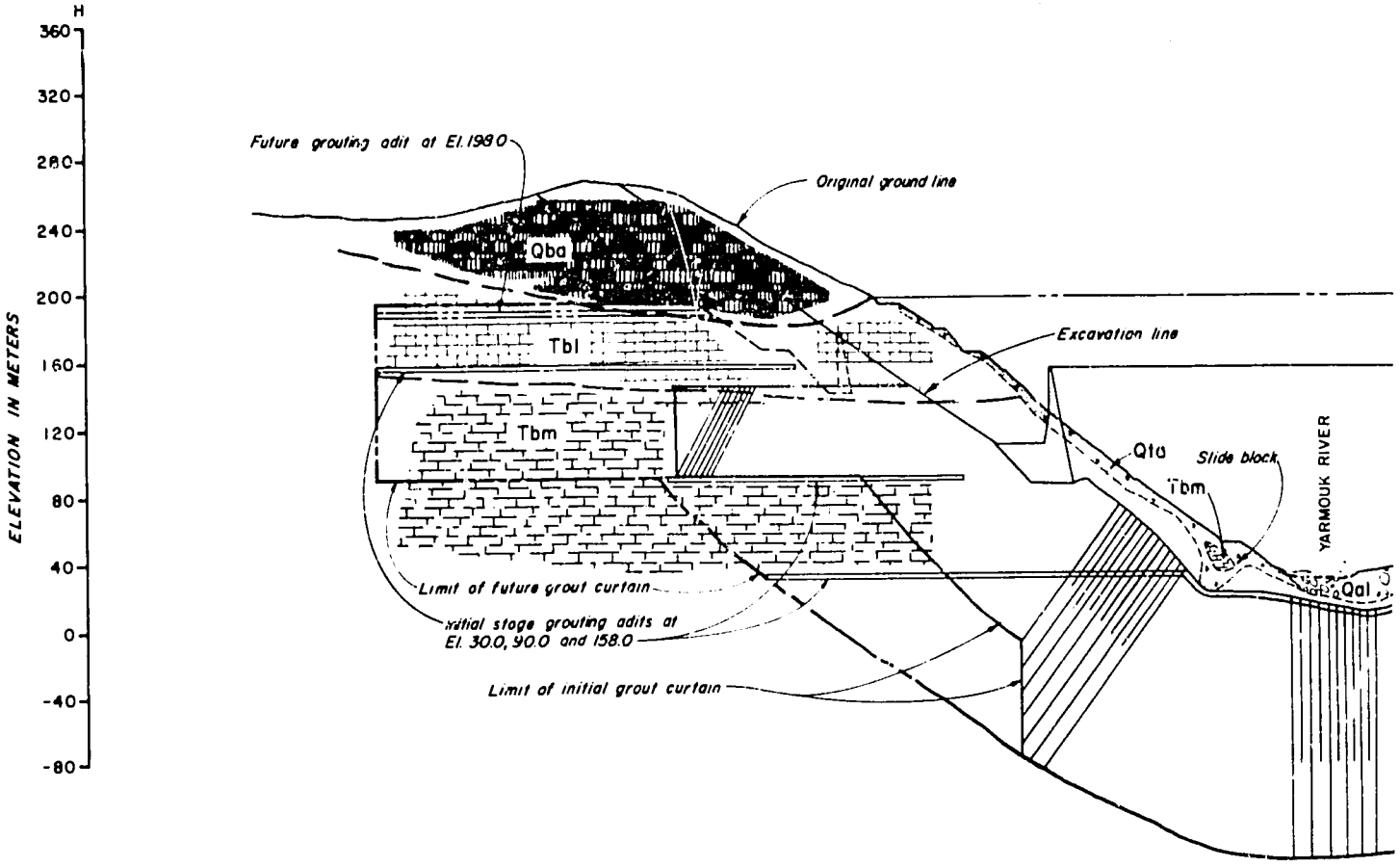
1. Contact between Tbl and Tbm refers to base of cliff-forming limestone marker bed mapped on surface which is the top of transition zone between the Chalky Limestone Unit and the Bituminous Marl Unit

Scale 0 50 100 Meters

GEOLOGIC SECTION G

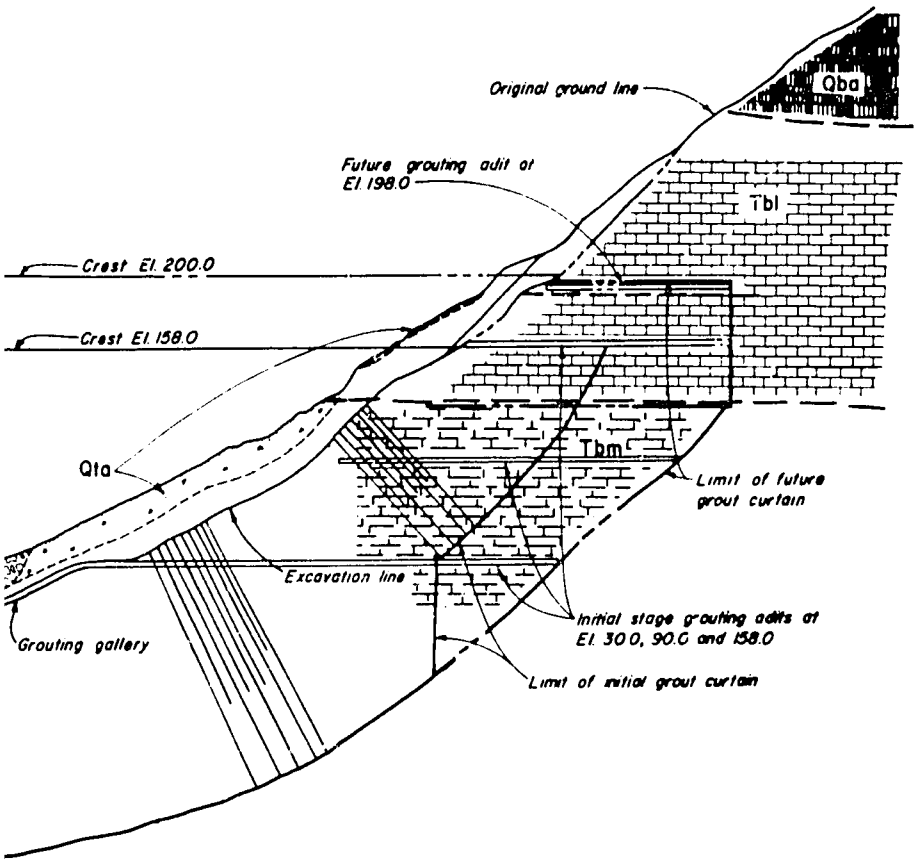
JORDAN VALLEY IRRIGATION PROJECT

STAGE II



DEVELOPED SECTION OF GROU

198



UT CURTAIN

H
360
320
280
240
200
160
120
80
40
0
-40
-80

LEGEND

- Qal — Alluvium
- Qt — Alluvial Terrace
- Qta — Talus
- Qls — Landslide
- Qs — Soil (Including pre-basalt soil)
- Qba — Basalt Flows
- Tbl — Chalky Limestone Unit
- Tbm — Bituminous Marl Unit
- Tbm — Bituminous Marl, Plastic and Clayey.
- Joints
- Calcite vein.
- Geological Contact.

NOTES

1. Contact between Tbl and Tbm refers to base of cliff-forming limestone marker bed mapped on surface which is the top of transition zone between the Chalky Limestone Unit and the Bituminous Marl Unit.

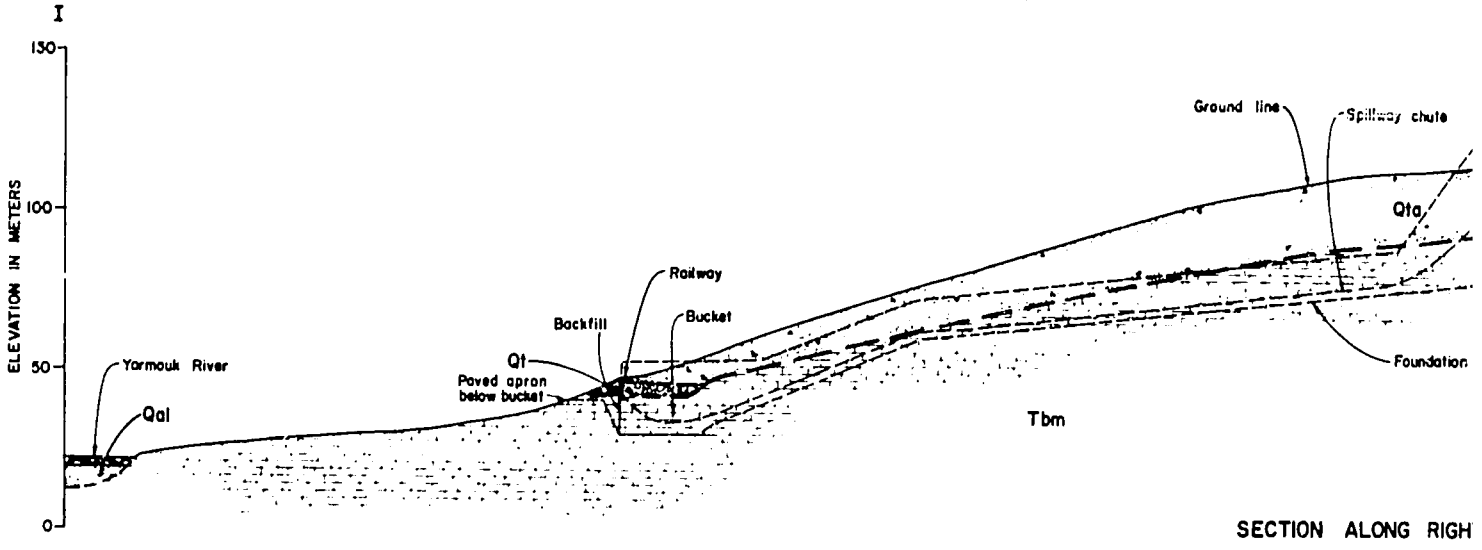
Scale 0 50 100 Meters

GEOLOGIC SECTION H

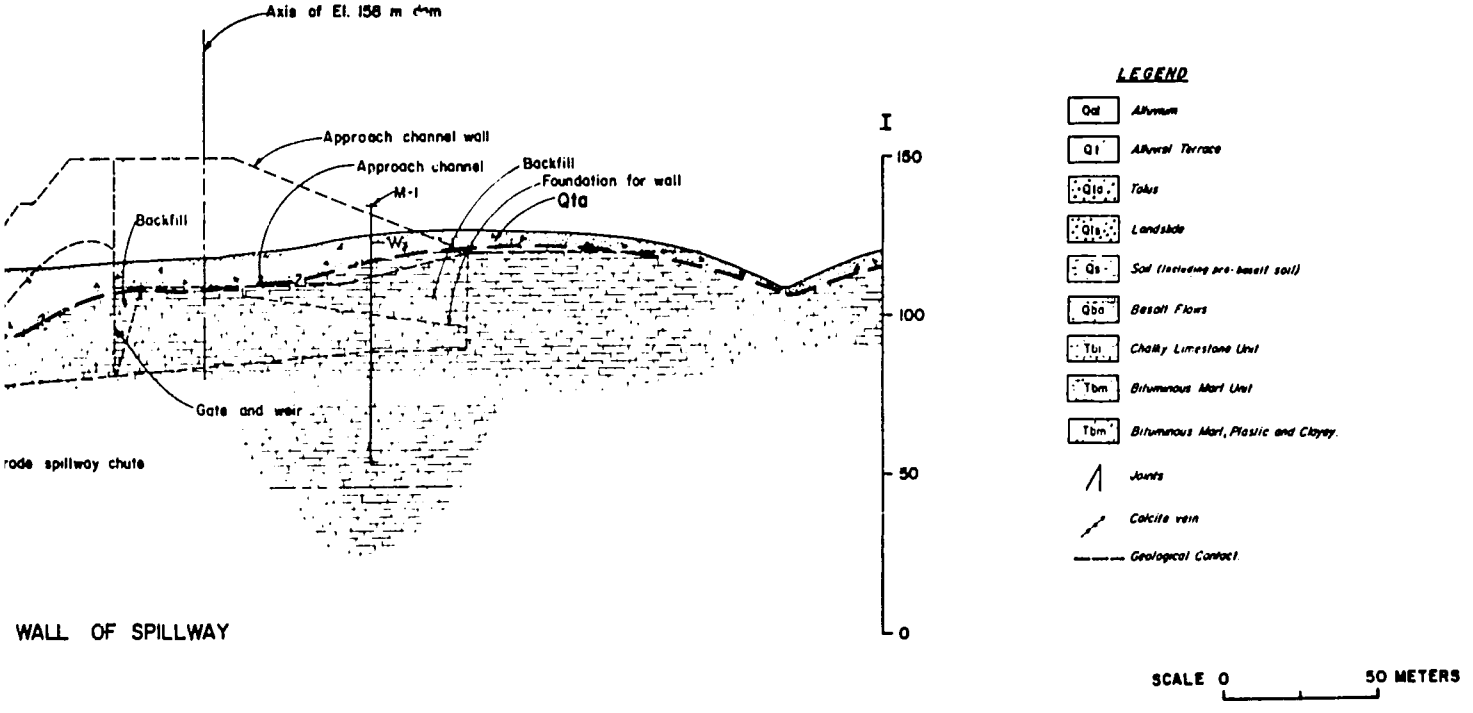
JORDAN VALLEY IRRIGATION PROJECT

STAGE II

199



SECTION ALONG RIGH

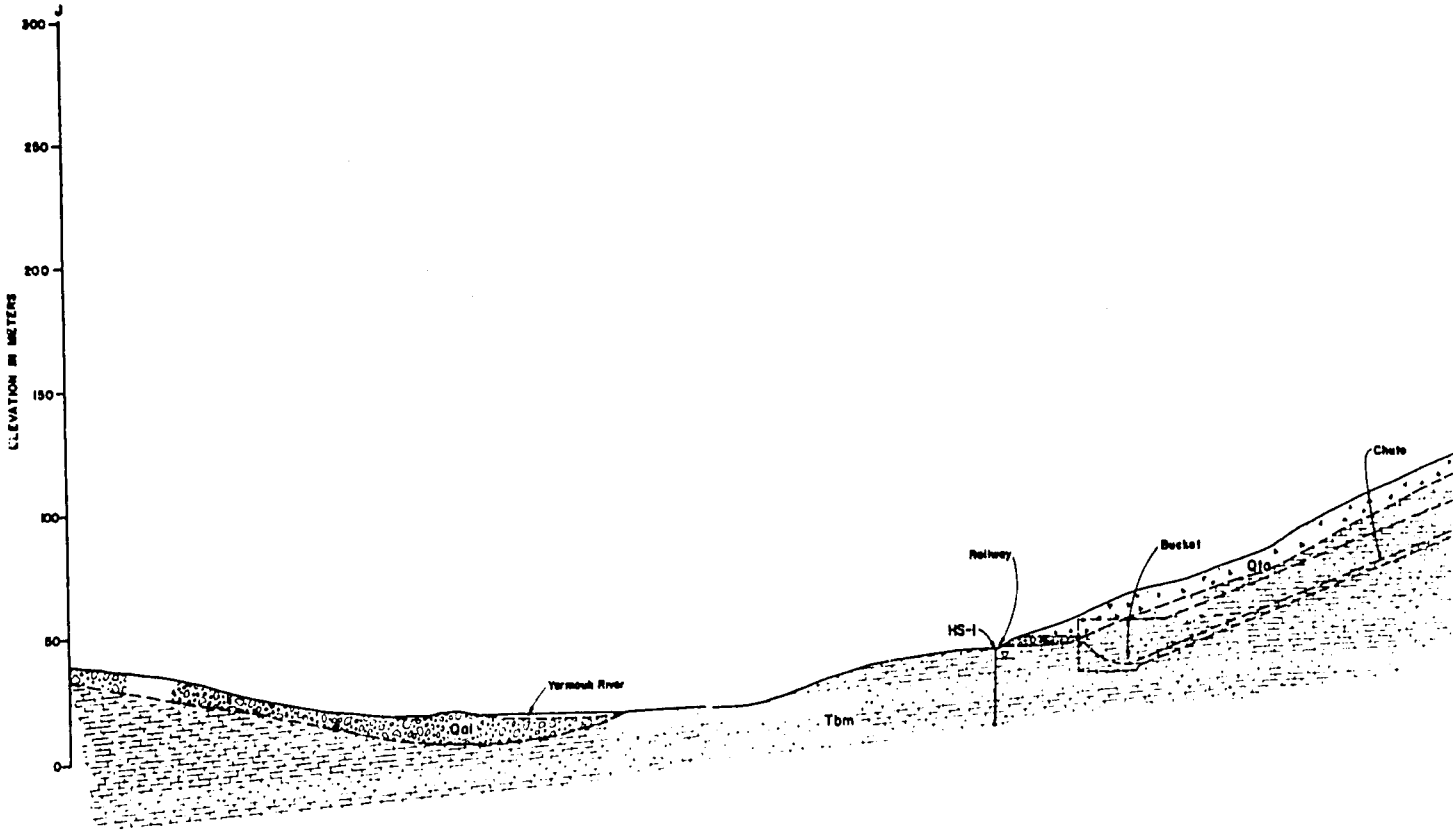


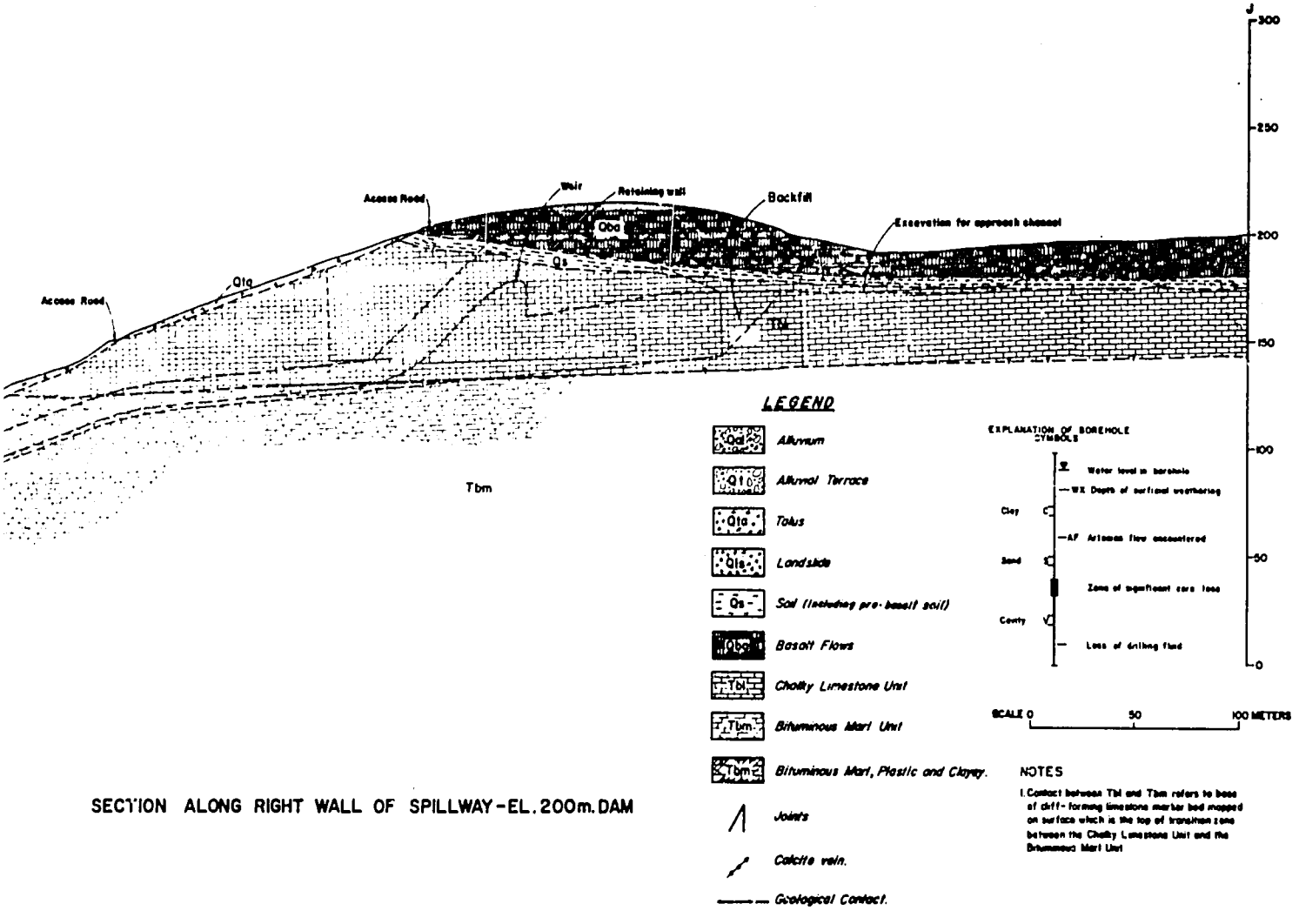
WALL OF SPILLWAY

GEOLOGIC SECTION I

JORDAN VALLEY IRRIGATION PROJECT

STAGE II


ELEVATION IN METERS
300
250
200
150
100
50
0
Yarmouk River
Qal
Tbm
HS-1
Railway
Bucket
Qfa
Chute



SECTION ALONG RIGHT WALL OF SPILLWAY-EL. 200m. DAM

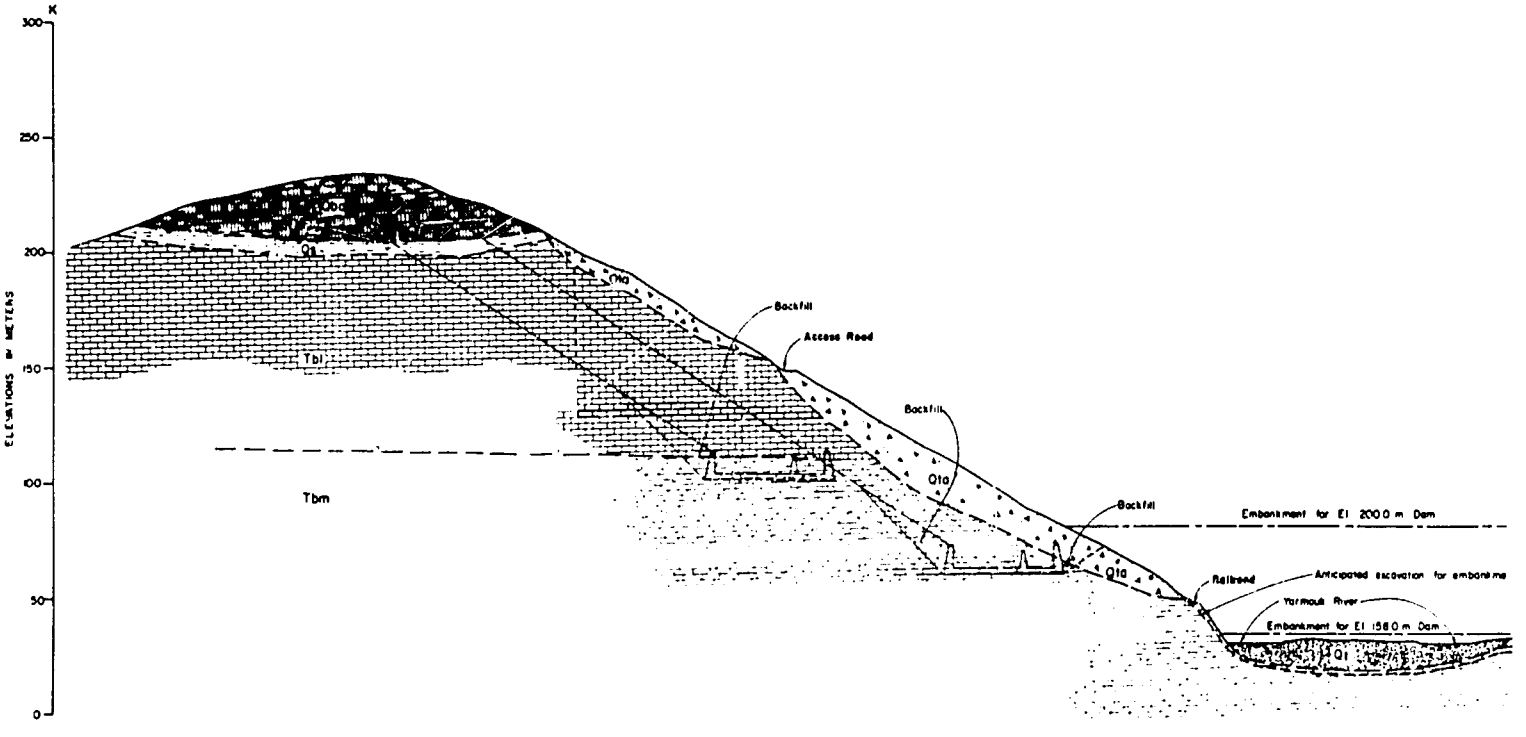
NOTES

1. Contact between Tbl and Tbm refers to base of cliff-forming limestone marker bed mapped on surface which is the top of transition zone between the Chalky Limestone Unit and the Bituminous Marl Unit

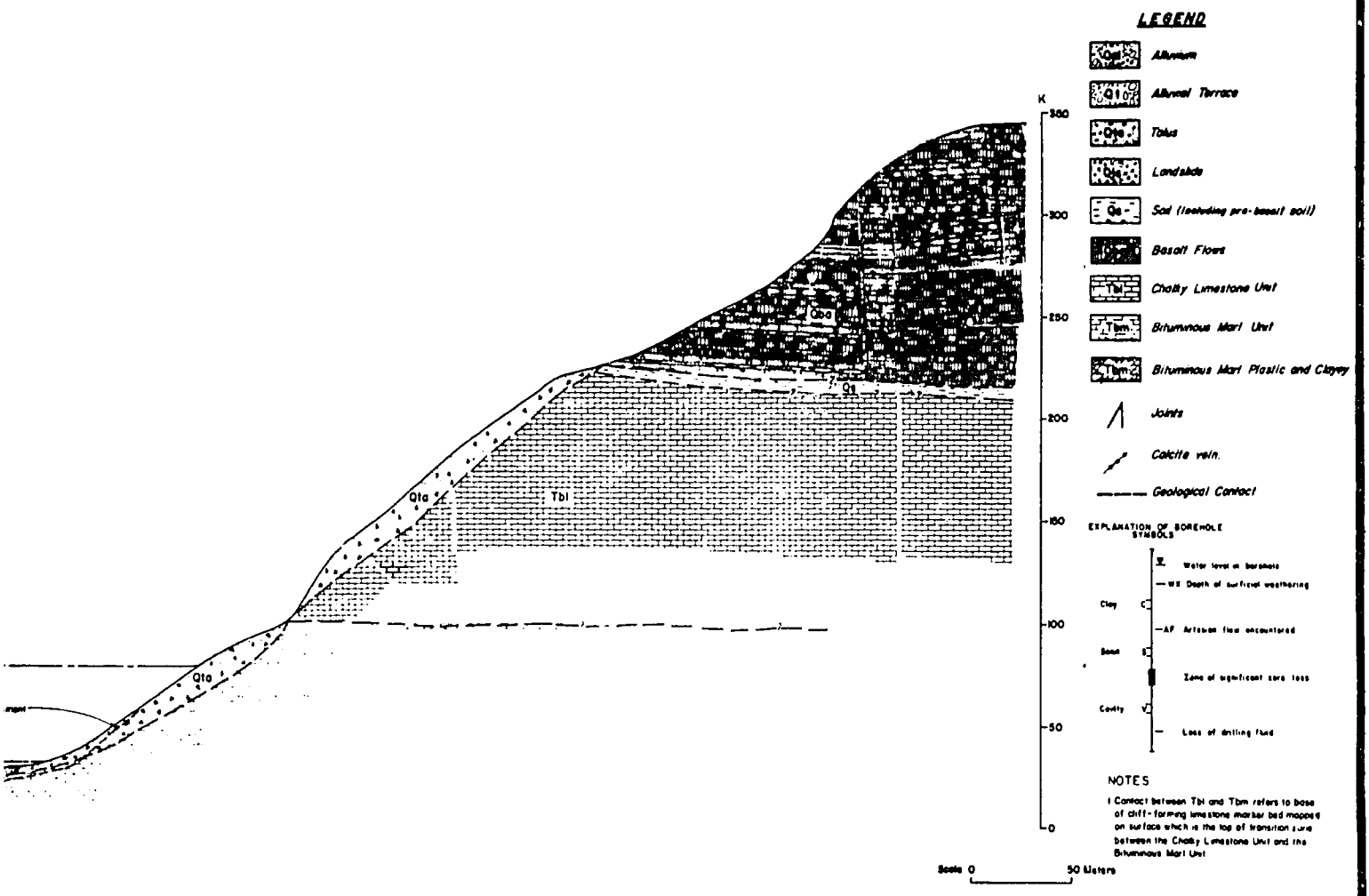
GEOLOGIC SECTION J

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



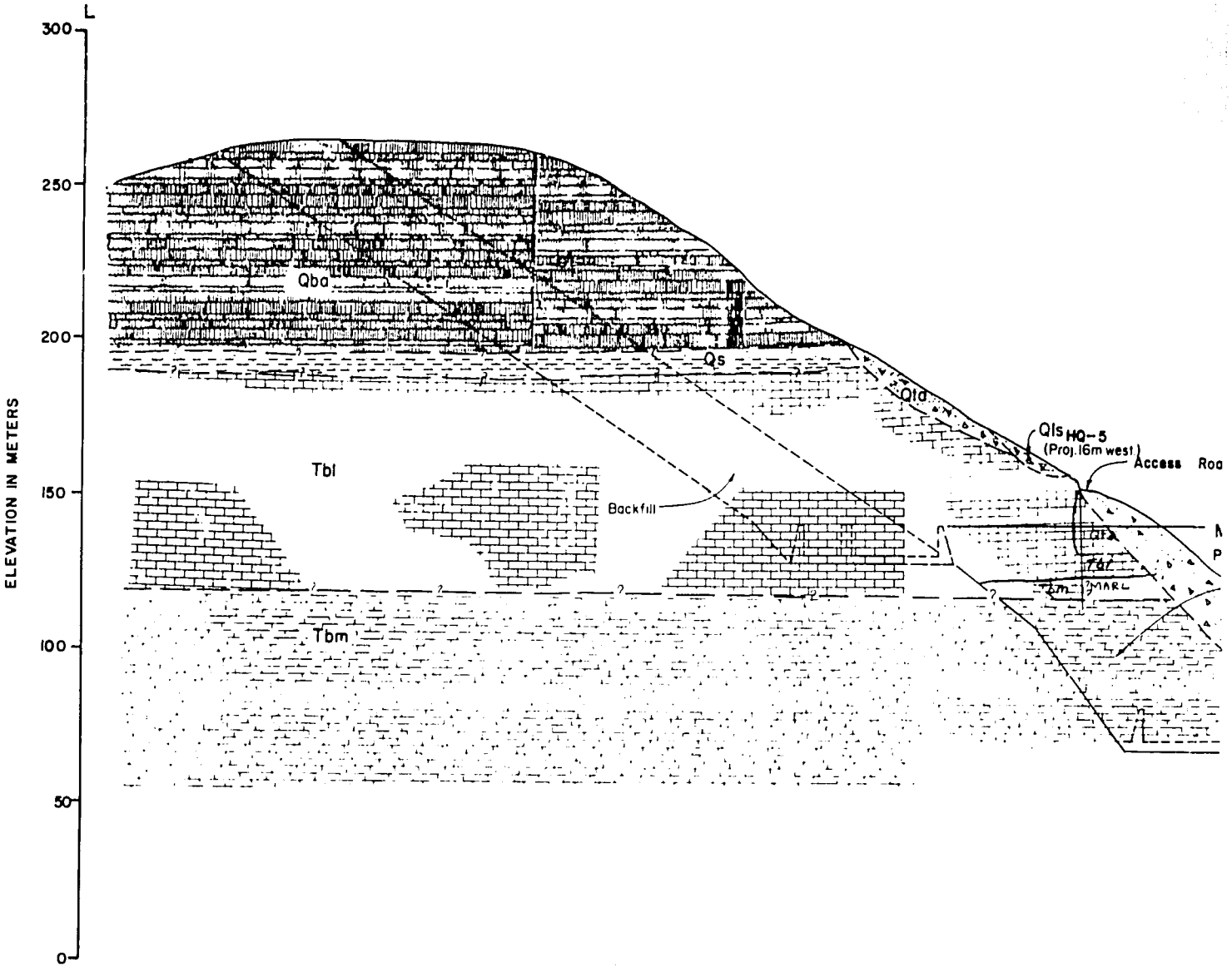
SECTION ACROSS SPILLWAY



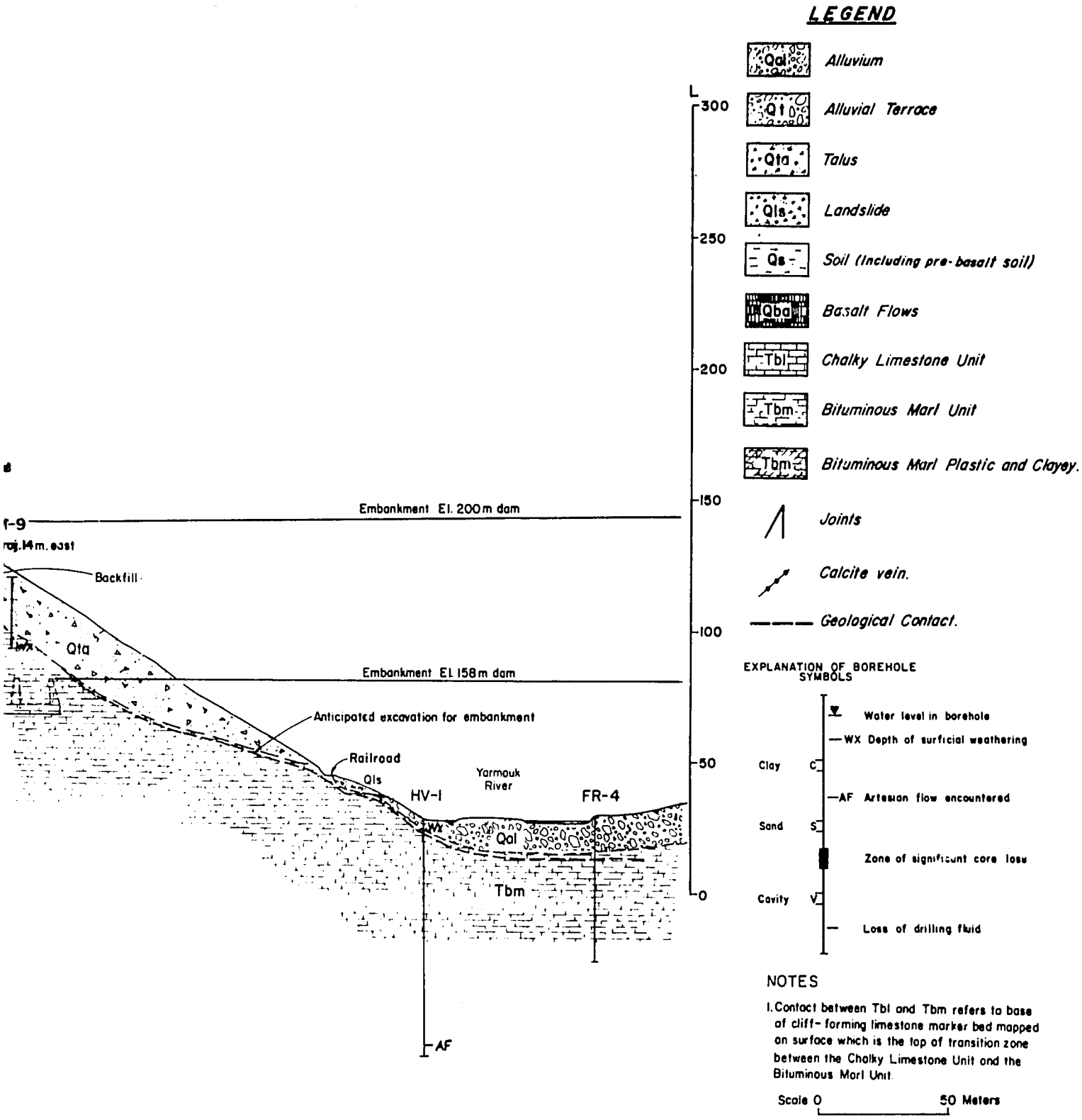
GEOLOGIC SECTION K

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



SECTION ACROSS SPILLWAY

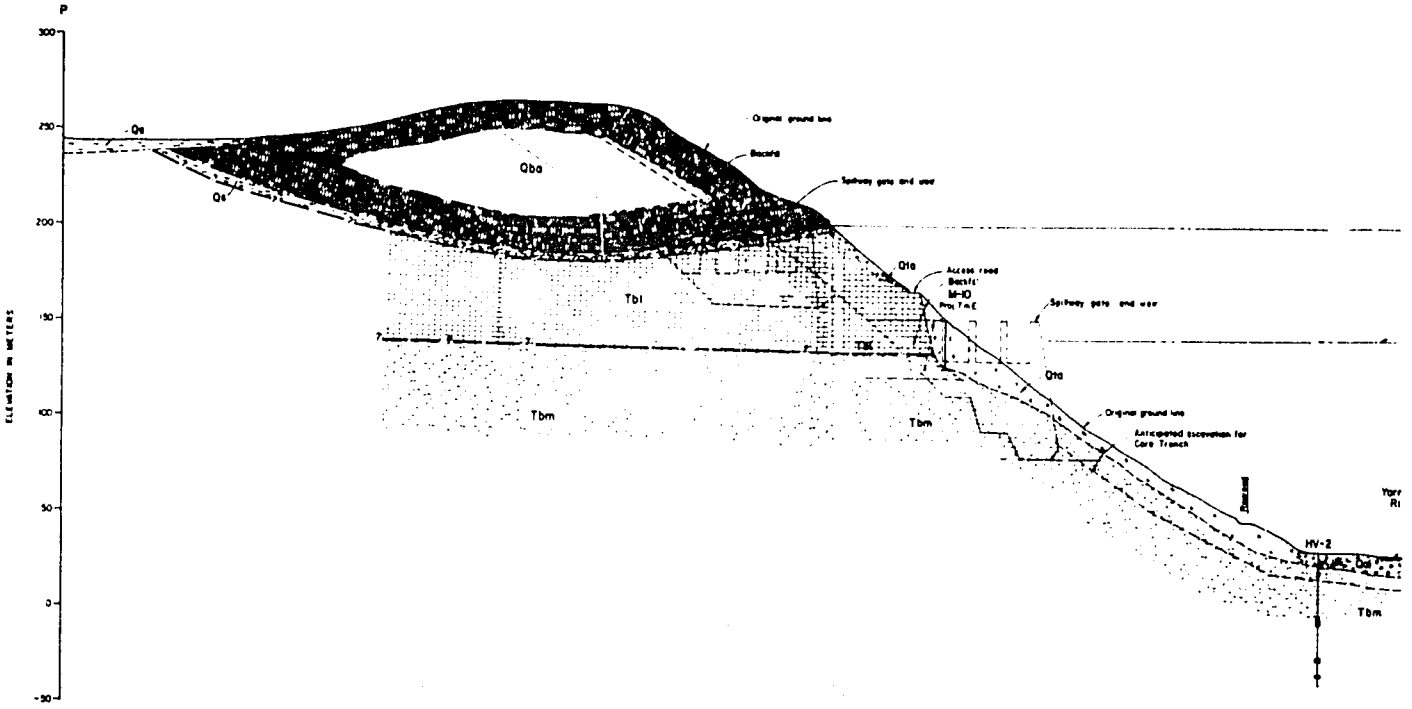


GEOLOGIC SECTION L

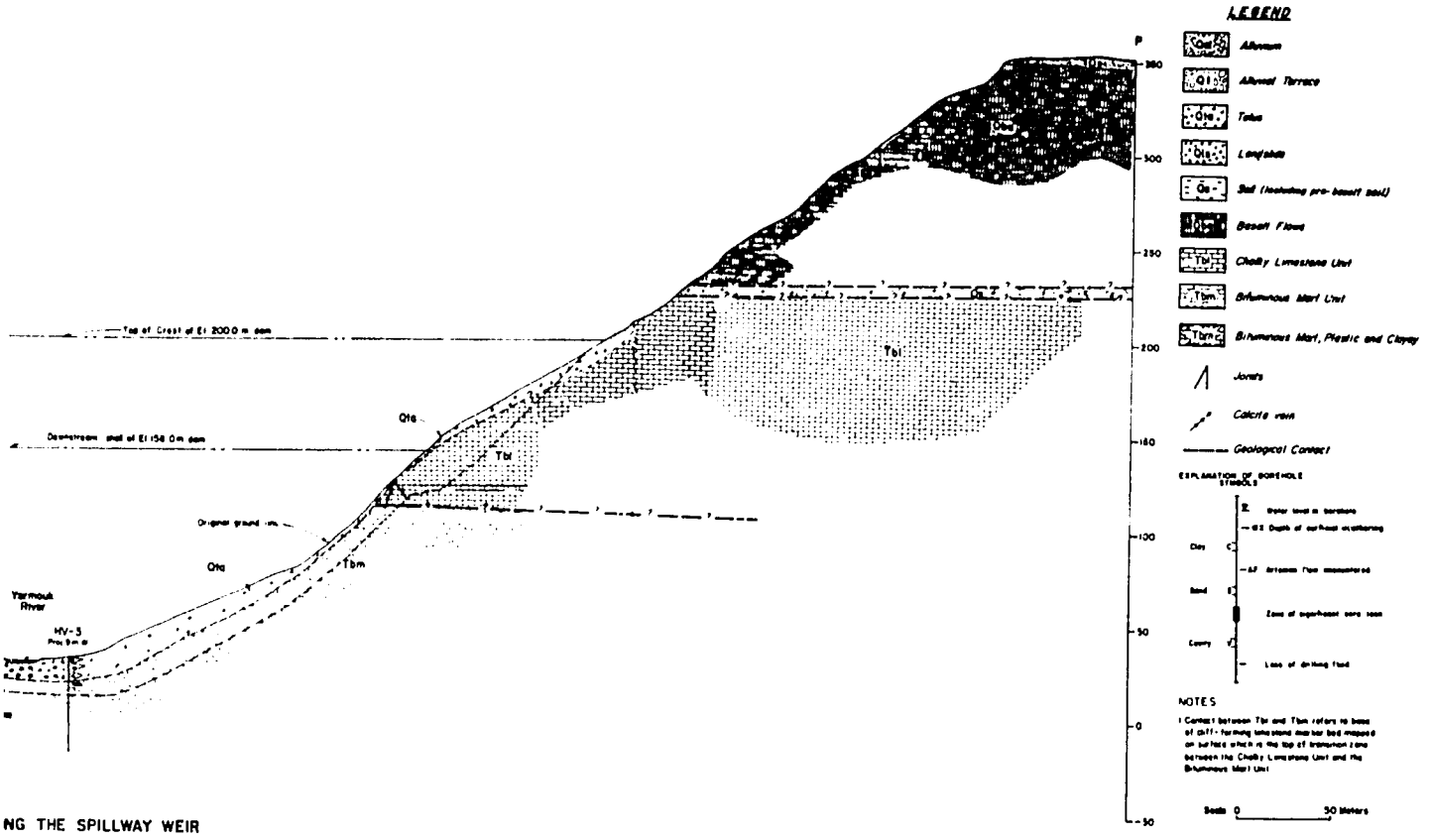
JORDAN VALLEY IRRIGATION PROJECT

STAGE II

201



SECTION ALONG

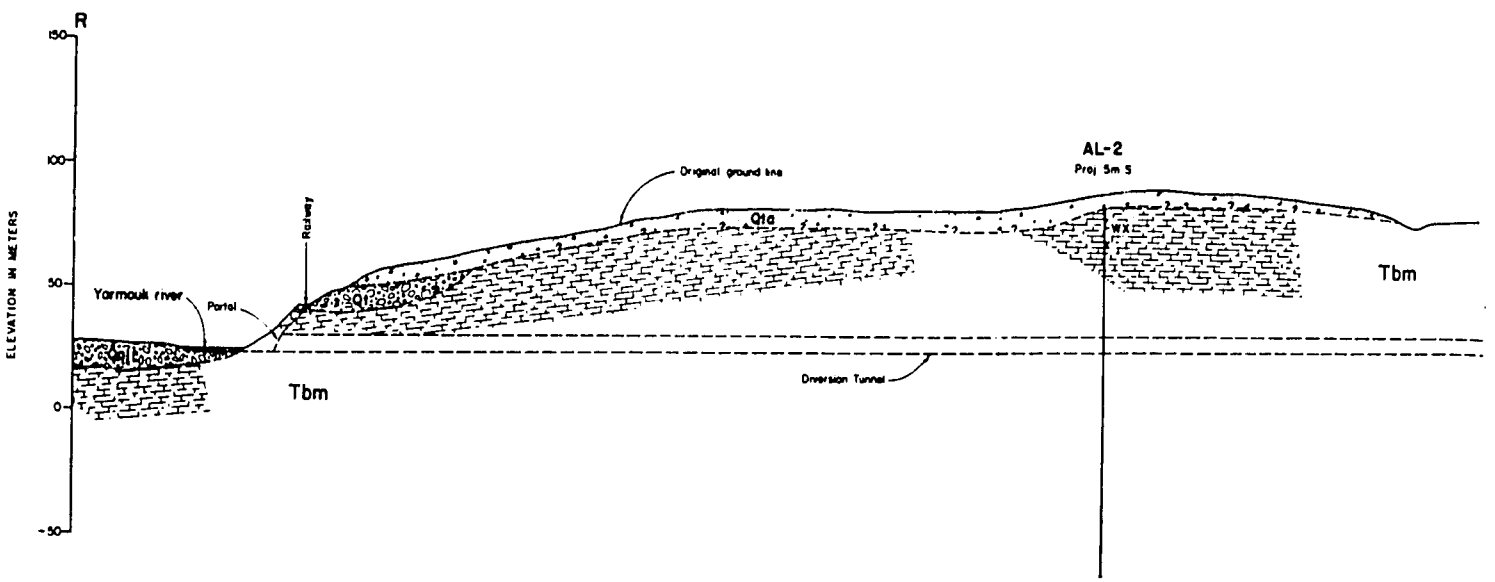


NG THE SPILLWAY WEIR

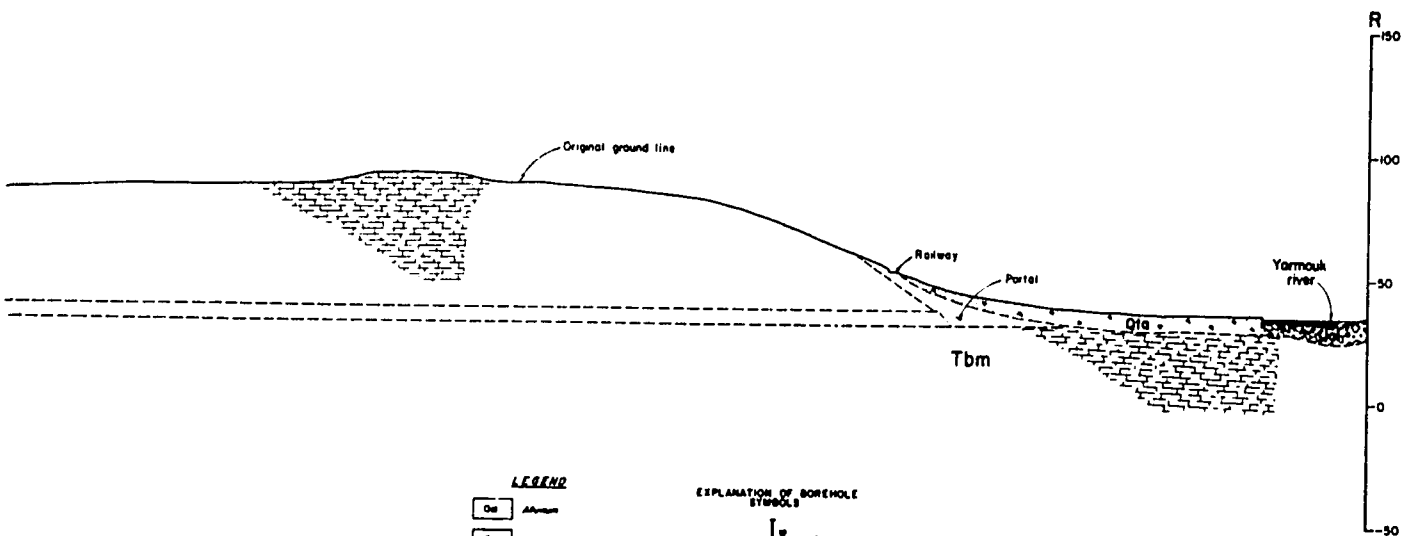
GEOLOGIC SECTION P

JORDAN VALLEY IRRIGATION PROJECT

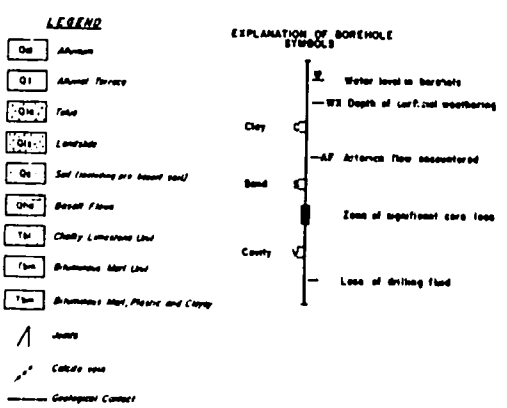
STAGE II



SECTION ALONG DIVERSION TU



N TUNNEL



NOTES

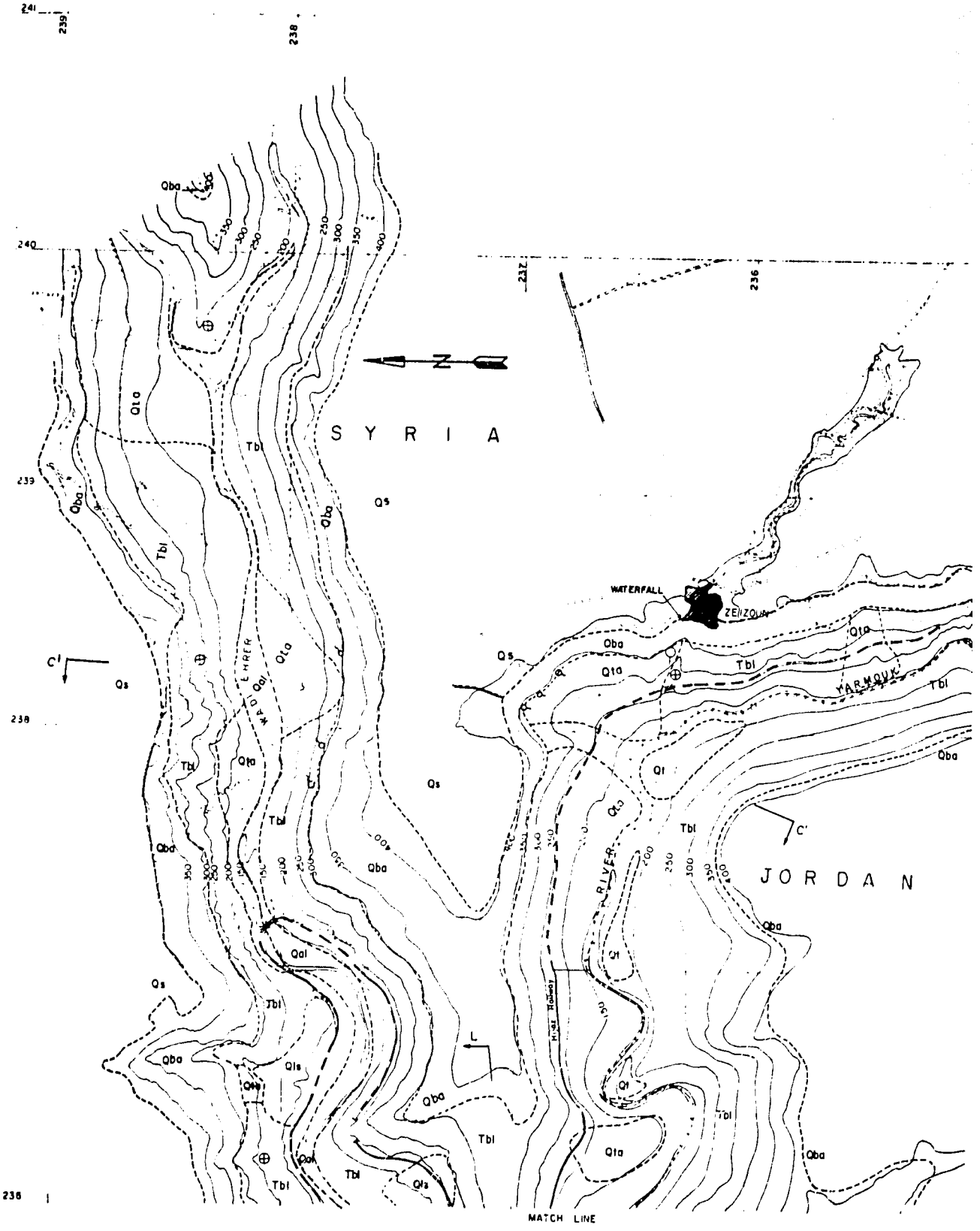
1. Contact between TM and Tbm refers to base of cliff-forming limestone marker bed mapped on surface which is the top of transition zone between the Chalky Limestone Unit and the Bituminous Marl Unit

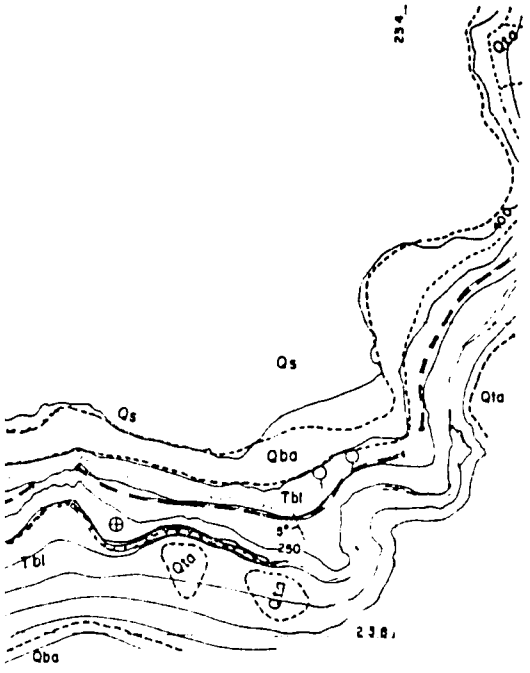
SCALE 0 50 100 METERS

GEOLOGIC SECTION R

JORDAN VALLEY IRRIGATION PROJECT

STAGE II


SYRIA
JORDAN
WATERFALL
ZEIZOUN
YARMOUK
RIVER
WADI EL HARR
Hijaz Railway
MATCH LINE
Qba
Qta
Tbl
Qs
Qal
Qls
Qt
C'
L
241
240
239
238
237
236



LEGEND

QUATERNARY

- **Qal** — ALLUVIUM. CEMENTED AND POORLY CONSOLIDATED RIVER GRAVEL.
- **Qta** — TALUS POORLY COSOLIDATED AND CEMENTED DETRITUS
- **Qt** — RIVER TERRACE
- **Qls** — LANDSLIDE
- **Qs** — SOIL: RESIDUAL SOIL
- **Qba** — BASALT FLOWS. OLIVINE BASALT FLOWS. THESE OCCUR AT VARIOUS ELEVATIONS.

TERTIARY BELQA SERIES

- **Tbl** — CHALKY LIMESTONE UNIT THICK-BEDDED, LIGHT-BROWN TO WHITE, MARINE, CHALKY LIMESTONE WITH NODULES AND LAYERS OF CHERT
- **Tbm** — BITUMINOUS MARL UNIT. SLABBY TO THICK-BEDDED, LIGHT-GREY, MARINE, MARLT LIMESTONE.

SYMBOLS

- APPROXIMATE CONTACT BETWEEN FORMATIONS
- F — FAULT
- 30 — STRIKE AND DIP OF BEDDING
- HORIZONTAL BEDDING.
- 30 — APPROXIMATE STRIKE AND DIP OF BEDDING
- 70 — STRIKE AND DIP OF JOINTING
- STRIKE AND DIP OF VERTICAL JOINTING
- ANTICLINAL AXIS
- Q — SPRING
- A — A — LOCATION OF SECTION
- INTERNATIONAL BOUNDARY

NOTE :-

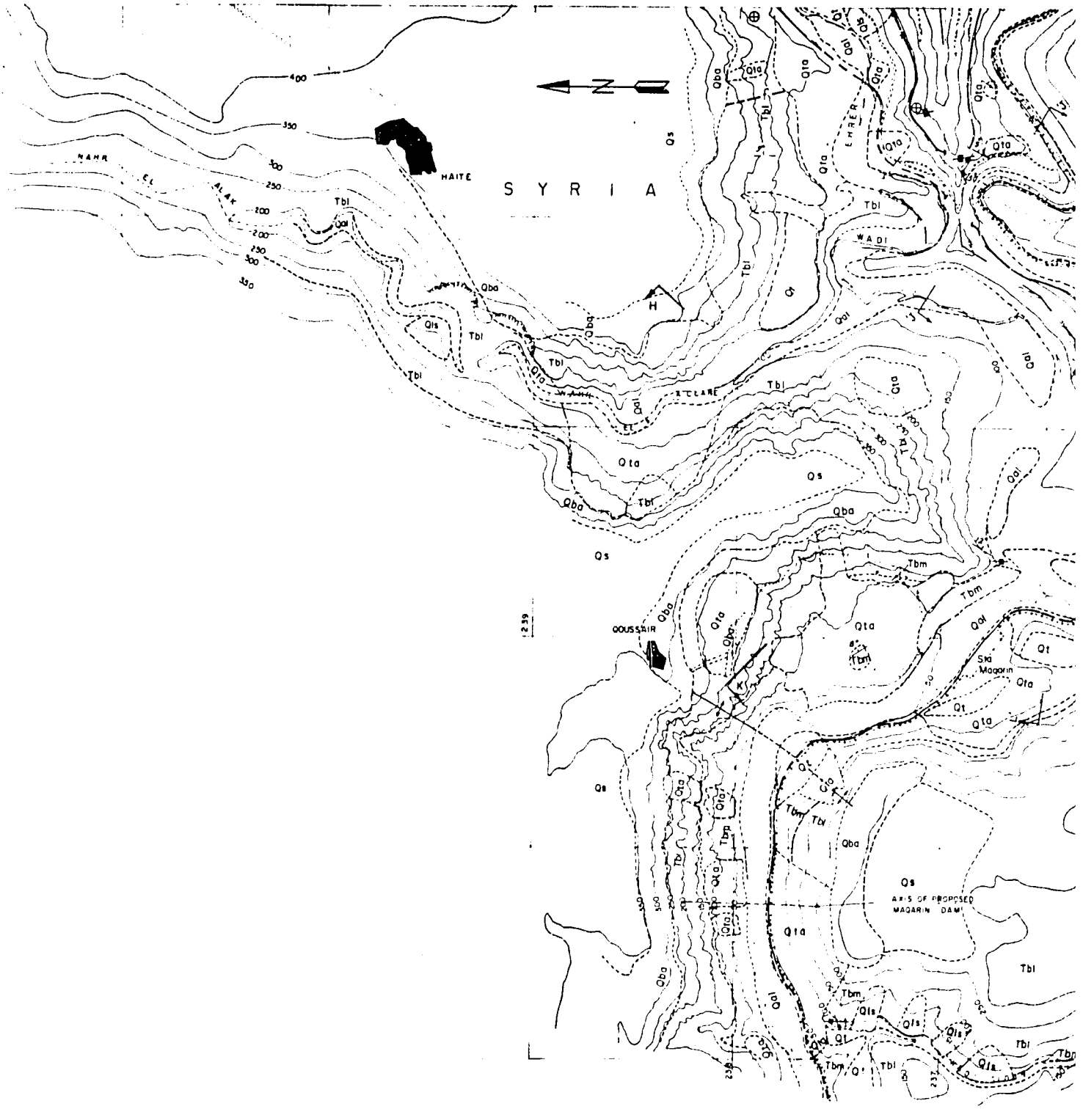
1 SEE EXHIBITS E-25 B FOR SECTIONS

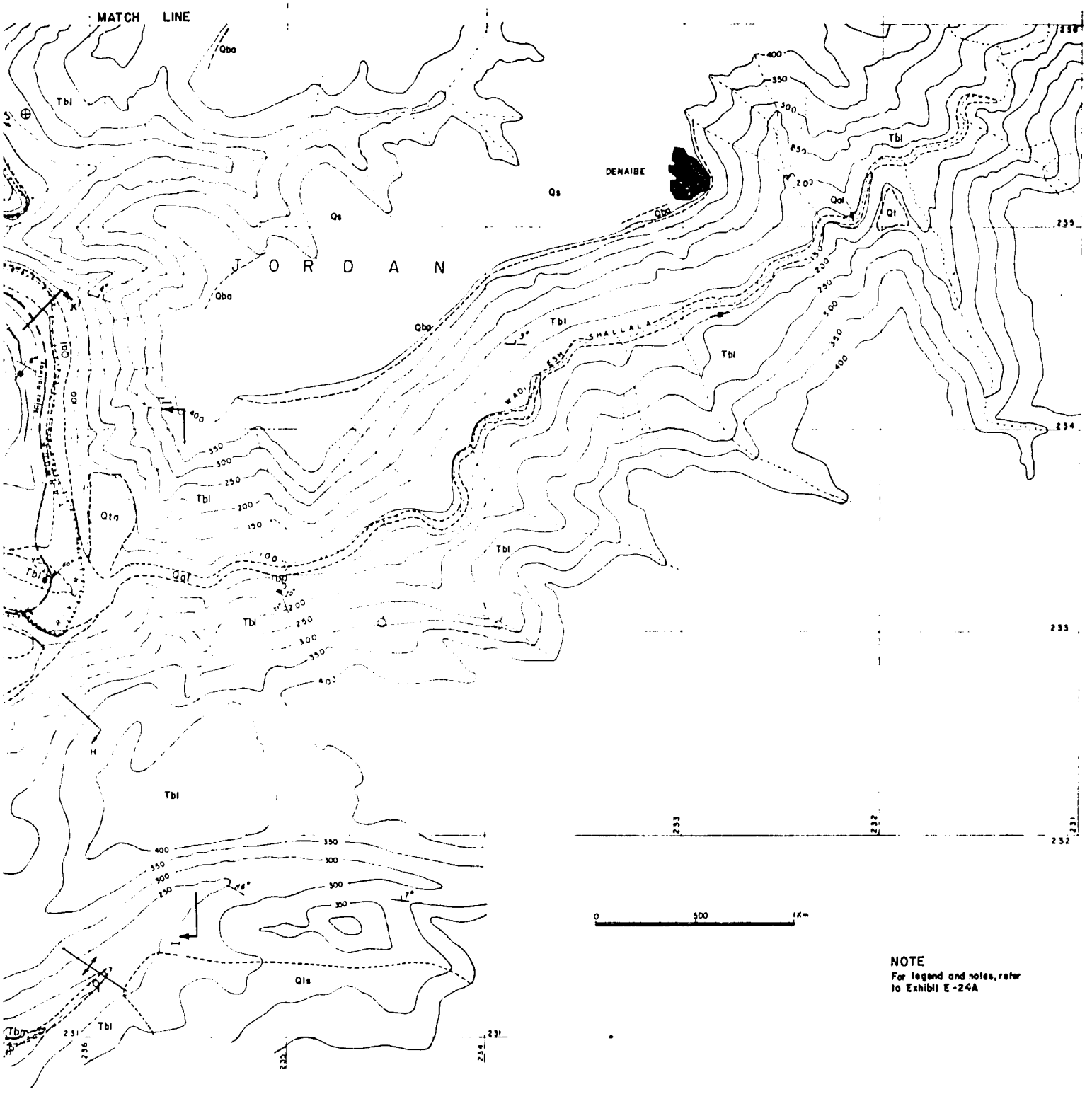
0 500 1Km

MAQARIN RESERVOIR GEOLOGIC MAP

JORDAN VALLEY IRRIGATION PROJECT

STAGE II


SYRIA
HAITE
NAHR EL ALAK
WADI
EL HAREA
EL CLARE
QOUSSAIR
Ski Magarin
AXIS OF PROPOSED MAGARIN DAM
400
350
300
250
200
Qs
Qba
Qta
Qal
Qls
Tbl
Tbm
Qt
H
K

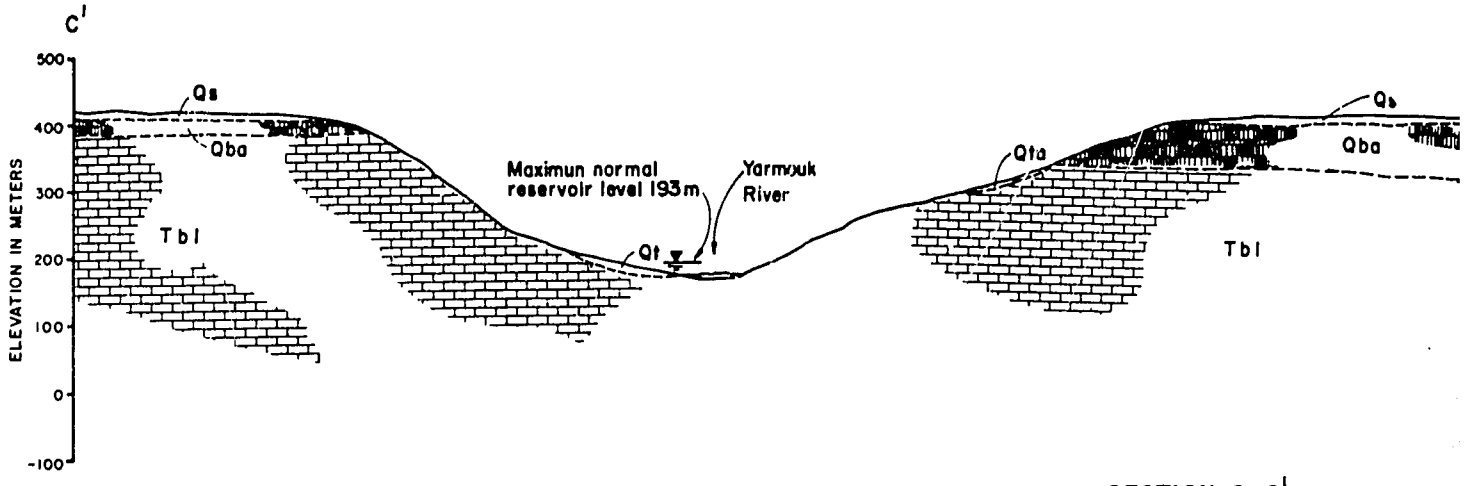


NOTE
For legend and notes, refer to Exhibit E-24A

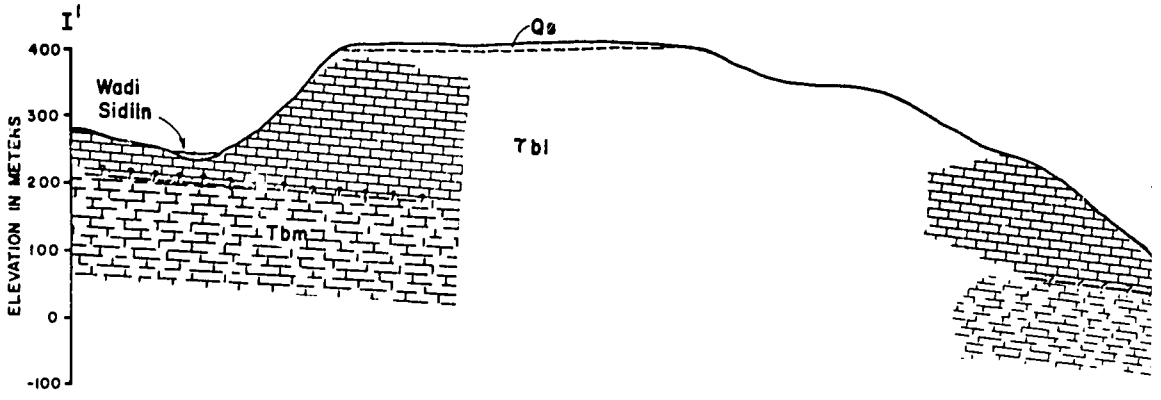
MAQARIN RESERVOIR GEOLOGIC MAP

JORDAN VALLEY IRRIGATION PROJECT

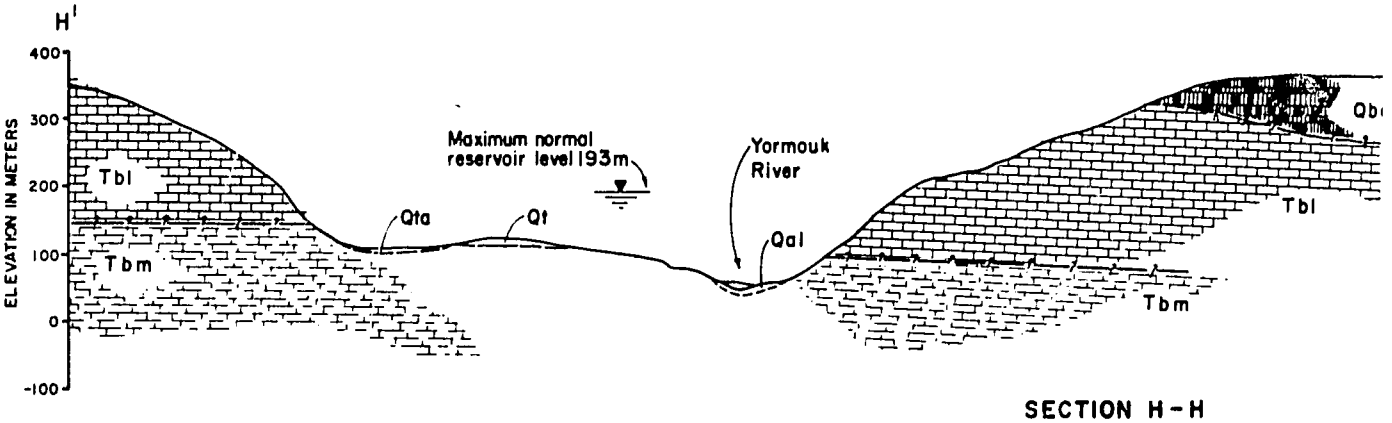
STAGE II



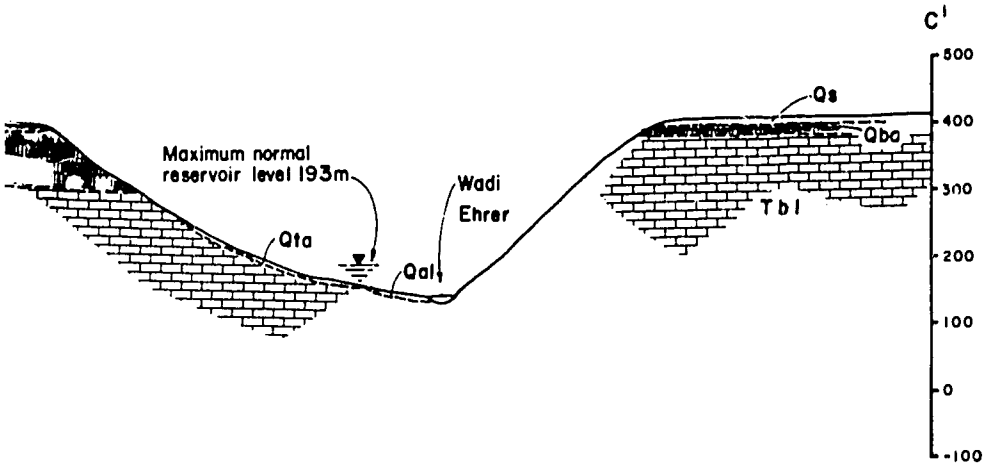
SECTION C-C'

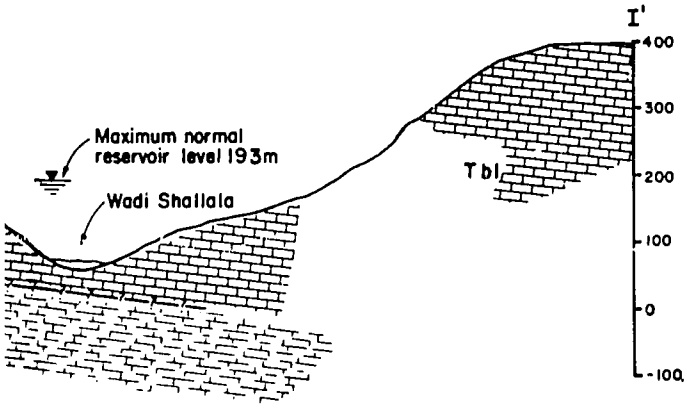


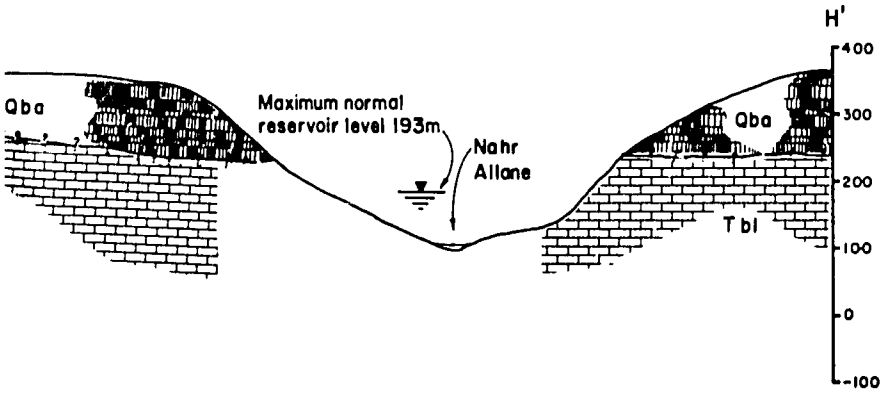
SECTION I-I'

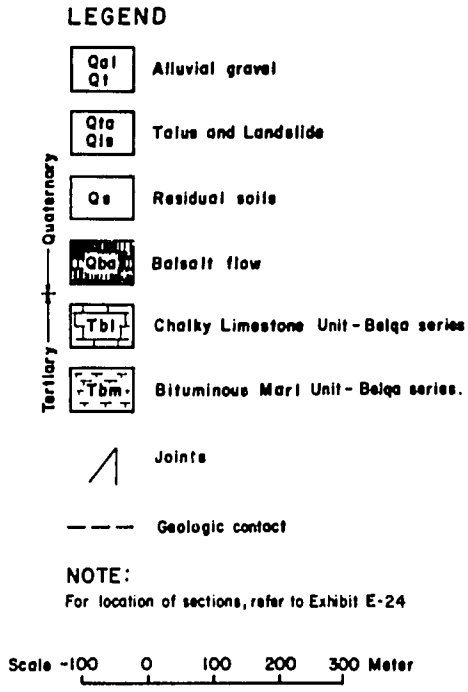


SECTION H-H

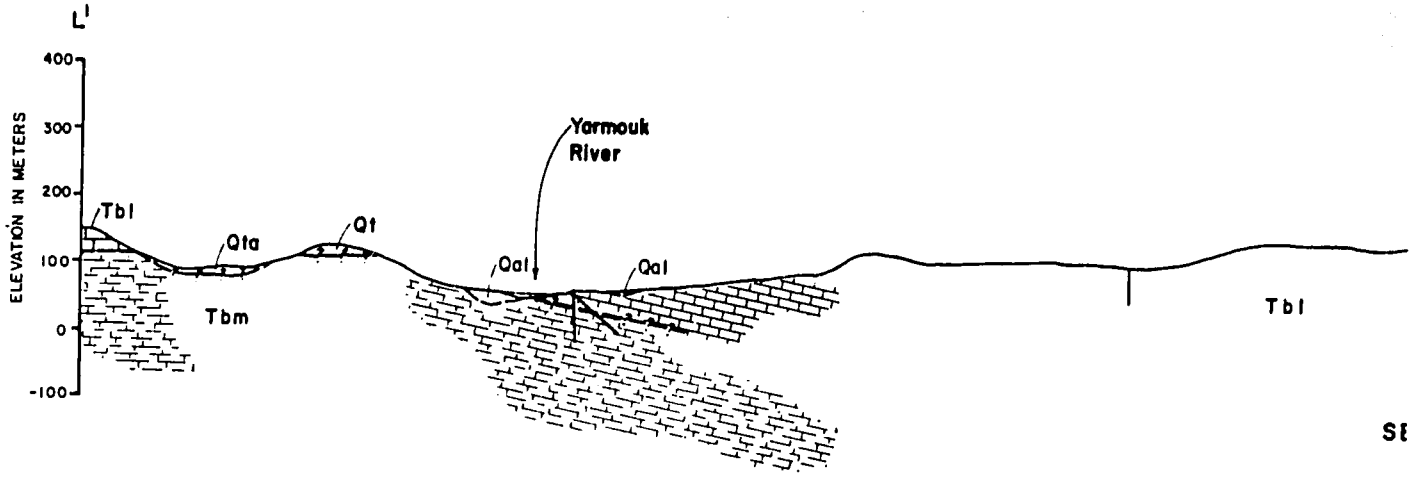


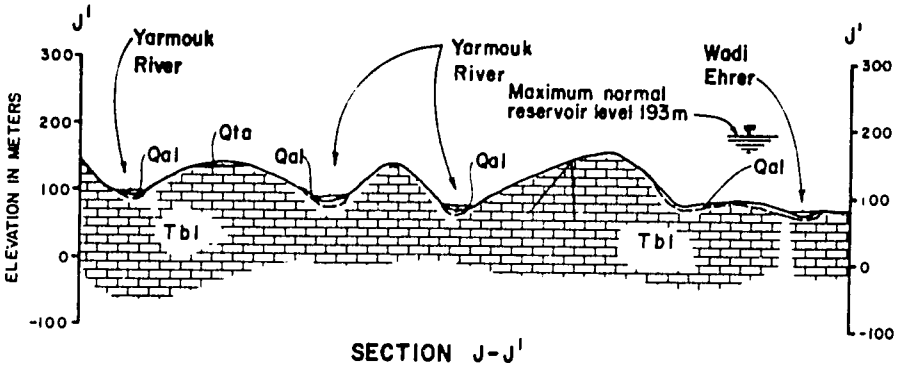




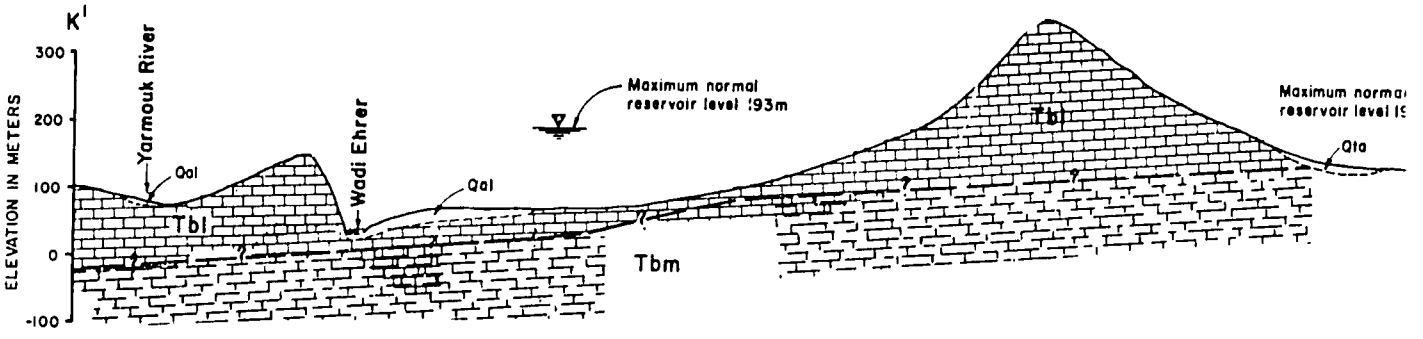


MAQARIN RESERVOIR
GEOLOGIC SECTIONS C-C', I-I' AND H-H'
JORDAN VALLEY IRRIGATION PROJECT
STAGE II

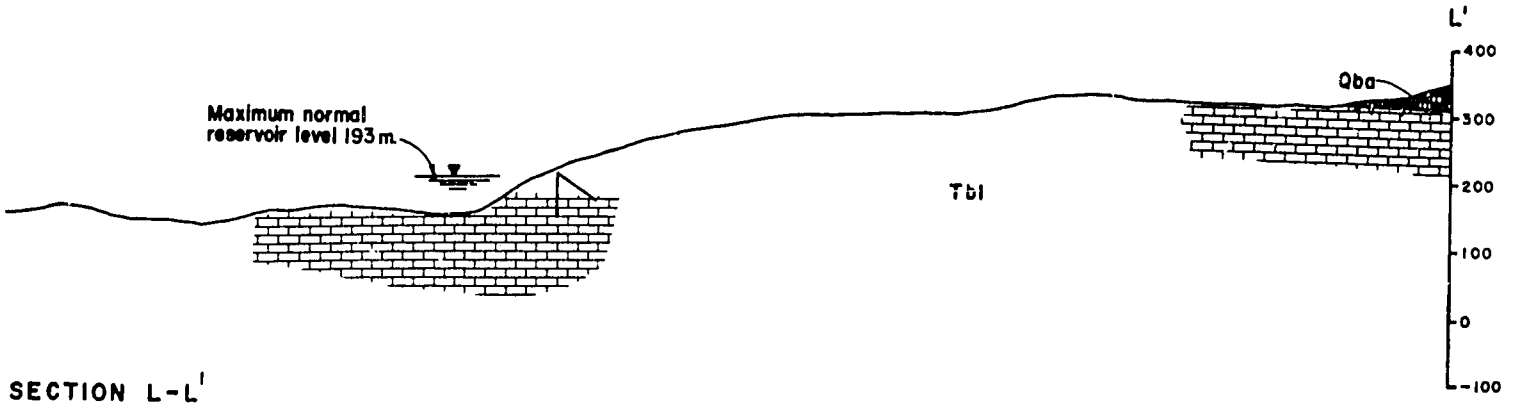




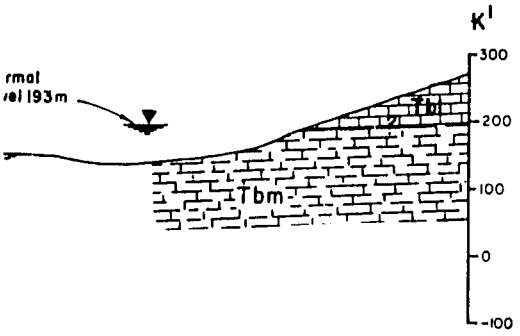
SECTION J-J'



SECTION K-K'



SECTION L-L'



LEGEND

Qal Qt	Alluvial gravel
Qta Qls	Talus and Landslide
Qs	Residual soils
Qba	Balsalt flow
Tbl	Chalky Limestone-Belqa Series
Tbm	Bituminous "Marl"-Belqa Series
	Joints
—?—?—	Contact line

Quaternary

Tertiary

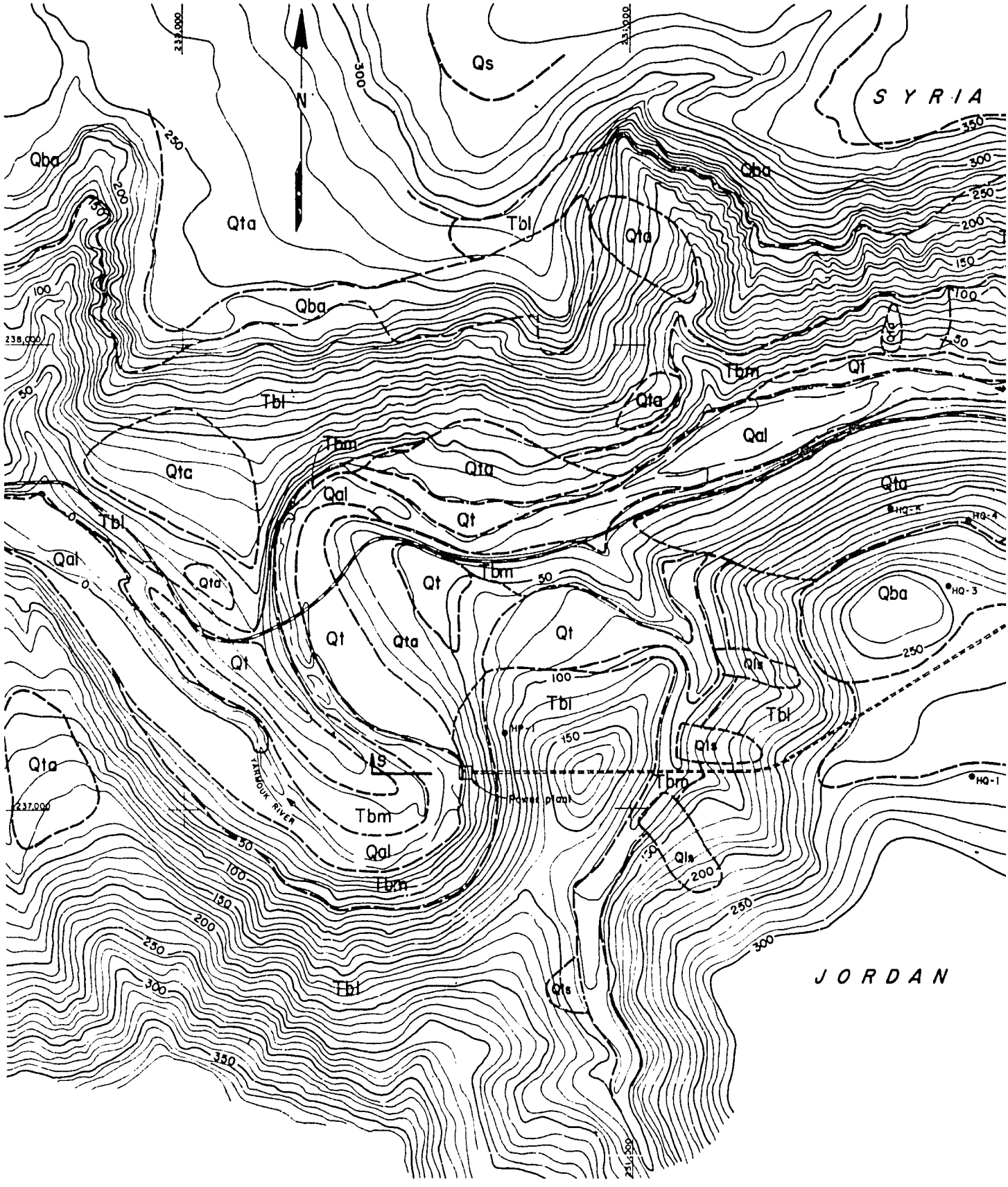
NOTE:
For location of sections refer to C-24

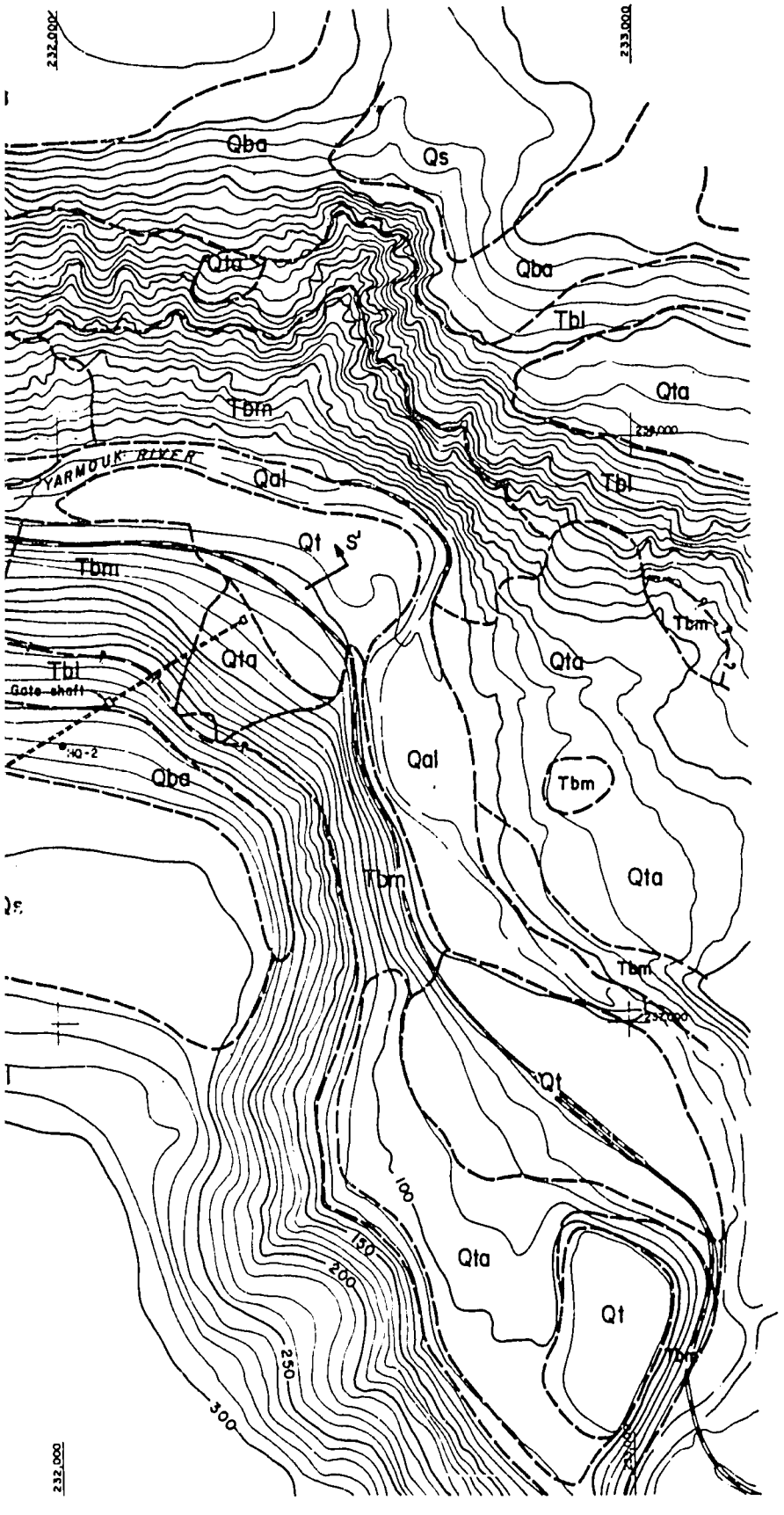
SCALE -100 0 100 200 300 METERS

MAQARIN RESERVOIR
GEOLOGIC SECTIONS L-L', J-J' AND K-K'

JORDAN VALLEY IRRIGATION PROJECT

STAGE II


SYRIA
JORDAN
N
Qs
Qba
Qta
Tbl
Tbm
Qt
Qal
Qls
Qtc
HQ-1
HQ-3
HQ-4
HQ-5
HP-1
YARMOUK RIVER
Power plant
S
233,000
238,000
237,000
251,500



LEGEND

Qal	*Alluvium*
Qt	*Alluvial Terrace*
Qta	*Talus*
Qts	*Landslide*
Qs	*Soil*
Qba	*Basalt Flows*
Tbl	*Chalky Limestone (Belqa Series).*
Tbm	*Bituminous Marl (Belqa Series).*
— — —	*Geologic Contact*
HQ-1	*Drill hole*
↳ ↲	*Location of section*

NOTE

1. *Base map is from the "Republique Syrienne – Plan coté de la Région du Yarmouk" by Royal Dutch Airlines for the Bureau d'Etudes Neerlandais (1953) and "The Hashemite Kingdom of the Jordan–Yarmouk Valley" by Hunting Aerosurveys Ltd (1951)*

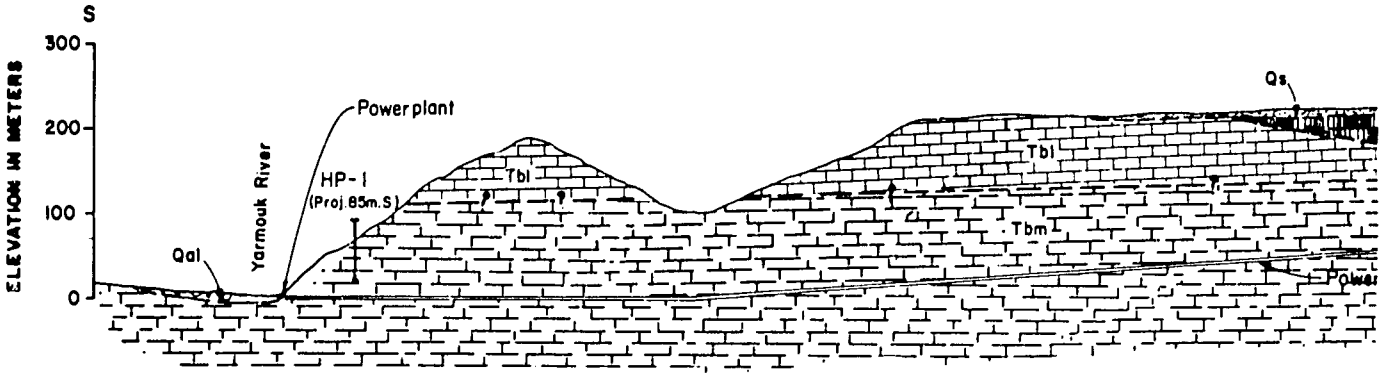
Scale 0 — 300 Meters

GEOLOGY OF MAQARIN POWERPLANT AND TUNNEL

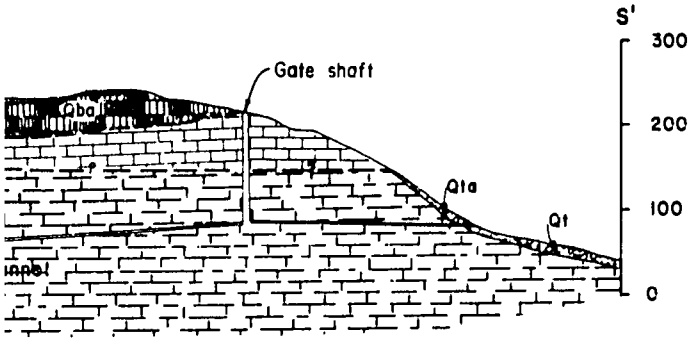
JORDAN VALLEY IRRIGATION PROJECT

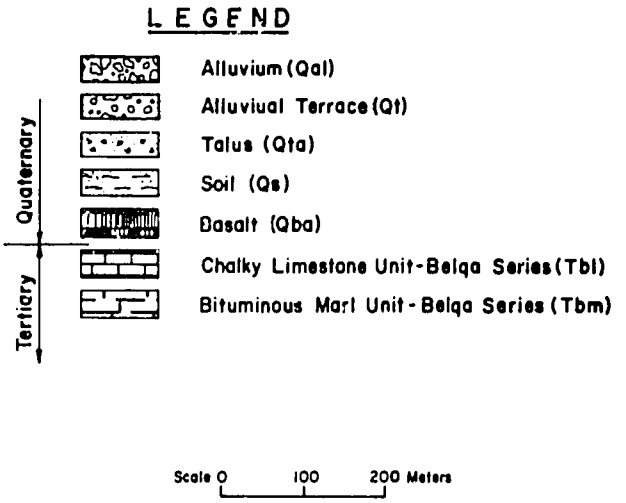
STAGE II

221



SECTION ALONG POWER TUNNEL



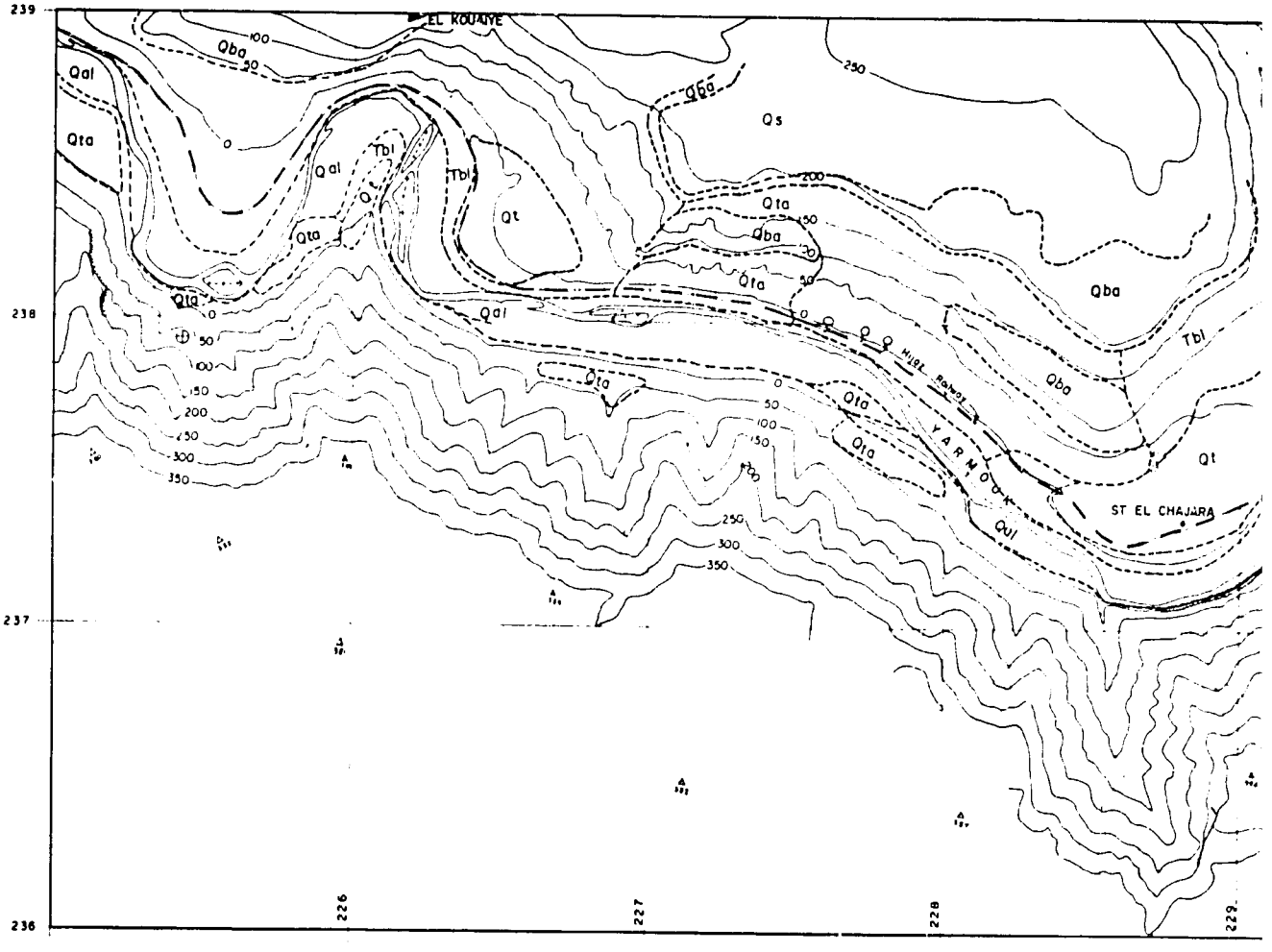


NOTE:
For location of section, refer to Exhibit E-27A.

GEOLOGIC SECTION S

JORDAN VALLEY IRRIGATION PROJECT

STAGE II



LEGEND

Quaternary

- **Qal** — ALLUVIUM CEMENTED AND POORLY CONSOLIDATED RIVER GRAVEL
- **Qtu** — TALUS POORLY CONSOLIDATED AND CEMENTED DETRITUS
- **Qt** — RIVER TERRACE
- **Qls** — LANDSLIDE
- **Qs** — SOIL RESIDUAL SOILS
- **Qn** — TRAVERTINE SOILS AND TALUS CEMENTED WITH TRAVERTINE AND TUFA
- **Qba** — BASALT FLOWS OLIVINE BASALT FLOWS.
- **Qk** — LAKE DEPOSITS FINE - GRAINED LAKE DEPOSITS

Tertiary

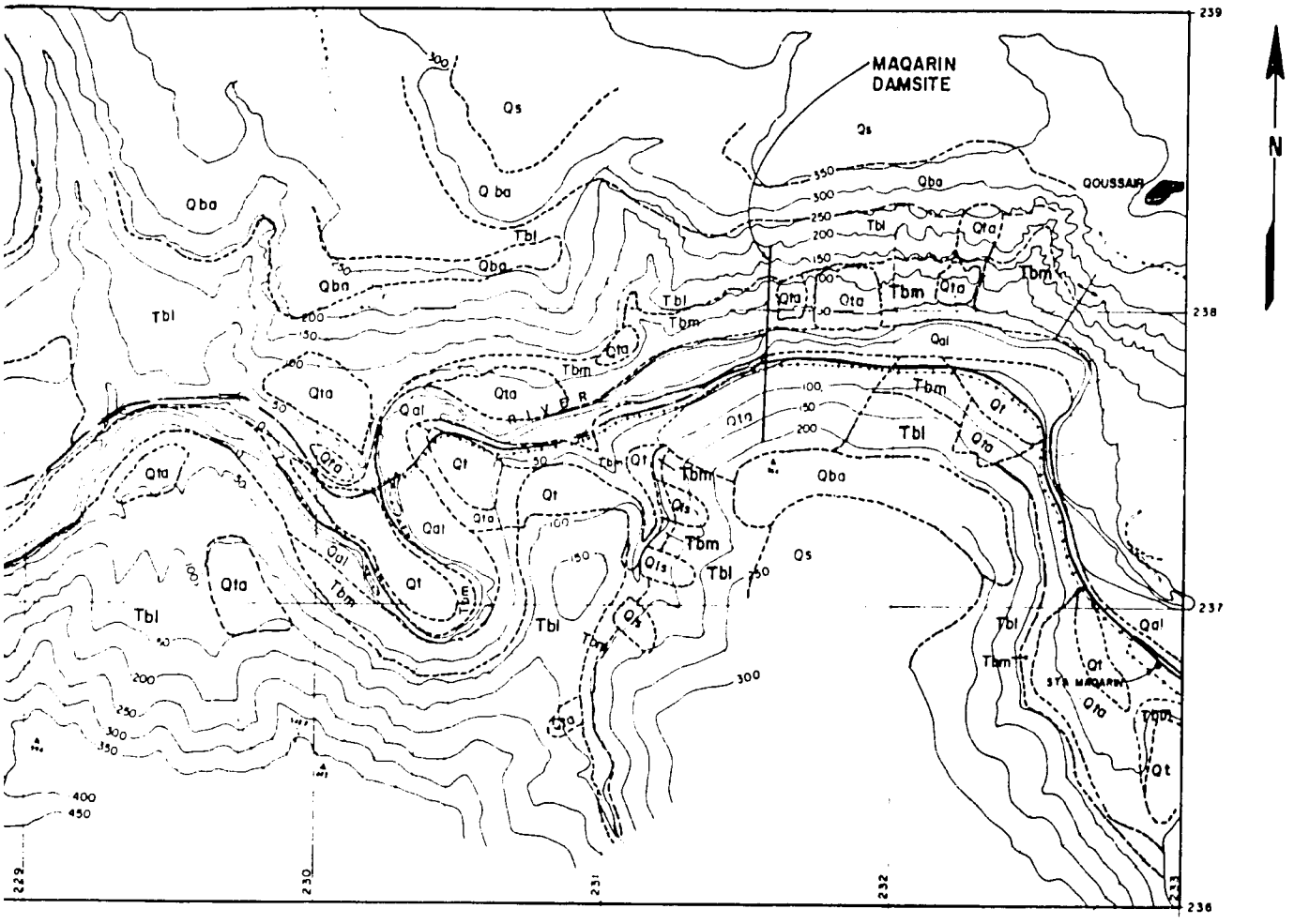
- **Tbl** — CHALKY LIMESTONE UNIT THICK-BEDDED, LIGHT-BROWN TO WHITE MARINE CHALKY LIMESTONE WITH LAYERS AND NODULES OF CHERT.
- **Tbm** — BITUMINOUS MARL UNIT SLABBY TO THICK-BEDDED, DARK GREY MARINE MARLY LIMESTONE

SYMBOLS

- APPROXIMATE CONTACT BETWEEN FORMATIONS
- F — FAULT
- 30 — STRIKE AND DIP OF BEDDING
- HORIZONTAL BEDDING
- 30 — APPROXIMATE STRIKE AND DIP OF BEDDING
- 70 — STRIKE AND DIP OF JOINTING
- STRIKE OF VERTICAL JOINTING
- ANTICLINAL AXIS
- SPRING

SCALE 0 500

HARZA OVERSEAS ENGINEERING COMPANY · JANUARY 1978



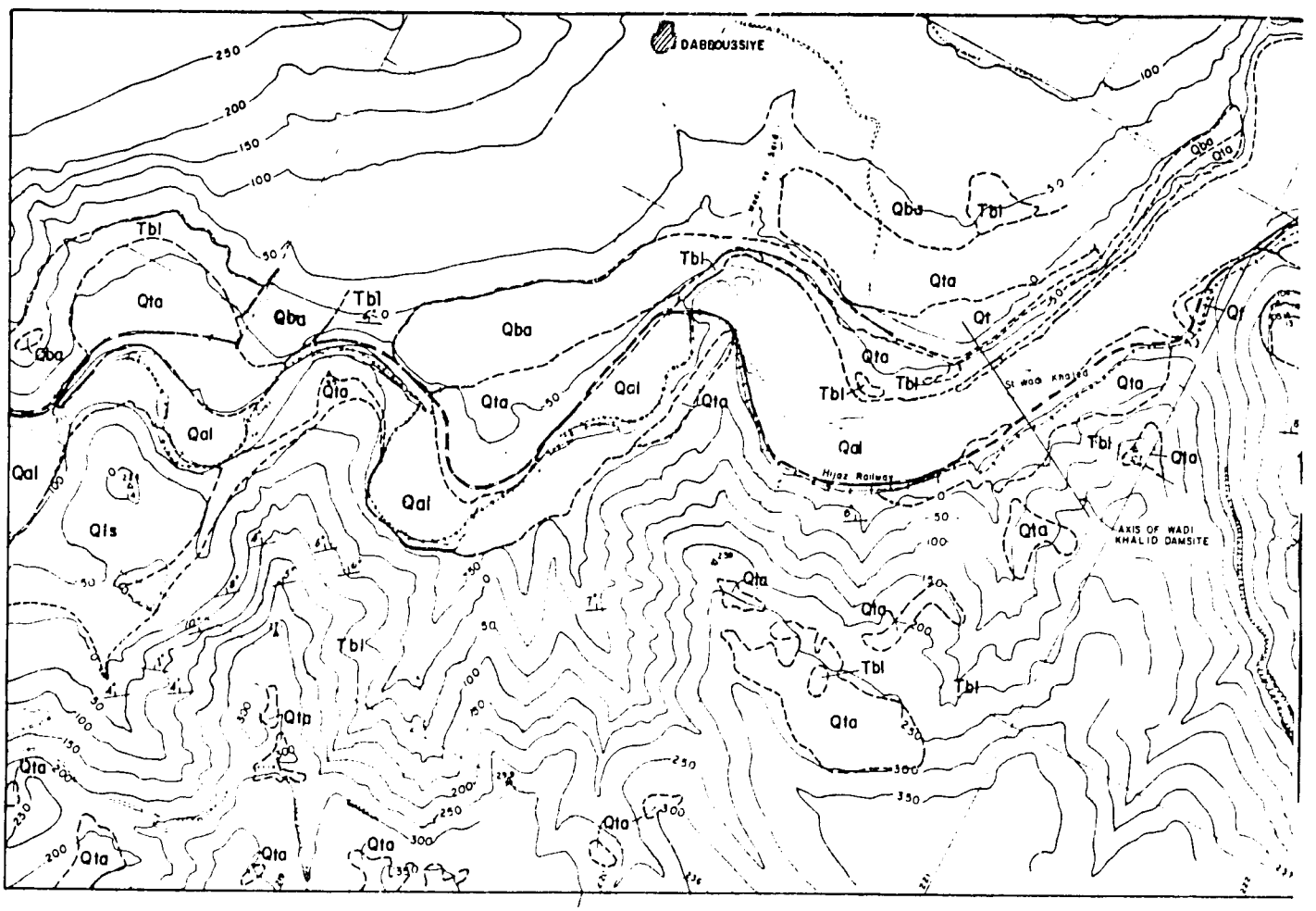
NOTE:
Geology is in part from "Yarmouk Project Khalid Bin Al Walid-Wadi Arab Scheme" by ENERGOPROJEKT (1967)

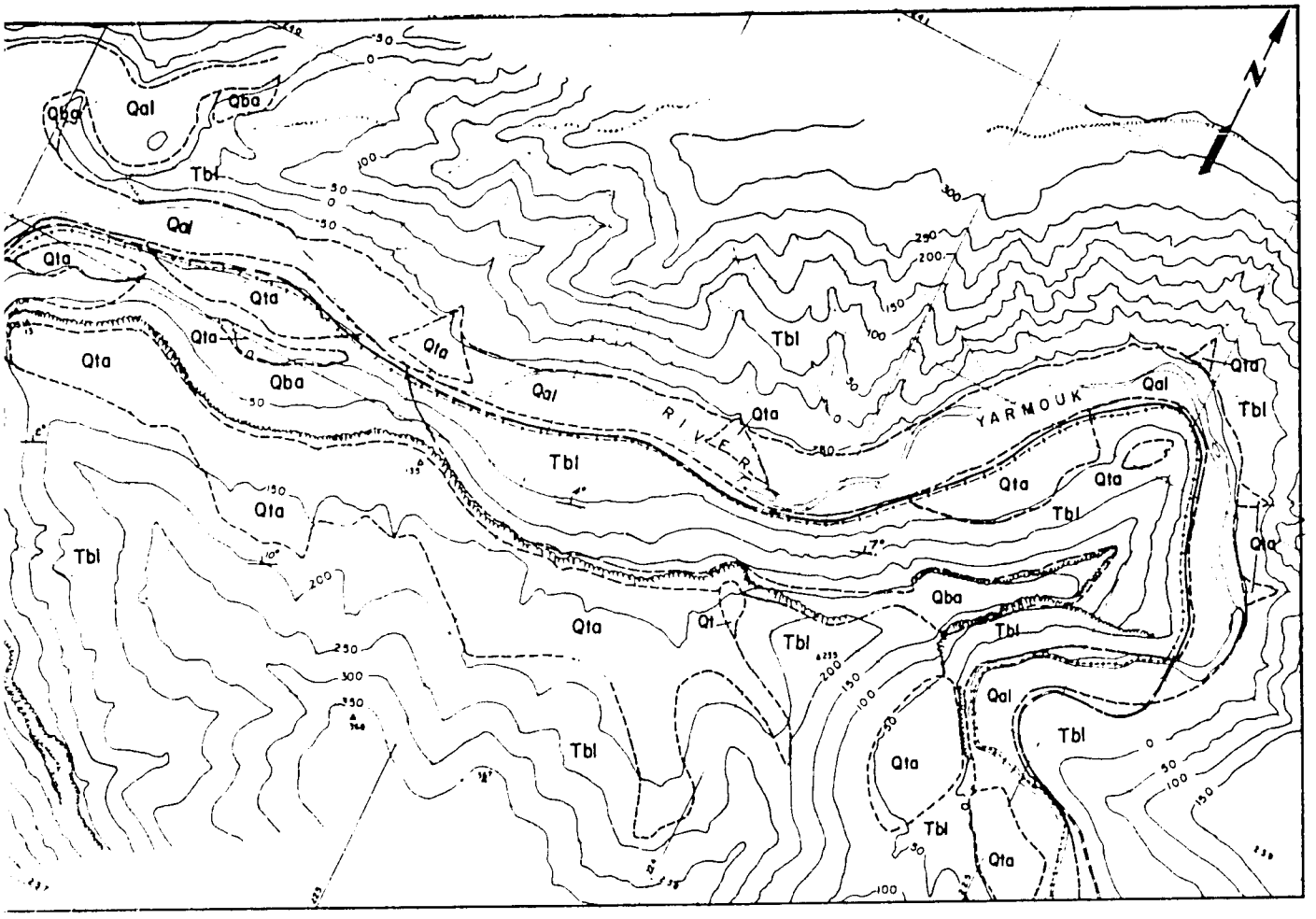
1000 METERS

GEOLOGY OF THE YARMOUK VALLEY

JORDAN VALLEY IRRIGATION PROJECT

STAGE II


DABBOUSIYE
Tbl
Qta
Qba
Qal
Qls
Qt
Hijaz Railway
AXIS OF WADI KHALID DAMSITE



SCALE: 0 500 1000 METERS

NOTE

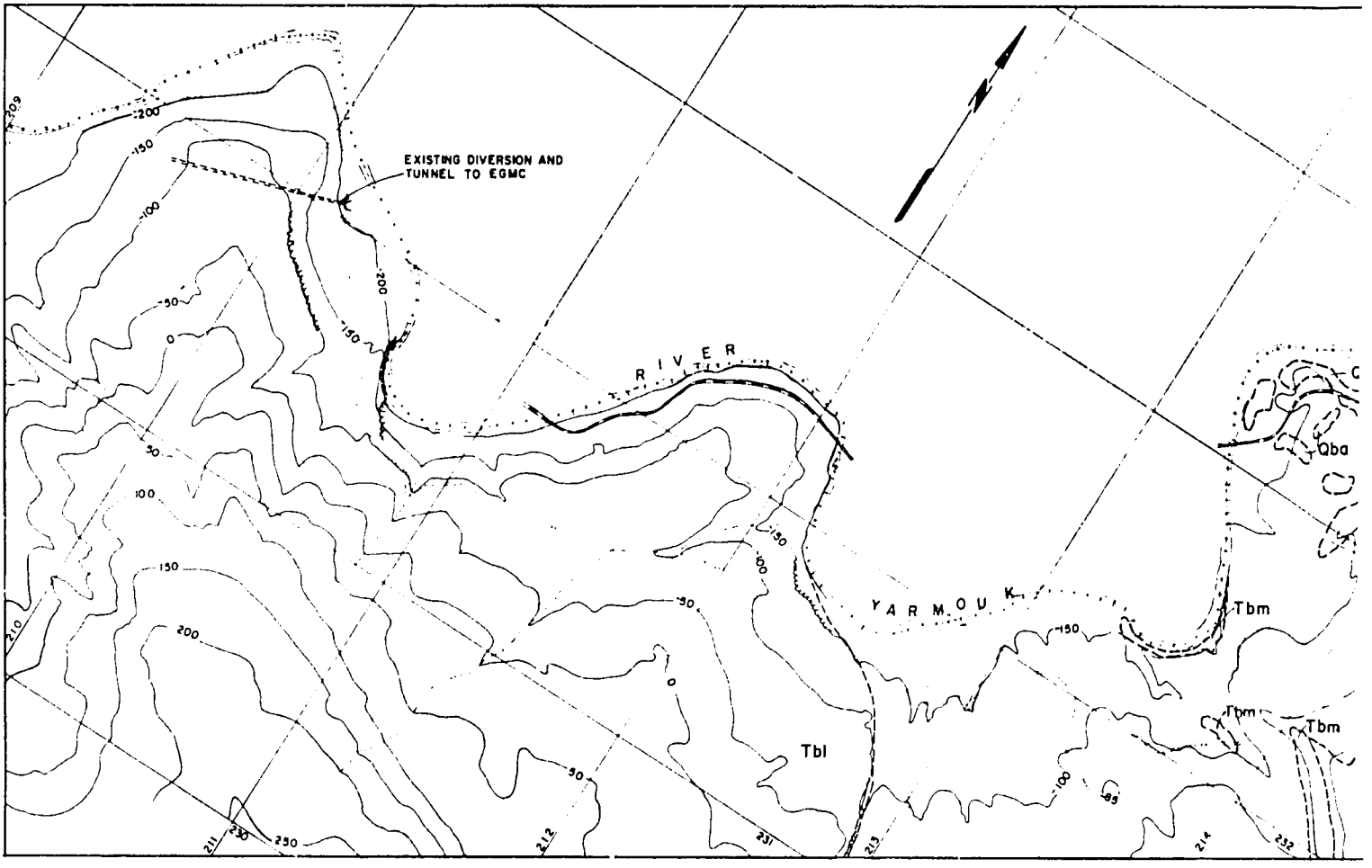
For legend and symbols refer to Exhibit C-28 A

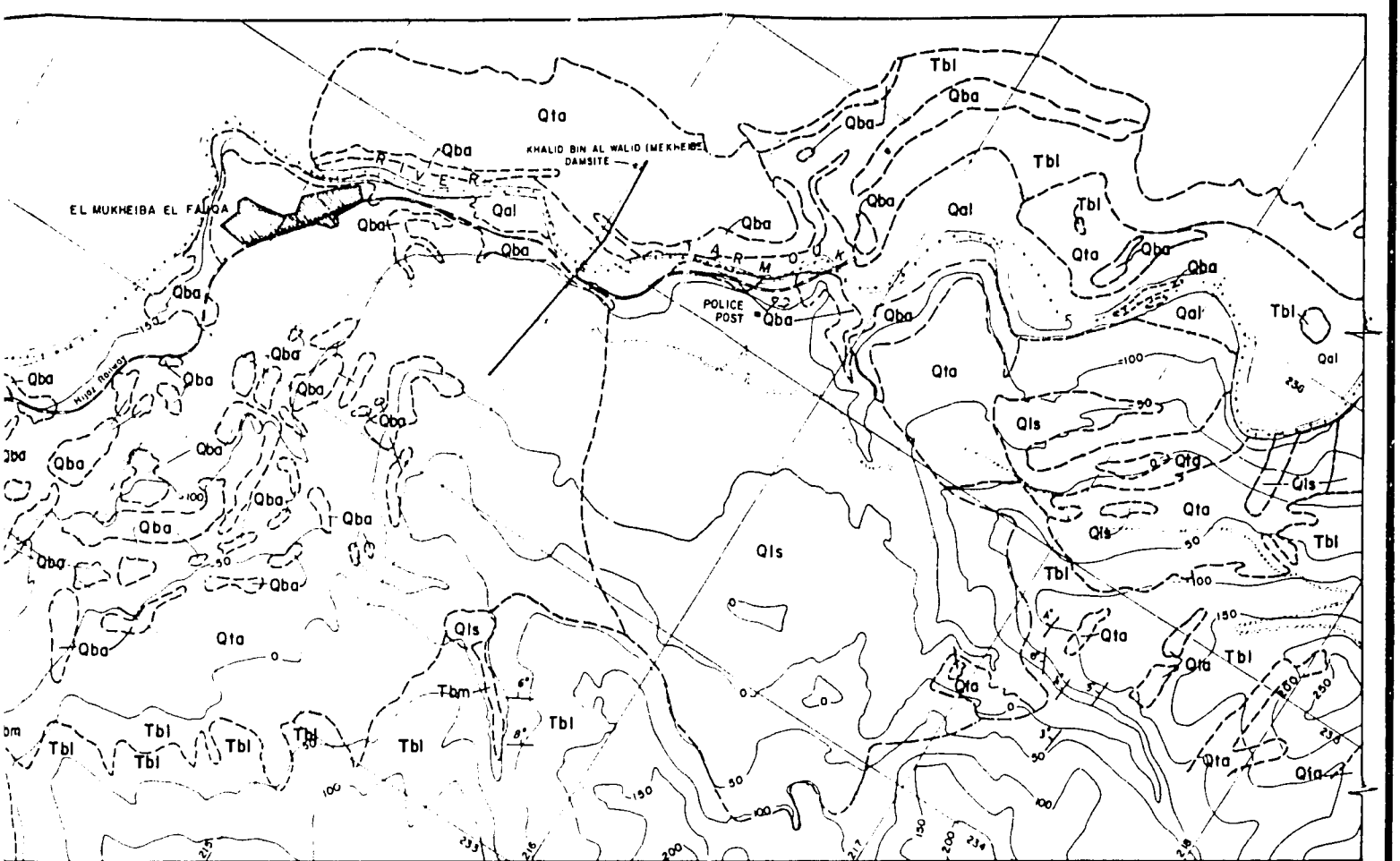
Geology is in part from Yarmouk Project Khalid Bin Al Walid-Wadi Arab Scheme by ENERGOPROJEKT (1967).

GEOLOGY OF THE YARMOUK VALLEY

JORDAN VALLEY IRRIGATION PROJECT

STAGE II


EXISTING DIVERSION AND
TUNNEL TO EGMC
RIVER
YARMOUK
Tbl
Tbm
Tbm
Tbm
Qba



SCALE 0 500 1000 METERS

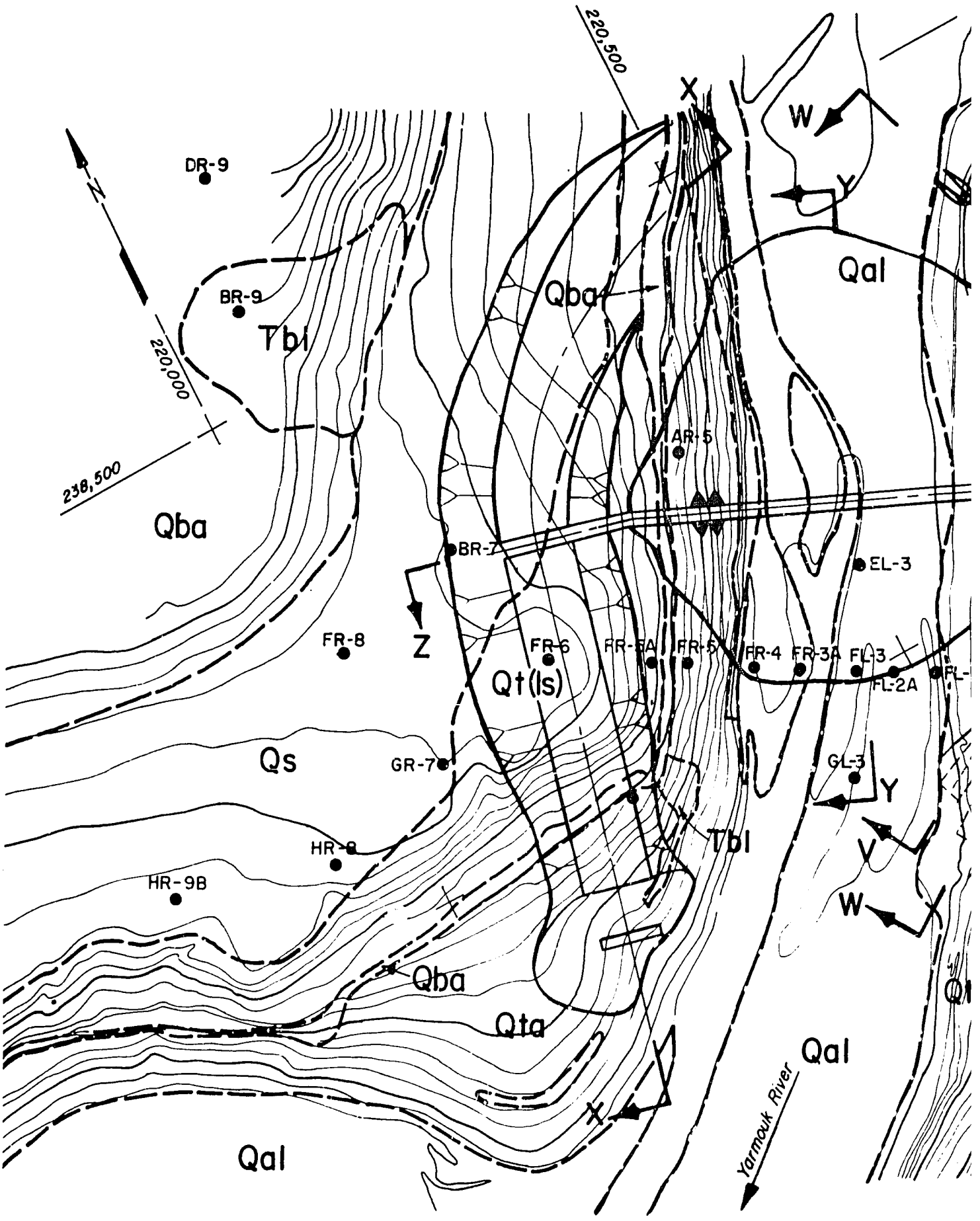
NOTE

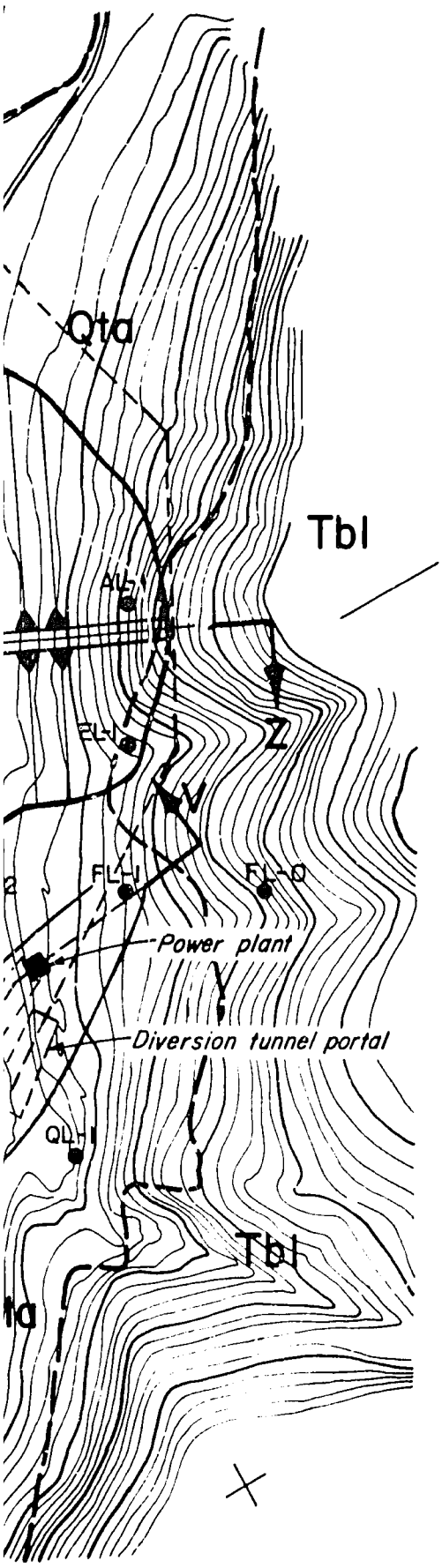
For legend and symbols refer to Exhibit E-28 A
Geology is in part from Yarmouk Project Khalid Bin Al Walid-Wadi Arab Scheme by ENERGOPROJEKT (1967)

GEOLOGY OF THE YARMOUK VALLEY

JORDAN VALLEY IRRIGATION PROJECT

STAGE II


220,500
X
W
Y
DR-9
N
BR-9
Tbl
220,000
238,500
Qba
Qal
AR-5
BR-7
EL-3
Z
FR-8
FR-6
FR-5A
FR-5
FR-4
FR-3A
FL-3
FL-2A
Qt(ls)
Qs
GR-7
GL-3
HR-8
HR-9B
Qta
Yarmouk River



LEGEND

Quaternary	Qal	Alluvium
	Qta	Talus
	Qs	Soil
	Qt(ls)	Terrace consisting mainly of debris from the chalky limestone
	Qba	Basalt flows
Tertiary	Tbl	Chalky limestone unit - Belqa Series

Contact

30 Dip and strike of beds

● Drill hole

NOTE

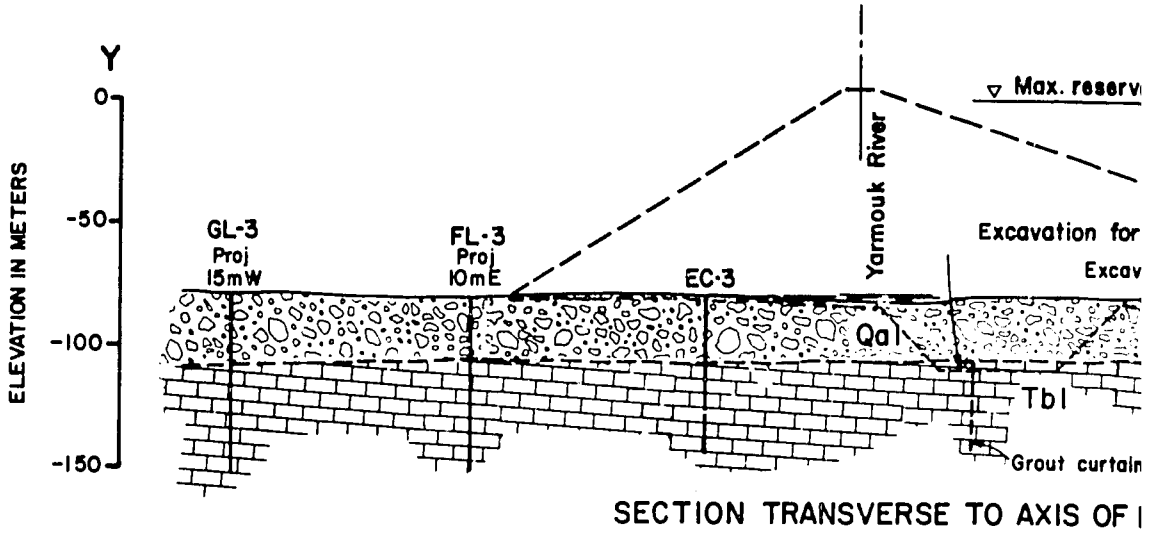
Adapted from the drawing "Areal Geology (Khalid)" (VI-A-6) in "Yarmouk - Jordan Valley Project - Master Plan Report" by Harza - Baker (1955)

Scale 0 100 200 300 Meters

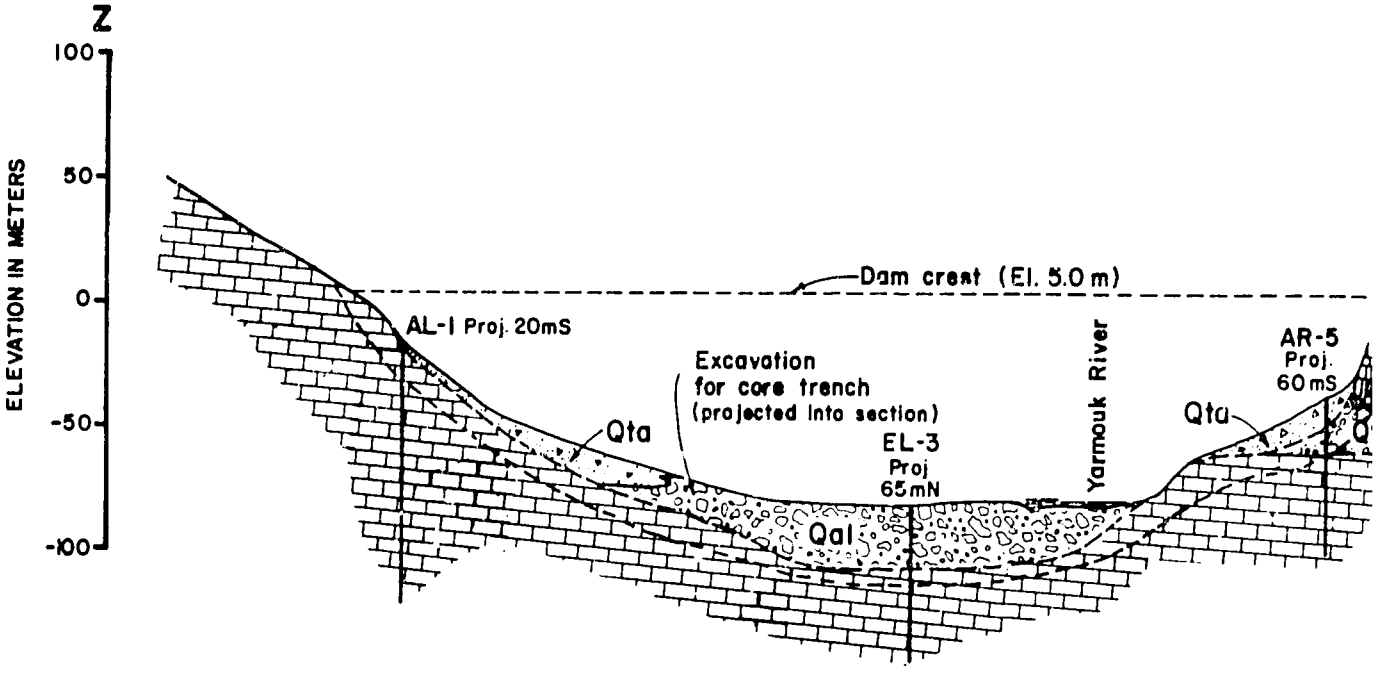
GEOLOGY OF THE WADI KHALID DAMSITE

JORDAN VALLEY IRRIGATION PROJECT

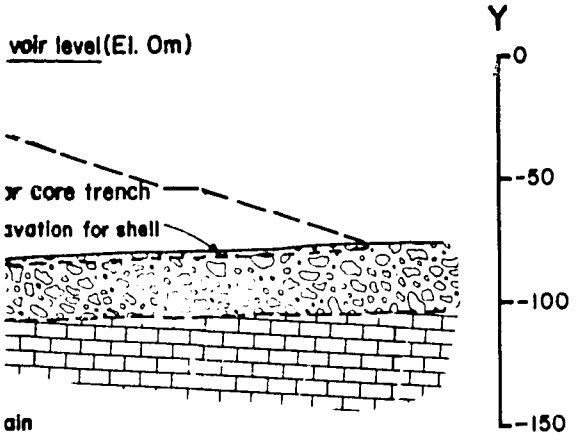
STAGE II



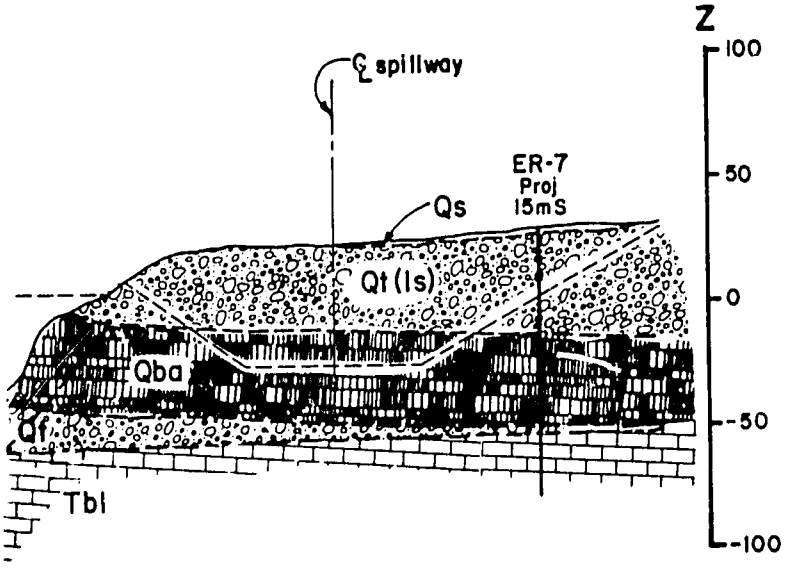
SECTION TRANSVERSE TO AXIS OF



SECTION ALONG AXIS OF DAM



F DAM



LEGEND

Quaternary

- Qal — Alluvium
- Qta — Talus
- Qs — Soil
- Terrace consisting mainly of debris from the chalky limestone
- Basalt flow
- Alluvial terrace

Tertiary

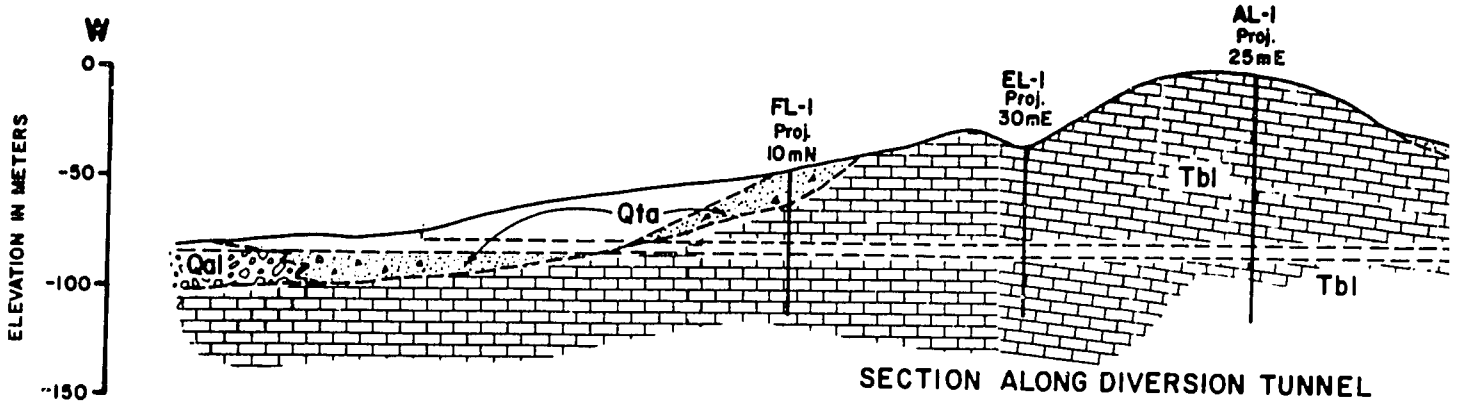
- Tbl — Chalky Limestone - Balqa Series

NOTE:

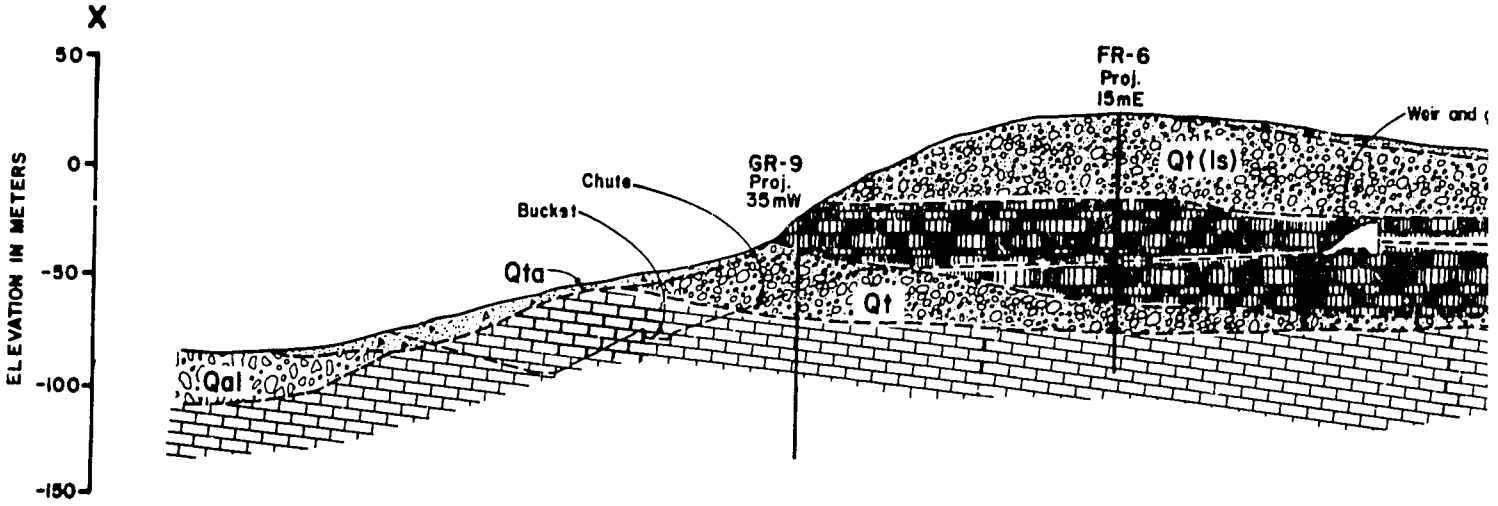
For locations of sections, refer to Exhibit E-29.

Scale 0 50 100 Meters

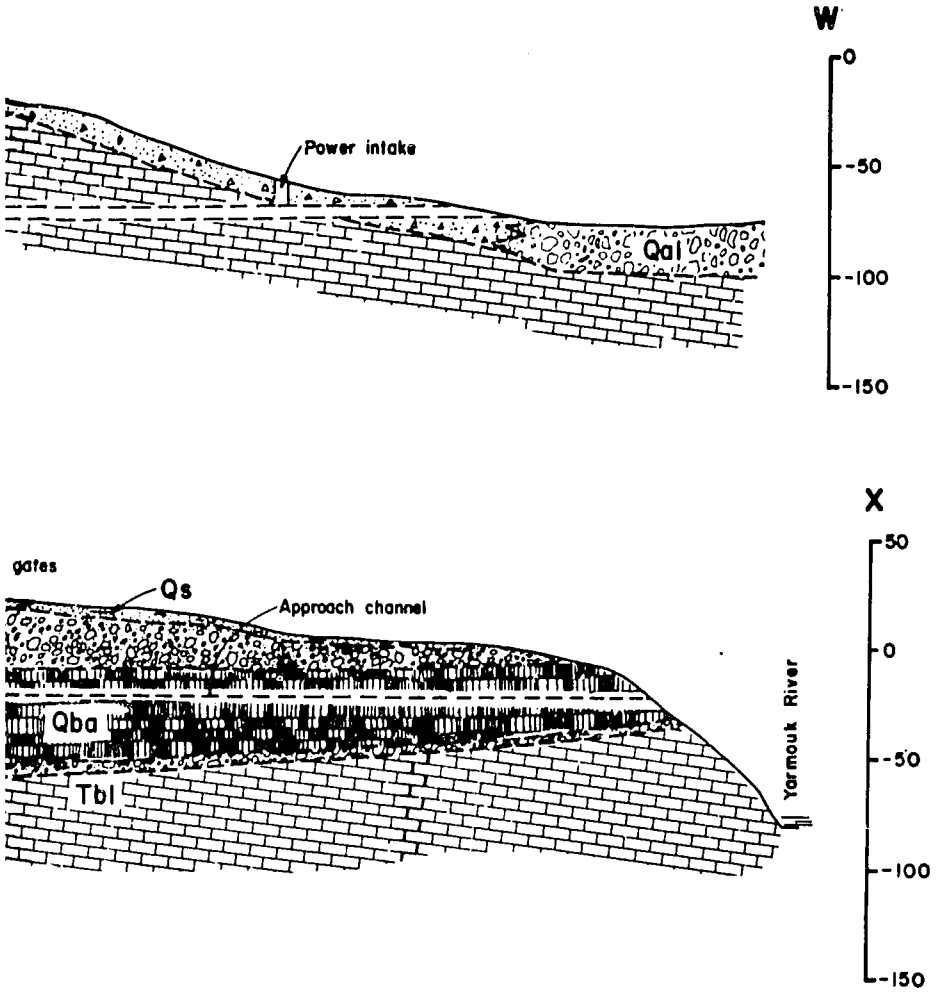
WADI KHALID DAMSITE
GEOLOGIC SECTIONS Y AND Z
JORDAN VALLEY IRRIGATION PROJECT
STAGE II



SECTION ALONG DIVERSION TUNNEL



SECTION ALONG SPILLWAY CENTERLINE



LEGEND

Quaternary
- Qal Alluvium
- Qta Talus
- Qs Soil
- Qt(b) Terrace consisting mainly of debris from the chalky limestone
- Basalt flow
- Qat Alluvial terrace

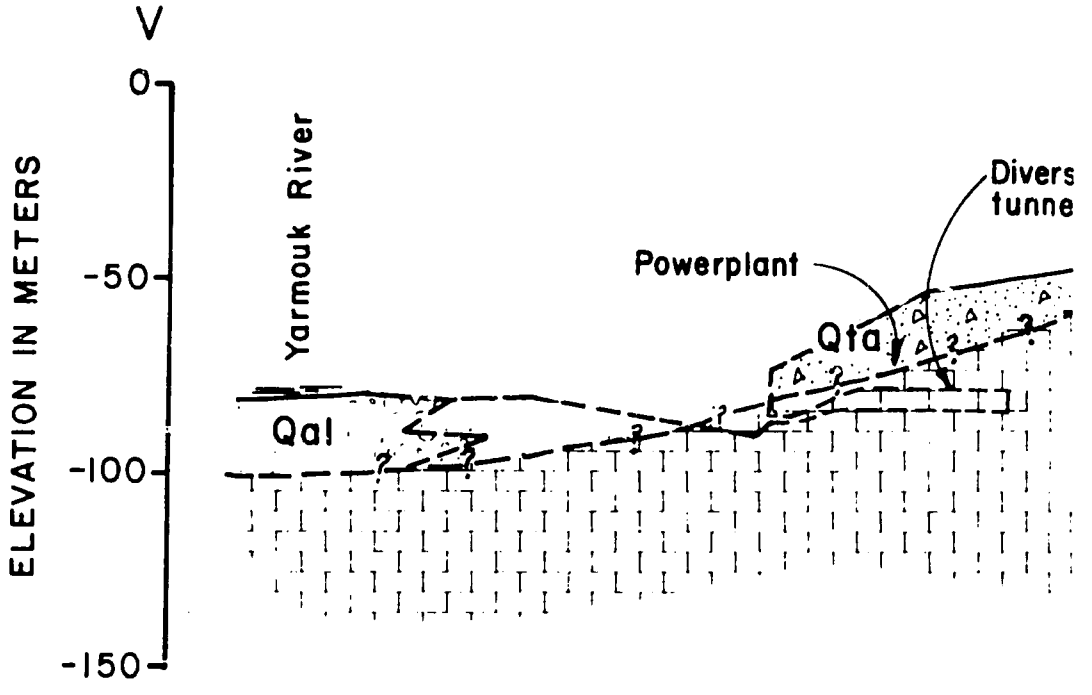
Tertiary
- Tbl Chalky Limestone Unit Belqa Series

NOTE:
For locations of sections, refer to Exhibit E-29

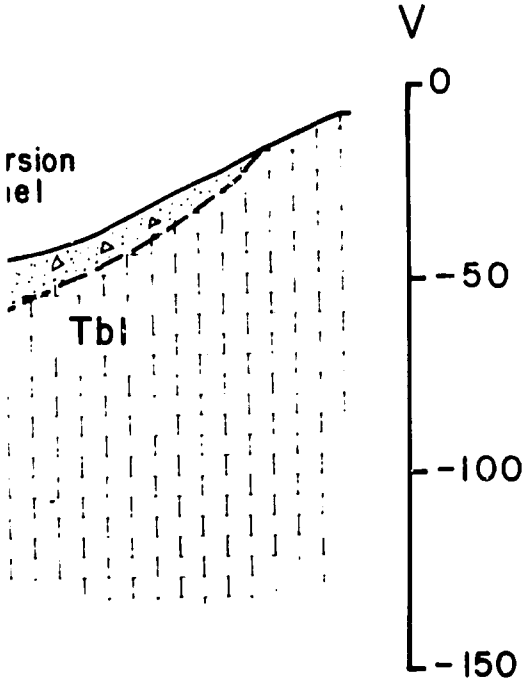
Scale 0 50 100 Meters

WADI KHALID DAMSITE
GEOLOGIC SECTIONS W AND X
JORDAN VALLEY IRRIGATION PROJECT
STAGE II

235



SECTION THROUGH POWERPLAN



NT

NOTE:
For location of section refer to Exhibit C-29

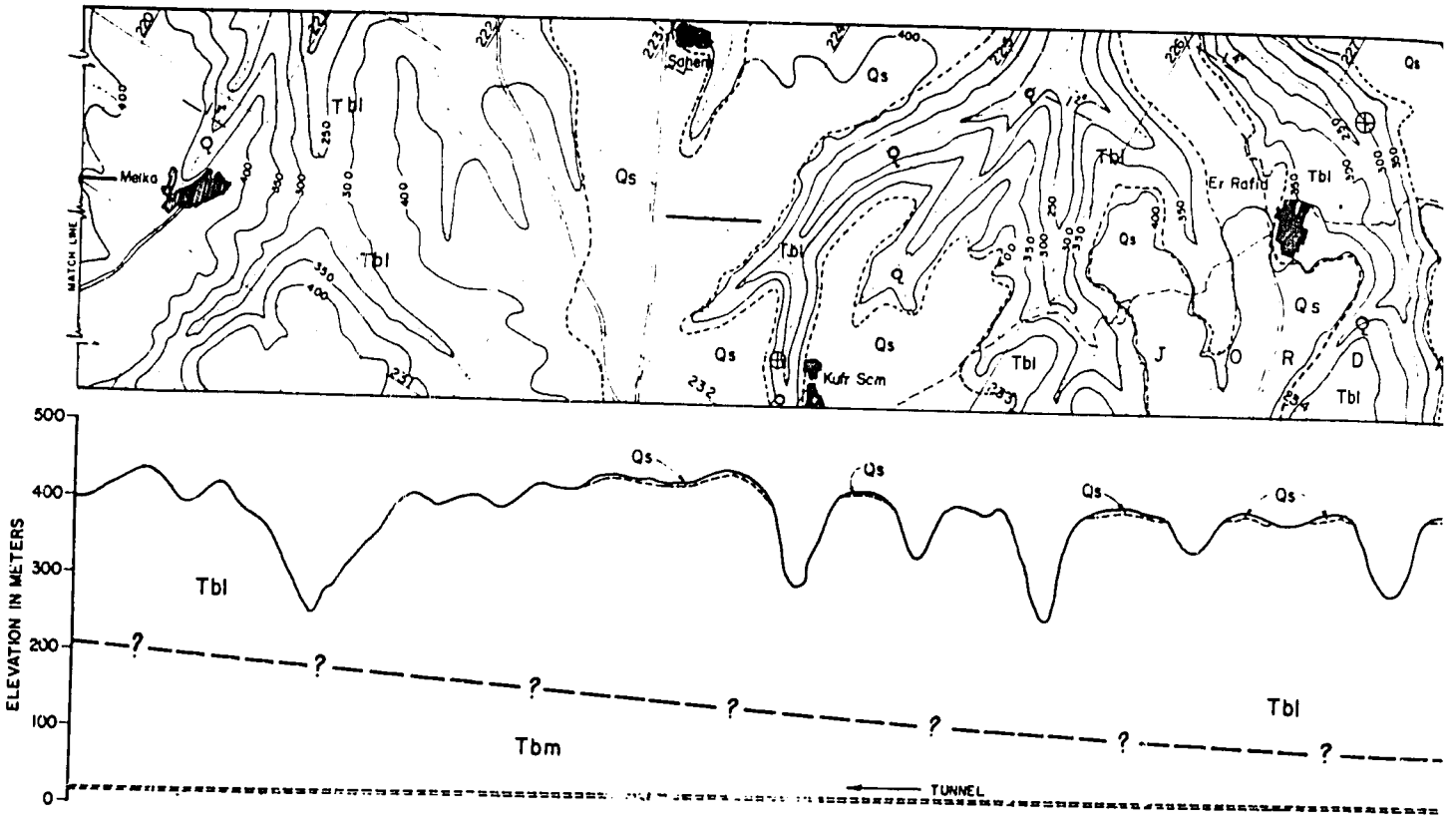
LEGEND

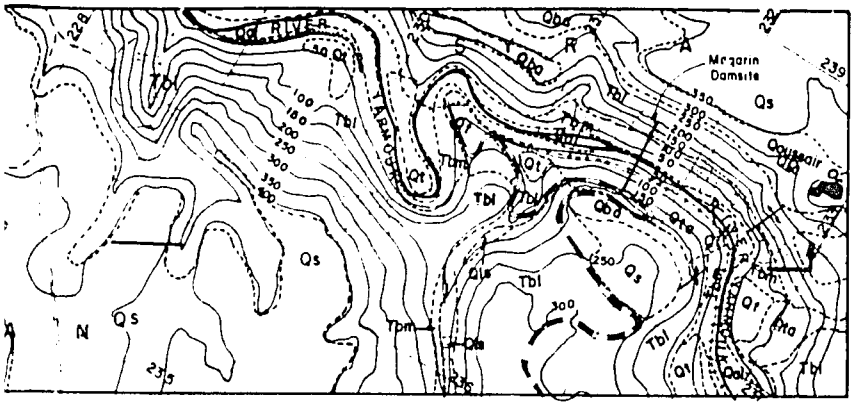
Quaternary
- Qal Alluvium
- Qta° Talus
- Qs Soil
- Qt(Tbl) Terrace consisting mainly of debris from the chalky limestone
- Qb Basalt flow
- Qt Terrace

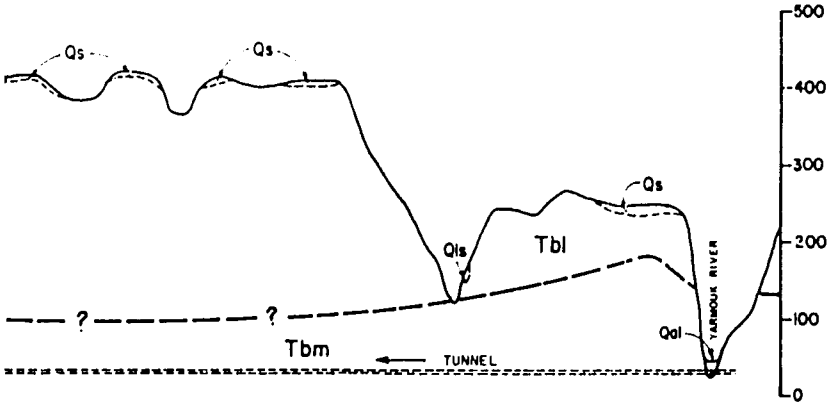
Tertiary
- Tbl Chalky limestone

Scale 0 1 Km

KHALID DAMSITE GEOLOGIC SECTION V
SECTION THROUGH POWERPLANT
JORDAN VALLEY IRRIGATION PROJECT
STAGE II


Meika
Sohem
Kufr Scm
Er Rafid
MATCH LINE
Tbl
Qs
Q
J
O
R
D
ELEVATION IN METERS
500
400
300
200
100
0
Tbm
TUNNEL





LEGEND

Quaternary	Qal	ALLUVIUM
	Qt	TERRACE
	Qls	LANDSLIDE
	Qta	TALUS
	Qs	RESIDUAL SOIL
	Qbs	BASALT FLOW
Tertiary	Tbl	CHALKY LIMESTONE UNIT - BELQA SERIES
	Tbm	BITUMINOUS MARL UNIT - BELQA SERIES

SYMBOLS

- DIP AND STRIKE OF BEDS.
- ESTIMATED DIP AND STRIKE OF BEDS
- HORIZONTAL BEDS.
- VERTICAL JOINT (PROMINENT).
- JOINT
- FAULT.
- SPRING
- LOCATION OF SECTION
- GEOLOGIC CONTACT (assumed)

NOTE:

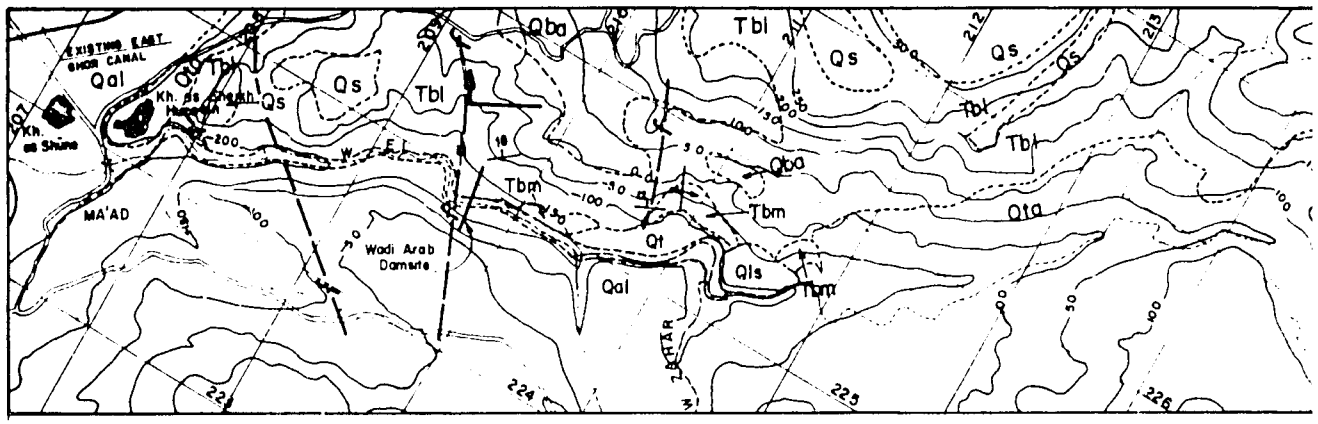
1. Modified from Yarmouk Project, Khalid Bin Al Walid Wadi Arab Scheme, phase B by ENERGOPROJEKT (1967) and geology of the Yarmouk Area by Wolfmann and Abdulatiff (1963), and Feasibility Report on wadi Arab Dam and Irrigation Project, Japan International Cooperation Agency (1976).

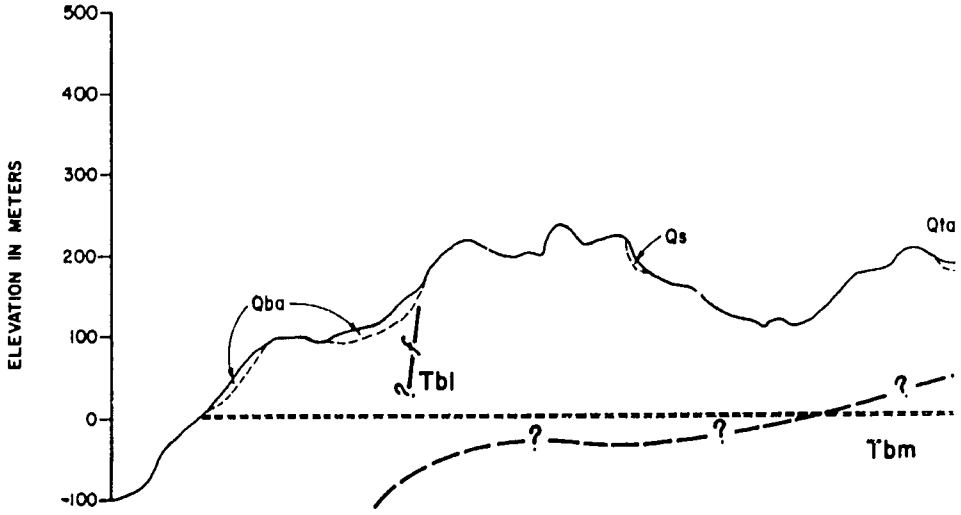
SCALE 0 1 KM.

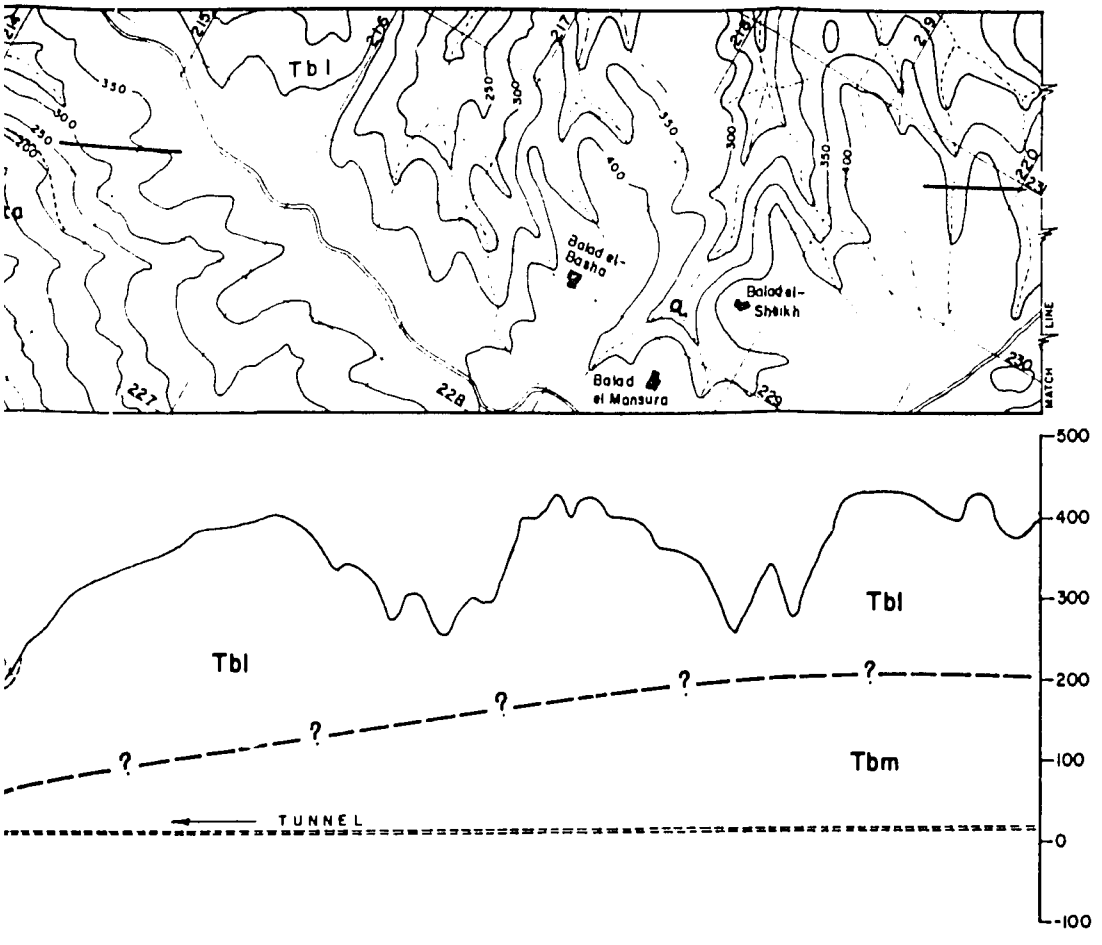
GEOLOGIC MAP AND SECTION
MAQARIN DAMSITE TO WADI ARAB TUNNEL

JORDAN VALLEY IRRIGATION PROJECT

STAGE II


EXISTING EAST SHOR CANAL
Qal
Kh. as Shiine
MA'AD
Qs
Tbl
Qba
Tbm
Qt
Qta
Qls
Wadi Arab Damsite
ZAHTAR
W
E
224
225
226


ELEVATION IN METERS
500
400
300
200
100
0
-100
Qba
Tbl
Qs
Qta
Tbm



NOTE
For notes and legend, refer to Exhibit E-33A

SCALE 0 1 KM.

GEOLOGIC MAP AND SECTION
MAQARIN DAMSITE TO WADI ARAB TUNNEL
JORDAN VALLEY IRRIGATION PROJECT
STAGE II