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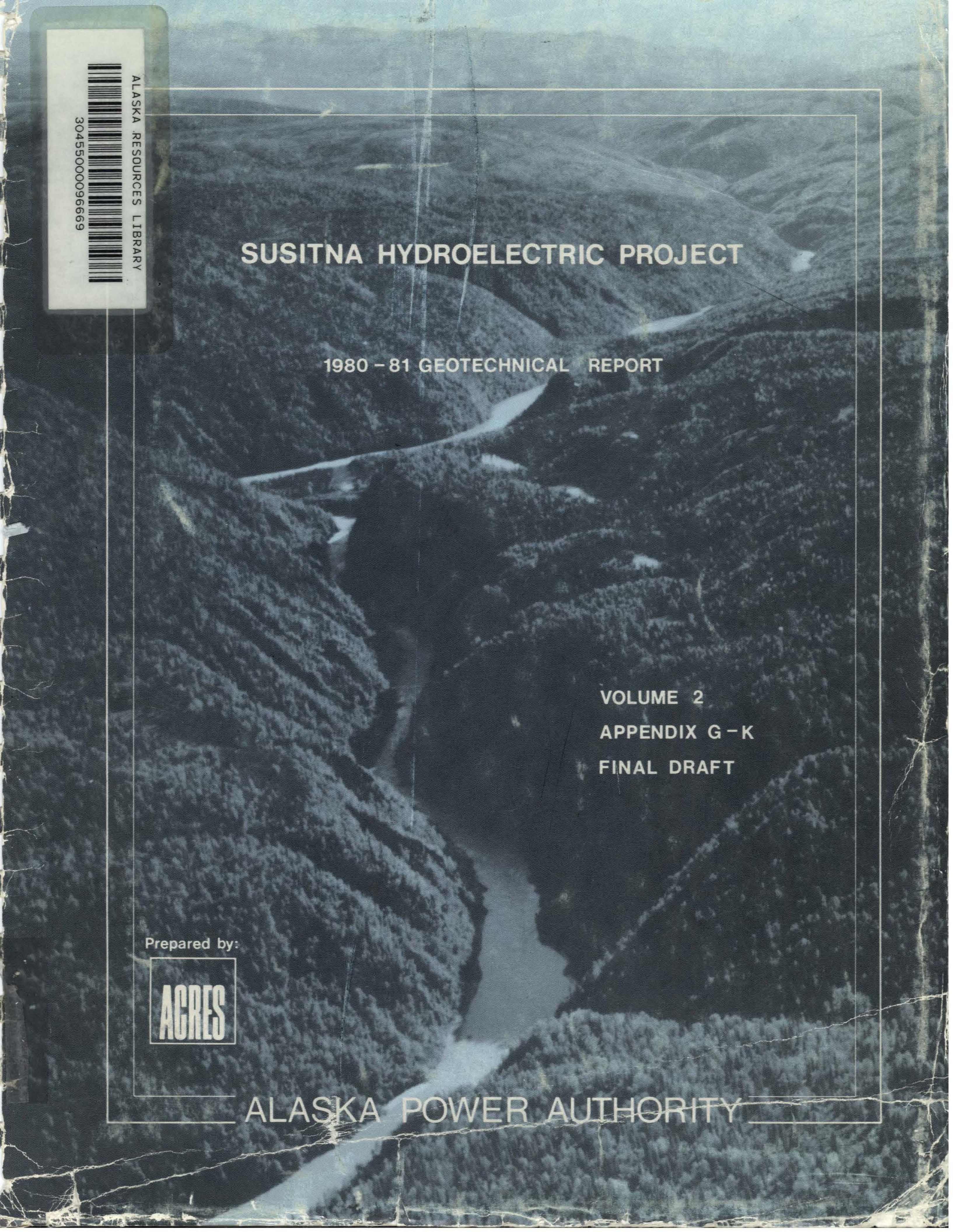

SUSITNA HYDROELECTRIC PROJECT

1980 - 81 GEOTECHNICAL REPORT

VOLUME 2

APPENDIX G - K

FINAL DRAFT

Prepared by:

ACRES

ALASKA POWER AUTHORITY

TK
1425
.S8
A23
no. 71

SUSITNA HYDROELECTRIC PROJECT

1980 - 81 GEOTECHNICAL REPORT

VOLUME 2

APPENDIX G - K

FINAL DRAFT

Merged With
ARLIS
ANCHORAGE, ALASKA

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ARLIS
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Anchorage, Alaska

Prepared by:

ACRES

ALASKA POWER AUTHORITY

VOLUME 2

APPENDIX

ARLIS
Alaska Resources
Library & Information Services
Anchorage, Alaska

APPENDIX G
DEVIL CANYON BORROW AREA INVESTIGATION

EXPLANATION OF SELECTED SYMBOLS

STANDARD SYMBOLS

ORGANIC MATERIAL	COBBLES & BOULDERS	IGNEOUS ROCK	SANDY SILT
CLAY	CONGLOMERATE	METAMORPHIC ROCK	SILT GRADING TO SANDY SILT
SILT	SANDSTONE	ICE, MASSIVE	SANDY GRAVEL, SCATTERED COBBLES (ROCK FRAGMENTS)
SAND	MUDSTONE	ICE - SILT	INTERLAYERED SAND & SANDY GRAVEL
GRAVEL	LIMESTONE	ORGANIC SILT	SILTY CLAY w/TR. SAND

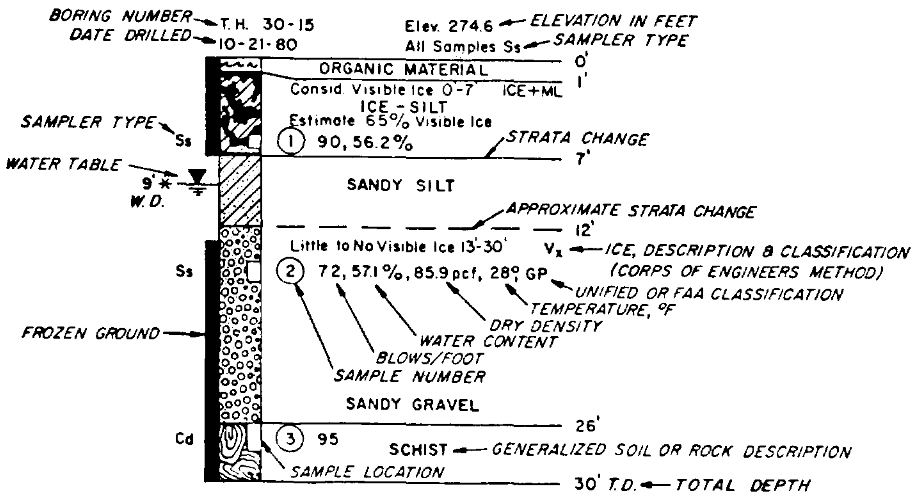
SAMPLER TYPE SYMBOLS

St . . . . . 1.4" SPLIT SPOON WITH 47 # HAMMER
Ss . . . . . 1.4" SPLIT SPOON WITH 140 # HAMMER
Sl . . . . . 2.5" SPLIT SPOON WITH 140 # HAMMER
Sh . . . . . 2.5" SPLIT SPOON WITH 340 # HAMMER
Sx . . . . . 2.0" SPLIT SPOON WITH 140 # HAMMER
Sz . . . . . 1.4" SPLIT SPOON WITH 340 # HAMMER
Sp . . . . . 2.5" SPLIT SPOON, PUSHED
Hs . . . . . 1.4" SPLIT SPOON DRIVEN WITH AIR HAMMER
Hl . . . . . 2.5" SPLIT SPOON DRIVEN WITH AIR HAMMER

Ts . . . . SHELBY TUBE
Tm . . . . MODIFIED SHELBY TUBE
Pb . . . . PITCHER BARREL
Cs . . . . CORE BARREL WITH SINGLE TUBE
Cd . . . . CORE BARREL WITH DOUBLE TUBE
Bs . . . . BULK SAMPLE
A. . . . . AUGER SAMPLE
G. . . . . GRAB SAMPLE

NOTE: SAMPLER TYPES ARE EITHER NOTED ABOVE THE BORING LOG OR ADJACENT TO IT AT THE RESPECTIVE SAMPLE DEPTH.

TYPICAL BORING LOG



DRILLING SYMBOLS

WD:	While Drilling	AB:	After Boring
WL:	Water Level	TD:	Total Depth
WS:	While Sampling		

<u>Note:</u> Water levels indicated on the boring logs are the levels measured in the boring at the times indicated. In pervious unfrozen soils, the indicated elevations are considered to represent actual ground water conditions. In impervious and frozen soils, accurate determinations of ground water elevations cannot be obtained within a limited period of observation and other evidence on ground water elevations and conditions are required.

PREPARED BY:

R&M CONSULTANTS, INC.

EXPLANATION OF SELECTED SYMBOLS

PREPARED FOR:

ACRES

SOILS
CLASSIFICATION AND CONSISTENCY

CLASSIFICATION: Identification and classification of the soil is accomplished in accordance with the Unified Soil Classification System. Normally, the grain size distirbution determines classification of the soil. The soil is defined according to major and minor constituents with the minor elements serving as modifiers of the major elements. Minor soil constitutents may be added to the classification breakdown in accordance with the particle size proportions listed below; (i.e., sandy silt with some gravel, trace clay).

no call - 0-3% trace - 3-12% some - 13-30% sandy, silty, gravelly - >30%

Identification and classification of soil strata which have a significant cobble and boulder content is based on the unified classification of the minus 3 inch fraction augmented by a description (i.e., cobbles and boulders) of the plus 3 inch fraction. Where a gradation curve, which includes the plus 3 inch fraction, exists (samples from test trenches and pits) a modifier is used to describe independently the percentage of each of the two plus 3 inch components. If there is no gradation curve incorporating the plus 3-inch fraction (as in auger holes), the plus 3-inch material is described as a single component (i.e., cobbles and boulders), and a modifier is used to indicate the relative percentage of the plus 3-inch fraction based on the field logs. The modifiers in each case are used as follows:

Scattered - 0-40% Numerous - >40%

SOIL CONSISTENCY - CRITERIA: Soil consistency as defined below and determined by normal field and laboratory methods applies only to non-frozen material. For these materials, the influence of such factors as soil structure, i.e. fissure systems, shrinkage cracks, slickensides, etc., must be taken into consideration in making any correlation with the consistency values listed below. In permafrost zones, the consistency and strength of frozen soils may vary significantly and unexplainably with ice content, thermal regime and soil type.

Cohesionless Soils	N* (blows/ft)	Relative Density
Very Loose	0 - 4	20%
Loose	4 - 10	20 to 40%
Medium Dense	10 - 30	40 to 60%
Dense	30 - 50	60 to 80%
Very Dense	>50	>80%

Cohesive Soils	N* (blows/ft)	qu - (tsf)
Very Soft	0 - 2	0 - 0.25
Soft	2 - 4	0.25 - 0.5
Medium	4 - 8	0.5 - 1.0
Stiff	8 - 15	1.0 - 2.0
Very Stiff	15 - 30	2.0 - 4.0
Hard	>30	>4.0

* Standard Penetration "N": Blows per foot of a 140-pound hammer falling 30 inches on a 2-inch OD split-spoon except where noted.

Often the split-spoon samplers do not reach the total intended sample depth. Where this occurs the graphic log notes a refusal (Ref.) and give an indication of the cause of the refusal. Tight soils are indicated by a blow count value followed by a penetration length in inches. The presense of large rock fragments is indicated by a cobble and boulder callout following the refusal callout. In certain instances a blow count of 100+ may be listed to indicate tight soils where total sampler penetration is possible with more than 100 blows per foot.

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PREPARED FOR:

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EXPLANATION OF ICE SYMBOLS

Percentage of visible ice has been grouped for the purpose of designating the amount of soil ice content. These groups have arbitrarily been set out as follows:

0%	No Visible Ice
1% - 10%	Little Visible Ice
11% - 20%	Occasional Visible Ice
21% - 35%	Some Visible Ice
>35%	Considerable Visible Ice

The ice description system is based on that presented by K. A. Linell, and C. W. Kaplar (1966). In this system, which is an extension of the Unified Soil Classification System, the amount and physical characteristics of the soil ice are accounted for. The following table is a brief summary of the salient points of their classification system as modified to meet the needs of this study.

ICE DESCRIPTIONS

GROUP SYMBOL	ICE VISIBILITY & CONTENT	SUBGROUP	
		DESCRIPTION	SYMBOL
N	Ice not visible	Poorly bonded or friable	N_f
		Well bonded: No excess ice	N_b: N_{bn}
		Well bonded: Excess ice	N_b: N_{be}
V	Ice visible, <50%	Individual ice crystals or inclusions	V_x
		Ice coatings on particles	V_c
		Random or irregularly oriented ice formations	V_r
		Stratified or distinctly oriented ice formations	V_s
ICE	Ice visible, >50%	Ice with soil inclusions	ICE + soil type
	Individual layer >6" thick *	Ice without soil inclusions	ICE

* In some cases where the soil is ice poor a thin ice layer may be called out by special notation on the log, i.e. 2" ice lens at 7'

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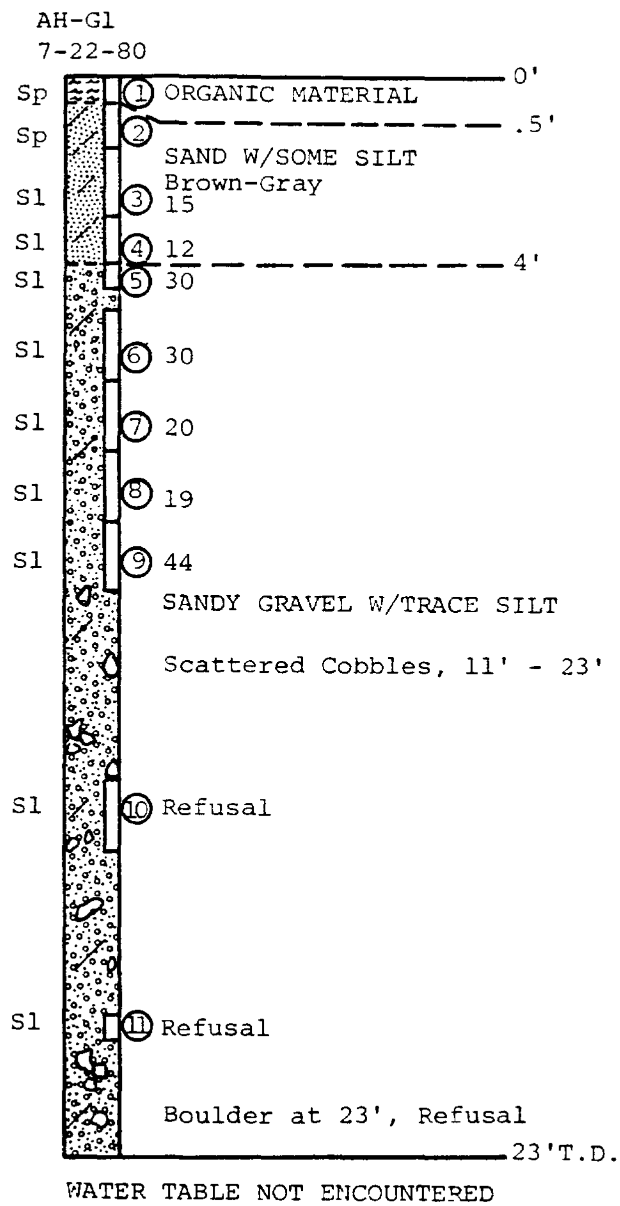
EXPLANATION OF ICE SYMBOLS

PREPARED FOR:

ACRES

G.1 BORROW SITE G

AUGER HOLE LOGS



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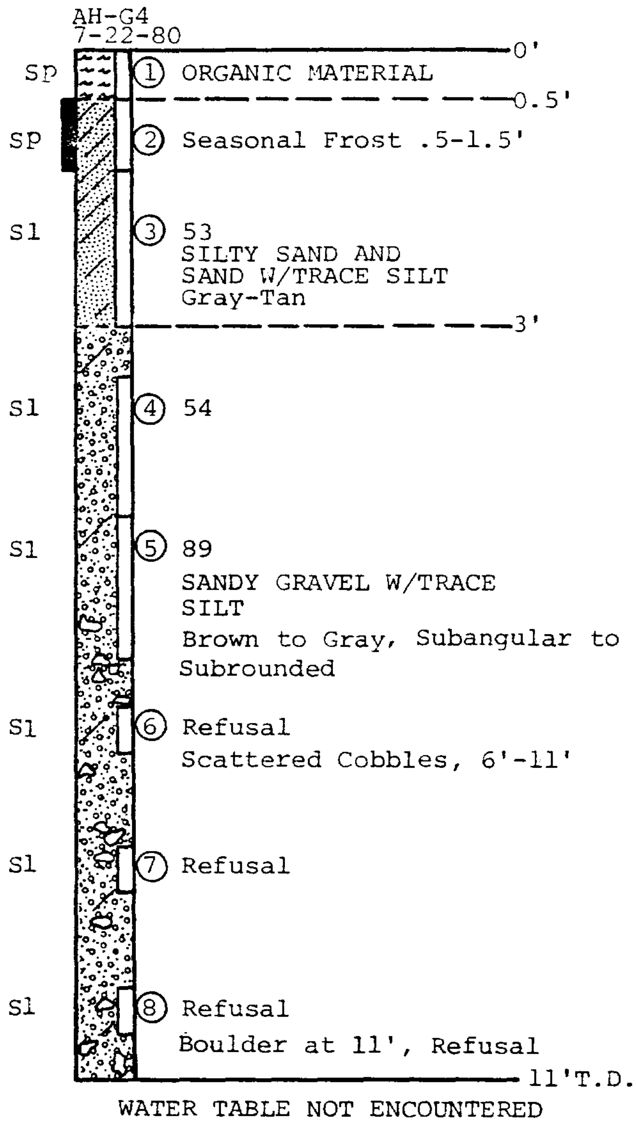
BORROW AREA G
AUGER HOLE AH-G1

Scale 1"=2'

PREPARED FOR:

ACRES



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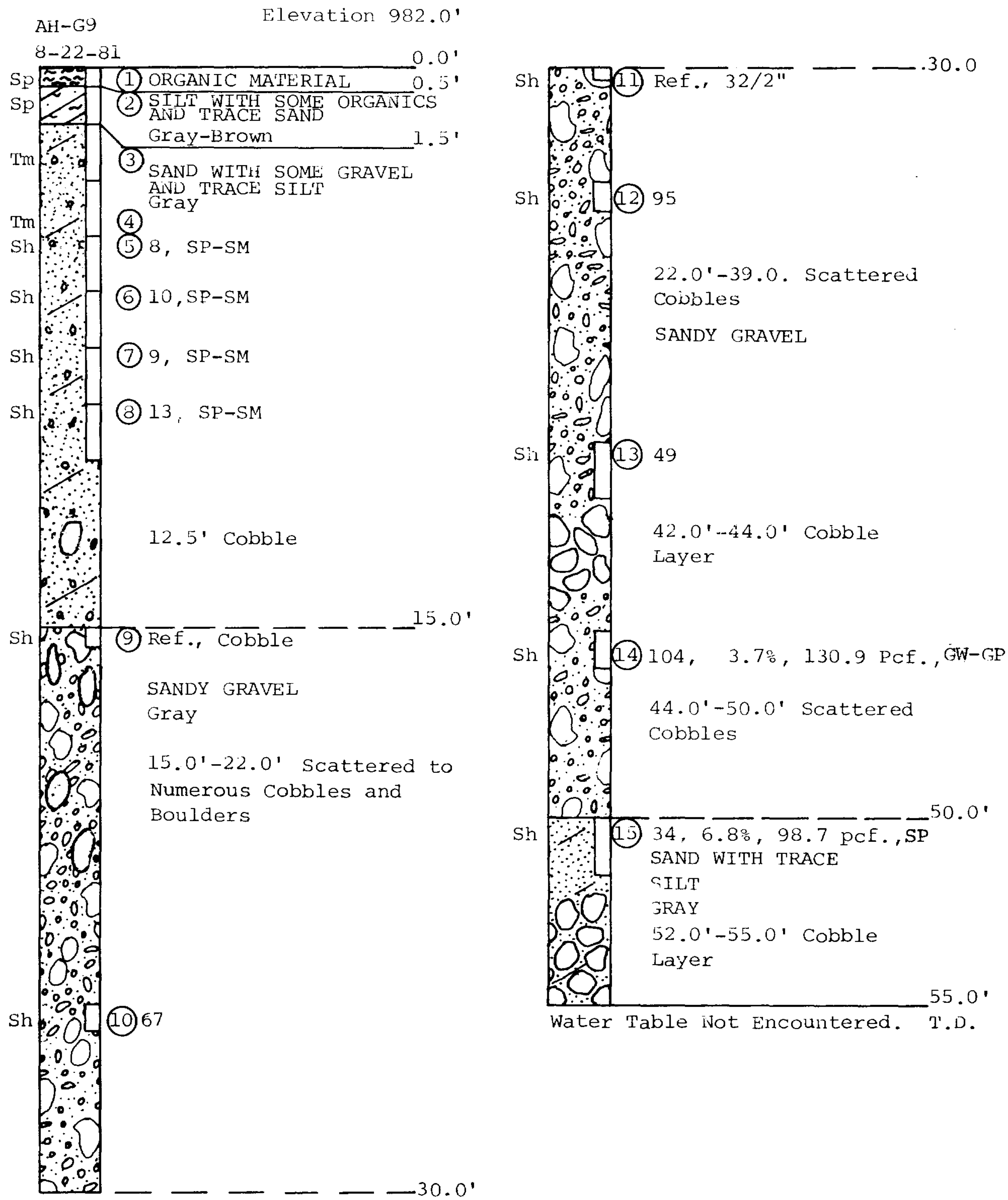
PREPARED FOR:

BORROW AREA G
AUGER HOLE AH-G4

Scale 1"=2'

ACRES



PREPARED BY:

R&M CONSULTANTS, INC.

BORROW AREA G
AUGER HOLE AH-G9

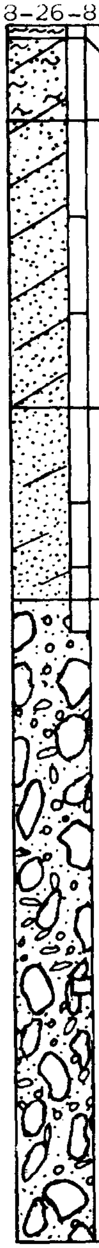
Scale: 1"=4

PREPARED FOR:

AH-G10

3-26-81

Elevation 980.0'



		Depth
		0.0'
Sp	(1) ORGANIC MATERIAL	0.3'
Sp	(2) SILTY SAND WITH SOME ORGANICS Gray Brown	1.5'
Tm	(3) SILTY SAND Gray	
Sh	(4) 4 , 30.9%, 72.7 pcf.,SM	
Sh	(5) 10, 15.7%, 89.6 pcf., SM	6.0'
Sh	(6) 11, 11.7%, 94.8 pcf., SP-SM SAND WITH TRACE SILT Gray	
Sh	(7) 6, 22.9%, 90.2 pcf., SP-SM	
Sh	(8) SP-SM	9.0'
Sh	(9) Ref., Cobble	
	SANDY GRAVEL WITH SCATTERED TO NUMEROUS COBBLES AND BOULDERS Grey	
Sh	(10) Ref., Cobble	
		19.0'T.D.

Water Table Not Encountered.

PREPARED BY:

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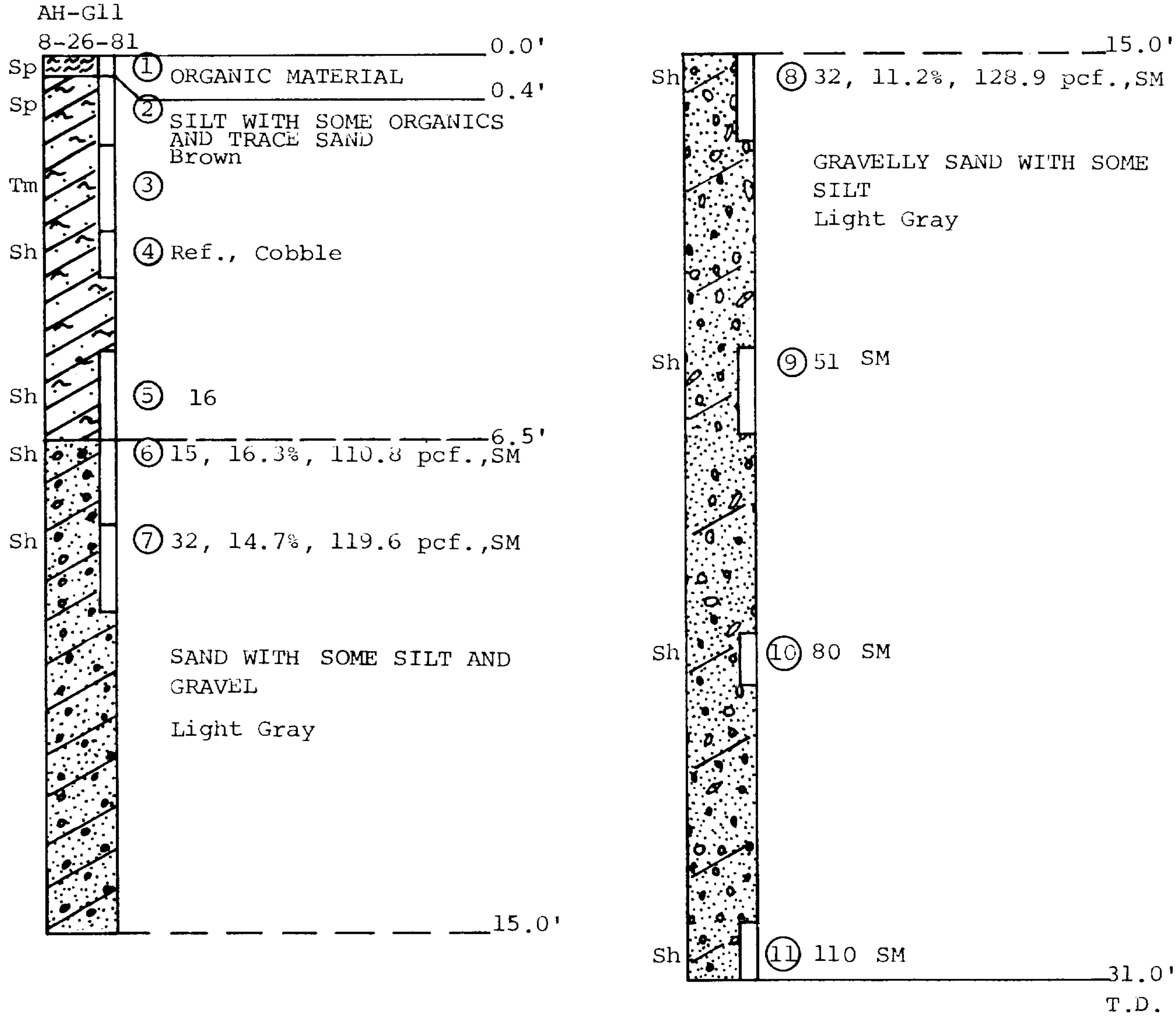
BORROW AREA G

AUGER HOLE AH-G10

Scale: 1"=3

PREPARED FOR:

ACRES



Thermal Probe Installed to 31.0'
Water Table Not Encountered.

PREPARED BY:

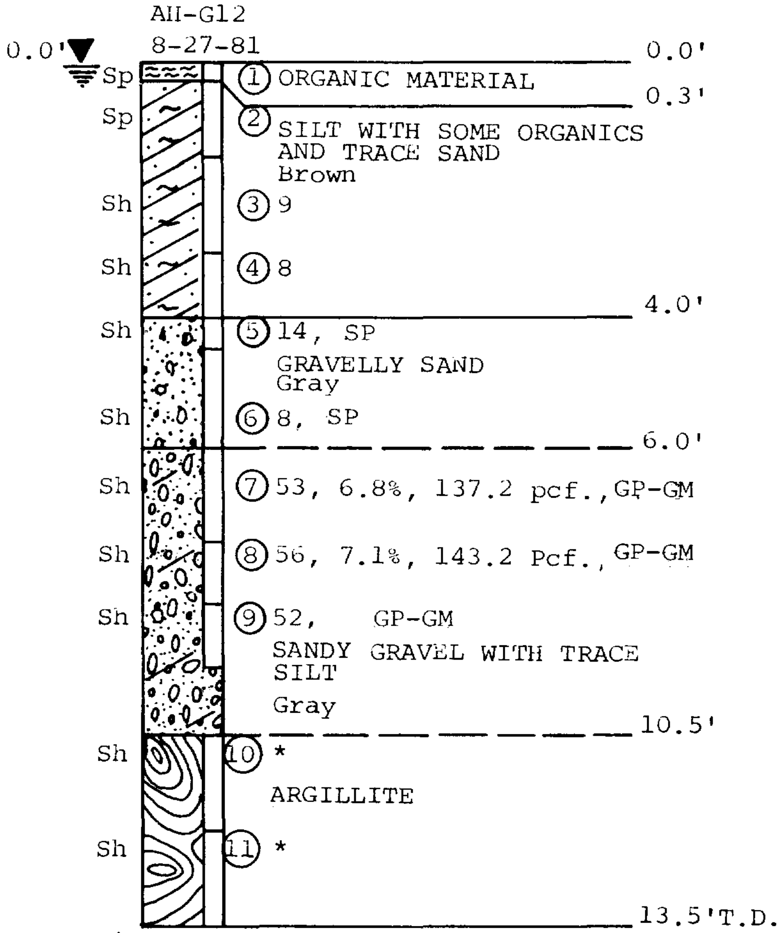
R&M CONSULTANTS, INC.

BORROW AREA G
AUGER HOLE AH-G11

PREPARED FOR:

ACRES

Scale: 1"=3



* Blow Counts Not Available

Thermal Probe Installed to 13.5 ft.

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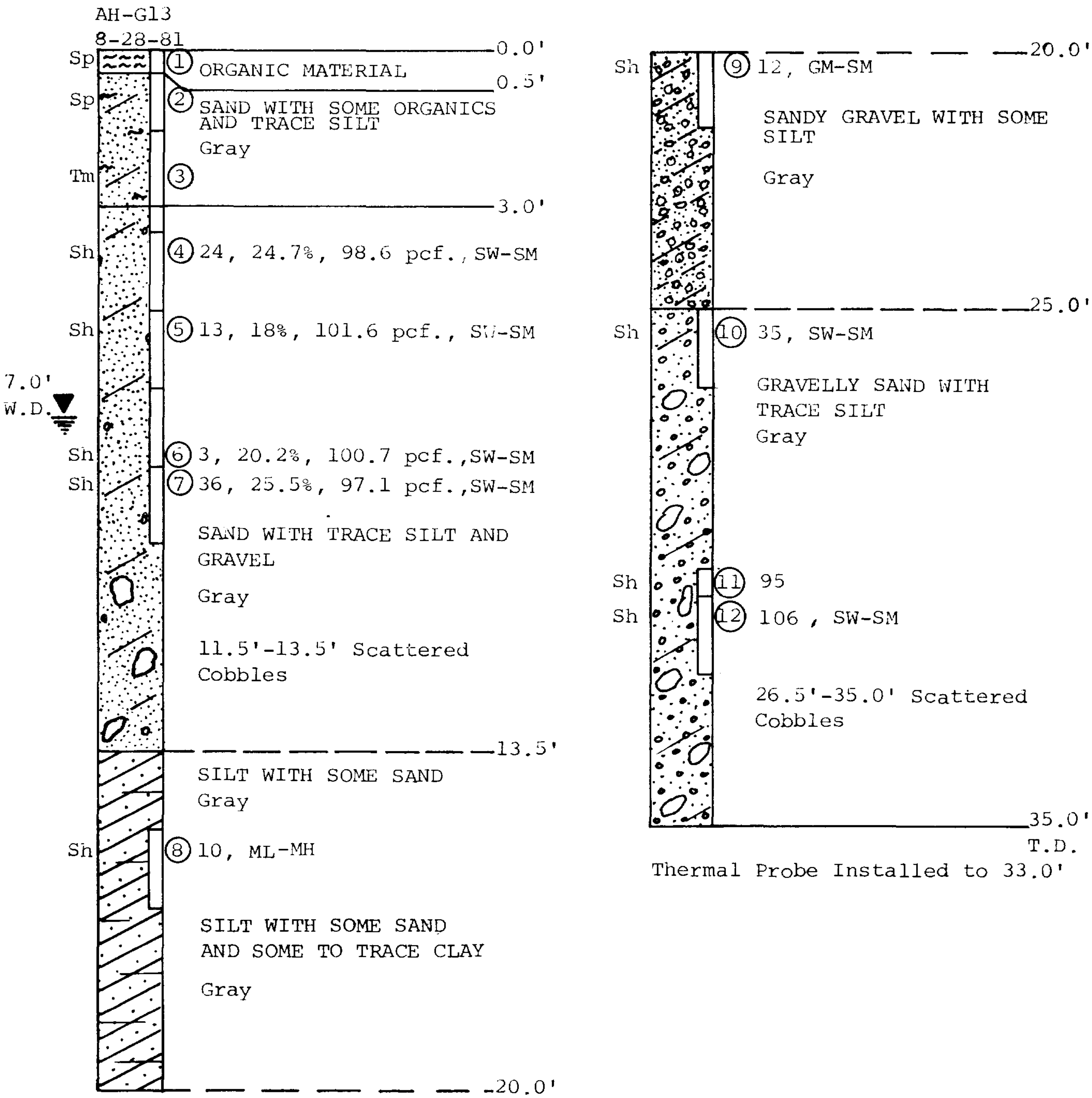
BORROW AREA G

AUGER HOLE AH-G12

Scale: 1"=3'

PREPARED FOR:

ACRES



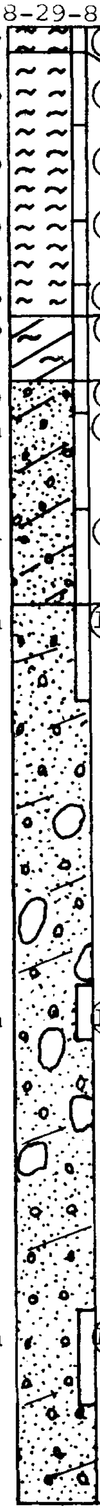
PREPARED BY: R&M CONSULTANTS, INC.

PREPARED FOR: ACRES

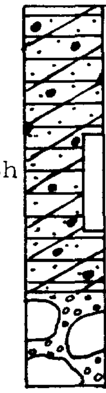
BORROW AREA G
AUGER HOLE AH-G13

Scale: 1"=3'

AH-G14
8-29-81



Sample type	No.	Description	Depth
			0.0'
Sp	1	ORGANIC MATERIAL	
			0.5'
Sp	2	PEAT Brown	
Sp	3		
Sp	4		
Sp	5		4.5'
Sp	6	SILT WITH SOME ORGANICS Brown	
			5.5'
Sp	7		
Sh	8	27, SM SAND WITH SOME GRAVEL AND SILT Gray	
Sh	9	19, 9.2%, 135.5 pcf.,SM	
			9.0'
Sh	10	44, 9,9%, 129.5 pcf.,SP-SM SAND WITH SOME GRAVEL AND TRACE SILT Gray	
Sh	11	Ref.,Cobble, SP-SM 12.0'-18.5' Scattered Cobbles	
Sh	12	89, 7.0%, 138.1 pcf.,SP-SM	
			23.0'



Sample type	No.	Description	Depth
			23.0'
		SILT WITH SOME SAND, SOME TO TRACE CLAY AND TRACE GRAVEL. Gray	
Sh	13	67, 23.5%, 101.4 pcf.,ML-MH	
			27.5'
		27.5'-29.0' Gravel and Boulders.	
			29.0' T.D.

Water Table Not Encountered
Thermal Probe Installed to 29.0'

PREPARED BY:

R&M CONSULTANTS, INC.

BORROW AREA G
AUGER HOLE AH-G14

Scale:1"=3'

PREPARED FOR:

ACRES

APPENDIX H
SEISMIC REFRACTION SURVEY-1980

TEST PIT/TEST TRENCH LOGS

LABORATORY TEST DATA

PROJECT NO. 052506
Client: Acres American, Inc.
PROJECT NAME Susitna Hydroelectric

R & M CONSULTANTS, INC.

SUMMARY OF LABORATORY TEST DATA

DATE November 10, 1981

TEST HOLE	SAMPLE NO.	DEPTH (feet)	6"-12"	3"-6"	2"	1½"	1"	3/4"	1/2"	3/8"	#4	10	20	40	80	100	200	FINE SPG	L.L.	CLASS	WET DENSITY	DRY DENSITY	MOISTURE CONTENT %
TTG 1	2	5.0'	100	67	67	63	59	56	52	48	35	20	9	6	2	2	0.9	2.73		SP-SW			
TTG 1	3	16.0'	72*	29**	29	29	27	26	23	22	16	10	7	5	3	2	1.4	2.76		SP-SW			
TTG 1	4	25.5'			100	96	86	72	54	42	23	12	8	7	4	4	2.6	2.72		GW			
TTG 1	5	37.0'	100	57	57	56	54	52	50	48	45	40	33	26	7	3	2.4	2.76		GW			
TTG 2	1	2.5'										100	99	98	92	87	84.8	2.82		ML-MH			
TTG 2	2	6.0'								100	99	82	40	14	2	1	0.4	2.78		SP			
TTG 2	3	6.5'		100	97	76	60	58	52	47	38	23	9	7	2	2	1.3	2.87		GP			
TTG 2	4	8.0'	57	26	26	26	23	22	20	18	16	13	9	5	2	1.9	0.7	2.86		SP			
TTG 2	5	15.0'	51	30	30	26	23	21	18	16	12	9	5	3	1	1	0.5	2.87		GP			
TTG 2	8	18.0'	80	57	55	51	44	38	32	27	20	16	12	7	4	3	1.2	2.79		GW			
TTG 2	9	24,5'	81	52	52	47	41	36	31	27	21	16	12	9	4	3	1.3	2.33		GW			
AHG 9	4-8	3.0-10.5			100	96	96	94	94	93	82	65	48	36	32	17	11.2	2.54		SP			
AHG 9	14	45.0-46.5			100	67	64	58	43	39	34	29	20	11	3	3	1.7	2.53		GW-GP	135.7	130.9	3.7
AHG 9	15	50.0-51.5										100	86	38	9	7	4.2	2.79		SP	105.4	98.7	6.8
AHG 10	3-5	1.5-6.0									100	99	99	98	84	75	36.1	2.63		SM			
AHG 10	4	3.0-4.5																			94.5	72.2	30.9
AHG 10	5	4.5-6.0																			103.7	89.6	15.7
AHG 10	6-8	6.0-9.0									100	95	89	85	39	29	9.1	2.64		SP-SM			

REMARKS: * 9"-12"
** 3"-9"

NOTE: SIEVE ANALYSIS = PERCENT PASSING

PROJECT NO. 052506
CLIENT: Acres American, Inc.
PROJECT NAME Susitna Hydroelectric

R & M CONSULTANTS, INC.

SUMMARY OF LABORATORY TEST DATA

DATE November 10, 1981

PARTY NO. ______ PAGE NO. 2 of 3

		DEPTH (feet)			2"	1½"	1"	3/4"	1/2"	3/8"	#4	10	20	40	80	100	200	L.L.		CLASS	WET DENSITY	DRY DENSITY	MOISTURE CONTENT %
AHG10	6	6.0-7.5																			105.8	94.8	11.7
AHG10	7	7.5-8.5																			110.8	90.2	22.9
AHG11	6,7	6.5-9.5						100	98	95	83	74	61	50	33	29	17.9			SM			
AHG11	6	6.5-8.0																			128.9	110.8	16.3
AHG11	7	8.0-9.5																			137.2	119.6	14.7
AHG11	8-11	15.0-31.0				100	93	89	86	79	66	55	46	40	26	22	14.1			SM			
AHG11	8	15.0-16.5																			143.3	128.9	11.2
AHG12	5,6	4.0-6.0				100	93	86	82	79	66	56	45	36	21	16	2.4			SP			
AHG12	7-9	6.0-9.5			100	91	80	74	64	60	47	38	29	23	15	12	8.1			GP-GM			
AHG12	7	6.0-7.5																			146.5	137.2	6.8
AHG12	8	7.5-8.5																			153.3	143.2	7.1
AHG13	4-7	3.5-9.5						100	97	96	93	86	72	56	25	20	11.4			SW-SM			
AHG13	7	8.0-9.5																			121.9	97.1	25.5
AHG13	4	3.5-5.0																			122.9	98.6	24.7
AHG13	5	5.0-6.5																			119.9	101.6	18.0
AHG13	6	6.5-8.0																			121.0	100.7	20.2
AHG13	8	15.0-16.5									100	99	97	97	93	92	75.5			ML-MH			

REMARKS:

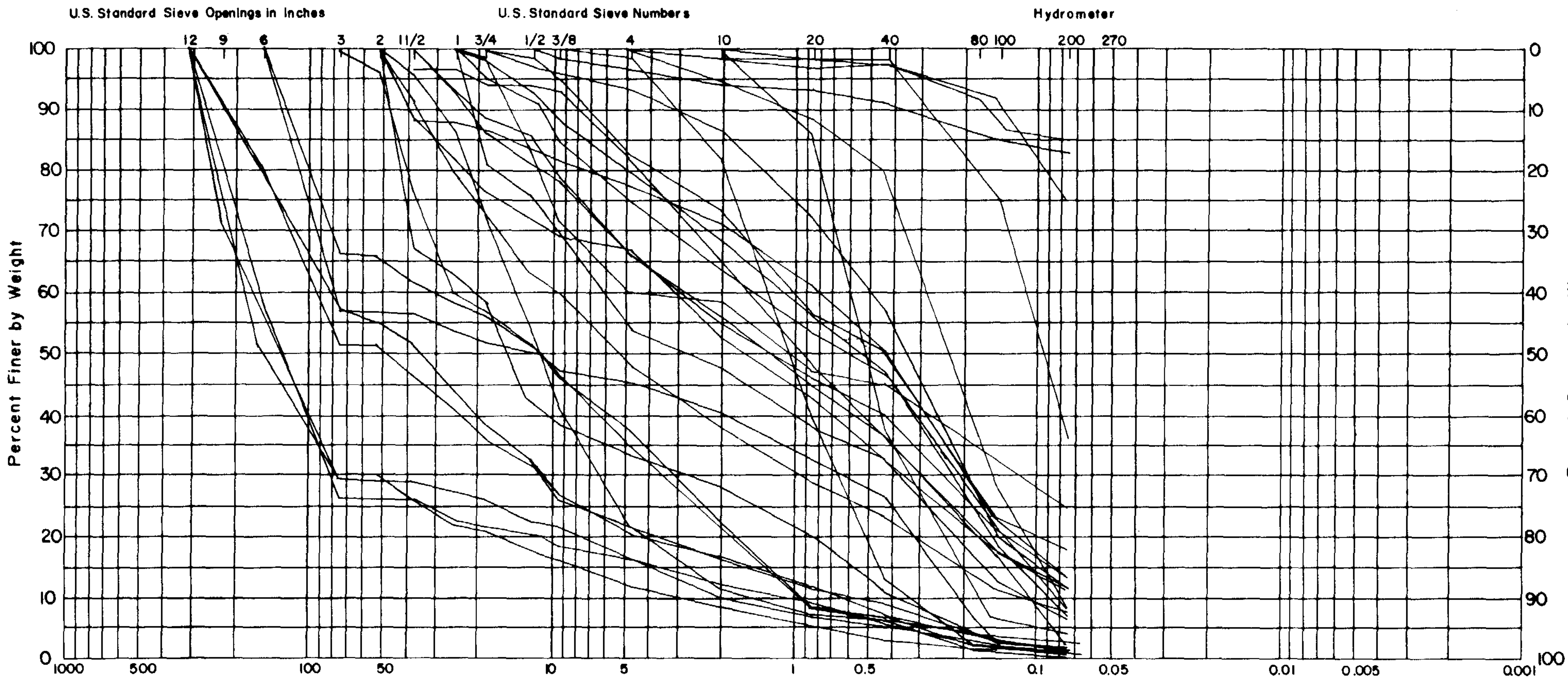
NOTE: SIEVE ANALYSIS = PERCENT PASSIN(

PROJECT NO. 052506	R & M CONSULTANTS, INC.	DATE November 10, 1981
CLIENT: Acres American, Inc.		
PROJECT NAME Susitna Hydroelectric	SUMMARY OF LABORATORY TEST DATA	PARTY NO. ____ PAGE NO. 3 of 3

TEST HOLE	SAMPLE NO.	DEPTH (feet)	6"-12"	3"-6"	2"	1½'	1"	3/4"	1/2"	3/8"	#4	10	20	40	80	100	200	L.L.	P.I.	CLASS	WET DENSITY	DRY DENSITY	MOISTURE CONTENT %
AHG13	9	20.0-21.5					100	98	84	72	60	58	47	45	36	33	24.9			GM-SM			
AHG13	10,12	25.0-32.0			100	88	82	77	73	69	67	53	43	33	20	18	11.4			SW-SM			
AHG14	8,9	6.0-9.0			100	88	88	87	84	82	78	72	61	50	35	29	14.3			SM			
AHG14	9	7.5-9.0																			148.1	135.5	9.2
AHG14	10	9.0-10.5					100	98	93	88	80	68	56	47	33	22	8.2			SP-SM	142.3	129.5	9.9
AHG14	11	15.0-16.0					100	82	77	70	59	48	38	33	22	13	6.5			SP-SM			
AHG14	12	20.0-21.5					100	95	91	85	75	64	54	46	28	19	6.5			SP-SM	147.7	138.1	7.0
AHG14	13	25.0-26.5							100	98	96	94	93	91	87	85	82.9	49	16	ML-MH	125.2	101.4	23.5

NOTE: SIEVE ANALYSIS = PERCENT PASSIN

REMARKS:



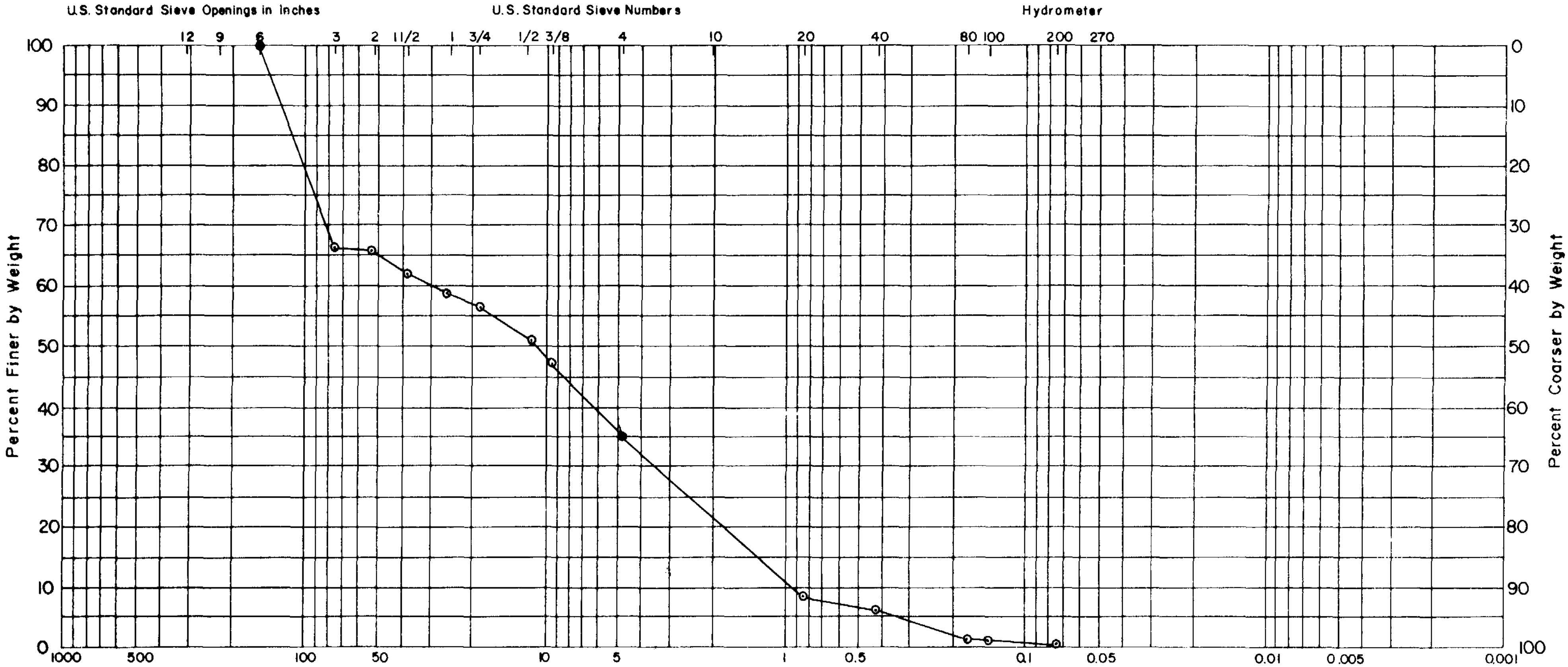
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASSIFICATION & DESCRIPTION

R&M CONSULTANTS INC.

BORROW AREA G
COMPOSITE GRADATION CURVE

DRAWN BY:
APPROVED BY:
DATE:
PROJECT NO.



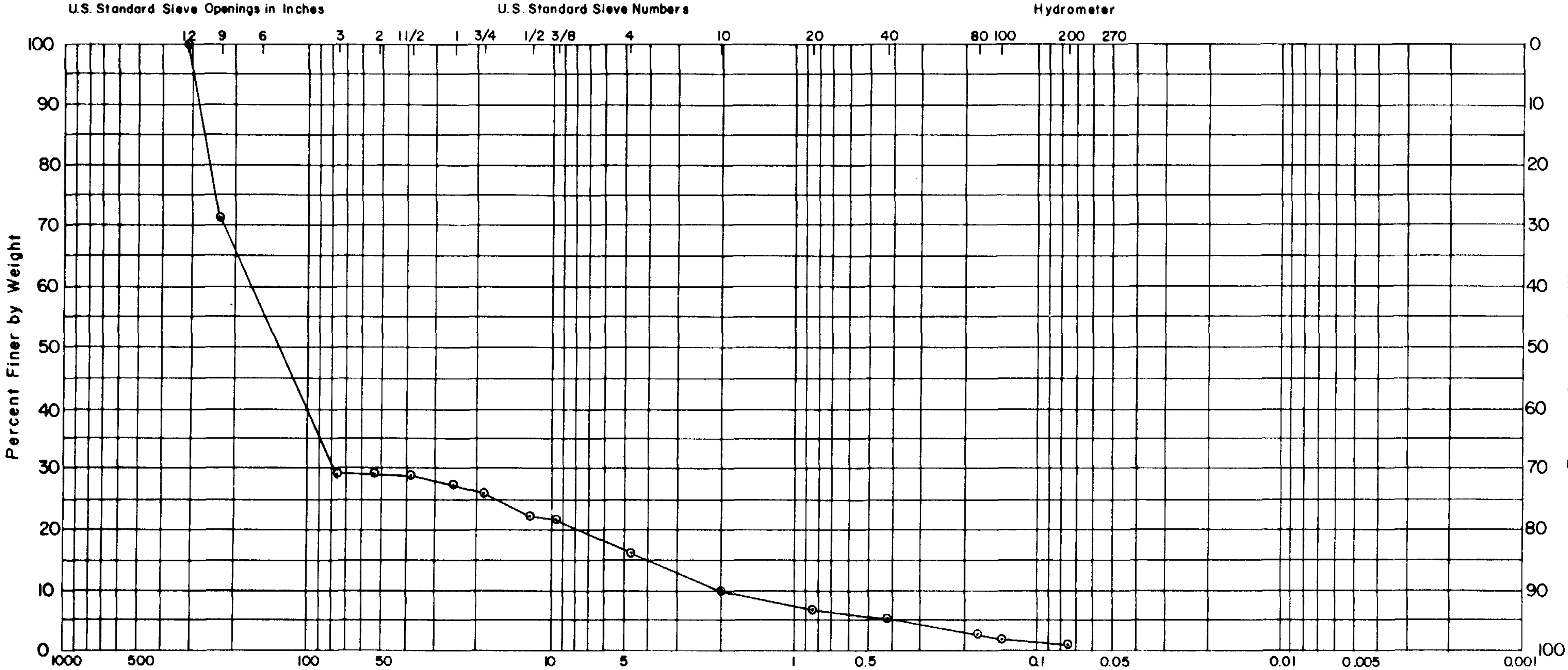
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G1 #2					SP-SW	GRAVELLY SAND WITH SCATTERED COBBLES.

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G1

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



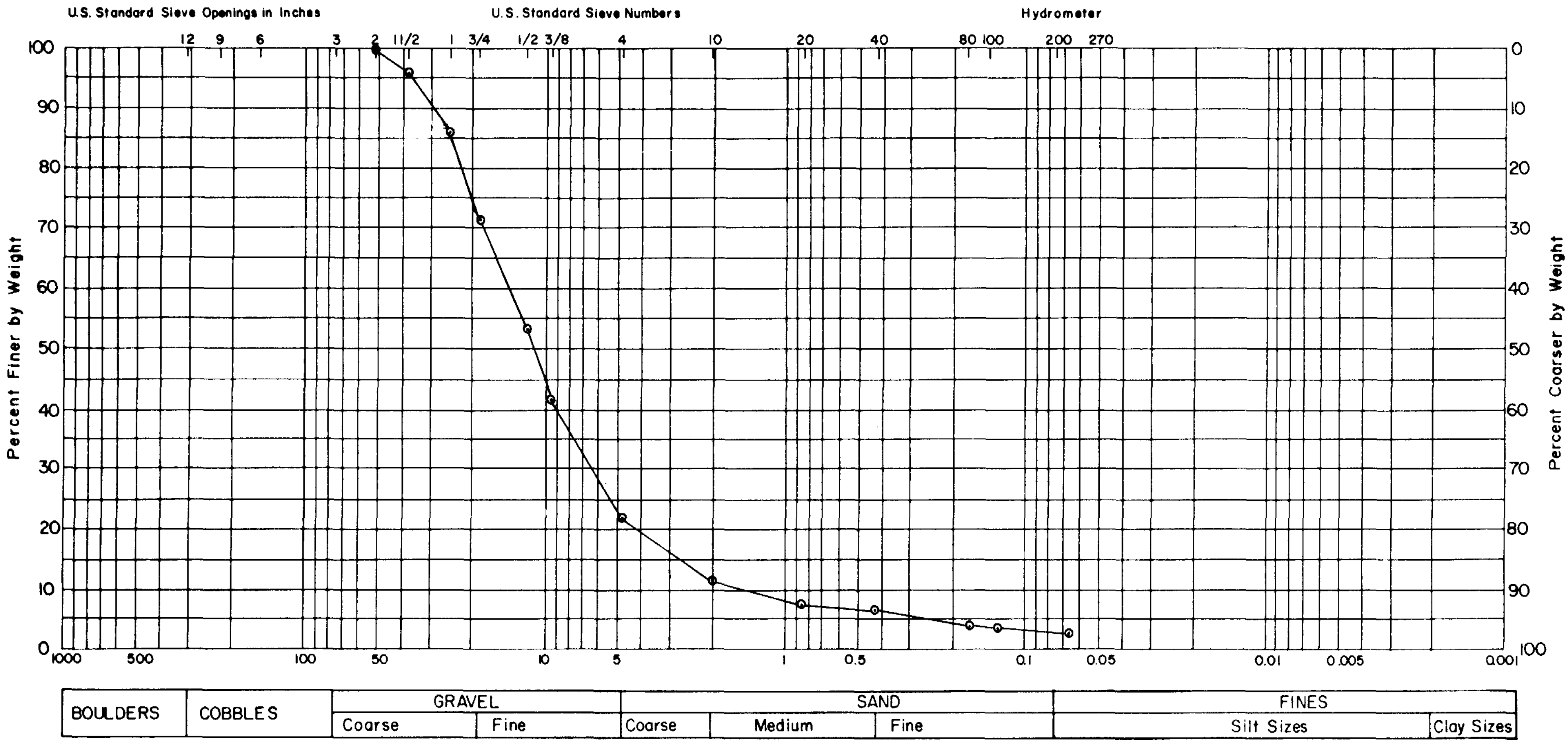
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G1 #3					SP-SW	GRAVELLY SAND WITH TRACE SILT AND NUMEROUS COBBLES

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G1

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

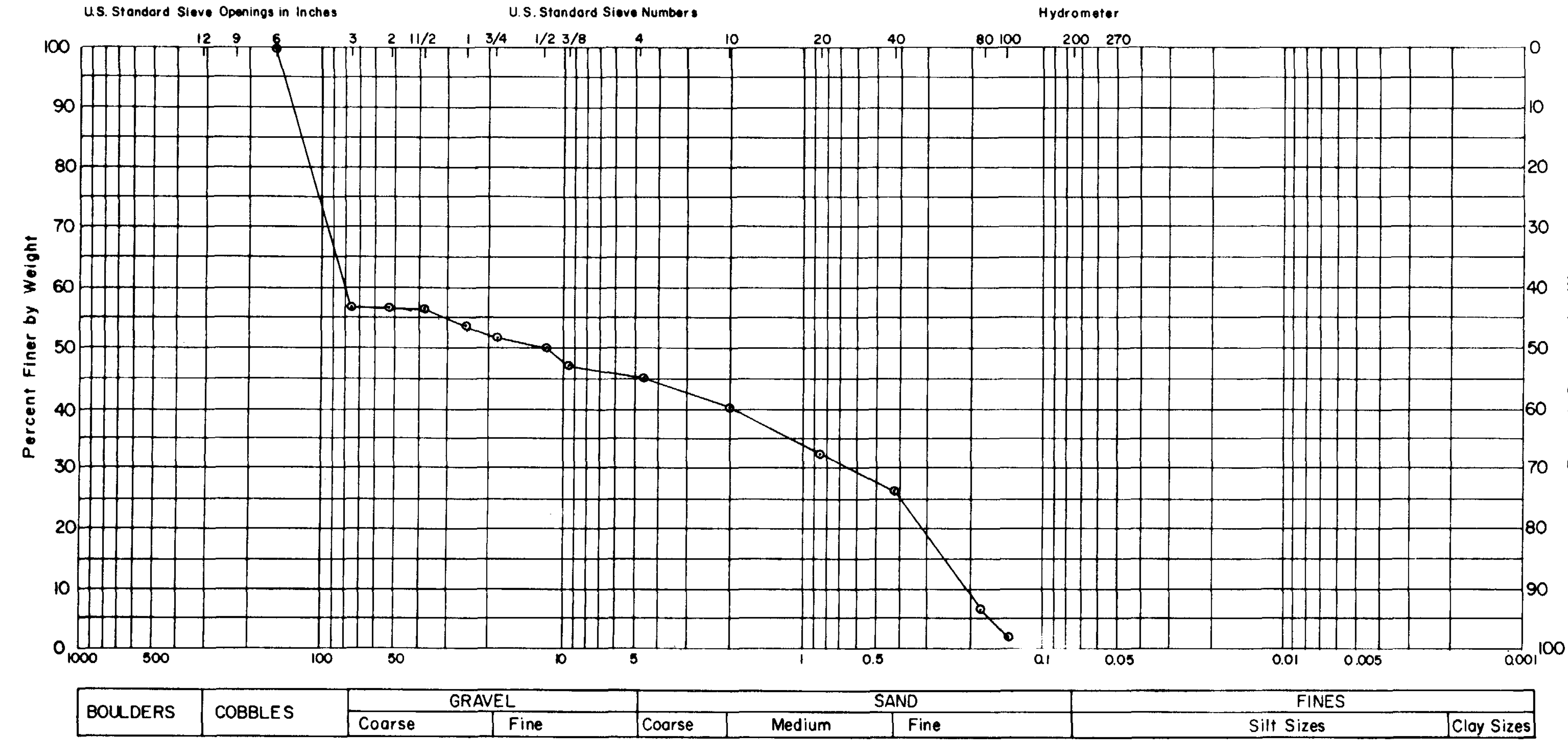


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G1 #4					GW	GRAVEL WITH SOME SAND

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G1

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec 1981
PROJECT NO. 052506



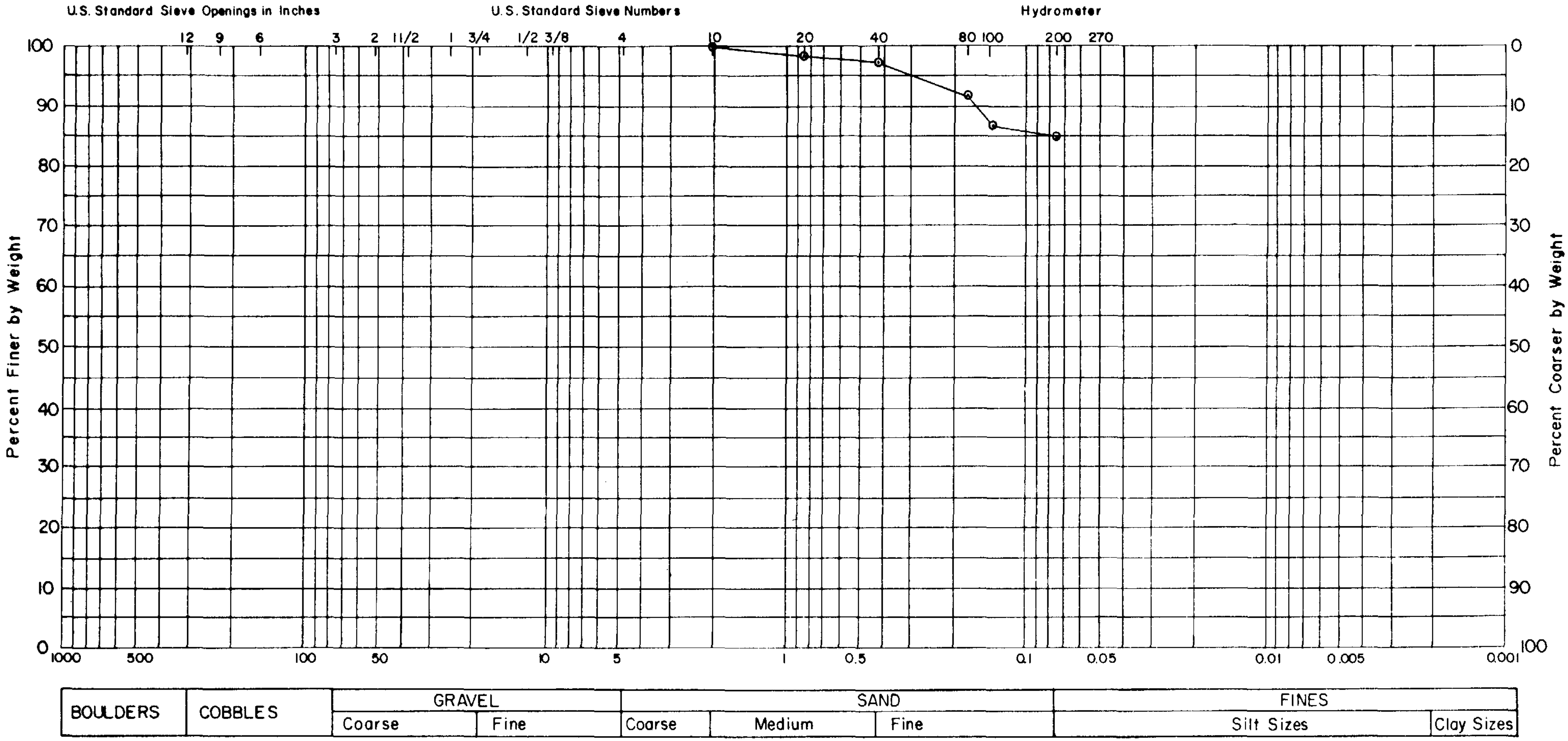
SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G1 #5					GW	SAND WITH SOME GRAVEL AND NUMEROUS COBBLES

R&M

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G1

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

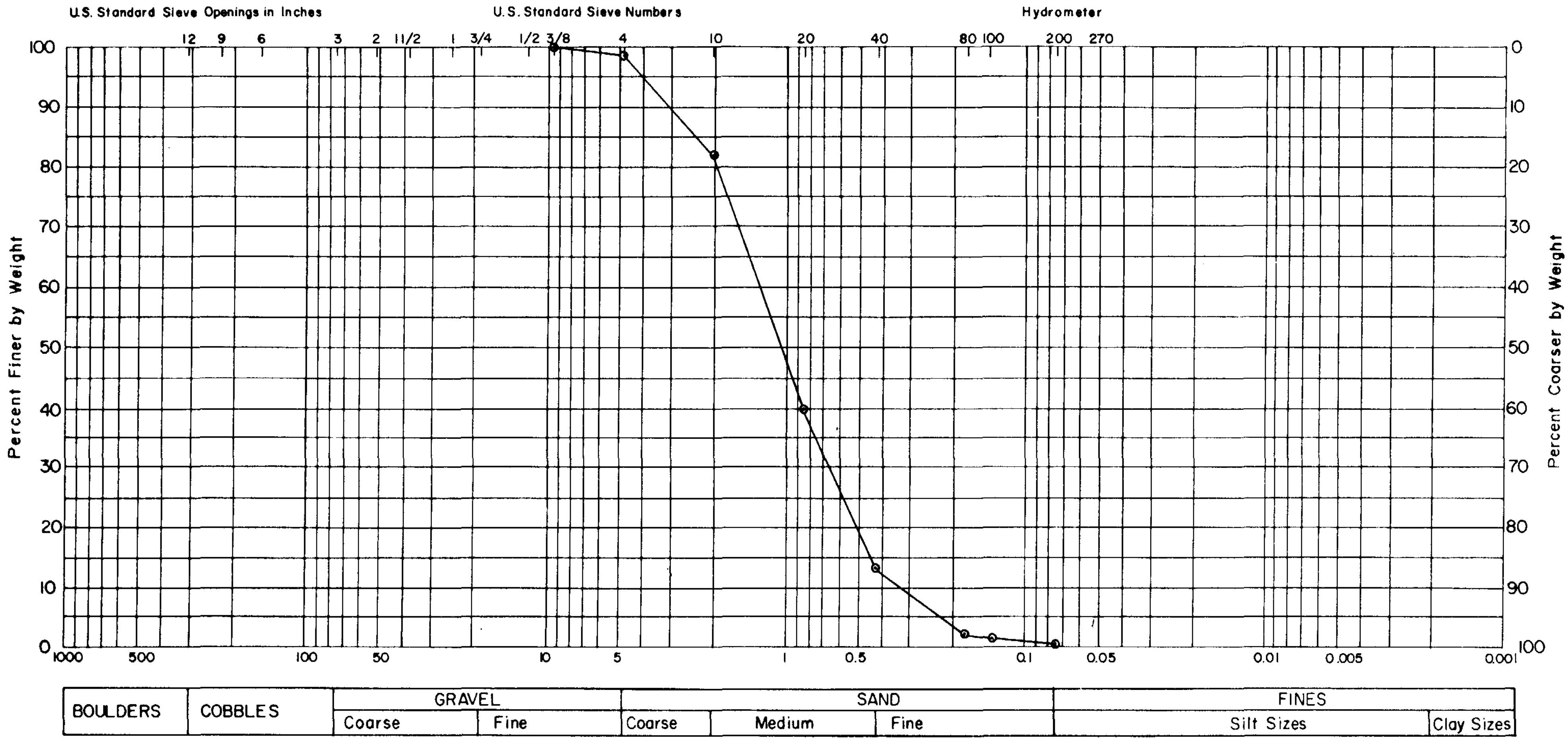


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G2 #1					ML-MH	SILT WITH SOME SAND AND CLAY

R&M
R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G2

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

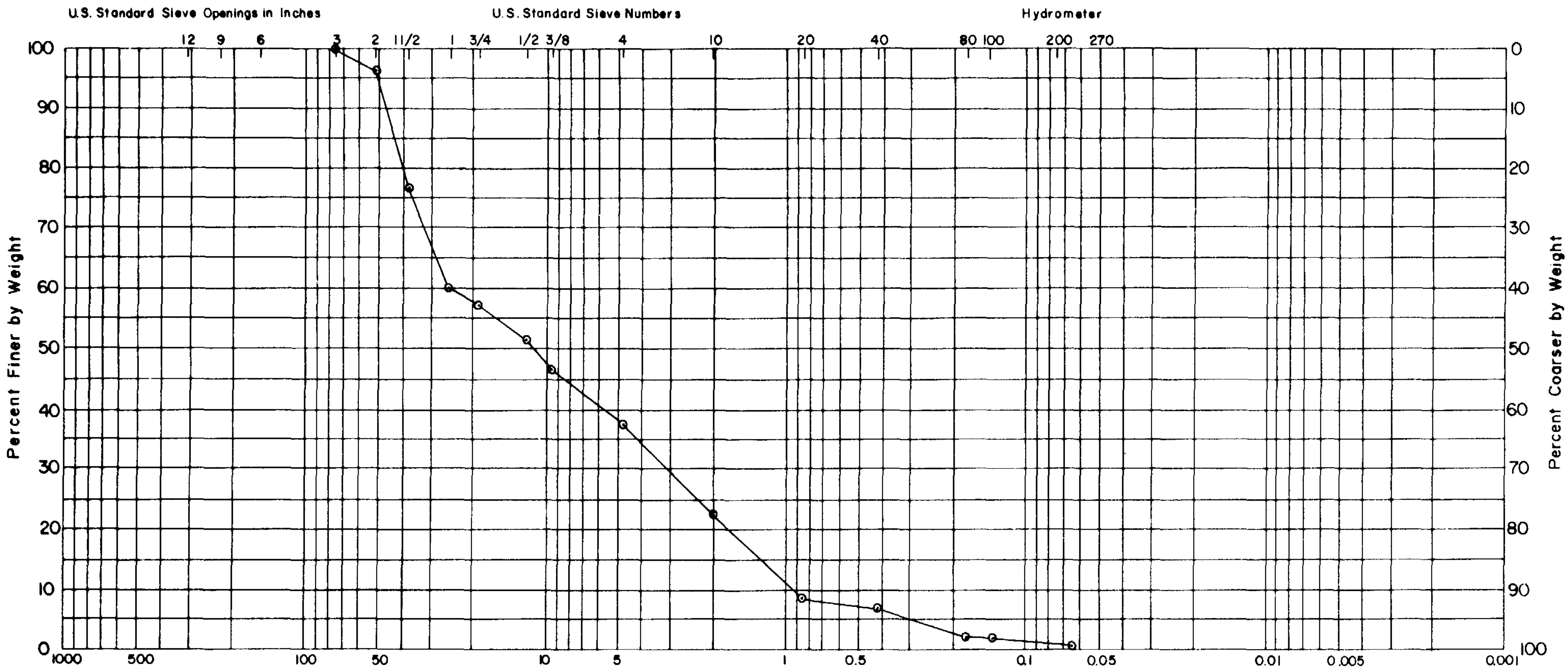


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G2 #2					SP	SAND

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G2

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



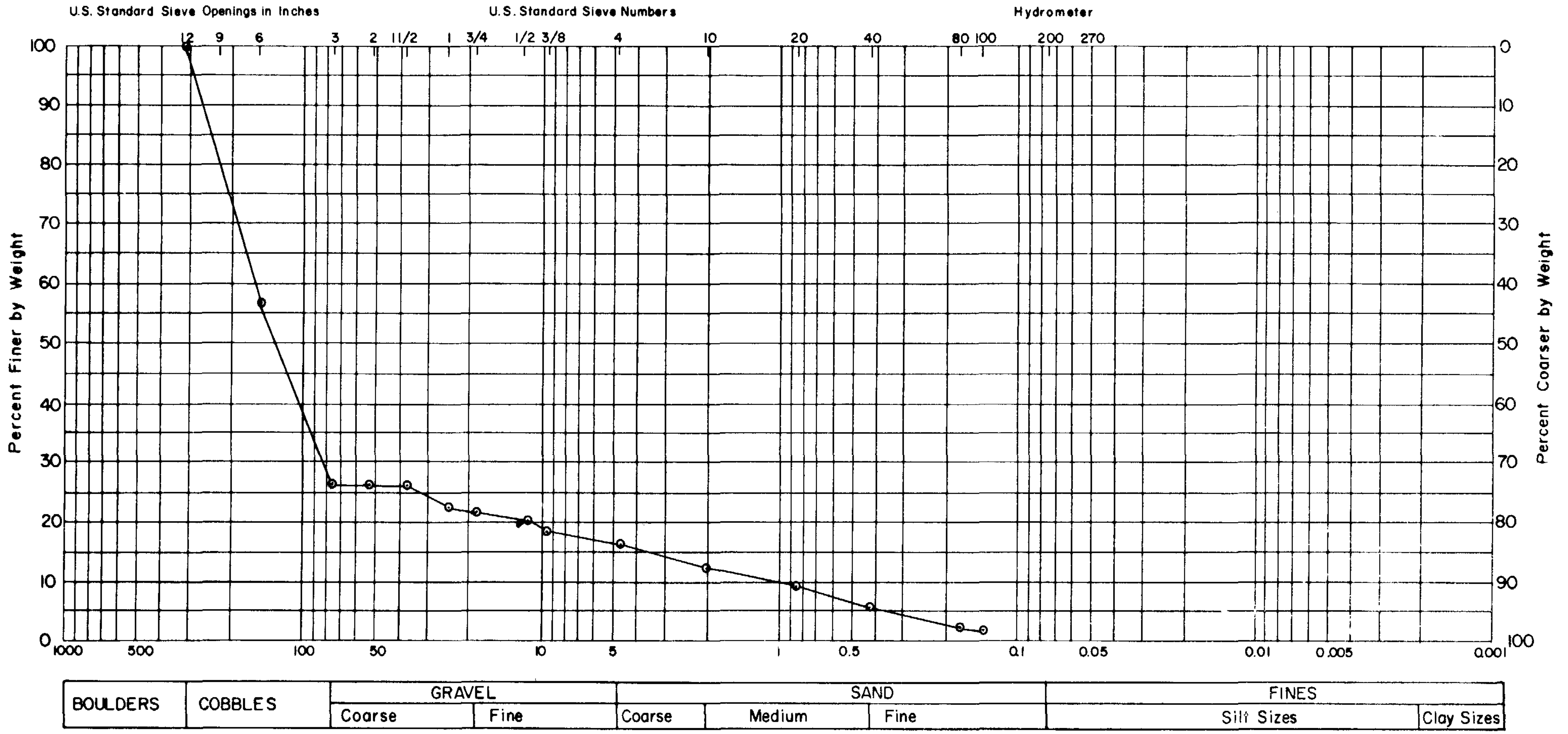
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G2 #3					GP	SANDY GRAVEL

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G2

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

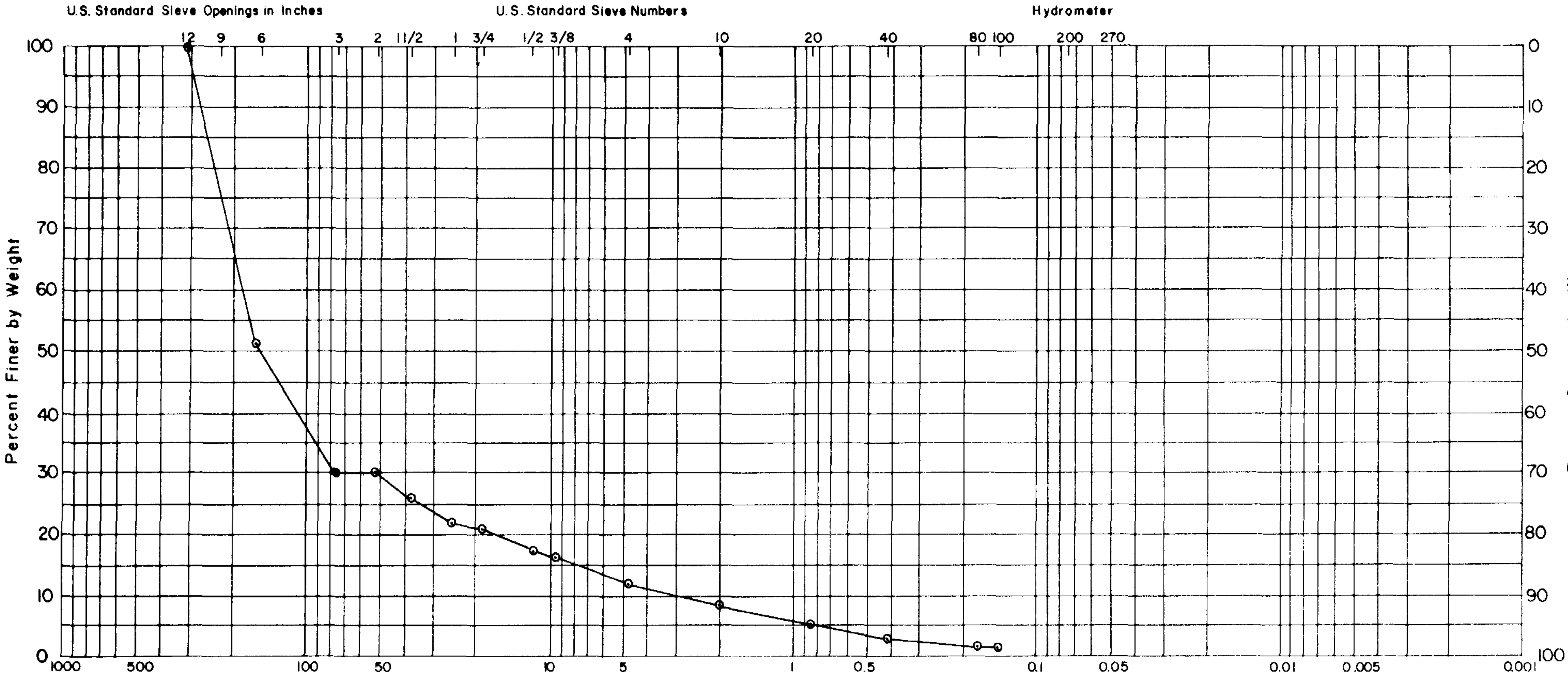


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G2 #4					SP	GRAVELLY SAND WITH TRACE SILT AND NUMEROUS COBBLES

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G2

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



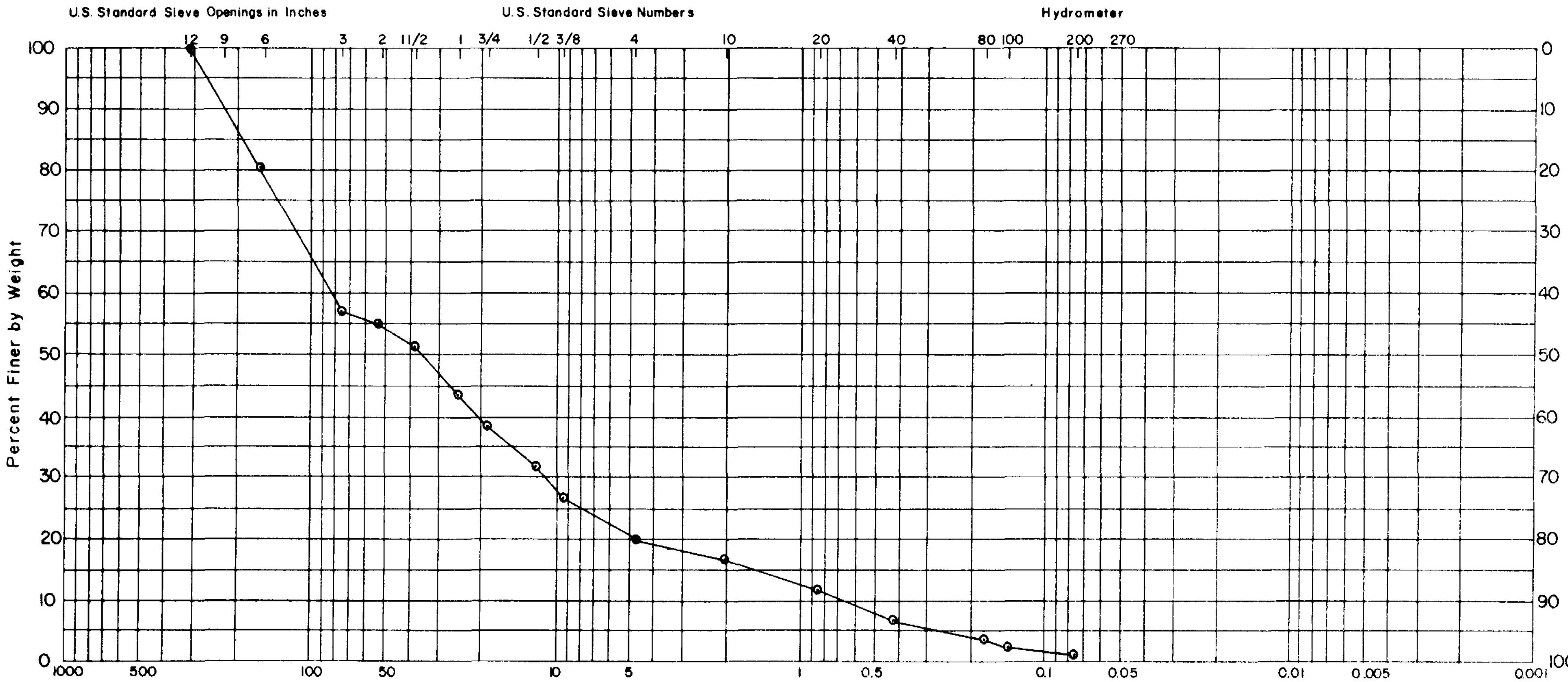
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G2 #5					GP	SANDY GRAVEL WITH TRACE SILT AND NUMEROUS COBBLES

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G2

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



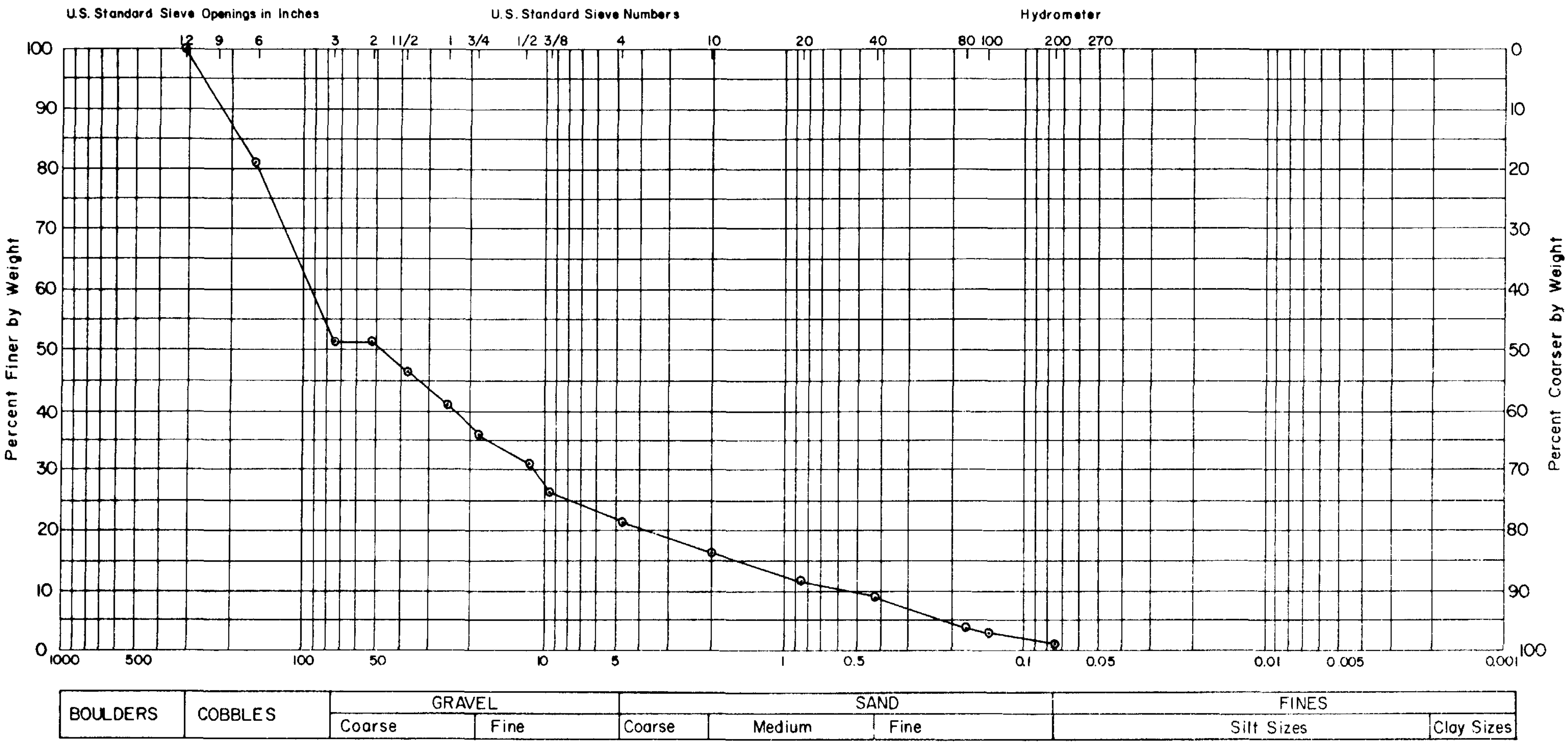
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G2 #8					GW	SANDY GRAVEL WITH NUMEROUS COBBLES

R&M CONSULTANTS, INC.

BORROW AREA G
TEST TRENCH TT-G2

DRAWN BY:	J.M.
APPROVED BY:	T.I.
DATE:	Dec. 1981
PROJECT NO.	052506

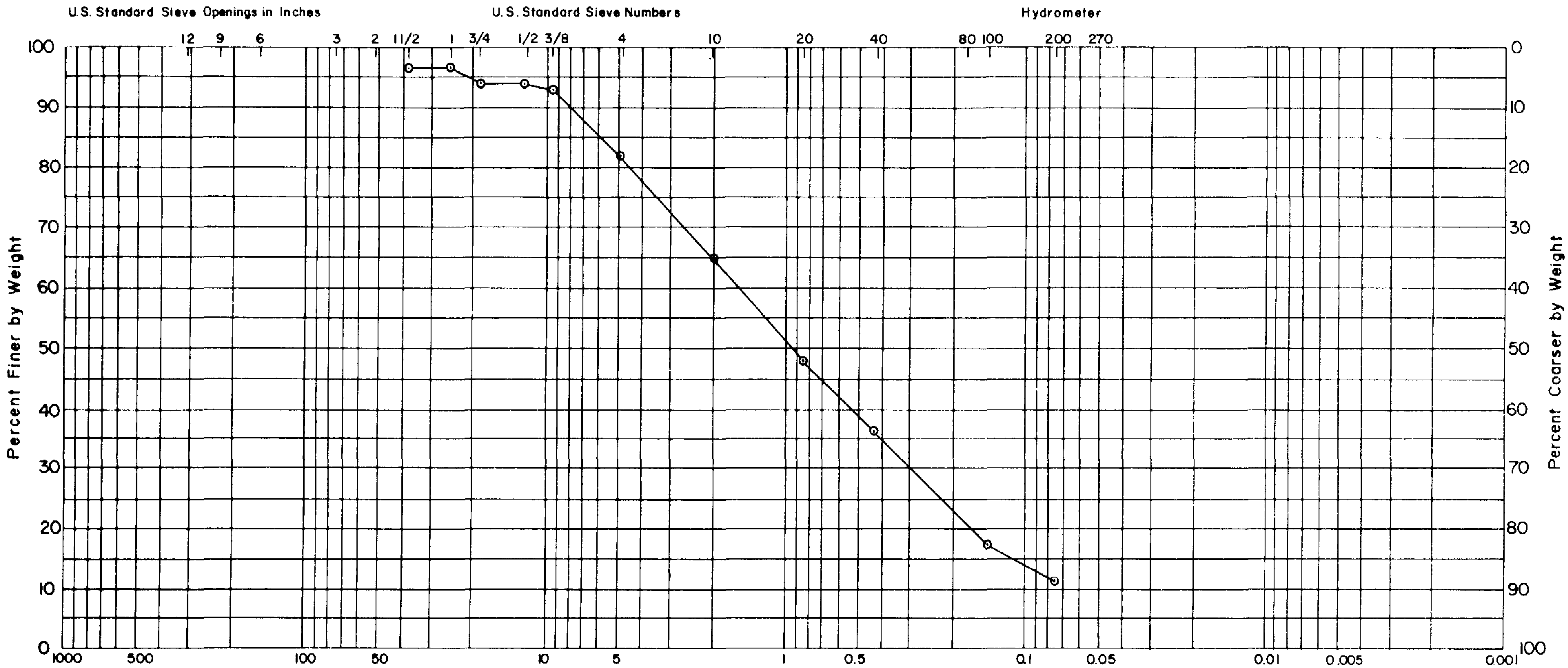


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
TT-G2 #9					GW	SANDY GRAVEL WITH NUMEROUS COBBLES

R&M CONSULTANTS INC.

BORROW AREA G
TEST TRENCH TT-G2

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO 052506



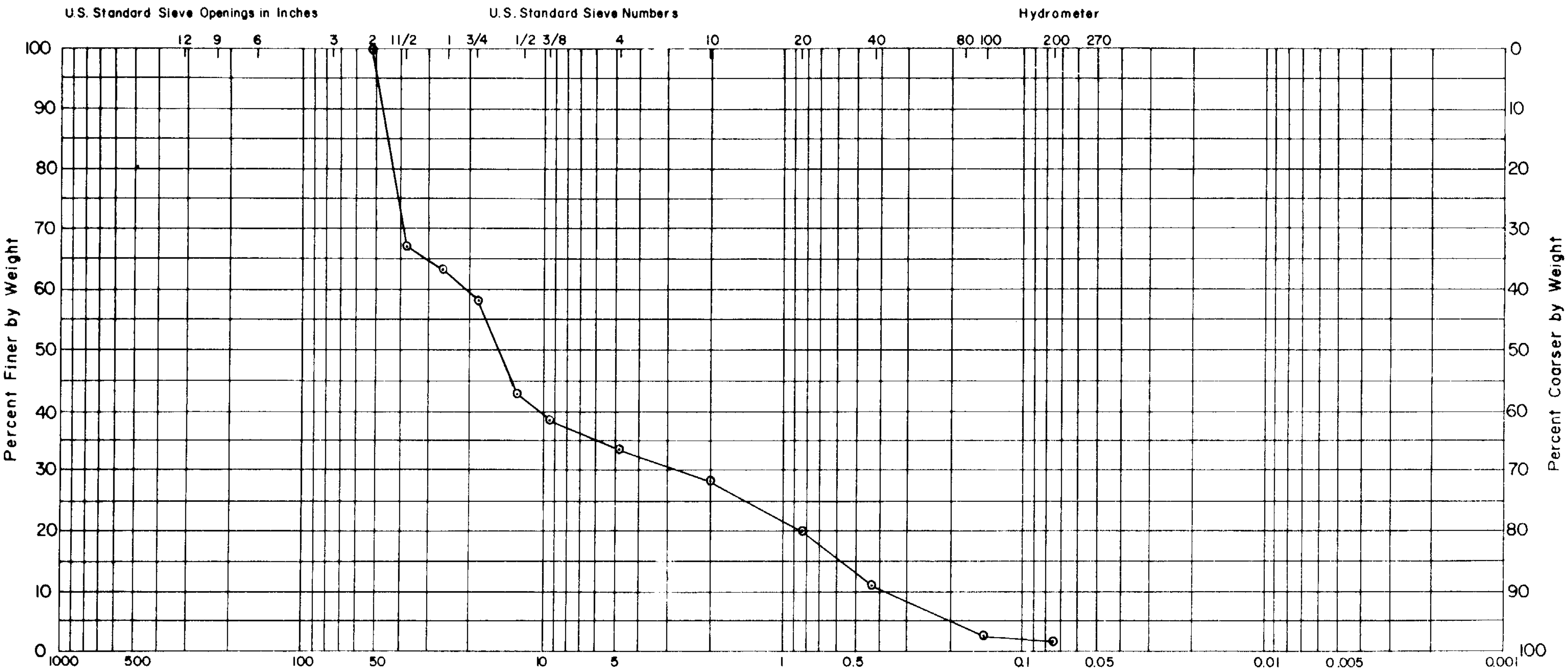
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G9 #4-8					SP-SM	SAND WITH SOME GRAVEL, TRACE SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G9

DRAWN BY:	J.M.
APPROVED BY:	T.I.
DATE:	Dec. 1981
PROJECT NO.	052506



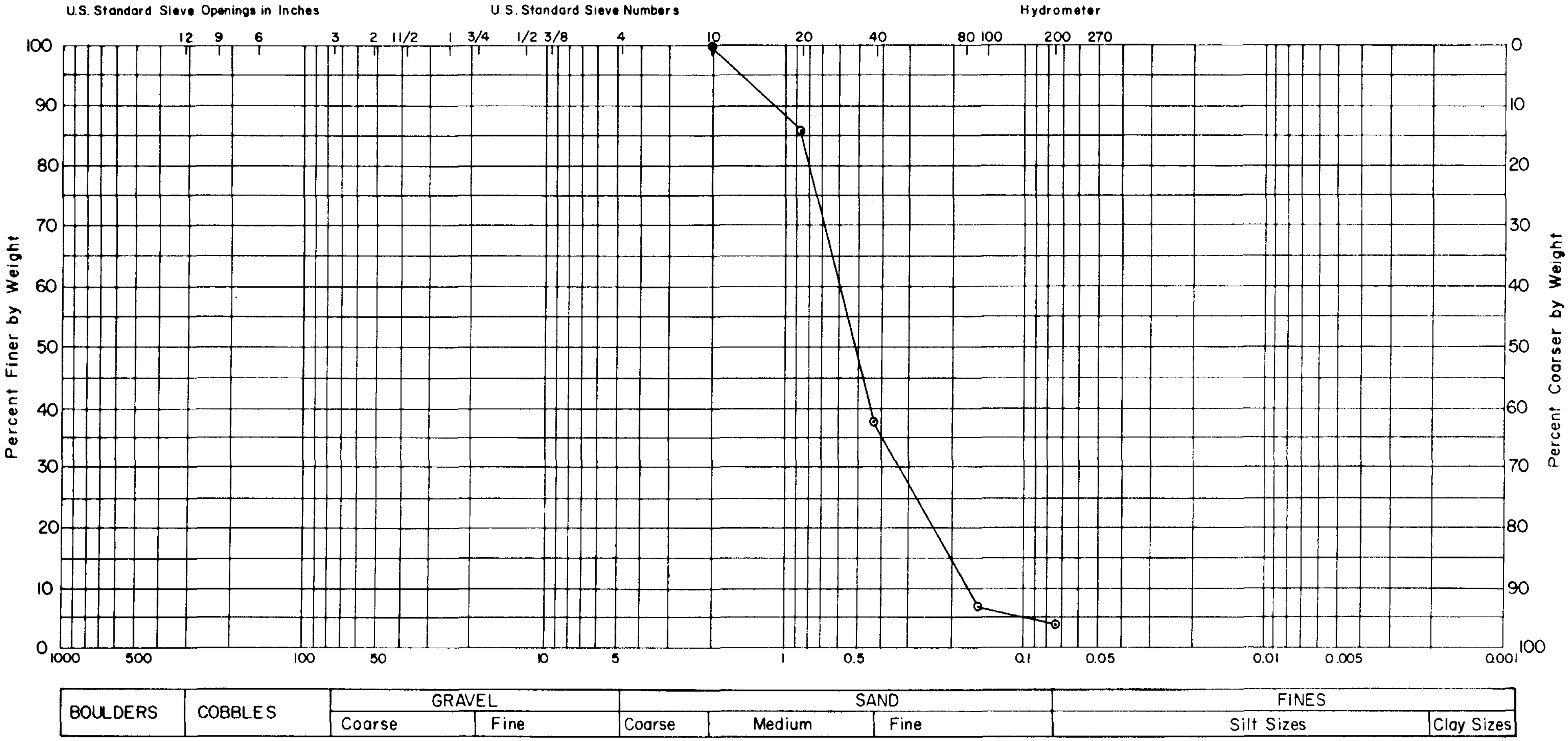
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G9 #14	3.7	130.8			GW-GP	SANDY GRAVEL

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G9

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

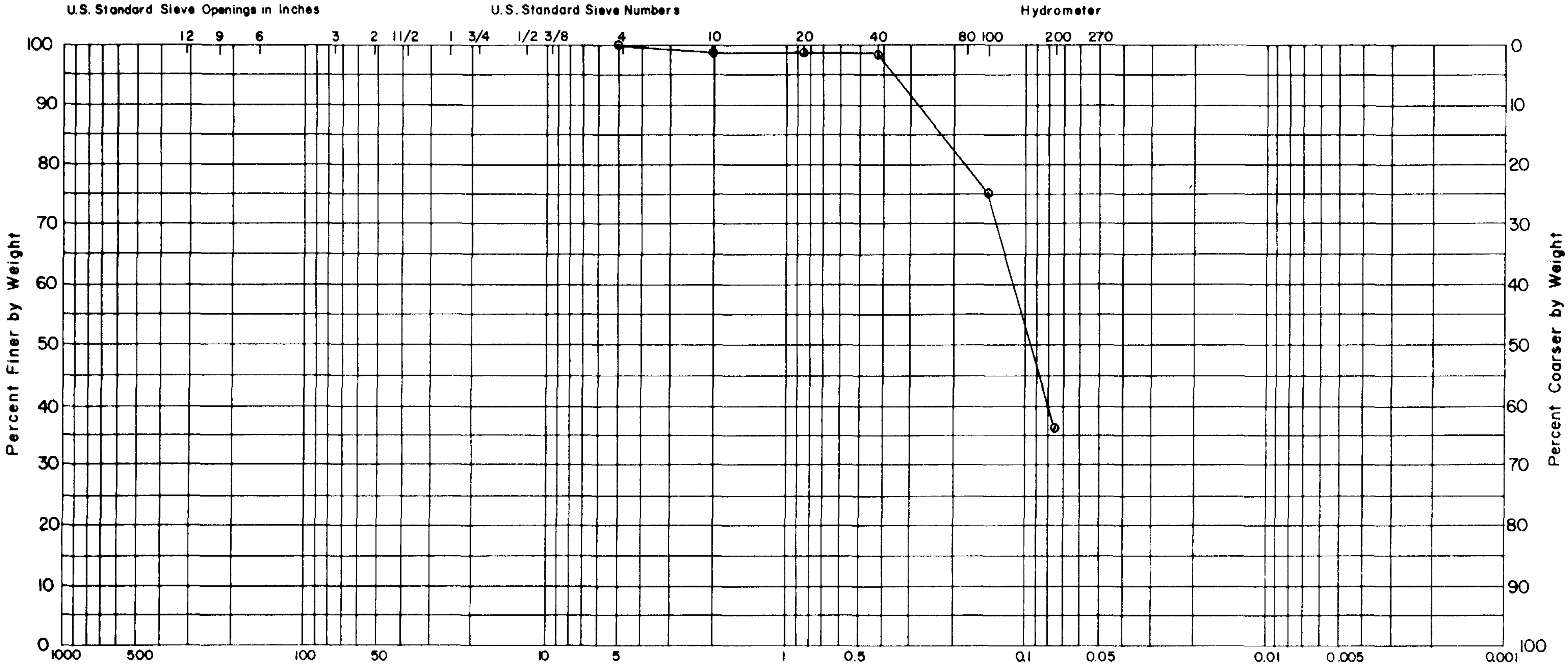


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G9 #15	6.8	98.7			SP	SAND WITH TRACE SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G9

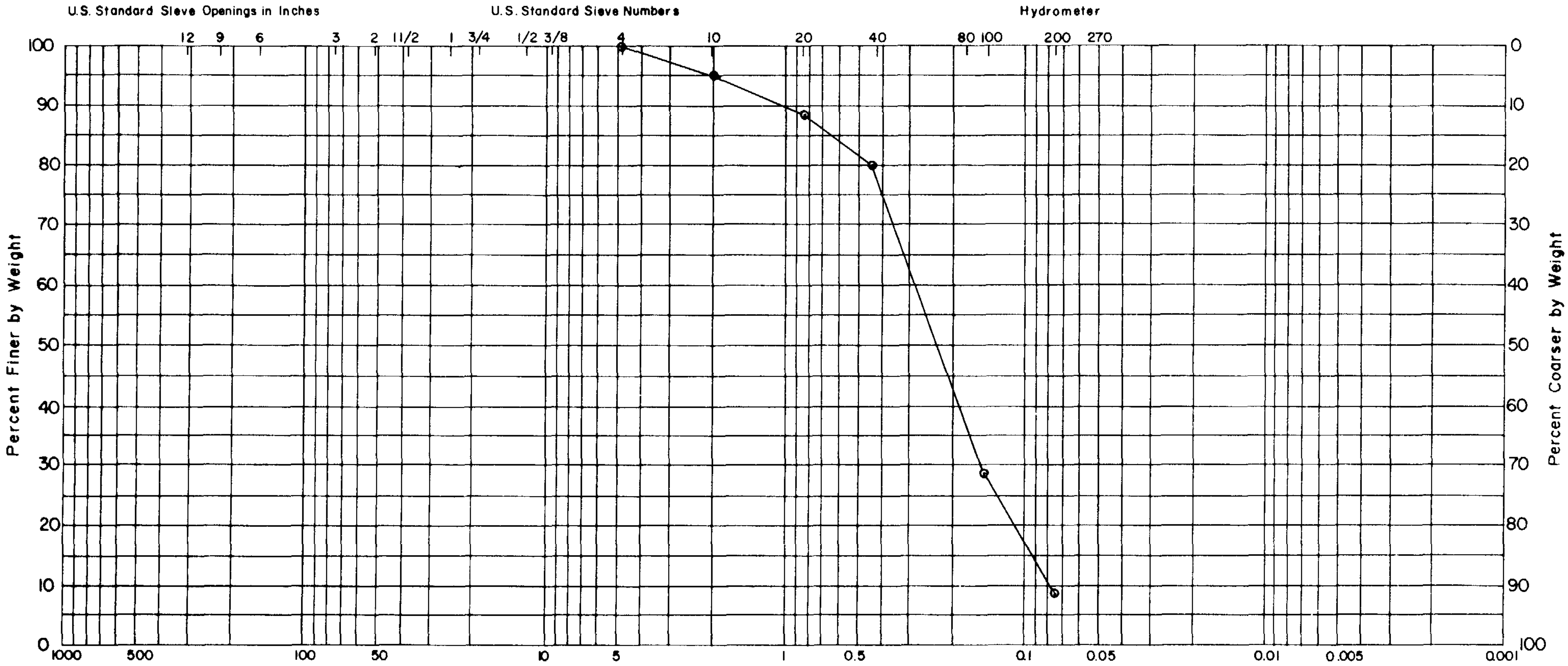
DRAWN BY:	J.M.
APPROVED BY:	T.I.
DATE:	Dec. 1981
PROJECT NO.	052506



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G10 #3-5					SM	SILTY SAND

R&M CONSULTANTS INC.	BORROW AREA G AUGER HOLE AH-G10	DRAWN BY: J.M. APPROVED BY: T.I. DATE: Dec. 1981 PROJECT NO. 052506



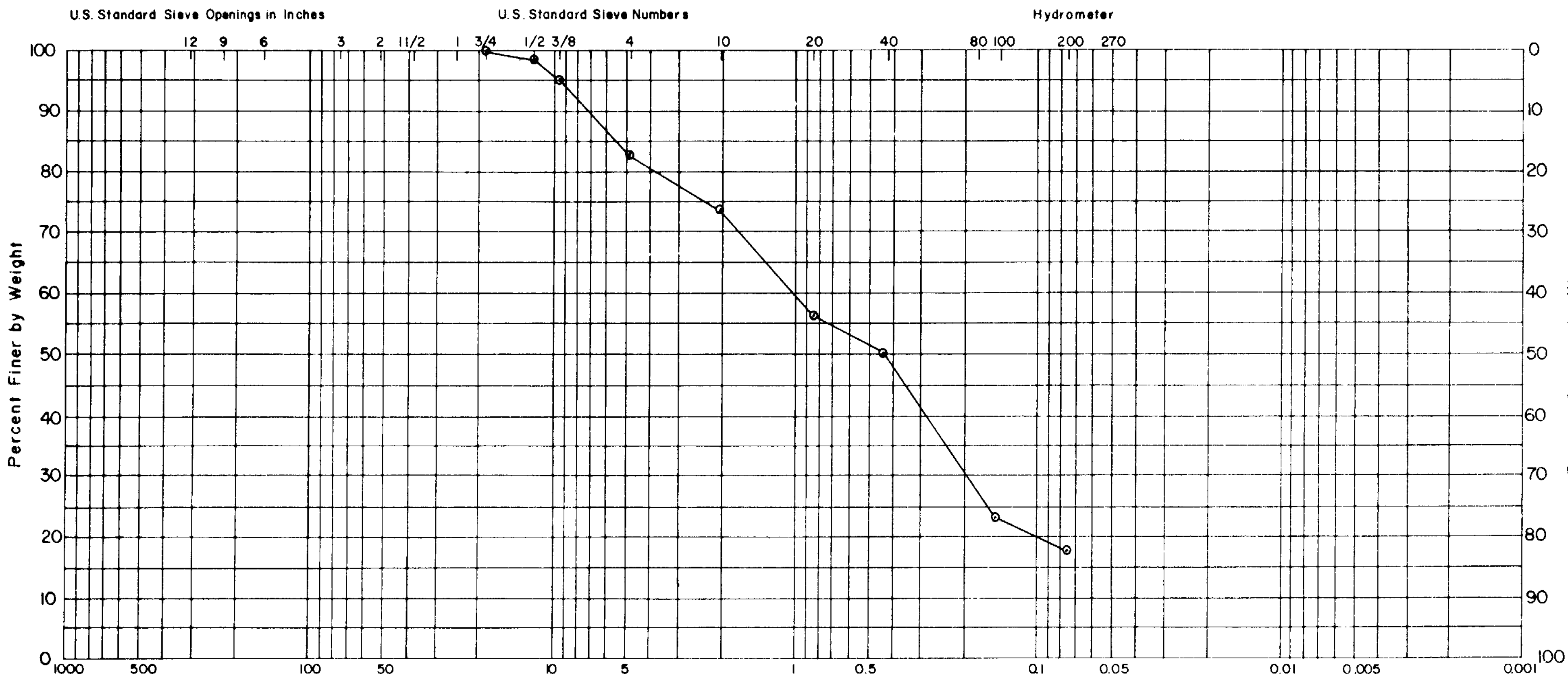
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G10 #6-8					SP-SM	SAND WITH TRACE SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G10

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G11 #6,7					SM	SAND WITH SOME SILT AND GRAVEL

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G11

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

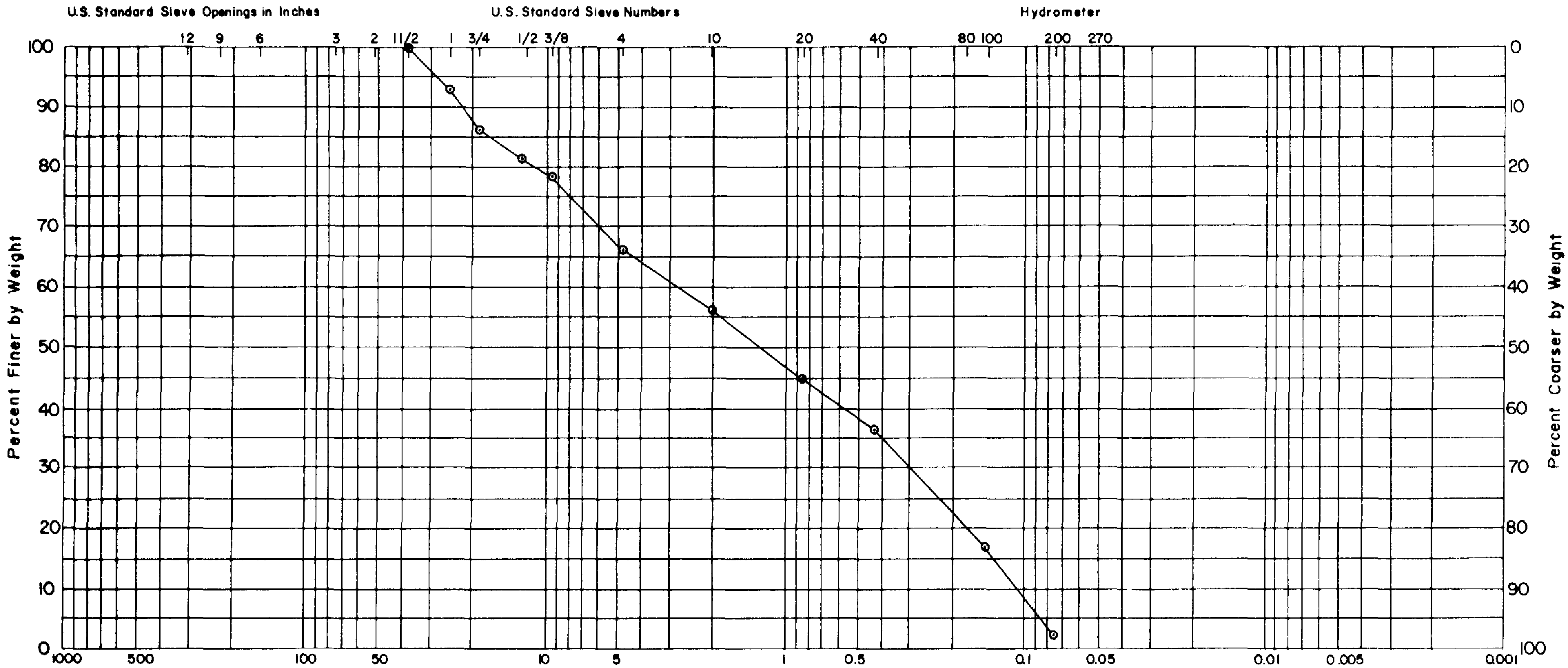
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G11 #8-11					SM	GRAVELLY SAND WITH SOME SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G11

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO 052506



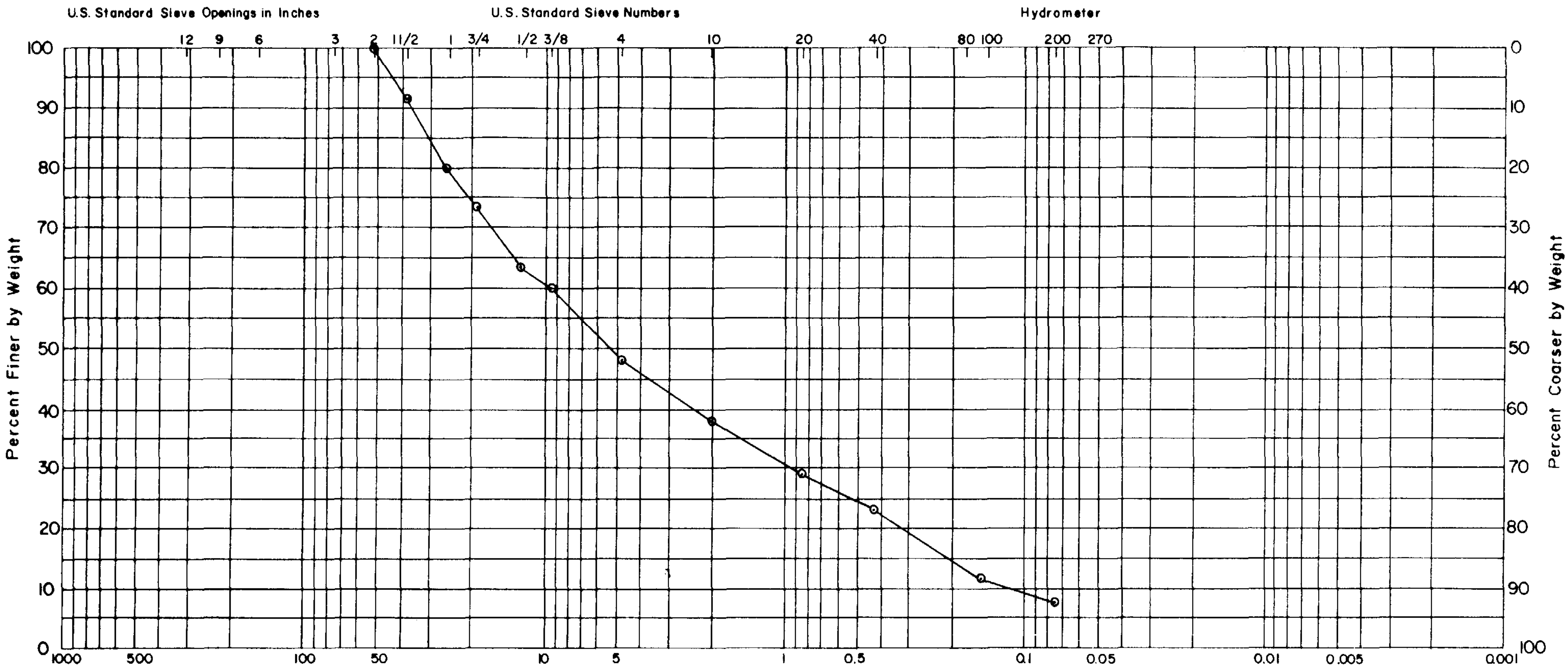
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G12 #5,6					SP	GRAVELLY SAND

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G12

DRAWN BY:	J.M.
APPROVED BY:	T.I.
DATE:	Dec. 1981
PROJECT NO.	052506



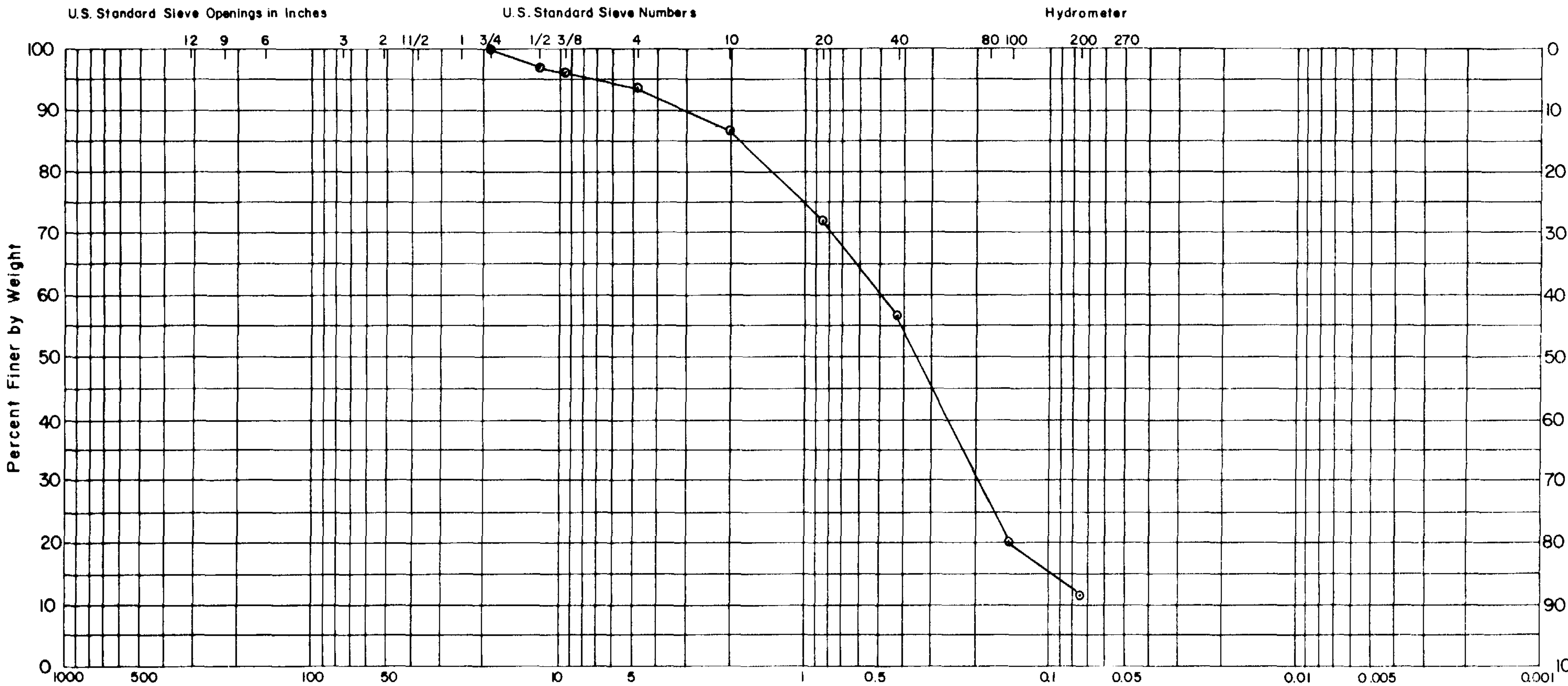
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G12 #7-9					GP-GM	SANDY GRAVEL WITH TRACE SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G12

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



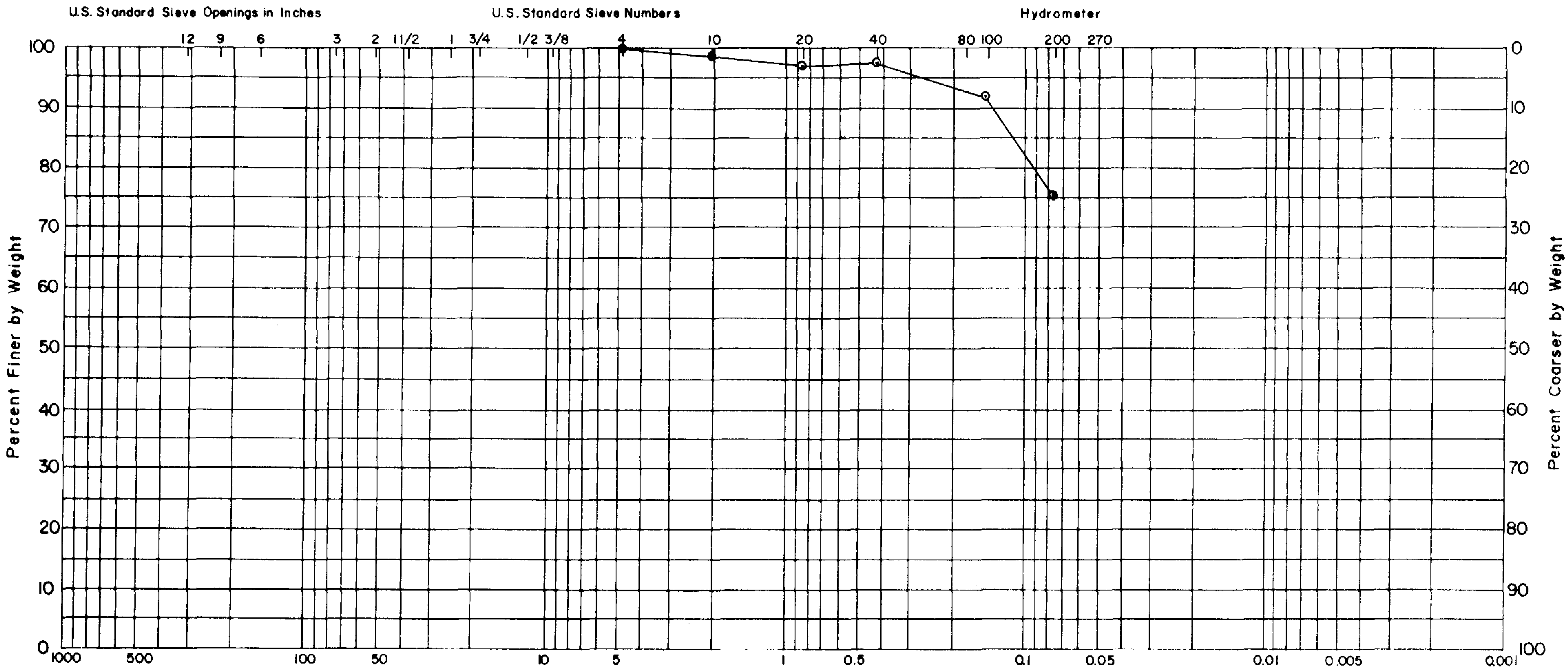
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G13 #4-7					SW-SM	SAND WITH TRACE SILT AND GRAVEL

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G13

DRAWN BY:	J.M.
APPROVED BY:	T.I.
DATE:	Dec. 1981
PROJECT NO.	052506



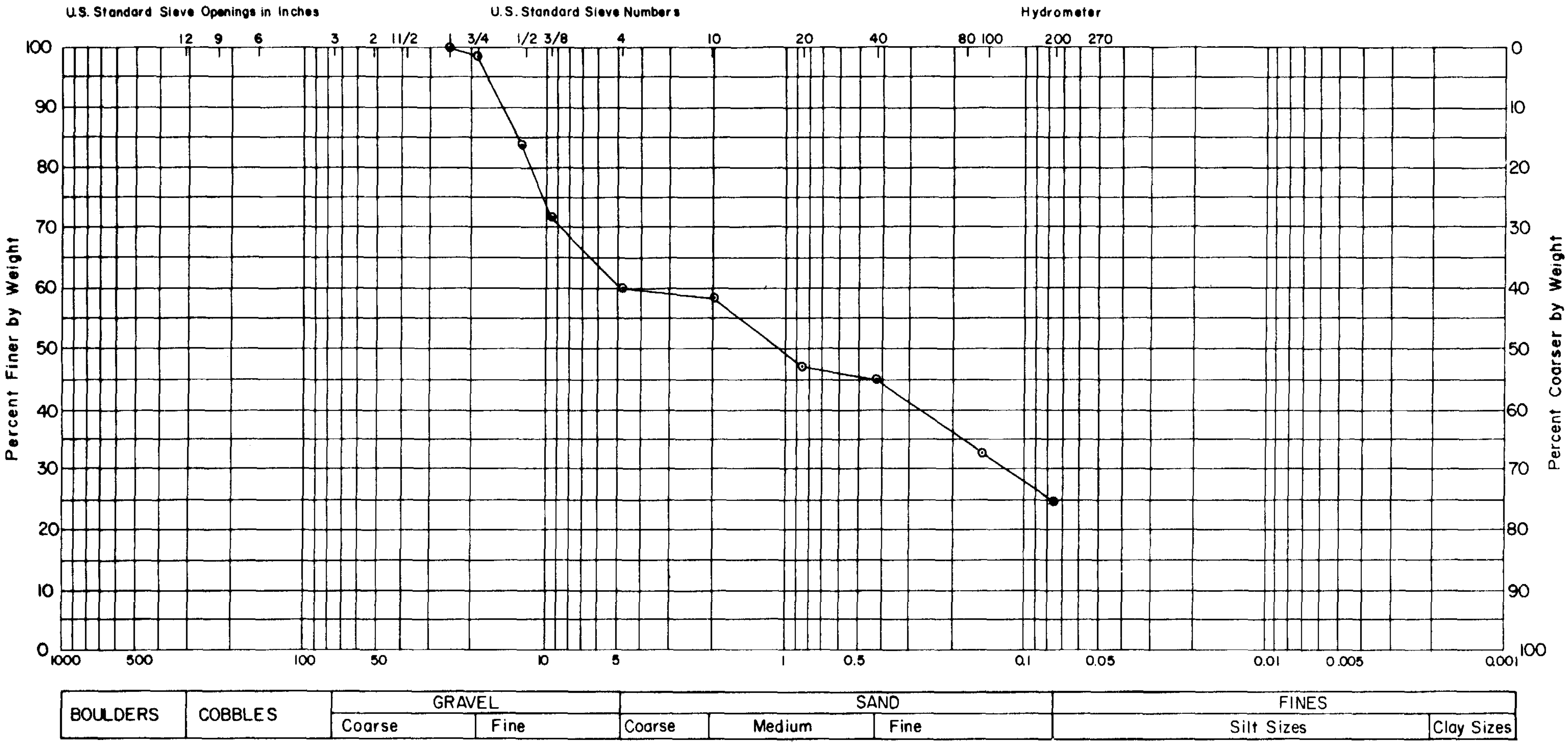
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G13 #8					ML-MH	SILT WITH SOME SAND, SOME TO TRACE CLAY

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G13

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

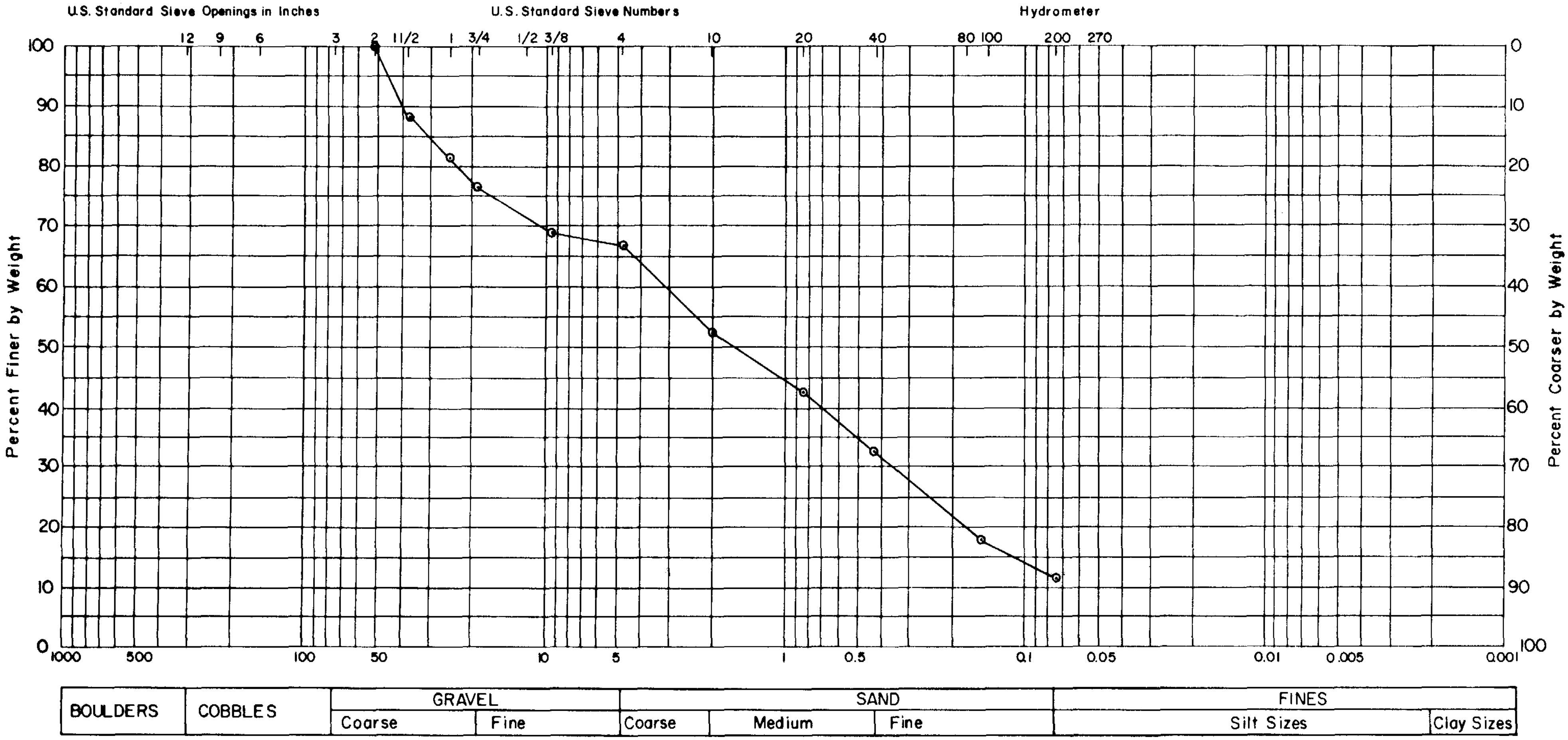


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G13 #9					GM-SM	SANDY GRAVEL WITH SOME SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G13

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

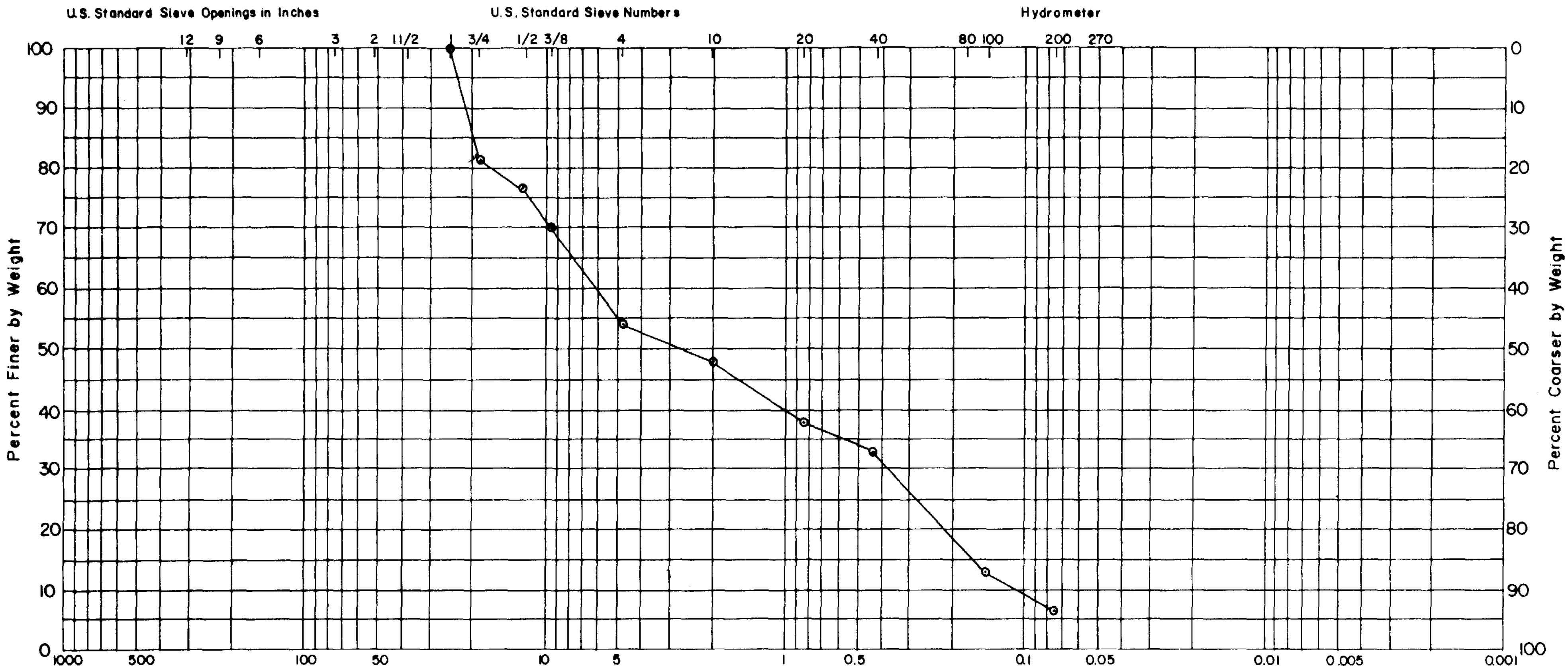


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G13 #10,12					SW-SM	GRAVELLY SAND WITH TRACE SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G13

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



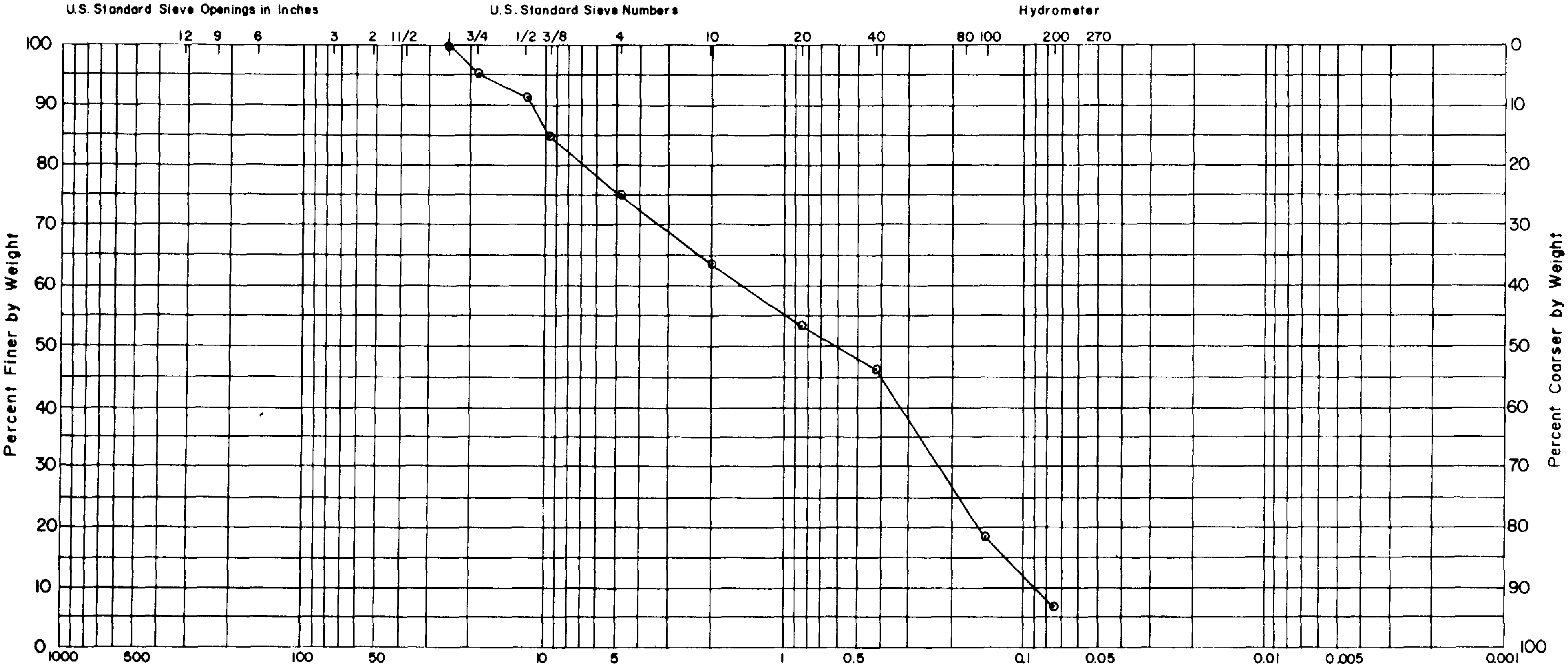
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G14 #11					SM-SP	GRAVELLY SAND WITH TRACE SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G14

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



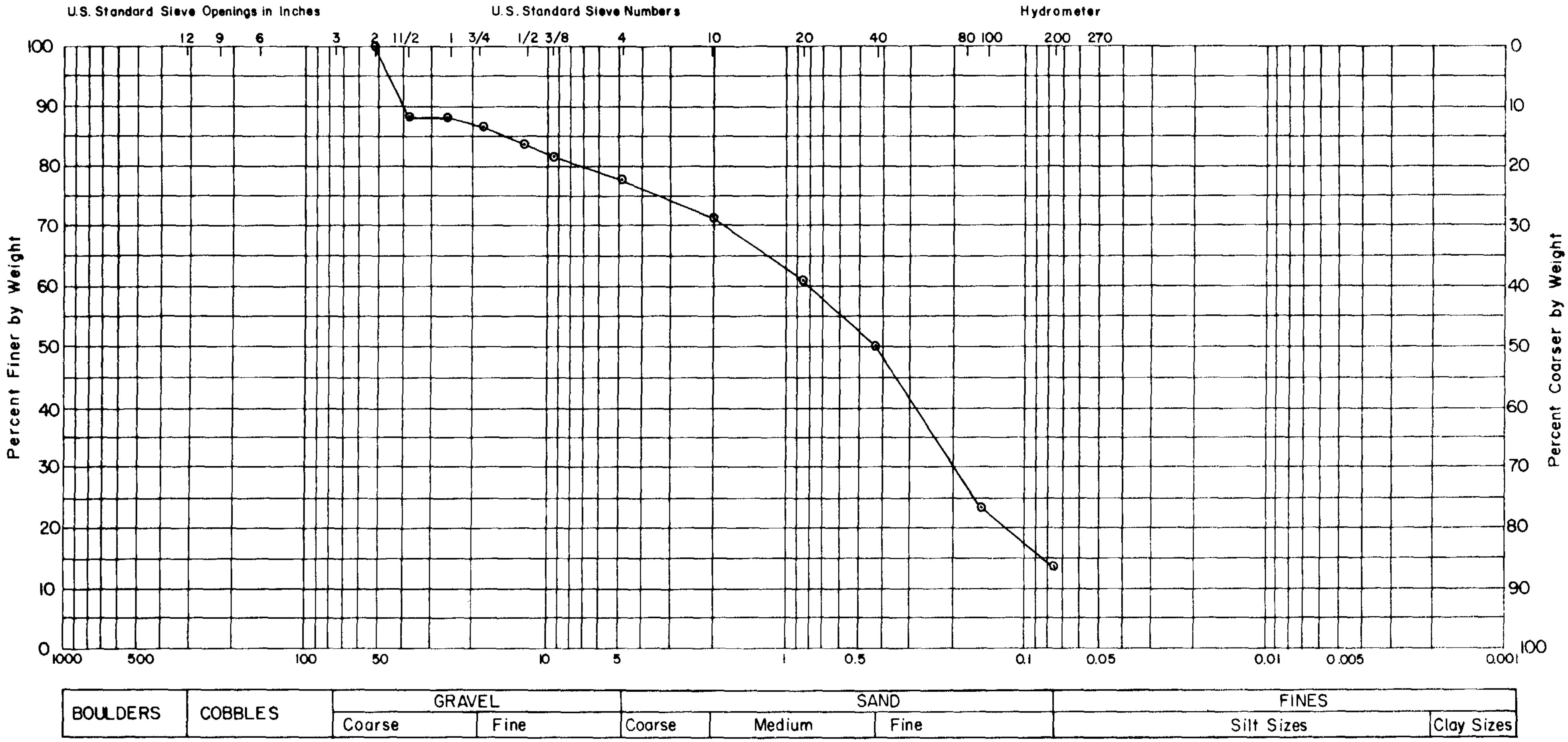
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G14 #12	7.0	138.1			SP-SM	SAND WITH SOME GRAVEL AND TRACE SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G14

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

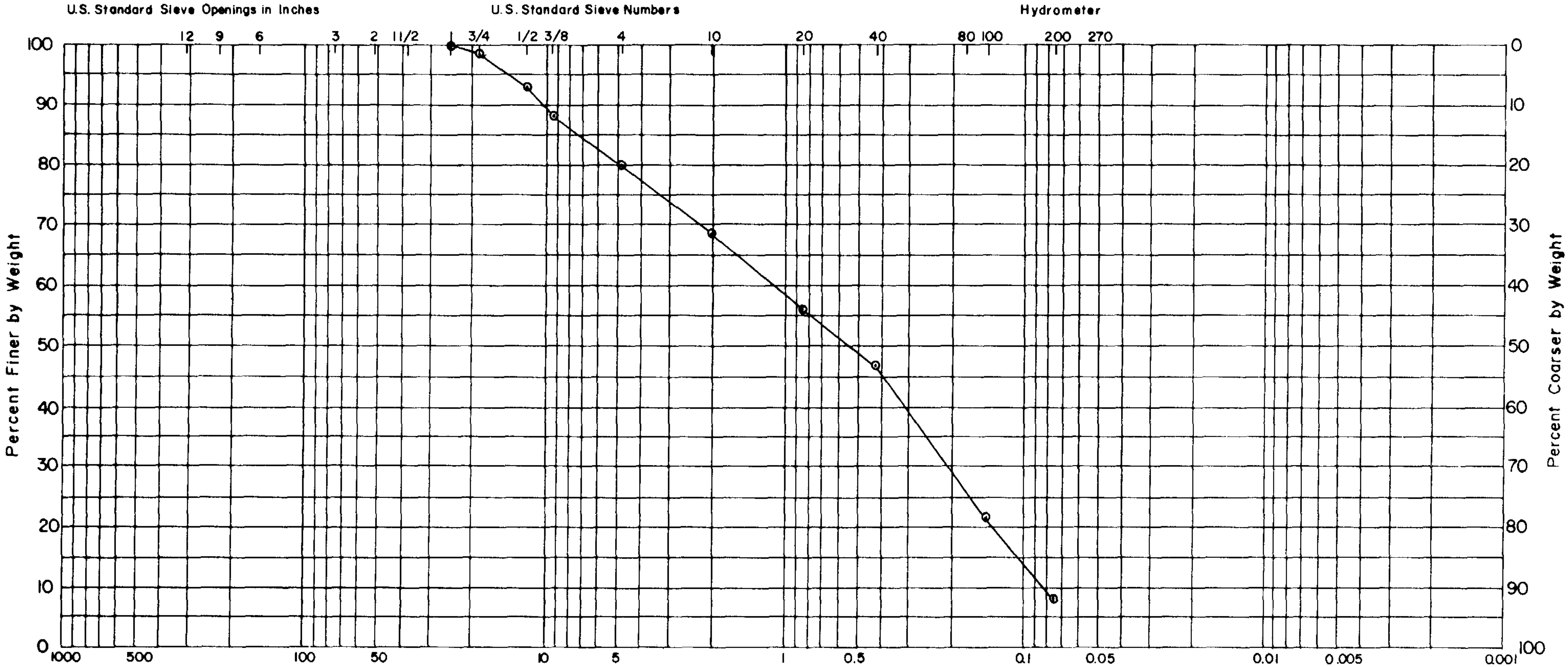


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G14 #8,9					SM	SAND WITH SOME GRAVEL AND SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G14

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506



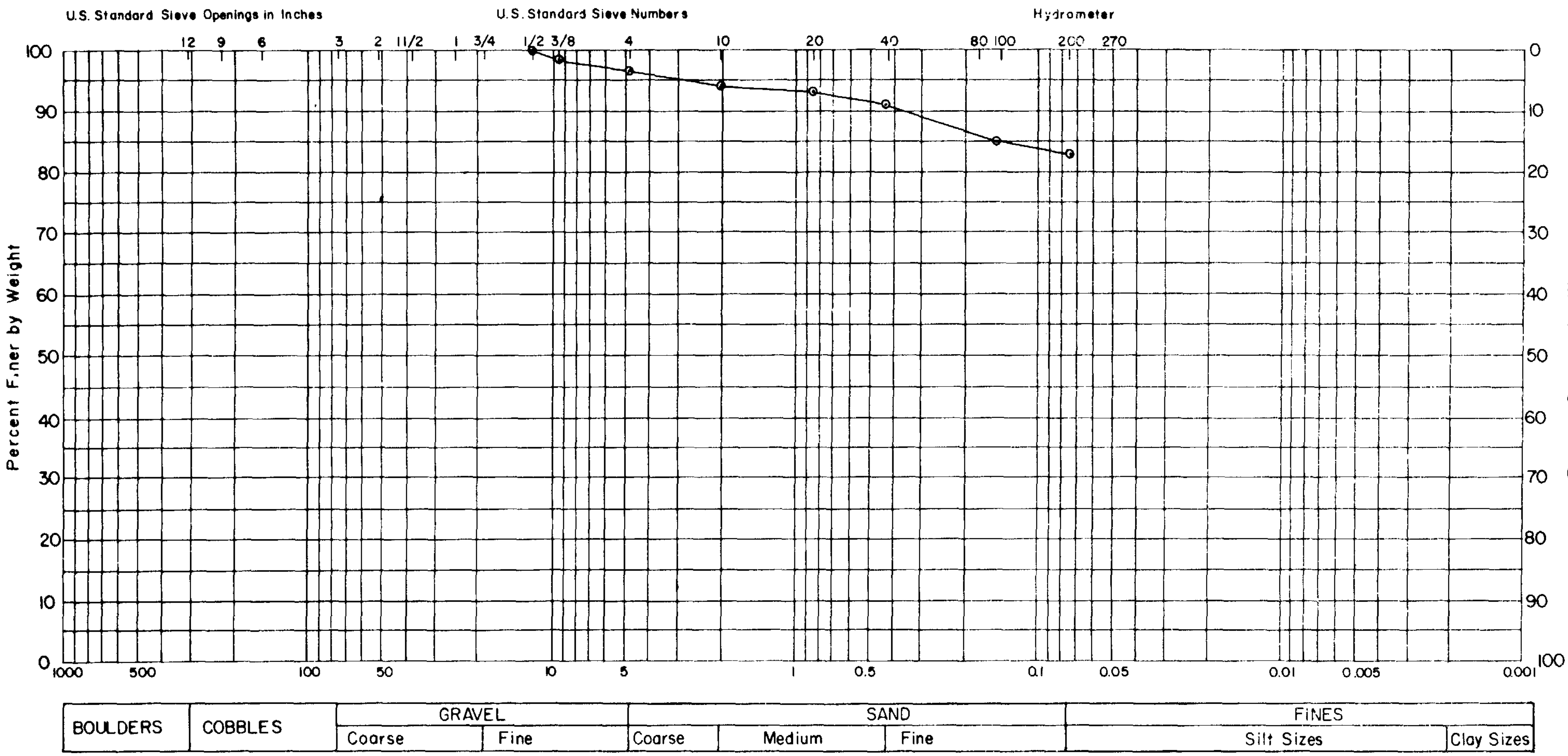
BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G14 #10	9.9	129.5			SP-SM	SAND WITH SOME GRAVEL AND TRACE SILT

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G14

DRAWN BY:	J.M.
APPROVED BY:	T.I.
DATE:	Dec. 1981
PROJECT NO.	052506



SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASS	CLASSIFICATION & DESCRIPTION
AH-G14 #13	23.5	101.4	49	16	ML-MH	SILT WITH SOME SAND, SOME TO TRACE CLAY, AND TRACE GRAVEL

R&M CONSULTANTS INC.

BORROW AREA G
AUGER HOLE AH-G14

DRAWN BY: J.M.
APPROVED BY: T.I.
DATE: Dec. 1981
PROJECT NO. 052506

FINAL REPORT
SUSITNA HYDROELECTRIC PROJECT
SEISMIC REFRACTION SURVEY
SUMMER, 1980

Submitted To

R & M Consultants
5024 Cordova
Anchorage, Alaska 99502

19 December 1980
Project No. 41306I

R & M Consultants
5024 Cordova
Anchorage, Alaska 99502

Attention: Mr. Gary Smith

Gentlemen:

SUBJECT: FINAL REPORT - SUSITNA HYDROELECTRIC PROJECT
SEISMIC REFRACTION SURVEY, SUMMER, 1980

Enclosed are 10 copies of our Final Report from the geophysical survey conducted under our agreement of July 23, 1980. This report reflects your comments and those of Acres American to our draft report dated October 23, 1980.

As requested by Mr. Robert Henschel of Acres American in our meeting earlier this month, we are preparing a set of recommended additional surveys to investigate areas where uncertainties still exist. These recommendations will be forwarded under separate cover. Mr. Henschel also requested revision of the profile figures in this report to reflect true elevations rather than relative elevations. We will make the appropriate changes and forward revised drafts when datum elevations become available.

We have enjoyed working with you on this project. Please call us if you have any questions or comments.

Very truly yours,

Jan D. Rietman, Ph.D.
Deputy Director of Geophysics

Dennis E. Jensen
Project Geophysicist

JDR:DEJ/ab

Enclosures

TABLE OF CONTENTS

1.0 INTRODUCTION

This report presents the results of a seismic refraction survey performed during June and July, 1980, on the Upper Susitna River, Alaska, approximately 125 miles north of Anchorage. The survey was performed under contract with R & M Consultants as part of their subcontract with Acres American Incorporated.

Most of the survey was performed on the abutments and in borrow areas for the proposed earth and rockfill dam near the confluence of Watana Creek and the Susitna River. The locations of lines run at the Watana site are shown on Figures 1 and 2.

The remainder of the survey was performed across a possible saddle dam location adjacent to a proposed concrete dam at Devil Canyon, approximately 27 miles west of the Watana site. The locations of lines at the Devil Canyon site are shown on Figure 3.

1.1 Purpose

The purpose of this survey is to provide additional data for the continuing feasibility studies for the Susitna Hydroelectric Project proposed by the Alaska Power Authority. This survey is to supplement borings, geologic mapping, and previous geophysical surveys accomplished over the past several years.

Line locations were selected by Acres American based on previous studies. Line lengths, geophone spacing and field procedures were designed to investigate the nature and distribution of bedrock and overburden materials.

1.2 Scope of Work

A total of 27,800 feet of seismic line was run as 11 separate traverses. Thirty-six geophone spreads were tested at 122 shot points. The scope of the field work was limited by several factors including planned duration of the program, weather, and logistics. Several lines were deleted or altered with the concurrence of Acres and R & M field representatives. A few additional lines were added. In particular, lines planned across the river at both dam sites were not considered feasible because of the high rate of flow at that time. Deleted line locations are shown on Figures 1, 2, and 3.

R&M personnel laid out and brushed all seismic lines and provided a survey of relative elevations and spacing of geophone and shot locations which had been flagged during seismic testing.

The accumulated data were reduced and interpreted in the Orange, California office of Woodward-Clyde Consultants. Previous seismic studies by Dames & Moore, 1975, and by Shannon and Wilson, 1978, were used as background for the present interpretation. Field observations and the judgment of a Woodward-Clyde Consultants' geologist, who was part of the survey crew, were included in the interpretation.

2.0 DATA ACQUISITION

The majority of geophone spreads for this survey were 1,100 feet long with 100 feet spacing between geophones. Shorter spacing of 10, 20, 25, 40, and 50 feet were used where terrain limited the length of a particular spread or where greater detail was desired. For traverses of more than one spread, end geophones on adjustment spreads were located at the same point.

For most spreads, shots were placed at half-geophone spacing beyond the end geophones and at the middle of the line. Explosive charges of one pound provided sufficient seismic energy for lines as long as 1100 feet. For about half of the spreads, greater depths to bedrock required shots at greater offsets from the ends to achieve refraction from deeper interfaces. The largest offsets were 1,000 feet from the end geophone, resulting in a shot to furthest geophone distance of 2,100 feet. Usually, an explosive charge of two pounds was required for these longer shots. For short lines explosives were not necessary and a hammer and plate were used as the energy source.

The signature of seismic waves arriving at geophones from each shot was recorded on a geoMetrics/Nimbus model ES-1210F 12-channel stacking seismograph. Recording gains were selected by trial and error and filters were used when background noise levels were high such as during heavy rain or near the river.

The stacking feature of the seismograph employs an analog/digital converter and an internal memory which stores wave traces from each geophone separately. A digital/analog converter is then used to display the stored traces on an oscilloscope. The input from multiple shots can be summed into the memory and the summed or "stacked" traces displayed on the oscilloscope. Stacking of multiple shots tends to enhance coherent seismic signals while the influence of random background noise is reduced by destructive interference. Stacking was used on this survey for shorter lines where multiple hammer blows provided seismic energy instead of explosives. The overall amplitude of the single or stacked wave traces can be amplified or reduced by the seismograph before a hard copy of the record is produced by an electrostatic printer.

For each shot, a field plot was made of distance to each geophone versus the time of arrival of the compressional seismic wave picked from the recorded wave trace. This was done to assure that sufficient information had been obtained for later interpretation. At the same time, notes were made as to terrain and exposed geologic features.

3.0 DATA REDUCTION PROCEDURES

Methods of reducing raw data to values suitable for interpretation were generally those described by Redpath (1973). These general techniques have been augmented to some degree through our experience on past projects.

First, field records were reviewed and picks of arrival times tabulated. Final time-distance plots were constructed to reflect changes in arrival times from those used for field plots. These plots are shown in Appendix A, Figures A1 through A10. Apparent layering, apparent seismic velocities, and variations in arrival times from those expected from a particular layer, were used to direct subsequent data reduction.

Representative "true" velocities were calculated from differences in arrival times at each geophone from shots at opposite ends of the line. Where sufficient data were available, delay times were calculated beneath each geophone for each layer. Layer thicknesses were then calculated using the representative velocity. If sufficient information was not available for rigorous delay-time determination, approximation methods were used to estimate depths.

In many cases, a layer which was well expressed on one spread, or believed to be present from previous investigations, would not be apparent on an adjacent spread. In these cases, a judgment was made as to the continuation of the layer, as a hidden layer or blind zone, beneath the spread in question to produce the most geologically reasonable interpretation. This often required adjustment of other layer thicknesses to account for the total delay time.

4.0 DISCUSSION OF RESULTS

The locations of the seismic lines are shown on Figures 1 through 3. Profiles along each seismic line illustrating subsurface conditions interpreted from the survey are presented as Figures 4 through 13. On these profiles, layer thicknesses and surface topography are shown at a twofold vertical exaggeration. This distortion is required to illustrate the interpreted thickness of thin, shallow layers.

Lines of contact between layers of differing velocities vary on the profiles according to the confidence placed on the interpretation. Solid lines represent a well controlled contact with depths shown probably within 15 percent of the true total depth. Dots on the line represent points of control where the depth is well constrained by the data. Dashed lines are less well controlled. Short dashed lines with no control-point dots represent assumed contacts based on information other than that resulting directly from data reduction.

The following paragraphs discuss the setting of each traverse, the results of our interpretation, and anomalous or ambiguous conditions which became apparent during data reduction and subsequent review of data from borings, test trenches, and surficial geologic mapping.

4.1 Traverse 80-1

This traverse consists of six 1,100 foot geophone spreads and three 225 foot detail spreads. As shown on Figure 1, the line extends northward about 3300 feet from the right abutment downstream from the proposed Watana Dam, and then northeastward an additional 3300 feet across the proposed spillway alignment. Topography is relatively steep at both ends of the line and relatively gentle elsewhere.

The interpreted profile for traverse 80-1 is shown on Figure 4. Bedrock velocities along the line appear to be relatively uniform, ranging from 14,500 fps (feet per second) to 16,000 fps. Intermediate layer velocities range from 5,250 fps to 13,000 fps and shallow layer velocities from 1,300 fps to 3,600 fps. The lower velocities represent loose surficial materials and possibly, in part, fine-grained lake deposits such as encountered in boring DR-6 (the location of borings designated DR are shown in U. S. Army Corps of Engineers [1979]).

At the southern end of the line, a 50-foot-thick layer of 10,000 fps material probably represents weathered bedrock. Near the northern end of spread 80-1E, this layer thickens to over 100 feet and may represent an anomaly similar to that shown on Shannon and Wilson (1978), line 2 (SW2) to the southeast. We understand that a prominent gouge zone is exposed on the steep slopes near the anomaly shown on SW2. The anomaly on line 80-1E may represent a continuation of that zone in which case, its trend would be approximately N40W.

A thick 13,000 fps layer is present near the center of the traverse. It probably represents weathered diorite bedrock but may be a different lithology such as volcanic rock which has been mapped in the vicinity. Another possibility is that the 13,000 fps material is part of a vertical tabular fractured or altered zone which extends from the intersection of traverses 80-2 and SW2 where material of the same velocity has been detected. Although the 13,000 fps zone is shown to be underlain by higher velocity material on Figure 5, the higher velocity material may instead be to the side. Additional refraction lines or borings will be required to resolve this possibility.

The thin irregular edges of the relict channel discussed in previous reports are apparent on spreads 80-1A and 80-1B. Channel fill beneath these lines, which is probably bouldery glacial detritus, ranges from 7000 to 9000 fps. The configuration of the channel beneath line 80-1B is probably much more complicated than shown on Figure 4. The profile shows depths which are based on approximation reduction methods because of the complexity of the time-distance plot (Figure A-1, Appendix A) for which no reasonable mathematical solution could be found. Depth to bedrock is shown to be more than 150 feet but is probably highly irregular and much shallower especially near the center of the line. Boring DR-6 just southeast of the center of the line encountered bedrock at a depth of 65 feet.

The channel appears to be the same as that documented by the 1975 Dames and Moore survey and on line SW3. It is also well expressed on lines 80-2 and 80-6 which are discussed in later paragraphs. The southwestern edge of the channel and the apparent thalweg are shown by dashed lines on Figure 1. The eastern edge of the channel appears to be immediately north of line 80-7 and appears to be expressed at the northern end of 80-8.

4.2 Traverse 80-2

Traverse 80-2 consists of five 1100 foot spreads on the right abutment extending from near the toe of the proposed Watana Dam, northward across the proposed spillway. It roughly parallels Traverse 80-1 between 1,800 and 2,200 feet to the east and southeast (Figure 1). The topography is relatively steep at the southern end and moderate to gentle elsewhere. The interpreted profile for traverse 80-2 is shown on Figure 5.

Bedrock velocities are similar to those of 80-1 ranging from 14,000 to 17,000 fps. Intermediate layers consist of thick 13,000 fps layers beneath the southern slopes and channel fill at the northern end of the line ranging from 6,000 to 8,000 fps. Near surface velocity layers range from 1250 to 2800 fps.

The lowest bedrock velocity encountered on the traverse is beneath spread 80-2D and underlies an anomalously deep portion of the relict channel. Borings DR-18 and DR-19, northwest and southeast of the spread respectively, confirm the depth to bedrock shown on the profile and indicate that the rock in that area is highly fractured diorite with apparent clay gouge zones. This low velocity zone may represent a continuation of a shear zone known as "The Fins" exposed adjacent to the river to the southeast. The trend of this possible continuation projects toward the northeastern end of spread 80-1B which, as previously discussed, produced a highly irregular seismic record.

The 13,000 fps layer at the southern end of the traverse appears to be weathered bedrock based on the shape and location of the layer. Line SW2 which crosses the traverse near its southern end (see Figure 1), also shows the 13,000 fps layer and the same depth to bedrock at the intersection. A 6,000 fps layer shown on SW2 was not detected on 80-2. The 13,000 fps layer is shown on SW2 as continuous for about 2400 feet parallel to the river. The shape of the material shown on the profile of 80-2 (Figure 5) is not inconsistent with the suggestion by Shannon and Wilson (1978) that it may be involved in landsliding.

The channel fill at the northeastern end of the line consists of two distinct velocity zones similar to those detected on traverse 80-1. The southern portion of the fill ranges from 6,500 to 8,000 fps. Boring DR-20 appears to have encountered this material southeast of the line where it consists of saturated sandy gravels with finer grained interlayers. Boring DR-18, northwest of the line, appears to have penetrated lower velocity material detected at the northeasternmost end of the traverse. This material, ranging from 5,400 to 6,000 fps, appears to be mostly silty sands and sandy silts with some clay and scattered gravels and boulders.

Surficial materials near borings DR-18 and DR-20 appear to be sandy silts. Seismic velocities of the surface layer near the borings are generally less than 2,000 fps. Velocities to the south along the traverse range are up to 2,800 fps and interpreted as representing more gravelly or better compacted sediments than those near the borings.

4.3 Traverse 80-3

Traverse 80-3 was run on the rugged steep slopes of the abutments across the proposed upstream portion of the dam. The profile, shown as Figure 6, is based on one 1,000 foot spread on the left abutment and three spreads, 1,000 feet, 265 feet, and 300 feet respectively, on the right abutment. A proposed segment of the traverse across the river was not considered feasible at the time of the survey due to high water levels, and was therefore not performed.

Bedrock is shallow on both abutments. On the south side, bedrock appears to be of a uniform 15,000 fps velocity. The top of the southern slope is underlain by 5,200 fps material which may reflect frozen soil exposed in a shallow trench in that area. Farther down the slope, surficial velocities drop to about 2,200 fps. This appears to be very loose talus on the slope, at least at the center shot point. The base of the slope is underlain by 7,000 fps material which appears to be highly weathered bedrock.

Representative bedrock velocities on the north side range from about 15,000 fps near the top to as high as 22,000 fps lower on the slope. Surficial material on the north side is generally about 15-foot-thick and between 1,500 and 2,200 fps on the upper slope. Surficial material is thinner and lower in velocity near the bottom. Most of the upper slope is covered with loose talus.

Geophone spread 80-3D was run parallel to the river along the north bank. This line detected a 7,000 fps layer 50-foot-thick which probably projects beneath the river. This layer was not apparent on spread 80-3C near the base of the north slope. It appears as if 80-3C was run above a resistant bedrock spur and that the 7,000 fps material is present to each side of the spur near the base of the slope.

Lines 80-4 and 80-5 which were planned across the river at the proposed dam axis and beneath the upstream toe, respectively, were not run due to high water conditions. It may be possible to complete these lines after the river has frozen.

4.4 Traverse 80-6

This traverse consisted of one 1,100 foot spread and a coincident shorter 600 foot detail spread across an apparently anomalous topographic depression approximately 4,000 feet upstream from the proposed dam axis on the north side of the river. The profile presented as Figure 7, shows the edge of the relict channel discussed in conjunction with Traverses 80-1 and 80-2.

Bedrock velocity ranges from 11,500 fps near the western end of the line to 20,000 fps beneath the channel. The channel appears to be filled with 7,000 fps material which also is thinly distributed beneath the western portion of the line. Overlying this is a layer of 2,300 fps material and, in part, a thin surface layer of 1,100 fps material.

The increase in bedrock velocity across the traverse from west to east may be related to effects of "The Fins" shear zone which is exposed about 700 feet southwest of the end of spread 80-6A. This increase in bedrock velocity east of the shear zone is also expressed on the 1975 seismic line and on SW-3 which are both to the northwest of 80-06. Progressively higher velocity zones on those three traverses are roughly correlatible and appear to form bands generally parallel to the shear zone.

The nearest borings to traverse 80-6 are more than 1,000 feet away. The channel fill material is therefore interpreted to be similar to that interpreted for line SW-3 and for traverses 80-1 and 80-2 as previously discussed. The 7,000 fps velocity of the fill is more uniform than seen elsewhere and probably represents an averaging of both higher and lower velocity materials such as saturated alluvium and glacial detritus.

The Shannon and Wilson, 1978, interpretation of nearby line SW-3 shows a shallower channel containing 4,500 fps material within the larger relict channel feature. This layer can also be interpreted to underlie 80-6 based on the time-distance plot (see Appendix A, Figure A-5). However, the present interpretation of a slight thickening of the 2,300 fps layer is also reasonably consistent with the data.

Surficial materials are probably similar to those at depth but less saturated. The 2,300 fps layer may also be finer grained. The low velocity of the 1,100 fps layer suggests it is very loose and probably dry.

4.5 Traverse 80-7

Traverse 80-7 consists of two 1,100 foot spreads oriented north-south across the western end of Borrow Area D. The line is shown on both Figures 1 and 2. Ground surface rises gently to the north along the line.

Velocity analysis indicated that bedrock was uniformly 15,500 fps even though the time-distance plots showed higher values. The differences are attributed to geometry of the bedrock surface and not to lateral changes. The interpreted profile for traverse 80-7 is shown on Figure 8.

The line appears to be located over the northeastern side of the relict channel. Channel fill material ranges from 7,400 to 9,000 fps. It is generally about 200-feet-deep but is shallower near the north end. At the south end, it may deepen to as much as 400 feet. Line SW3, which crosses spread 80-7A near its northern end, shows a similar depth and velocity for bedrock at that point. The velocity of the channel fill is given as 7,000 fps on SW3.

Boring DR-26, which is located west of the north end of line 80-7B, encountered silty sand, clayey silt, gravels, and sandy silt with boulders at depths equivalent to the channel fill material interpreted from seismic data.

The velocity of surface materials along the line appears to be uniformly 1,850 fps. Several exposures along the line indicate that the upper portion of this unit consists of boulder accumulations with little or no matrix. Borings and trenches in the vicinity have encountered gravelly sands below the immediate surface.

4.6 Traverse 80-8

The two 1,000 foot lines that comprise Traverse 80-8 extend southward from the end of line SW5 at the edge of Borrow Area D near Deadman Creek across proposed Quarry Source B as shown on Figure 2. The line crosses moderate and then very steep topography southward.

Four continuous layers are interpreted on the profile presented as Figure 9. These include a shallow 1,350 to 1,600 fps layer and intermediate velocity layers of 5,000 to 7,000 fps and 8,400 to 9,000 fps. Bedrock appears to change laterally from 12,500 fps near the north end to 23,500 fps at the center, and to 16,500 fps near the south end.

The highest bedrock velocity is at the middle of the traverse where the rock apparently forms a buried resistant ridge. The bedrock surface may be as deep as 500 feet at a point below the middle of spread 80-8A. At the north end of the line bedrock does not appear to be as deep as shown in Shannon and Wilson, 1978, line SW5. However, this location is near the end of both lines and additional control is lacking.

It does not appear likely that hard rock is near enough to the surface to provide an adequate quarry source along the line of the profile. We have no information as to possible outcrops elsewhere within the designated area. The intermediate velocity layers appear to be similar to those filling the relict channel to the west as previously discussed. The 5,000 to 7,000 fps layer probably represents a younger episode of channeling and filling similar to that shown on traverses 80-1 and 80-2. Both intermediate units probably consist of saturated alluvial deposits and bouldery glacial detritus.

A number of test pits in the vicinity of the traverse indicate that the shallow materials 1,350 to 1,600 fps surface layers are highly variable. Most pits encountered loose, unsaturated silty gravely sands.

4.7 Traverse 80-9

Traverse 80-9 was a single 1,100-foot-line at the western end of Borrow Area E extending upslope from previous line SW14. The present interpretation, shown on Figure 10, is in good agreement with that line.

A relatively uniform mantle of low velocity material (1,100 to 1,800 fps) appears to cover the slope 30 to 50 feet deep. Shallow exposures suggest that the 1,100 fps material at the base of the hill is a loose gravel. Higher on the hill, the surface is mantled by organic soil.

A higher velocity layer (6,000 to 7,250 fps) underlies the surficial deposits and thickens northward. These velocities are similar to those of saturated alluvium and glacial detritus found elsewhere. Bedrock with an approximate velocity of 15,000 fps, is about 100 feet below the surface at the base of the hill and may be as deep as 300 feet at the north end of the line.

4.8 Traverse 80-11

This traverse was run north and west of Tsusena Creek near the eastern end of Borrow Area E. The alignment was changed from east of the creek when surface reconnaissance showed that area to be underlain primarily with bouldery glacial deposits.

Spread 80-11A was run from the bank of Tsusena Creek northward 1,100 feet across gentle topography to the base of a hill (Figure 2). A second 1,100 foot spread, 80-11B, was run from the center of the first in a northeasterly direction. This line hd not been previously staked or brushed and when surveyed later, was found to bend to the north as shown on Figure 2. Two shorter detail spreads (80-11C and 80-11D) were also run near the middle of spread 80-11A.

On the southern end of the traverse 80-11A, a 2,800 fps layer of loose surficial deposits appears to be about 30 feet thick and thins to the north. This appears to be underlain by a 11,000 fps weathered bedrock layer about 100 feet thick which also thins to the north. Bedrock velocity beneath the area is between 16,000 and 17,000 fps.

In the northern part of the area the 11,000 fps layer wedges out beneath an apparent relict channel filled with 5,000 fps material which may be loose saturated sands and gravels. A 7,000 fps intermediate zone at the north end of spread 80-11A is not apparent on 80-11B. Instead, the northern part of 80-11B shows shallow bedrock beneath about 20 feet of 1,400 fps surficial deposits. The 7,000 fps material may be similar to the relict channel fill detected on lines previously discussed.

4.9 Traverses 80-12, 80-13, and 80-15

These three traverses were run across a small lake and on the adjacent slopes above the left abutment of the proposed Devil Canyon Dam as shown on Figure 3. Traverse 80-12 consisted of a 250 foot hydrophone spread across the western part of the lake and two 500 foot geophone spreads up steep adjacent slopes to the north and south. Traverse 80-13 consisted of a similar combination across the eastern part of the lake. Traverse 15 was a single hydrophone line, 500 foot long, extending northwest to southeast across the lake.

The profiles shown on Figures 12 and 13 indicate similar bedrock velocities of between 16,800 and 18,800 fps. Profile 80-12 shows a distinct intermediate layer beneath the slopes of between 7,000 and 10,000 fps. This may be highly weathered bedrock or glacial deposits. A 5,000 fps intermediate layer beneath the relatively flat north end of 80-13, probably indicates water table in otherwise low velocity sediments. Surficial deposits on the slopes are generally between 1,400 and 2,200 fps. The 4,000 fps indicated beneath the north-facing slope on line 80-13 probably represents partically frozen ground.

A layer of approximately 5,000 fps underlies the lake on all three profiles. This is probably saturated soft sediments which may be as deep as 50 feet near the center of the lake as shown on profile 80-15. Time-distance plots from all three spreads run across the lake are very irregular and subject to alternative interpretations. Data from spread 80-15 appear to indicate that high-velocity bedrock directly underlies the saturated sediments beneath most of the lake. The other two profiles, however, indicate that only weathered rock is present beneath part of the area.

The possibility of a shear zone trending approximately east-west beneath the lake was suggested by Shannon and Wilson (1978) based on results of line SW-17, which parallels 80-12, 400 feet to the west. On that line, bedrock velocities underlying 7,000 fps channel fill near the center of the line were interpreted to be lower than beneath the slopes to either side. Three of 5 borings drilled along that line encountered highly fractured or sheared phylltic bedrock.

The results of the present survey can neither confirm nor deny the presence of a shear zone. Although the time-distance plots appear to be anomalously irregular, reasonable mathematical interpretations were obtained from the data. Lower velocities were obtained for bedrock beneath the lake than on the adjacent slopes (as on SW-17) but the reason for these lower velocities is not clear from the data. They may indicate sheared material or, alternatively, dense fill material or weathered, surficially fractured bedrock.

5.0 GENERAL OBSERVATIONS AND CONCLUSIONS

Materials represented by velocity layers interpreted for this report have been assigned, at least in general terms, where boring and test pit data have been available. In areas where this control has not been available, similarities in layering and velocities with better controlled areas have allowed assignment of material types with a reasonable degree of confidence.

In general, bedrock velocities near the Watana site vary between 14,000 and 23,000 fps. Velocities of 18,000 to 23,000 fps are representative of hard, unfractured diorite as exposed in the immediate site vicinity. Lower velocities indicate increasing degrees of fracturing and weathering if the rock is indeed diorite. These lower velocities may also represent other lithologies such as metamorphic zones or volçanics such as have been mapped on the right abutment downstream from the dam.

Velocities as low as 10,000 fps in intermediate layers overlying higher velocity bedrock may represent highly weathered diorite. Apparent layers of 13,000 fps material found near the middle of traverse 80-1 and at the south end of 80-2 have been interpreted as weathered bedrock but may represent a different lithology.

Lateral changes in bedrock velocity have been noted on several lines for this and previous surveys near the Watana site. These changes appear to form bands of increasing velocity eastward from "The Fins" shear zone as presently interpreted, and may also form northwest trending bands farther to the west. Present data, however, is insufficient to verify this pattern.

Portions of the relict channel at the Watana site have been defined by the present interpretation. The channel is apparent on traverses 80-1, 80-2, 80-6, 80-7, and 80-8. Channel fill material ranges from 5,000 to 9,000 fps and has been shown by borings to be highly variable but predominantly alluvial sands and gravels, bouldery glacial silts and sands, and to a lesser extent lacustrine silts and clays. Two episodes of channeling are apparent on traverses 80-1, 80-2, and 80-8. Materials on traverses 80-9, and 80-10 with similar velocities appear to be lithologically similar to those in the relict channel.

At the Devil Canyon site, the highest bedrock velocity detected was nearly 18,000 fps. This is the velocity reported for fresh phyllite in the area by Shannon and Wilson (1978). Lower velocity bedrock interpreted from the present survey may reflect weathering or lateral lithologic changes.

Intermediate layer velocities at the Devil Canyon site range from 5,000 to 10,000 fps. Velocities as low as 7,000 fps could represent weathered bedrock in the metamorphic terrain. The 5,000 fps layers interpreted from this survey appear to be equivalent to the 7,000 fps layer on SW-17 to the west of the lake. Borings in that area showed the material to be predominantly sand with some gravel and boulders.

Surficial deposits are highly variable in the area of the survey and are therefore difficult to discuss in general terms. Surficial materials are best investigated with short lines and small geophone spacing. Since most of the lines for this survey used wide geophone spacing, the information obtained about surficial layers is highly generalized. Most of the surficial velocities reported herein are probably averages of several smaller distinct layers and are more related to the distance from shot point to the first geophone than to the velocity of any particular material.

With regard to structure, two possible shear zones have been interpreted from this survey. These are northwest trending zones extending from the right abutment at the Watana site and are discussed with respect to traverses 80-1, and 80-2 in earlier sections. Information regarding a possible shear zone beneath the saddle dam site at Devil Canyon was indeterminate.

The data from the present survey were sufficient to make fairly definite interpretations. However, specific depths and material types should be confirmed by borings in critical areas. We suggest that when sufficient boring control becomes available, that all three refraction surveys be re-evaluated to more accurately portray conditions between borings.

The interpretation resulting from the present survey are considered the most reasonable based on available information. They are not the only interpretations possible. The limitations of the seismic method and the present data are discussed further in Appendix A and the references.

REFERENCES

Dames and Moore, 1975, Subsurface exploration, proposed Watana Dam site on the Susitna River, Alaska: Report for Department of the Army, Alaska District, Corps of Engineers, Contract DACW85-C-0004.

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Shannon and Wilson, Inc., 1978, Seismic refraction survey, Susitna Hydroelectric Project, Watana Dam site: Report for Department of the Army, Alaska District, Corps of Engineers, Contract DACW85-78-C-0027.

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APPENDIX A*

* This appendix deleted from Task 5, Appendix H. Refer to project files for Woodward-Clyde Consultants report.

APPENDIX I
SEISMIC REFRACTION SURVEY-1981

SUSITNA HYDROELECTRIC PROJECT
SEISMIC REFRACTION SURVEYS
1981

Submitted to

R & M Consultants
5024 Cordova
Anchorage, Alaska 99502

6 January 1982

R & M Consultants
5024 Cordova
Anchorage, Alaska 99502

Attention: Mr. Gary Smith

Gentlemen:

SUBJECT: SUSITNA HYDROELECTRIC PROJECT
SEISMIC REFRACTION SURVEYS - 1981

Enclosed are five copies of the subject report which documents geophysical work in support of site engineering studies during 1981. At the request of Acres American Incorporated, we are also sending five copies directly to their office in Buffalo, New York.

We have enjoyed working with you on this project and hope we can be of further service in the future. If you have questions regarding the material contained in this report, please call at your convenience.

Very truly yours,

Dennis E. Jensen
Project Geologist

Jan D. Rietman, Ph.D.
Deputy Director of Geophysics

DEJ/md

Enclosure

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1.0 INTRODUCTION

This report presents the results of geophysical surveys performed during the spring, summer, and fall of 1981 on the Upper Susitna River, Alaska, approximately 125 miles north of Anchorage. These surveys were performed under contract with R & M Consultants (R & M) as part of their subcontract with Acres American Incorporated (AAI).

The 1981 geophysical program was essentially a continuation of surveys performed during 1980 under the same contract. Results of the 1980 surveys were submitted to R & M in a report dated 19 December 1980. Interpretations included in this report are based in part on the 1980 work, on previous seismic refraction surveys (Dames and Moore, 1975; Shannon and Wilson, 1978), and on limited boring and surface mapping information.

Locations of all refraction traverses from 1975 through 1981 are shown in Figures 1, 2, and 3. Figure 1 covers the immediate area of the proposed Watana Dam site and Figure 2 shows line locations outside of the immediate site area but in the same vicinity. Figure 3 shows line locations near the proposed Devil Canyon Dam site.

1.1 Purpose

Geophysical surveys from 1981 and from past years were accomplished as part of feasibility studies for the Susitna Hydroelectric Project proposed by the Alaska Power Authority. Seismic refraction and limited magnetometer surveys were intended to investigate the nature and distribution of bedrock and overburden materials and to supplement data from other sources such as borings and geologic mapping.

For all surveys run during 1980 and 1981, line locations were specified by AAI. Some of the 1981 locations were recommended by Woodward-Clyde Consultants at the close of the 1980 season, and incorporated in the 1981 program.

1.2 Scope

A total of 72,900 ft of refraction line was run in 1981 during three separate field efforts (spring, summer, and fall) to bring the two-year total to approximately 100,000 linear feet. In addition, approximately 3,000 ft of magnetometer line was run near Devil Canyon in an unsuccessful attempt to detect buried mafic dikes.

The spring seismic refraction survey consisted of 21,900 ft of line at 12 locations (Lines 81-1 through 81-12) across the river and adjacent low-lying areas near the Watana site (Figures 1 & 2). Field work was accomplished between 1 April and 14 April 1981 when the river was frozen. The low water level and low water velocity plus access afforded by ice allowed refraction surveys to be run in areas where they would be infeasible later in the year. A draft report of the results of the spring work was submitted to R & M dated 18 June 1981.

A total of 22,200 ft of refraction line was run during the month of July as 10 separate traverses (Lines 81-13 through 81-22). Nine of these were run at the Watana site (Figure 1), some as continuations of existing lines. One traverse was run on the proposed south abutment at Devil Canyon (Figure 3).

From 26 October to 15 November, 1981, a 28,800 ft traverse was run from rock outcrops near the proposed Watana south abutment to a point approximately 5 miles to the east. The locations of lines 81-FL-1 through 81-FL-48 are shown on Figures 1 & 2. This traverse crossed an area of suspected buried channels in the Fog Lakes area.

The alignments of all traverses were flagged by R & M or AAI personnel prior to refraction surveying. During refraction work, the location of all shot points and geophones were flagged. The coordinates and elevations of each of the shot and geophone points for spring and summer traverses were subsequently surveyed by R & M. For the fall work (Fog Lakes) R & M provided coordinates and elevations at all turning points and breaks in slope.

Data for all seismic refraction traverses accomplished during 1980 and 1981 are summarized in Table 1. The table includes line numbers used in this report, line numbers used by R & M for coordinate and elevation surveys, presentation data, line configuration data, and comments. This report discusses the interpretation of 1981 traverses in detail and references 1980 lines where they are in proximity to the 1981 survey lines.

2.0 DATA ACQUISITION AND REDUCTION

Field procedures used during the 1981 season were similar to those of the 1980 survey (Woodward-Clyde Consultants, 1980). A Geometrics/Nimbus model ES-1210F twelve-channel stacking seismograph and an explosive energy source was used for all lines. Line lengths and geophone spacing varied as discussed later in separate sections.

Data reduction for the 1981 surveys was accomplished in a similar manner as for the 1980 lines, essentially following the procedures of Redpath (1973). Rigorous delay time methods were used for only a few lines for which data was sufficient and too complex for adequate interpretation by approximation methods.

Time-distance plots of the data are included in Appendix A (spring surveys), Appendix B (summer surveys), and Appendix C (fall-Fog Lakes surveys). Interpretation of these lines are shown as Figures 4 through 23 and are discussed in Sections 4.0, 5.0, and 6.0. These sections discuss the setting of each traverse, our interpretation, and anomalous or ambiguous conditions which became apparent during data reduction and subsequent review of all available data.

Our confidence in the contacts between layers of differing velocities on the figures is variable. Solid lines represent well controlled contacts with the depths shown probably within 20 percent of the true total depth. Dots on a line represent depths calculated by the delay time method or by approximation techniques. Dashed lines are less well controlled with an estimated possible deviation from true depths on the order of 30%. Queried dashed lines are assumed contacts that are based on assumed velocities and information other than that resulting directly from data reduction, or that are inferred by the data but are not mathematically explicit.

3.0 LIMITATIONS

Seismic refraction is a widely used and well suited exploration tool for engineering projects but is subject to certain limitations which should be kept in mind when evaluating the interpretations presented in the following sections. The effects of inhomogeneities, irregular contacts, "blind zones" and hard-over-soft conditions are discussed below. Other limitations which result from the site environment and from the specified scope of these surveys apply particularly to seismic work performed at the Susitna sites.

The seismic refraction technique depends upon measuring the first arrival of a seismic wave at geophones placed on the ground surface progressively further from an explosive charge or other seismic source. Arrivals at nearest phones generally indicate travel directly through low-density surface materials. At points further from the source, the seismic wave arrives sooner than would be expected from travel through surface materials, having traveled in part through deeper, more dense, and therefore higher velocity layers. If subsurface layers are uniform, horizontal and the seismic velocities progressively increase with depth, a mathematical model can be developed from the arrival time data that approximates actual conditions. Several conditions exist in nature, however, which make interpretation of the data less precise and introduce ambiquity into the model.

In ideal situations, plots of arrival times versus distance (see Appendices A, B, and C) produce straight lines, the inverse slopes of which represent the seismic velocity of the subsurface material. Deviations of the data from straight lines indicate inhomogeneity within layers, irregular layer contacts, or inaccuracy in identification of first arrival time. Sufficient data is seldom available to distinguish amoung these possibilities. It is also difficult to determine if irregularities occur in near-surface layers or at depth. In many cases, the data resulting from local or lateral velocity changes can also be interpreted as contact irregularities.

Thin layers at depth also present a problem. Ideally each layer is represented on a time-distance plot as a separate straight line. Thin layers may produce no indication of their existance in the data regardless of the detail of the survey. Such "blind zone" cases can affect the calculated depth to deeper layers, such as bedrock, by a theoretical maximum of 30 percent.

Layers with seismic velocities less than overlying layers are not detectable by refraction. This situation is suspected to exist in several areas, at the Watana site in particular, where less dense sediments may underlie frozen, more dense ground. Non-seismic information, such as boring data, is required to resolve hard-over-soft conditions, enabling correction of the refraction model, which is otherwise likely to be in error by as much as 30 percent for the depth of deeper layers.

Several conditions occur which preclude collection of the optimum quantity and quality of data. These include weather, ground conditions and, of course, the time available to resolve operational problems which may arise. For the Susitna work, field data reduction was performed to assure the sufficiency of results from each line. In some cases, however, time and budget constraints precluded running additional lines which may have resolved some uncertainties.

In interpreting data which is less than straight forward, the tendency is to produce as simple a model as possible without violating the restraints of the data. In these cases, the experience and judgement of the interpreter is important in producing a geologically reasonable picture. The presence of an experienced geologist during shooting of the lines and during interpretation, combined with the results of previous investigations, increased the likelihood that profiles presented herein reflect a fairly accurate model of existing conditions suitable for evaluation of the feasibility of the project. Further exploration is required to resolve the uncertainties identified during these surveys.

4.0 SPRING TRAVERSES

The twelve traverses (lines 81-1 through 81-12) run during April each crossed the Susitna River, which was almost completely frozen at the time. Geophones at ice locations were placed in holes bored through the ice to soil or, in some cases, water. The phones were then firmly affixed to the soil or river bottom by weights. Explosive charges were detonated away from the river to provide the seismic energy source.

During the surveys, ice thickness ranged up to four feet with only a few open leads. The Susitna River was at its low point for the year but still retained sufficient velocity to interfere with seismic signals. Explosive charges up to 20 lbs were required to overcome the river noise in some cases. Also, seismic signals traveling through the ice at 11,000 fps (feet per second) often masked first arrivals through shallow, less dense sediments.

The locations of lines 81-1 through 81-6 are shown in Figure 1. Lines 81-7 through 81-12 are shown in Figure 2.

4.1 Traverse 81-1

This traverse consists of one 1,000 ft geophone spread and three shotpoints. The line crosses the Susitna River near the mouth of Deadman Creek. The south terminus is at the base of the steep slope on the southern bank of the Susitna River while the northern terminus is at the toe of the slope at the northern side of the valley. The southern third of this line is over the ice-covered Susitna River.

The interpretated profile for traverse 81-1 is shown in Figure 4. Bedrock has a calculated velocity of 16,700 fps. Bedrock appears to be very near the surface at the southern end of the profile and reaches a depth of about 120 ft near the northern end of the profile. There is a bedrock high in the center of the profile which brings bedrock to within 70 ft of the surface at that point.

An average velocity of 4,600 fps was found for the surficial materials. In our experience, this velocity is typical of recent river deposits of varying saturation and grain size.

4.2 Traverse 81-2

This traverse consists of two 1,000 ft spreads and six shotpoints. The line setting is similar to that of traverse 81-1 but is 3,000 ft further west, downstream. The northern half of the traverse was over the active river channel at the time of the survey. River ice with a velocity of about 11,000 fps, effectively masked the arrivals from the surficial materials under the river.

The interpreted profile for traverse 81-2 is shown in Figure 4. The calculated bedrock velocity on this profile averages about 16,000 to 18,000 fps but is not well constrained due to the masking effect of the ice. Bedrock is near surface on the south end of the profile and becomes deeper towards the north to a postulated depth of about 150 feet. There appears to be a bedrock high similar to that noted on profile 81-1, which brings bedrock to within 100 ft of the surface.

Surficial layer velocities vary from 5,000 fps on land to possibly 8,000 fps under the river. These velocities probably represent recent water saturated river deposits.

4.3 Traverse 81-3

This traverse consists of one 500 ft spread and two shotpoints. The line crosses the Susitna River approximately 3,000 ft downstream from traverse 81-2 in the area where the river and valley are narrow. The southern traverse terminus is on exposed bedrock and the northern terminus is near the base of steep northern valley slope.

The interpreted profile for traverse 81-3 is shown in Figure 5. Ice velocities of 11,100 fps were encountered. The bedrock velocity and depth is unknown. A minimum depth calculation indicates there is probably at least 50 ft of 5,000 fps overburden under the center of the river. The bedrock gradient noted on the upstream profiles (81-1 and 81-2) suggests that the probable depth is more likely to be at least 100 ft.

4.4 Traverse 81-4

This traverse consists of one 1,100 ft spread and three shotpoints. A prominent structural feature on the north abutment, the "Fins", trends toward the location of the line. Rock is exposed near both ends of the line. Virtually the entire length of the line is over the ice-covered river.

The interpreted profile for traverse 81-4 is shown in Figure 5. Bedrock appears to be shallow and to have a relatively low velocity of 14,000 fps. This velocity is similar to that measured across the "Fins" on the north abutment (Shannon and Wilson, 1979, and line 81-15, this report). It is also possible that the 14,000 fps material is unusually high velocity frozen gravels and boulders derived from local talus slopes and that competent bedrock may be present at a greater depth. A minimum thickness calculation was made which assumed a higher bedrock velocity (e.g., 17,000 fps). This calculation shows that the depth of such high velocity material would have to be greater than 120 feet. This deeper contact places bedrock at an elevation similar to that both upstream and downstream from this traverse. It is also possible that the boulder deposit, which is exposed at the surface, has approximately the same seismic velocity as underlying weathered rock. In this case it would not be possible to detect the contact by refraction.

A thin wedge of surficial materials with an average velocity of about 6,500 fps may be as thick as 35 ft near the north terminus of the line. A similar wedge appears to be present at the south end.

4.5 Traverse 81-5

This traverse consists of one 650 ft spread and three shotpoints. The line crosses traverse 81-4 and is slightly farther downstream for most of its length.

The interpreted profile for traverse 81-5 is shown in Figure 5. The calculated apparent bedrock velocity of 12,000 fps is very low but not inconsistant with the 14,000 fps of velocity on line 81-4. The small difference could be due to anisotropy across a linear fracture zone or to inhomogeneity of the boulder deposit. If present, higher velocity rock (17,000 fps) would probably be over 100 ft deep.

Thin surficial materials appear to be as thick as 15 ft at the north terminous of the traverse.

4.6 Traverse 81-6

This traverse consists of one 500 ft spread with two shotpoints. The line crosses a narrow portion of the

Susitna River under the upstream shell of the proposed dam. Both ends terminate at the rock walls of the Susitna River valley. The traverse connects the two segments of traverse 80-3 (Woodward-Clyde Consultants, 1980).

The interpreted profile for traverse 81-6 is shown in Figure 6. The bedrock velocity and depth is unknown from the present data because of the masking of first arrivals from the bedrock refractor by direct arrivals through the river ice. Delayed arrival times at the end-points of the present line suggest there is about 30 to 40 ft of overburden near the river banks. Minimum depth calculations assuming the higher velocities interpreted for the rock slopes (line 80-3) suggest that the overburden is at least 60 ft thick near the center of the river. This interpretation is similar to that of Dames and Moore (1975) for a line across the river at about the downstream toe of the proposed dam.

4.7 Traverse 81-7

This traverse consists of three spreads, each about 1,000 ft long, and a total of nine shotpoints. The line crosses the river near the downstream limit of Borrow Area E. The Susitna River divides into several branches with the main course near the north terminus of the traverse.

The interpreted profile for traverse 81-7 is shown in Figure 6. Bedrock has a velocity which varies from 19,000 fps at the south terminus to 15,000 fps at the north terminus. Depth to bedrock is typically 100 ft deep. The bedrock surface has a gently undulating interface. The bedrock depth appears to increase near the north terminus of the line and correlates well with previous line SW-14 which is located about 1,000 ft to the northeast of line 81-7.

The surficial materials, probably saturated recent river deposits, have velocities of about 5,000 fps. There is no evidence in the data for an intermediate velocity layer although previous lines in the area indicate this is possible. A thin, undetectable layer underlying the 5000 fps layer with a velocity of 7,000 to 9,000 fps (typical of glacial materials elsewhere), if present, could cause an over estimation of overburden thickness by about 30 percent.

4.8 Traverse 81-8

This traverse consists of three spreads, totaling about 2,500 ft long, and six shotpoints. The line crosses the river valley about 5,000 ft downstream from traverse 81-7. The eastern end of the profile crosses the active river channel.

The interpreted profile for traverse 81-8 is shown in Figure 7. Bedrock velocities range from 15,000 fps at the west end of the line to 18,000 fps over most of the line. The depth to bedrock typically varies from 50 to 100 feet.

The surficial sediments have velocities of 3,800 fps to 4,800 fps, suggesting only partial saturation. As in traverse 81-7, an intermediate velocity layer, if present as a hidden layer, could decrease the interpreted low velocity overburden thicknesses and increase depth to bedrock by up to 30 percent.

4.9 Traverse 81-9

This traverse consists of two spreads about 1,000 ft. long and six shotpoints. This line crosses the Susitna River about 2 miles downstream from traverse 81-8. The line crosses the river at its northwest terminus. Thin, unsafe ice prevented complete data acquisition.

The interpreted profile for traverse 81-9 is shown in Figure 7. Bedrock velocities range from 14,000 fps at the southeast end of the line to 18,000 fps elsewhere. The depth to bedrock varies from 100 to 180 feet. The deepest portion is under the center of the valley.

An intermediate layer having a velocity of about 6,500 to 7,500 fps occurs under the entire line. This layer probably represents older and more consolidated gravels possibly of glacial origin. Recent surficial materials, probably alluvial sands and fine gravels, form a thin veneer, 20 to 30 ft thick, with velocities of 3,800 to 4,800 fps.

4.10 Traverse 81-10

This traverse consists of two spreads, each about 1,100 ft long and six shotpoints. The line crosses the valley at a westward bend of the river about 8 miles downstream from the proposed dam. The southern end of the line crosses the river.

The interpreted profile for traverse 81-10 is shown in Figure 8. No bedrock velocities were observed on this traverse. Minimum depth calculations show that the depth to bedrock is probably greater than 300 ft based on an assumed velocity of 18,000 fps. Lower assumed bedrock velocities would produce a shallower calculated depth.

An intermediate layer velocity of 8,300 fps to 9,500 fps occurs under the entire line. The depth to this layer, which appears to be well consolidated or possibly frozen glacial deposits, decreases from about 70 ft at the north end of the traverse to 10 ft at the south end. Surficial materials have velocities of about 4,000 fps.

4.11 Traverse 81-11

This traverse consists of three spreads and nine shotpoints. Two spreads are about 1,000 ft long while the third is 700 ft long and offset from the other two. This line is about 6,000 ft downstream from traverse 81-10 and crosses the Susitna River bottom lands. The center section of the line crosses the river.

The interpreted profile for traverse 81-11 is shown in Figure 8. Bedrock appears to be about 400 ft deep assuming a bedrock velocity of 18,000 fps.

An intermediate layer, similar to that beneath line 81-10, with a velocity of 8,000 to 10,000 fps occurs under the entire line. The highest velocities occur near the south end of the line. The depth to this layer is 20 to 30 feet. Thin surficial materials, which are probably partially saturated sands and gravels, have velocities of 3,000 to 3,500 fps.

4.12 Traverse 81-12

This traverse consists of two 1,000 ft spreads with seven shotpoints. The line is about 4,000 ft downstream of traverse 81-11. The north end of the line crosses the river.

The interpreted profile for traverse 81-12 is shown in Figure 9. No bedrock velocities were observed on this traverse. Minimum depth calculations indicate that the depth to bedrock is probably greater than 300 feet, assuming a bedrock velocity of 18,000 fps.

An intermediate layer velocity of 6,700 to 8,000 fps occurs under the entire profile. Velocities increase northwards. Although they are somewhat lower than encountered on lines 81-10 and 81-11, they probably represent similar deposits.

Surficial materials 10 to 30 ft thick have velocities which range from 4,500 fps at the south terminus to 3,500 fps at the north terminus.

5.0 SUMMER 1981 SURVEYS

Traverses 81-13 through 81-19 were located on the north side of the river, upstream from the proposed Watana Dam. This area is underlain by a buried or "relict" channel. Velocities of channel fill material vary considerably as discussed in relation to the individual traverses below. From borings discussed in the 1980 report (Woodward-Clyde Consultants, 1980), these materials are known to include well consolidated glacial tills and outwash deposits, younger alluvial deposits, and some lacustrine sediments, all possibly frozen in part or entirely. Although the seismic velocities of the channel fill referenced with each traverse are a reflection of material properties, no subsurface boring data was available in the vicinity of the 1981 traverses to identify the type of material that might be represented by a particular velocity range.

Traverses 81-20 through 81-22 were run in areas of shallow bedrock on the south abutment at Watana and on the south abutment at Devil Canyon. For these as well as for the other lines, higher velocity bedrock (ie 15,000 to 20,000 fps) is presumably more competent than lower velocity bedrock (ie 10,000 to 14,000 fps). Specific rock types or degrees of weathering, however, cannot generally be distinguished by velocity alone. Correlation of the seismic velocities reported herein with the most recent surface mapping and boring information may provide a better idea of the extent of particular mapped units and structural features away from their locations known from outcrops or cores.

5.1 Traverse 81-13

Three 1,100 ft geophone spreads overlapped line 80-1 by 500 ft and continued that traverse an additional 2,800 ft to the northeast as shown in Figure 1. The traverse crosses undulating topography which rises gently to the northeast. The interpreted profile of traverse 81-13 (Figure 10) shows a continuation of the relict channel with a relatively uniform depth toward the northeast end of the line where it shallows. Bedrock, with seismic velocities ranging from 13,000 to 15,000 fps is from 200 to 250 ft deep beneath most of the traverse. Channel fill material ranges from 6,000 to 8,000 fps and surficial sediments, which are thicker toward the southwest end of the line where it overlaps 80-1, average 2,200 fps. Several irregularities in the time-distance plot (Figure B-1) appear to be due to topographic effects.

5.2 Traverse 81-14

The southwest end of traverse 81-14 is located about 600 ft from the northeast end of traverse 80-2. Three 1,100 ft lines were used to extend traverse 80-2 to the northeast. The northern end of the line turns north to the edge of a small lake as shown in Figure 1. Relatively smooth topography rises gently to the northeast to within 1,000 ft of the small lake, then drops gently toward the lake. The topography along the northern 1,000 ft was not surveyed; the profile shown in Figure 11 for that area was approximated from small scale maps and field notes.

The interpretation of traverse 81-14 (Figure 11) shows 18,000 fps bedrock to be 500 ft deep beneath the southwest end of the line. This requires a drop of about 200 ft from the northeast end of line 80-2 which is not inconsistent with the 1980 interpretation. The 500 ft depth places the thalweg of the channel at an elevation of about 1,700 ft, which is similar to that found on line 80-1 to the west and somewhat deeper than on lines to the southeast. This deepening to the northwest is consistent with the interpretation from other considerations that the ancient stream flow was in that direction.

To the northeast, on traverse 81-14, bedrock shallows to a depth of 100 ft, effectively the edge of the relict channel, about 1,000 ft south of the lake. Along the northern extension towards the lake, bedrock maintains a depth of between 100 and 150 ft, and an average velocity of 15,000 fps.

Two layers of channel fill are apparent on the profile. Material with a velocity ranging from 9,000 to 10,500 fps as thick as 400 ft occupies the bottom of the relict channel and is overlain by a 50 to 150 ft thick 6,000 fps layer that continues to the north beyond the limits of the relict channel. The velocity of the deeper layer is similar to that interpreted as possible permafrost elsewhere in the area. If it is indeed frozen, then it may be underlain by less dense, unfrozen sediments and the depth to bedrock may be as much as 100 ft shallower than shown in Figure 11. This is assuming that only the upper 100 ft is frozen and that the velocity of the underlying material is about 7000 fps.

Velocities of surficial deposits range from 1,200 to 1,800 fps beneath traverse 81-14 and vary from 20 to 30 ft in thickness.

5.3 Traverse 81-15

The center portion of traverse 81-15 consisted of two 550 ft geophone spreads across the apparent topographic expression of the Fins structure near the top of the valley wall on the north side of the river. Topography across this central portion is somewhat irregular due, presumably, to the underlying structure. Slopes to either side of this central portion were too steep for continuation of the line. Therefore, two extensions were run off the east and west ends of the central traverse but shifted about 200 ft further upslope to an area of more subdued topography (Figure 1).

Data from traverse 81-15 indicates no intermediate layer (7,000 fps) such as found on nearby line SW-3. Instead, the most reasonable interpretation (Figure 12) of the data shows relatively low velocity bedrock (11,000 to 12,700 fps) underlying relatively thin surficial materials with velocities of 1,000 to possibly as much as 4,000 fps. A bedrock velocity change at the southwest end of the extension to 16,000 fps may indicate the downstream boundary of the shear zone.

All apparently anomalous arrival times (Figure B-3) can be explained by topographic effects or by slight thickness changes in surficial materials. Two possible locations of resistant ridges in bedrock within the zone are beneath the northeast end of the extension where arrivals are considerably more irregular than elsewhere. No such irregularities occur along the central portion of the line.

5.4 Traverse 81-16

This traverse consisted of two 1,100 ft geophone spreads across a deep section of the relict channel adjacent to the Susitna River slopes upstream from the proposed dam site. Topography in this area is gently rolling and fairly level. The east end of traverse 81-16 is within 100 ft of the south end of traverse 80-7.

The interpretive profile of traverse 81-16 (Figure 12) shows the depth to bedrock to vary between 200 ft at the west end and 450 ft at the east end of the line. Bedrock velocity is 18,000 to 19,000 fps. Channel fill ranges from 5,500 to 10,000 fps and thin surficial materials, 1,300 to 1,800 fps. The 5500 fps materials appears to be a younger filled channel. The shape of this channel, however, is not well defined.

Bedrock elevation near the east end of the line is about 1,775 feet. This appears to be about the deepest part of the channel in the area. The elevation agrees with that noted on SW-3 to the north.

5.5 Traverse 81-17

A single 1,100 ft geophone spread was run northerly from the east end of traverse 81-16. The line is about 300 ft east and parallel with traverse 80-7. The configuration and velocities shown on the interpretive profile (Figure 13) agree with those interpreted for traverse 80-7.

Bedrock with a probable maximum velocity of 20,000 fps shallows from 400 ft at the south end, near the east end of line 81-16, to about 200 ft at the north end. Channel fill material averages about 8,000 fps and surficial materials about 1,800 fps.

5.6 Traverse 81-18

This traverse consisted of a single 1,100 ft line which was run in conjunction with line 81-19 across the southern edge of Borrow Area D north of Quarry Source B. A prominent gully separated the two lines and precluded their being run as a single traverse. The topography along traverse 81-18 is relatively flat, sloping gently to the east.

The profile of line 81-18 shown in Figure 13, indicates 20,000 fps bedrock at a fairly uniform depth of 325 feet.

Bedrock depth at the eastern end of the line is based on depths interpreted for line 81-19. Intermediate velocity material is predominently 6,500 fps with a wedge of 8,000 fps material, below the eastern end of the line which is consistent with traverse 81-19. Surficial materials ranging from 1,200 to 2,000 fps thin toward the east from a maximum thickness of 60 ft near the west end.

5.7 Traverse 81-19

This traverse consisted of two 1,100 ft geophone spreads extending easterly from about 600 ft east of traverse 81-18. The traverse crosses line 80-8 near the midpoint. The line was approximately parallel to contours sloping gently toward the west. The slope is very steep toward the south.

The interpretive profile of line 81-19 (Figure 14) shows an irregular bedrock surface ranging from 300 to 450 ft deep. The deepest portion is near elevation 1700 which is the lowest noted during this survey. Bedrock velocity ranges from 13,000 to 16,000 fps.

Two layers of intermediate velocity materials are apparent. They consist of a 6,000 fps layer 80 to 150 ft thick overlying a 7,500 to 8,000 fps layer. Although thicknesses vary somewhat, this is consistent with the interpretation for line 80-8 where the lines cross. Surficial deposits are up to 40 ft thick with velocities from 1,200 to 2,500 fps.

5.8 Traverse 81-20

This traverse extends line SW-1 on the south abutment of the proposed Watana Dam. Total extension was about 1000 ft to the east. The traverse consisted of overlapping 550 and 300 ft geophone spreads with two 225 ft spreads over the east side of the traverse to produce more detailed data in that area. Gently rolling topography along the traverse rises slightly toward the east.

Figure 15 shows that bedrock, interpreted to be about 18,000 fps, underlies the entire traverse at shallow depth, generally less than 10 ft. A small wedge, up to 50 ft thick, of intermediate velocity material, averaging 7,000 fps overlies bedrock near the east end of the line. This material was identified as varved silts and clays in boring DH-25 (U.S. Army Corps of Engineers, 1979).

5.9 Traverse 81-21

Four overlapping 550 ft geophone spreads and several 225 ft detail spreads were run across the suspected projection of the Fingerbuster structural feature on the south abutment of the proposed Watana Dam. The total length of the line was about 1900 ft. It crosses line 81-20 near its northeastern end. The topography rises steeply to the southwest along the traverse.

The purpose of traverse 81-21 was to delineate, if possible, the Fingerbuster zone in order to locate a drill site for further exploration of the zone. As shown on the interpretive profile of the traverse (Figure 15), the structural zone appears to occur as an area of 12,000 fps bedrock flanked by more competent 18,000 fps bedrock. This is overlain by 1,500 to 3,500 fps surficial materials which range in thickness from zero to 40 feet.

The location of the zone was thought to be known more precisely from apparent anomalies on field time distance plots. Several anomalies apparent on the time-distance plot (Figure B-6), can be attributed for the most part to topographic irregularities and to changes in thickness of the near surface layer. The zone appears to be delineated by a prominent slope break to the west and a rapid thinning of surficial deposits to the east. It appears that a topographic low exists over the central portion of the zone. The depression appears to be due to erosion by a crossing stream.

5.10 Traverse 81-22

This traverse was run as three overlapping 550 ft geophone spreads along the ridge on the south abutment of the proposed Devil Canyon Dam. The eastern portion of the traverse crosses the southern ends of lines 80-12 and 80-13. The somewhat irregular ground surface along the traverse slopes downward toward the east end.

The interpretive profile of traverse 81-22, shown in Figure 16, shows very shallow bedrock ranging from 11,000 to 15,000 fps overlain by surficial materials of 1,800 to 2,000 fps. The surficial material appears to average about 10 ft thick but thickens to as much as 30 ft at one location near the east end. Intermediate layers of 5,000 and 10,000 fps interpreted for the south ends of 80-12 and 80-13 were not apparent from the data for 81-22.

6.0 FALL TRAVERSES-FOG LAKES AREA

The Fog Lakes traverse consisted of 48-500 ft geophone spreads with common end shot points. The location of the traverse was selected to cross areas of possible buried channels which could contribute to seepage from the reservoir. Topography along the line is gently rolling and relatively flat locally. Elevations range from less than 2,300 ft across the Fog Lakes valley, approximately five miles east of the proposed Watana Dam, to about 2,400 ft near the proposed south abutment.

The interpretation of the data for the traverse, shown in Figures 17 through 23, indicates that apparent bedrock velocities vary substantially along the traverse, from 20,000 fps to as low as 10,000 fps.

Two types of intermediate material are apparent. The first ranges from 4,500 to 7,000 fps and is interpreted to consist of poorly consolidated, saturated glacial deposits. The second ranges from 8,000 fps to as much as 10,500 fps. This is suspected to be well consolidated glacial sediments in part or entirely frozen. Surficial deposits range from 1,000 to 3,000 fps, are as thick as 50 ft in some areas, and are absent in others.

Several areas along the traverse appear to be underlain by buried channels which extend below the proposed reservoir level. The two most prominent of these are near the west end of the traverse (Figure 17) and beneath the Fog Lakes Valley (Figures 22 and 23). Near the west end, a channel which may be as deep as 300 ft (to elevation 2,030) is filled mainly with low velocity (4300 to 6000 fps) deposits. Higher velocity channel fill (9000 fps) is indicated near the east side of the channel but the contact between the two types of channel fill is uncertain. It is possible that the higher velocity material is permafrost, in which case unfrozen sediments (with lower velocities) could be present below it and the total depth of the channel could be somewhat less than shown on the profile. The width of the deepest part of the channel appears to be about 1,000 feet.

The apparent channel in the Fog Lakes Valley is more than a mile wide. The deepest part appears to underlie the lowest part of the valley at an elevation of about 1,940, 350 ft below ground surface. Much of the rest of the channel, which extends below the topographic high northwest of the valley, is below an elevation of 2,100 feet.

The shape of the channel shown on the profile is based on marginal arrival-time data from distant offsets and from minimum depth calculations where distant offsets did not penetrate sufficiently to detect rock. The shape, therefore, could be significantly different, especially on the west side where depths could be greater. The interpretation shown, however, is considered to be a reasonable estimate of the maximum depth within the limits of the uncertainties of the data.

The most critical uncertainty is the nature of the 8,000 to 11,000 fps apparent channel fill material. If this material is interpreted to be well consolidated glacial deposits then the interpreted profile as shown in Figures 22 and 23 is appropriate. However, if the material is frozen, then lower velocity material could underlie the permafrost and depths to bedrock could be shallower than shown on the Figures.

A third possibility, which is not likely, is that the apparent channel fill could instead be weathered bedrock, at least in part. If this were true the bedrock velocity would be so close to that expected for frozen or well consolidated sediments that the contact between them could not be distinguished. It is remotely possible that the apparent indications of high velocity bedrock at depth are the result of irregularities in shallower, very low velocity weathered rock or from steeply dipping contacts between weathered bedrock and high velocity channel fill.

An attempt was made to resolve the nature of high velocity apparent channel fill material using shallow reflection at the location of refraction line 81-FL-3. Results were not definitive but the most likely reflection appears to place the bedrock contact at a depth of 170 ft below ground surface which is similar to the depth indicated by refraction in that area. This depth, however, indicates an anomalous high near the middle of the broad channel which makes the interpretation even more tenuous.

Other areas of apparent channeling are present along the central portion of the traverse. These channels, although broad in some cases, are all above elevation 2,150 and generally shallower than elevation 2,200.

At several locations along the Fog Lakes Traverse, bedrock lows appear to coincide with higher seismic velocities which is contrary to conditions elsewhere in the vicinity. No explanation for this is evident from the present data.

7.0 MAGNETOMETER SURVEYS

Approximately 3,000 ft of magnetometer surveys were run as two long traverses and three shorter traverses in an attempt to locate buried mafic dikes on the south abutment of the proposed Devil Canyon Dam. One of the long traverses was run along the alignment of refraction line 81-22.

No significant anomalies were detected which could not be attributed to cultural features or to topography. The method was found to be not applicable for mapping the dikes and therefore the program was discontinued after these trials.

8.0 GENERAL OBSERVATIONS AND CONCLUSIONS

In general, results of the 1981 seismic refraction surveys are in good agreement with surveys interpreted during 1980 and in previous years. Only a few cases were found where independent interpretations did not agree. The most notable of these were the lack of intermediate velocity material indicated on lines 81-15 and 81-22 which crossed or were near to existing lines for which shallow, intermediate velocity material had been interpreted. This difference may be a simple result of differing interpretation procedures or possibly an indication of rapid lateral changes. Boreholes, or possible additional, more detailed seismic lines, are needed to resolve these differences.

As previously discussed, the seismic refraction method is subject to a number of limitations which affect the confidence one can place on the details of interpretations based soley on refraction data. For example, a great deal of uncertainty exists as to the nature of the apparent channel-fill material along the Fog Lakes traverse. A few borings in the interpreted channel areas, however, should resolve these uncertainties and provide a basis for further evaluation of possible seepage problems during design studies.

The interpretation of material types represented by various velocities have been discussed in previous reports and are covered only in general terms herein. The present profiles were developed assuming the material types and velocities encountered in this survey were similar to those encountered in previous surveys which were based, in part, on boring information.

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APPENDIX A*

TIME-DISTANCE PLOTS - SPRING SURVEYS

* This appendix deleted from Task 5, Appendix I. Refer to project files for Woodward-Clyde Consultants report.

APPENDIX B *

TIME-DISTANCE PLOTS - SUMMER SURVEYS

* This appendix deleted from Task 5, Appendix I. Refer to project files for Woodward-Clyde Consultants report.

APPENDIX C*

TIME-DISTANCE PLOTS - FALL SURVEYS (FOG LAKE)

* This appendix deleted from Task 5, Appendix I. Refer to project files for Woodward-Clyde Consultants report.

APPENDIX J

AIR PHOTO INTERPRETATION

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

ACRES

R&M

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ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

TABLE 1

1980-1981 Seismic Refraction Line Data

WCC Line No.	R & M Survey No.	Location Figure	Profile Figure	Time-Distance Plot Figure	Line Length (ft)	Number of Segments/Shots	Comments
80-1	80-1	2	*	*	6,600	8/31	Watana Rt Abutment-Relict Channel--Extended NE by 81-13
80-2	80-2	2	*	*	5,500	5/19	Watana Rt Abutment-Relict Channel--Extended NE by 81-14
80-3	80-3	2	*	*	2,000	4/11	Watana Rt & Lft Abutments Upstream--81-6 Crosses River in Middle
80-4	---	---	---	---	---	---	Not Used
80-5	---	---	---	---	---	---	Not Used
80-6	80-6	2	*	*	1,100	2/5	Watana RT Abutment--Relict Channel Area
80-7	80-7	2	*	*	2,200	2/10	Watana RT Abutment--Relict Channel Area
80-8	80-8	2	*	*	2,200	2/10	Watana Quarry Source B--Extends SW-5 to South
80-9	80-9	1	*	*	1,100	1/3	Watana Borrow Area E--Extends SW-14 to NW
80-10	---	---	---	---	---	---	Not Used
80-11	80-11	2	*	*	2,200	4/13	Watana Borrow Area E--Adjacent to Tsusena Creek
80-12	80-12	3	*	*	1,120	3/8	Devil Canyon Saddle Dam Area--Left Abutment
80-13	80-13	3	*	*	1,120	3/8	Devil Canyon Saddle Dam Area--Left Abutment
80-14	---	---	---	---	---	---	Not Used
80-15	80-15	3	*	*	440	1/2	Devil Canyon Saddle Dam Area--Left Abutment
81-1	81-1	2	4	A-1	1,000	1/3	Run Over River Ice, 2.1 Miles Upstream from Proposed Watana Dam Centerline.
81-2	81-2	2	4	A-1	2,000	2/6	Run Over River Ice, 1.6 Miles Upstream from Proposed Watana Dam Centerline.
81-3	81-3	2	5	A-1	500	1/2	Run Over River Ice, 1.1 Miles Upstream from Proposed Watana Dam Centerline.
81-4	81-4	2	5	A-1	900	1/3	Run Over River Ice, 0.6 Miles Upstream from Proposed Watana Dam Centerline.

* Profiles and time-distance plots included in previous report (Woodward-Clyde Consultants, 1980).

INTRODUCTION

The feasibility study for the Susitna Hydroelectric Project includes geological and geotechnical investigation of the area extending from the Parks Highway 80 miles east to the mouth of the Tyone River and from the Denali Highway 50 miles south to Stephan Lake. The most cost effective method of generating and compiling baseline geologic information about this large, little-investigated region is through the methods of photointerpretation and terrain unit mapping.

This text and the accompanying terrain unit maps present the results of aerial photograph interpretation and terrain unit analysis for the area including the proposed Watana and Devil Canyon damsite areas, the Susitna River reservoir areas, construction material borrow areas, and access and transmission line corridors. The task was performed for the Alaska Power Authority by R&M Consultants, Inc., working under the direction of Acres American, Inc.

Scope of Work and Methods of Analysis

Work on the air photo interpretation subtask consisted of several activities culminating in a set of Terrain Unit Maps delineating surface materials and geologic features and conditions in the project area.

The general objective of the exercise was to document geological features and geotechnical conditions that would significantly affect the design and construction of the project features. More specifically the task objectives included the delineation of terrain units of various origins on aerial photographs noting the occurrence and distribution of geologic factors such as permafrost, potentially unstable slopes, potentially erodible soils, possible buried channels, potential construction materials, active flood plains and organic materials. Engineering characteristics listed for the delineated areas allows assessment of each terrain unit's influence on project features. The terrain unit analysis serves as a data bank upon which interpretations concerning geomorphologic development, glacial geology, and geologic history could be based. Additionally, this subtask provides base maps for the compilation and presentation of various other Susitna Hydroelectric project activities.

The area of photo coverage was divided into units of workable size, resulting in 18 map sheets. Base maps were prepared from photo mosaics and the terrain units were delineated on overlay sheets.

Physical characteristics and typical engineering properties were developed for each terrain unit and are displayed on a single table.

The execution of this project progressed through a number of steps that ensured the accuracy and quality of the product. The first step consisted of a review of the literature concerning the geology of the Upper Susitna River Basin and transfer of the information gained to high-level, photographs at a scale of 1: 125,000. Interpretation of the high-level photos created a regional terrain framework which would help in the interpretation of the low-level 1:24,000 project photos. Major terrain divisions identified on the high-level photos were then used as an areal guide for delineation of more detailed terrain units on the low-level photos. The primary effort of the subtask was the interpretation of 300-plus photos covering about 800 square miles of varied terrain. The land area covered in the mapping exercise is shown on the index map sheet and displayed in detail on the 21 photo mosaics.

During the low altitude photo interpretation a preliminary work review and field check was undertaken by R&M and L.A. Rivard, terrain analysis consultant. A draft edition of the Terrain Unit maps and report was completed and submitted for review to ACRES and L.A. Rivard. Comments and questions generated in the review of the draft report were analyzed by R&M and a second field check was undertaken. The final revised maps are included herein.

Terrain units composed of or including bedrock are shown on the interpretation. However, these divisions are interpreted only as weathered or unweathered bedrock. Detailed petrologic designations and age relations of the rock units have been synthesized from U.S. Geological Survey sources (Csejtey, 1978) and project field mapping accomplished to date. Rock unit designations from these sources are included on the maps. Lineaments, features-of-interest, and potential faults have not been shown as their delineation is outside the scope of R&M's work.

Limitations of Study

This is a generalized study which is intended to collect geologic and geotechnical materials data for a relatively large area. Toward this goal, the work has been successful, however, there are certain limitations to the data and interpretations which should be considered by the user. The engineering characteristics of the terrain units have been generalized and described qualitatively. When evaluating the suitability of a terrain unit for a specific use, the actual properties of that unit should be varified by on-site subsurface investigation, sampling, and laboratory testing.

An important factor in evaluating the engineering properties, composition and geologic characteristics of each terrain unit is extensive field checking and subsurface investigation. The scope of the current project allowed only limited field checking and all subsurface investigations to date have been restricted to three terrain units clustered around the Watana site. This lack of ground-truth data further restricts the use of the terrain unit maps and engineering interpretation chart for site specific applications.

TERRAIN UNIT ANALYSIS

A landform is defined (Kreig and Reger, 1976) as any element of the landscape which has a defineable composition and range of physical and visual characteristics. Such characteristics can include topographic form, drainage pattern, and gully morphology. Landforms classified into groups based on common modes of origin are most useful because similar geologic processes usually produce similar topography, soil properties, and engineering characteristics. The terrain unit is defined as a special purpose term comprising the landforms expected to occur from the ground surface to a depth of about 25 feet. It has the capability to describe not only the most surfical landform, but also, an underlying landform when the underlying material is within about 25 feet of the surface (i.e. a compound terrain unit), and areas where the surficial exposure pattern of two landforms are so intimately or complexly related that they must be mapped as a terrain unit complex. The terrain unit is used in mapping landforms on an areal basis.

The terrain unit maps for the proposed Susitna Hydroelectric Project area show the areal extent of the specific terrain units which were identified during the airphoto investigation and were corroborated in part by a limited on-site surface investigation. The terrain units, as shown on the following sheets and described in this text, document the general geology and geotechnical characteristics of the Susitna Hydroelectric Project area.

On the maps each terrain unit is identified by letter symbols, the first of which is capitalized and indicates the genetic origin of the deposit. Subsequent letters differentiate specific terrain units in each group and when separated by a dash, identify the presence of permafrost.

During terrain unit mapping bedrock was identified, as per established techniques, only as weathered bedrock or unweathered bedrock. Details of bedrock geology shown on the mosaic maps is derived from Csejtey's USGS open file report on The Geology of the Talkeetna Mts. (1979) and from Acres American (unpublished data, 1981). The letter designations are used here as those authors defined them and the rock units are shown only where the photointerpretation located bedrock on the maps. There has been no attempt to correlate units across areas of limited exposure or to modify the outcrop pattern. Bedrock symbols are shown in slanted letters with the capital letters defining the age of the unit and following lower case letters describing the rock type.

Terrain Unit Descriptions

For this photo interpretation exercise, the soil types, engineering properties and geological conditions have been developed for the 14 landforms or individual terrain units briefly described below. Several of the landforms have not been mapped independently but rather as compound or complex terrain units. Compound terrain units result when one landform overlies a second recognized unit at a shallow depth (less than 25 feet), such as a thin sheet of glacial till overlying bedrock or a mantle of lacustrine sediments overlying till. Complex terrain units have been mapped were the surficial exposure pattern of two landforms are so intricatly related that they must be mapped as a terrain unit complex, such as some areas of bedrock and colluvium. The compound and complex terrain units behave and are described as a composite of individual landforms comprising them. The stratigraphy, topographic position and areal extent of all units are summarized on the terrain unit properties and engineering interpretations chart.

Bx - BEDROCK:	In place rock that is overlain by a very thin mantle of unconsolidated material or exposed at the surface. Two modifiers have been used for all types of bedrock whether igneous, sedimentary or metamorphic. Weathered, highly fractured, or poorly consolidated bedrock is indicated by the modifiers "w" (as in Bxw); unweathered, consolidated bedrock is indicated by the modifier "u" (as in Bxu). A modifier or special symbol for frozen bedrock has not been used, although bedrock at higher elevations may be frozen.
C - COLLUVIAL DEPOSITS:	Deposits of widely varying composition that have been moved downslope chiefly by gravity. Fluvial slopewash deposits are usually intermixed with colluvial deposits.
Cl - Landslide:	A lobe- or tongue-shaped deposit of rock rubble or unconsolidated debris that has moved downslope. Includes rock and debris slides, slump blocks, earth flows and debris flows. Young slides are generally unfrozen while older slides may be frozen.
Cs-f - Solifluction Deposits:	Solifluction deposits are formed by frost creep and the slow down-slope, viscous flow of saturated soil material and rock debris in the active layer. This unit is generally used only where obvious solifluction lobes are identifiable. Includes fine-grained colluvial fans formed where solifluction deposits emerge from confined channel on a hillside onto a level plain or valley. These landforms are often frozen as denoted by "-f".
Ffg - Granular Alluvial Fan:	A gently sloping cone generally composed of granular material with varying amounts of silt deposited upon a plain by a stream where it issues from a narrow valley. The primary depositional agent is running water (for solifluction fans, see Colluvial Landforms). Can include varying proportions of avalanche or mudflow deposits, especially in mountainous regions. Fans are generally unfrozen.
Fp - Floodplain:	Deposits laid down by a river or stream and flooded during periods of highest water in the present stream regimen. Floodplains are composed of two major types of alluvium. Generally granular riverbed (lateral accretion) deposits and generally fine-grained cover (vertical accretion) deposits laid down above the riverbed deposits by streams at bank overflow (flood) stages.
Fpt - Old Terrace:	An old, elevated floodplain surface no longer subject to frequent flooding. Occurs as horizontal benches above present floodplains, and generaly composed of materials very similar to active floodplains.
Gta - Ablation Till:	Relatively younger ablation till sheets with more pronounced hummocky moraine topography and less dissected than older till sheets. These deposits are predominently of the Naptowne Glaciation, contain abundent cobbles and boulders, and consist of water-worked till. The ablation till may be sporadically frozen in the Denali Highway access corridors.
Gtb-f - Basal Till:	Basal glacial till sheets, with subdued moraine morphology, which in the Watana Creek-Stephan Lake area are relatively older (probably deposited during Eklutna and older glaciations)and elsewhere are as young as Naptowne age. Often frozen in the Watana - Stephan Lake area with a higher silt and ground ice content as denoted by modifier "-f"; generally unfrozen in the Gold Creek - Indian River area; and possibly frozen between Watana Camp and the Denali Highway.
GFo - Outwash:	Coarse, granular relatively level floodplain formed by a braided stream flowing from a glacier.
GFe - Esker Deposits:	Long ridges of granular ice-contact deposits formed by streams as they flow in or under a glacier.
GFk - Kame Deposits:	Hills, crescents and cones of granular ice-contact deposits formed by streams as they flow on or through a glacier.
L-f - LACUSTRINE DEPOSITS:	Generally fine-grained materials laid down in the Copper River proglacial Lake and gravelly sands deposited in the Watana Creek - Stephen Lake proglacial lake. Often frozen as denoted by modifier "-f".
O - ORGANIC DEPOSITS:	Deposits of humus, muck and peat generally occurring in bogs, fens and muskegs. Frequently overlies frozen material.

Special Symbols and Landforms

In addition to the terrain unit symbols, several special symbols are used on the Terrain Unit maps to denote landslide scars, terrace scarps, frozen soils, buried channels and trails.

Well defined landslide scarps, which indicate relatively recent failure, are shown as lines following the scarp trace with arrows indicating the direction of movement. Visible on the aerial photos within many of the terraces and outwash deposits are several different surfaces which may be related to sedimentation at a temporary base level which was followed by renewed incision. The various outwash and stream terraces are noted by lines following the scarps separating the different elevation surfaces, with tick marks on the side of the lower surface. Permafrost soils have been delineated on the terrain unit maps through the use of an -f following the terrain unit letter designation. By convention the symbol -f is used where the permafrost is thought to occur at least discontinously. Sporadically frozen areas have not been defined on the maps, however, the possible occurrance of frozen material within a terrain unit is described in the preceeding section on definitions and on the engineering interpretation chart.

Buried channels along the Susitna River have been delineated by the use of opposing parallel rows of triangular teeth. Most of these features are minor and should have no impact on the present studies, however three buried channels south of the southern abutment at the Devil Canyon damsite, should be investigated to assess potential leakage around the dam. A similar but larger buried channel extends from near the mouth of Deadman Creek to Tsusena Creek. The trough is filled with quaternary sediments of several different types and ages some of which may have a high transmissibility. Because this channel bypasses the Watana damsite detailed work should be directed towards determining its width, depth, soil types, and potential for reservoir leakage.

Existing jeep and/or winter sled trails have been noted on the Terrain Unit maps by a dash-dot line.

Terrain Unit Properties and Engineering Interpretation Chart

In order to evaluate the impact of a terrain unit with respect to specific project features an interpretation of the engineering characteristics of each unit is provided. On the chart the terrain units are listed in horizontal rows and the engineering properties and parameters being evaluated are listed as headings for each column. Within the matrix formed are relative qualitative characterizations of each unit. Several of the engineering properties and evaluation criteria are briefly discussed below. The chart is presented for general engineering planning, and environmental assessment purposes. In this form, the data are not adequate for design purposes but when additional laboratory and field information is acquired and synthesized, site specific development work can be minimized.

SEE SHEET II FOR CONTINUATION

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ACRES
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
SUBTASK 5.02
PHOTO INTERPRETATION
SUMMARY REPORT
R&M CONSULTANTS, INC.
DATE OCTOBER 1981
DEPARTMENT
PROJECT 052502
SCALE
DRAWING NO.
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Engineering Interpretation Definitions:

Slope Classification

Following guidelines established by the U.S. Forest Service, the Bureau of Land Management and the American Society of Landscape Architects, slopes in the project corridor have been divided into the following classes: Flat - 0 to 5%; Gentle - 5 to 15%, Moderate - 15 to 25% and steep - greater than 25%. References have been made to steep local slopes to account for small scarps and the similar short but steep slopes which characterize ice contact glacial drift.

Probable Unified Soil Types

Based on the laboratory test results, field observations, previous work in similar areas, and definitions of the soils, a range of unified soil types has been assigned to each terrain unit. Often several soil types are listed, some of which are much less prevelant than others. Information in the soil stratigraphy column will aid in understanding the range and distribution of soil types. Study of the borehole logs and lab test results will give site specific unified soil types.

Drainage and Permeability

How the soils comprising the terrain units handle the input of water is characterized by their drainage and premeability. Permeability (hydraulic conductivity) refers to the rate at which water can flow through a soil. Drainage describes the the wetness of the terrain unit, taking into account a combination of premeability, slope, topographic position, and the proximaty of the water table.

Erosion Potential

Erosional potential as described here, considers the materials likelyhood of being moved by eolian and fluvial processes such as sheetwash, rill and gully formation, and larger channelized flow. In general this relates to the partical size of the soil, however, the coarse sediments of floodplains have been rated as high because the surface is very active, and likewise coarse terrace deposits can have a high rating because of their proximaty (by virture of the their origin) to streams. (Mass wasting potential is considered under slope stability).

Ground Water Table

Depth to the ground water table is described in relative terms ranging from very shallow to deep. In construction involving excavation and foundation work, special techniques and planning will be required in most areas with a shallow water table and in some of the areas with a moderately deep water table. In areas of impermeable permafrost a shallow perched local water table may occur.

Probable Permafrost Distribution

The occurance of permafrost and the degree of continuity of frozen soil is described on the Engineering Interpretation Chart, by the following relative terms: Unfrozen- generally without any permafrost; Sporadic - significantly large areas are frozen. Site specific work may be required before design; Discontinous - most of the area is underlain by frozen soils - site specific work is required unless design incorporates features relating to permafrost; Continous - the entire area is frozen. All designs should be based on occurrance of permafrost.

Frost Heave Potential

Those soils which contain significant amounts of silt and fine sand have the potential to produce frost heave problems. A qualitative low, moderate, and high scale rates the various soils based on the potential severity of the problem. Where the soil stratigraphy is such that a frost susceptible soil overlies a coarse grained deposit, a dual classification is given; for these soils it may be possible to strip off the frost suseptable material.

Thaw Settlement Potential

Permafrost soils with a significant volume of ice may show some settlement of the ground surface upon thawing. In general, clays, silts and fine sands have the greatest settlement potential, forming the basis for the three fold classification presented on the chart. Unfrozen soils do not have the potential for thaw settlement, as denoted by "not applicable" (NA). Thawing problems may be initiated or accellerated by disturbance of the surficial soil layers or the organic mat.

Bearing Strength

Based on the terrain unit soil types and stratigraphy a qualitative description of bearing strength is given. In general coarse grained soils have a higher bearing strength than fine grained soils, but the presence of permafrost may significantly increase the strength of some fine grained soils (as indicated on the chart by the thermal state qualifying statement).

Slope Stability

The slope stability qualitative rating was derived through evaluation of each terrain units' topographic position, slope, soil composition, water content, ice content, etc. The stability assessment considers all rapid mass wasting processes (slump, rock slide, debris slide, mudflow, etc.). Several terrain units which have characteristically gentle slopes and are commonly in stable topographic positions have been oversteepend by the recent, active undercutting of streams and/or man (or by older processes not currently active such as glacial erosion and tectonic uplift and faulting). The stability of the terrain units on oversteepend slopes and natural slopes is described on the Engineering Interpretation Chart.

Suitability as a Source of Borrow

Great quantities of borrow materials will be needed for all phases of construction. The rating considers suitability as pit run and processed aggregate or impervious core and takes into account the materials present as well as the problems associated with extracting material from the various terrain units.

REGIONAL QUATERNARY GEOLOGY

Quaternary glacial events throughout South-Central Alaska profoundly affected the soils, landforms, and terrain units occurring in the project area. This history has been discussed and partially deciphered in papers by Karlstrom (1964), Pewe (1965), Ferrians (1965), and Wahrhafting (1958). However, these investigations are of such scope as to make them of limited value here. The photo-interpretation and resultant terrain unit mapping is the most detailed study of the Upper Susitna River Basin. The following discussion of Quaternary Geology is a synthesis of the new information, derived during the photointerpretation, supplemented by data from published sources.

The major topographic features of Southcentral Alaska were established by the end of the Tertiary Period. What is now the Susitna project area was located in the relatively low northern portion of the Talkeetna Mountains, which separated the broad ancestral Copper River Basin lying to the east from the ancestral Susitna Cook Inlet Basin lying to the west. North and south of the Talkeetna Mountains and the adjacent large river basins stood, respectivily, the great arc of the Alaska Range and Chugach Mountains. Streams draining the region that would become the project study area may have flowed into either the ancestral Copper or Susitna River systems. During the Pleistocene the entire Susitna Project study area was repeatedly glaciated. Each of the glacial events would be expected to follow the same general pattern with several advances most likely reaching the maximum event described here.

The onset of a given glacial advance in Southcentral Alaska would be marked by the lowering of the snowline on the regions numerous mountain ranges and the growth of valley glaciers, first in the higher ranges and those closer to the Gulf of Alaska. Advancing glaciers from the Chugach, Wrangell, Alaska and southern Talkeetna ranges would flow out of their valleys and coalesce to form large piedmont glaciers spreading across the basin floors, while the ice of the northern Talkeetna Mountains (in the project area) would still exist as valley glaciers. The piedmont glaciers of the Chugach and Wrangell Mountains would at some point be expected to merge, damming the ancestral Copper River and creating an extensive proglacial lake in the Copper River Basin. Alaska Range glaciers flowing southward would block possible ancestral drainage paths of the upper Susitna River creating a second lake which covered much of the project area and merged with the lake filling the Copper River basin. Glaciers flowing from the Kenai Mountains and southern Alaska Range would also merge creating another proglacial lake in Knik Arm, Cook Inlet, and the Southern Susitna Basin. Continued glacial advance would fill the basins eliminating the lakes and possibly forming an ice dome. Ice shelves may have extended many miles into the Gulf of Alaska. At this maximum stage many mountains in the project area were completely buried by ice as evidenced by their rounded summits while numerous others existed as nunataks.

The deglaciation of Southcentral Alaska would follow a similar pattern but in reverse. Wasting of the ice would uncover peaks in the project area and the thinning and retreat of the glaciers in the Copper River, Upper Susitna and Cook Inlet regions would again allow lakes to form. Continued melting of the glaciers would remove ice dams blocking the proglacial lakes possibly creating a catastrophic (trench cutting) outburst flood. Intervals between glacial advances would be characterized by the fuvial entrenching of the Susitna and Copper Rivers and their tributaries. The earlier glacial events of the Quaternary Period are poorly known in the Upper Susitna Basin due to both the erosion of the older deposits and their burial beneath younger deposits. However, from the alpine topography and minor glacial sediments left on high slopes it can be demonstrated that early Pleistocene glaciers completely covered Southcentral Alaska as in the maximal event described above. Most of the glacial deposits that remain and the terrain units used to describe them have resulted from later glacial events.

The last glaciation to completely cover the project area is of uncertain age. It has been interpreted to be of Eklutna age by Karlstrom (1964) which may be correlated with the Illinoian glaciation of the Continental United States (Pewe, 1975), however, with the limited data available an early Wisconsin (Knik) age may be just as viable. Whatever the age, ice flowing from the Alaska Range, the Talkeetna Mountains and several local highland centers spread across the project lowlands depositing a sheet of gray, gravelly, sandy and silty, basal till (Gtb-f). The till varies greatly in thickness, ranging from the 100+ feet, displayed in some river cut exposures, to a thin blanket over bedrock. This till presumably overlies older, poorly exposed Quaternary sediments. It is recognized that the basal till, mapped as Gtb-f in the Stephan Lake-Watana Creek Area may actually represent several closely related events and that basal till in valleys north of Deadman Lake and downstream of the Devil Canyon site was probably deposited during younger glacial advances. Prominent lateral moraines of the major advance occur on the flanks of mountains bordering the central Watana Creek-Stephan Lake Lowland.

Overlying the basal till unit and representing the next major depositional event is a lacustrine sequence. Presumably the lacustrine materials were deposited during the Eklutna (?) Glacial retreat and during much of the younger Knik and Naptowne glacial events. During these stadial events glaciers from the Alaska Range blocked drainage down the present Susitna channel and probably through a low divide between Watana Creek and Butte Creek; Talkeetna River Valley glaciers blocked low divides between Stephan Lake and the Talkeetna River; and the Copper River Basin was occupied by an extensive proglacial lake. The lacustrine deposits mapped within the project area as L and L/Gtb-f, cover much of the Watana Creek-Stephan Lake Lowland and extend upstream along the Susitna River to the Susitna-Copper River Lowland. In the Watana Creek-Stephan Lake Lowland the unit is generally less than 20 feet thick and composed of medium to fine sand with a significant gravel content. The lake deposits of the Copper River Lowland are thought to be much thicker and finer-grained. The coarseness of the lacustrine sediments (i.e. gravelly sands in the Watana Creek-Stephan Lake area) is not unexpected as the ancient lake was impounded behind and ringed by glaciers which were activity calving into the lake. During the late Naptowne glacial event, in the Watana Creek-Stephan Lake portion of the proglacial lake, several deltas and strandline features were formed at about the 3,000-foot elevation. This shoreline level is higher than most reported shorelines of the proglacial lake occupping the Copper River Basin. It is possible then, that during the Naptowne staidial the Watana Creek - Stephan Lake proglacial lake stood at a higher level because it was impounded behing another ice dam in the Kosina Creek - Jay Creek area. It is also possible that an outlet exsisted for much of the life of the lake (conceivably in Kosina - Jay Creek area). Flow from the lake would remove great quantities of fine grained suspended sediment, causing a relative increase in the coarseness of the sediment deposited in the lake.

Hummocky coarse grained deposits of ablation till (Gta) overly lacustrine sediments between Tsusena and Deadman Creeks and basal till in the valleys north of Deadman Creek and in the Denali Highway area. These materials may be correlative with eskers and kames found along the Susitna River between the Oshetna and Tyone Rivers, and together they represent the extent of the last major advance of glacial ice into the project area. They are tentatively determined to be of Naptowne age (Late Wisconsin) (Karlstrom, 1964) suggesting that the Knik Age glaciers were less extensive and their deposits were overridden and masked by Naptowne deposits. Lacustrine sediments of the large glacial lake occupying the Stephan Lake - Watana Creek lowland have not been mapped overlying the ablation till, indicating that some of the ablation till and ancient Watana Creek-Stephan Lake lacustrine sediments were time syncronus and that the proglacial lakes were drained shortly after the Naptowne maximum. One should note that several isolated deposits of ablation till are not necessarily indicative of this late advance and ice of Naptowne age did not deposit ablation till in all localities (most importantly in the Portage-Devil Creek area and in the area between Deadman Lake and the Denali Highway); and that lacustrine sediments deposited in small isolated proglacial lakes have been found overlying ablation till.

Intervals between glacial advances would be characterized by fluvial erosion and entrenching of the project area portion of the ancestral Susitna and its tributary streams, however, the majority of the interstadial fluvial hisory has been destroyed by subsequent glacial and fluvial history. Remnants of the older entrenching events are preserved in several abandoned and buried channel sections along the modern Susitna River. One of the largest older channels found, at the Vee Canyon damsite has a bedrock floor (cut below the bedrock floor of the present Susitna channel) which is now filled with fluvial and glacio-fluvial debris. The second buried channel, between Deadman and Tsusena Creeks, just north of the Watana site is filled with outwash and lacustrine materials with intervening till layers (Corps of Engineers, 1979). Because ice of Naptowne and Knik ages presumably did not completely cover the project area, and the tills in the channel have characteristics similar to the basal till unit attributed to the Eklutna Glaciation, it appears that a portion of the ancestral Susitna River valley of similar size and depth to the present valley existed as early as the Eklutna Glacial event (Illinoian). Eklutna age till and associated lacustrine sediments also filled some of the present Susitna valley, however, most have been subsequently excavated. The Eklutna age valley may have been graded to drain

SEE SHEET III FOR CONTINUATION

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ACRES

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

SUMMARY REPORT

R&M CONSULTANTS, INC.

DATE OCTOBER 1981	SCALE	
DEPARTMENT	DRAWING NO.	REV.
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east into the Copper River Basin. The fact that the present Susitna River flows in a deep canyon across mountainous terrain (in the Portage-Devil Creek and Jay-Kosina Creek areas), and not across the low Susitna-Copper River of the Stephan Lake-Talkeetna River Divides may be the result of glacial derangement and/or the rapid drainage of proglacial lakes causing a pirating of portions of the Copper and Talkeetna River drainages.

Other minor channel remnants include three buried channels above and south of the southern abutment at the Devil Canyon damsite that may be related to the drainage of a proglacial lake or an older position of the Susitna River. The channels are probably shallow but should be thoroughly investigated to assess potential leakage around the dam. A small, partially buried channel downstream of Portage Creek and another near the mouth of Devil Creek are remnants of the downcutting phase of the Susitna River. Similar channels are found near the river level just upstream of the Watana Damsite and downstream of Watana Creek.

The present course of the Susitna River was probably established during or before the Wisconsin Glacial events. Sandy glacial till observed near the river level at the Devil Canyon site may have been deposited by the glaciers forming the Naptowne Age ice dam. If this is the case, and the till is in-situ then most of the bedrock downcutting and removal of Quaternary sediment from the Susitna channel was accomplished before the end of the Wisconsin. If the till deposit near water level in Devil Canyon is older than the Naptowne event (Knik or Ekultna), it would indicate, an earlier incision date and that the river followed its present course since the Eary Wisconsin at least.

Numerous modifications of the glaciated surfaces and the development of non-glacial landforms has characterized the Sustina project area since the Pleistocene. The stream incision, as previously discussed, has produced or at least excavated the V-shaped Susitna River Valley within the wide glaciated valley floor. This has rejuvenated many tributary streams which are now down - cutting in their channels, as is evidenced by the steep gradients in the lower portions of their channels, lower gradients in the mid-channel section and frequently a waterfall niche - point separating these stream segments. Several low terraces (Fpt) have been formed above the modern floodplain (Fp) of the Susitna and its major tributaries. Terraces at several different levels were found throughout the Susitna River Valley. Some occur high on the valley walls as eroded terrace remnants (upstream of Watana Creek); while others appear as very recent, low, flat planar features. Near the mouth of Kosina Creek and in several other locations, the terrace materials overlie relatively shallow bedrock such that they may more accurately be called bedrock benches). Between the Oshetna and Tyone Rivers the thin terrace gravels overlie glacial till. The terraces are frequently modified by the deposition of alluvial fan debris (Ffg) and/or the flow of solifluction lobes and sheets (Cs) across their surfaces. Correlation of the terrace levels on the air photos is difficult because of the lack of continuity and was, therefore, not attempted. In the Gold Creek area three different, low level terraces are clearly visible and in the Tyone-Oshetna Rivers area four terrace levels can be discerned. Between these areas the terraces rarely occur in groups and are more widely spaced. Most tributary streams also show multiple terrace levels with the best example being in Tsusena Creek where five or more levels appear as steps on the valley wall.

The stream terraces are frequently modified by the deposition of alluvial fan debris (Ffg) and/or the flow of solifluction lobes and sheets (Cs) across their surfaces. Alluvial fans have also been deposited where steep small drainages debouch onto floors of wider glaciated valleys.

Frost cracking, cryoturbation and gravity have combined to form numerous colluvial deposits. Steep rubbley talus cones have accumulated below cliffs and on slightly less precipitious slopes thin deposites of frost churned soils cover bedrock terrain (C). On numerous slopes in highland areas (as long Devil Creek) and on the broad lowlands solifluction has modified the surficial glacial till and/or lacustrine deposits.

The development of a number of landslides (Cl) has occurred throughout the project area. Most landslides were found within the basal till unit (Gtb-f or L/Gtb-f) on steep slopes above actively eroding streams. The incidence of failure within this material appears to be strongly related to thawing permafrost and consequent soil saturation. The basal till unit is frequently overlain by lacustrine material and the lacustrine materials fail with the till. Most failures occur as small shallow debris slides or debris flows, however, a few large slump failures occur. The slumps and debris flows are marked with a special symbol on the Terrain Unit Maps. Steep rock slopes are assumed to be stable. However, this is undoubtedly not the case where unfavorably oriented discontinuities dip out of the rock slope. Such discontinuities must be identified and their effects assessed during on-site rock slope stability investigations.

Finally, revegetation of poorly drained portions of the landscape has produced numerous scattered deposits of organic materials (O); and permafrost has developed in many areas.

REGIONAL BEDROCK GEOLOGY

The bedrock geology of the Talkeetna Mountains and Upper Susitna River Basin is examined in numerous publications varying in nature from site specific to regional. The most comprehensive report is by Bela Csejtey (1978), entitled the Geology of the Talkeetna Mountains Quadrangle. This paper and map deals with the ages, lithology, structure, and tectonics of the regions rock units. His results, supplemented by unpublished data from recent project field mapping, are the basis of this report's bedrock unit identification. Csejtey (1978) concludes that southern Alaska developed by the accretion of a number of northwestward drifting continental blocks on to the North American plate. Each of these terrains had a somewhat independent and varied geologic history, consequently, many lithologies with abrupt and complex contacts are found. Csejtey notes that "the rocks of the Talkeetna Mountains region have undergone complex and intense thrusting, folding, faulting, shearing, and differential uplifting with associated regional metamorphism, and plutonism". He recognizes at least three major periods of deformation: "a period of intense metamorphism, plutonism, and uplifting in the Late Early to Middle Jurassic, the plutonic phase of which persisted into Late Jurassic; a Middle to Late Cretaceous alpine-type orogeny, the most intense and important of the three; and a period of normal and high-angle reverse faulting and minor folding in the Middle Tertiary, possibly extending into the Quaternary". Most of the major structural features of the Talkeetna Mountains trend northeast to southwest and were produced during the Cretaceous Orogeny.

Major bedrock lithologies as mapped by Csejtey, and included on the terrain unit maps, are summarized as follows:

Tv	Tertiary volcanic rocks of subaerial and shallow intrusive origin with a total thickness of over 1,500 feet. The lower part of the sequence consists of small stocks, irregular dikes, flows and thick layers of pyroclastic rocks of quartz latite, rhyolite and latite composition. The upper part of the sequence consists of andesite and basalt flows interlayered with tuff. These rocks are mapped in Fog Creek and its major tributary.
Tsu	Tertiary nonmarine sedimentary rocks including fluviatile conglomerate, sandstone, and claystone with a few thin lignite beds. The only known exposures of this unit are in Watana Creek.
Tbgd	Tertiary biotite granodiorite forming stocks which are believed to be the plutonic equivalent of unit Tv. The most extensive exposures are found on either side of the Susitna River from just upstream of the Devil Canyon damsite to the northward bend in the river about six miles upstream of Devil Creek. An outcrop of Tertiary hornblende granodiorite (Thgd) is located just west of Stephan Lake.
Tsmg	Tertiary schist, migmatite, and granite which display gradational contacts. The schist and lit-par-lit migmatite are probably products of contact metamorphism with the entire unit possibly representing the roof of a large stock. The rocks occur in apprxoimately equal proportions with the largest exposures occurring in Tsusena Butte, west of Deadman Creek, and in the rectangular southern jog in the Susitna River. Csejtey maps this unit at the Watana damsite, however, more recent field work (ACRES, 1981) has shown that the Watana damsite bedrock consists of diorite and andesite.
TKgr	Tertiary and/or Cretaceous granitic rocks forming small plutons the largest of which is found in the headwaters of Jay Creek.
Jam	Jurassic amphibolite with minor inclusions of greenschist and occasional interlayers of marble. The unit is probably derived from neighboring basic volcanic formations. The amphibolite extends from the Vee Canyon damsite downstream for about 12 miles. Other Jurassic rocks which occur in extremely limited exposures include Trondjemite (Jtr) and granodiorite (Jgd) lithologies.
TRv	Triassic basaltic metavolcanic rocks form in a shallow marine environment as evidenced by thin interbeds of metachert, argillite and marble. The individual flows are reported as up to 10 meters thick and displaying pillow structure and columnar jointing. This unit is mapped, in the project area, in the mountains east of Watana Creek.
Pzv	Late Paleozoic basaltic and andesitic metavolcanogenic rocks which form a broad band across the central Talkeetna Mountains from the southwest to the northeast. The 5,000+ foot sequence is dominantly marine in origin suggesting that it is part of a complex volcanic ore system. The majority of the band of this unit crosses the project area just west of Tsisi, Kosina and Jay Creeks. Near the top of this unit several metamorphosed limestone reef deposits (Pls) have been mapped.
Kag	Cretaceous argillite and graywacke of a thick intensely deformed flyschlike turbidite sequence. Low grade dynametamorphism to the low greenschist facies has allowed several early investigators to map portions of this unit as phyllite. The graywacke beds form about 30% to 40% of the unit and tend to be clustered in zones 1 to 5 meters thick. This unit is exposed at the Devil Canyon site. It extends downstream beyond Gold Creek and forms the mountain immediately east of Gold Creek.
TRvs	Triassic metabasalt and slate in an interbedded, shallow marine sequence found in two allochthonous blocks in the upper sections of Portage Creek.

Several of the above units have been used to describe rocks mapped by Acres between the Watana and Devil Canyon damsites. Where this data was available it took precidence over Csejtey's map.

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DATE	NO.	REVISIONS	CH.	APP.	APP.

TERRAIN UNIT SYMBOL	TERRAIN UNIT NAME	TOPOGRAPHY AND AREAL DISTRIBUTION	SOIL STRATIGRAPHY	SLOPE CLASSI-FICATION	PROBABLE UNIFIED SOIL TYPES	DRAINAGE AND PERMEABILITY IN UNFROZEN SOILS	EROSION POTENTIAL	GROUND WATER TABLE	PROBABLE PERMAFROST DISTRIBUTION	FROST HEAVE POTENTIAL	THAW SETTLEMENT POTENTIAL	BEARING STRENGTH	SLOPE STABILITY	SUITABILITY AS SOURCE OF BORROW
Bxu	Unweathered, consolidated bedrock	Cliffs in river canyon rounded knobs on broad valley floor and mountain peaks.	–	Moderate to Near-Vertical	–	–	Low	Deep	–	Nil	Nil	Very High	Moderate to High	Fine - Poor Coarse - Good
C	Colluvial deposits	Predominantly found at the base of steeper bedrock slopes as coalescing cones and fans and rock glacier.	Angular frost cracked, blocks of rock, some silt and sand.	Moderate to Steep	GP, GW, GM SW, SM	Good/High	Moderate to High	Deep	Sporadic at Low Elevation. Discontinuous at High Elevations	Low to High	Low to Moderate	Low to Moderate	Low to Moderate	Fine - Poor Coarse - Variable
Cl	Landslide deposits	Hummocky unconsolidated deposits most common along the Susitna River and its major tributaries.	Silty gravels, silty sands and sandy silts; possible crude contorted layers.	Moderate to Steep	GM, SM, ML	Poor/Low	High	Shallow (perched)	Active - Unfrozen Inactive - Sporadic	High	High where frozen	Low	Low	Poor
Cs-f	Solifluction deposits	Relatively smooth to labate topography created by the flow of materials subjected to frequent freeze/thaw cycles.	Silty sand and sandy silt showing contorted layering.	Gently to Steeping Sloping	SW, SM, ML	Frozen	High	Shallow (perched)	Discontinuous to Continuous	High	High	High	Low	Poor
Ffg	Granular alluvial fan	Low cone shaped deposits formed where high gradient streams flow onto flat surfaces.	Rounded cobbles and gravel with sand and some silt, some sorting and layering of materials.	Moderate	GW, SW	Good/High	Moderate	Shallow	Unfrozen	Low	Low	High	High	Fine - Poor Coarse - Good
Fp	Floodplain deposits	Flat plains, slightly above and adjacent to the present Susitna River and its major tributaries.	Rounded cobbles, gravel and sand sorted and layered. With or without silt cover.	Flat to Gentle	GW, GP, SW SP, SM	Good/High	High	Very Shallow	Unfrozen	Generally Low (High for surface cover)	Low	Surficial Silts Low, Sands and Gravels High	High	Fihe - Poor Coarse - Good
Fpt	Terrace	Flat surface remnants of former floodplain deposits isolated above present floodplain.	Rounded cobbles, gravel and sand with some silt covered by a thin silt layers. Sorted and layered.	Flat to Gentle	GW, GP, SW, SP, SM, ML	Good/High	Low	Deep	Unfrozen	Generally Low (High for surface cover	Low	High	Low to Moderate	Fine - Poor Coarse - Good
GFo	Outwash deposits	Bottoms of U-shaped tributary valleys and adjacent to Susitna area.	Rounded & striated cobbles, gravel and sand, crudely sorted and layered.	Gentle	GW, SW	Good/High	Moderate	Shallow to Deep	Unfrozen	Low	Low	High	Low to High	Fine - Poor Coarse - Excellent
GFe	Esker deposits	Rounded to sharp crested sinuous ridges in upper Susitna area.	Rounded & striated cobbles, gravel, and sand. Crudely to well sorted and layered.	Steep Local Slopes	GW, SW	Good/High	Moderate	Deep	Unfrozen	Low	Low	High	Moderate	Fine - Poor Coarse - Excellent
GFk	Kame deposits	Rounded to sharp-crested, hummocky hills.	Rounded & striated cobbles, gravel, and sand. Crudely sorted and layered.	Steep Local Slopes	GW, SW	Good/High	Moderate	Deep	Unfrozen	Low	Low	High	Moderate	Fine - Poor Coarse - Excellent
Gta	Ablation till	Tributary valley side walls and valley bottoms in general, between Tsusena and Deadman Creek hummocky rolling surface, numerous channels.	Rounded and striated cobbles, gravel, and sand, no sorting or layering. Boulder-cobble lag covering surface.	Gentle to Steep	GW, GM, SW, SM	Moderate/Moderate	Moderate	Shallow to Moderately deep	Unfrozen to Sporadic	Low to Moderate	Low to Moderate	Moderate to High	Moderate	Fine - Poor Coarse - Fair
Gtb-f	Basal till (frozen)	Bottoms of larger U-shaped valleys and adjacent gentle slopes.	Gravely silty sand and gravely sandy silt; no layering or sorting; cobbles and boulders poorly rounded and striated.	Gentle to steep	GM, SM, ML	Frozen	Moderate	Shallow (perched) to Deep	Discontinuous to Continuous	High	High	Low if Thawed. High when frozen	Low	Fine - Fair Coarse - Poor
O	Organic deposits	In swales between small rises on lowlands and in high elevation bedrock areas. Flat surface to steplike terraces.	Decomposed and undecomposed organic material with some silt.	Flat	PT, OL	Poor/Moderate to High	Low	At Surface	Discontinuous	High	High	Very Low	Low	Nil
L-f	Lacustrines (frozen)	Lowlands (below 3000') flat surface in the Tyone - Oshetna River area.	Sandy silt and silty sand with occasional pebbles, to gravelly sand. Often sorted and layered.	Gentle	SP, SW, ML	Frozen	High	Shallow (perched)	Discontinuous to Continuous	High	High	Low when Thawed. High when Frozen	Low	Poor
L / Gta	Lacustrine sediments over ablation till	Gently rolling to hummocky surface surrounding Butte Lake	Stratified sandy silt and silty sand over unsorted silty sandy gravel.	Gentle to Moderate	SP, SW, ML / GW, GM, SW, SM	Poor/Moderate	Moderate	Shallow	Sporadic	Moderate to High	Moderate to High	Low if Thawed. High when Frozen	Low	Fine - Poor Coarse - Fair
L / Gtb-f	Lacustrine deposits over basal till	Lowlands, (below 3000') between Stephan Lake and Watana Creek, and extending upstream past the Tyone River.	Well sorted silty sand and sandy silt overlying basal till.	Gentle to Moderate	SP, SW, ML, / SM, SM, ML	Lacustrine-Good/Good Basal Till-Frozen	Lacustrine-High Basal Till-Moderate	Moderately deep	L - sporadic to Discontinuous Gtb-f - Discontinuous to Continous	High	High	Low if Thawed. High when frozen	Low	Poor
Cs-f / Gtb-f	Solifluction deposits (frozen) over basal till (frozen)	Smooth to lobate steplike topography on gentle slopes above the proglacial lake level, west of Tsusena Creek.	Unsorted gravels, sands & silts with thin ice layers, contorted soil layering.	Moderate to Steep	GM, SM, ML	Frozen	Moderate	Shallow (perched)	Discontinuous to Continuous	High	High	Low when Thawed. High when Frozen	Low	Poor
Cs-f / Gta	Solifluction deposits (frozen) over ablation till	Smooth to lobate and hummocky topography along Deadman Creek	Silty, sandy, gravel and silty gravely sand showing contorted layering.	Moderate to Steep	GW, SW GM, SM	Frozen	Moderate	Shallow (perched) to Deep	Discontinuous to Continuous	High	High	Low if Thawed. High when Frozen	Low	Poor
Cs-f / Fpt	Solifluction deposits (frozen) over terrace sediments	Smooth to lobate flows of frozen fine grained materials, found on terrace of the Susitna, frequent between the Tyone and Oshetna Rivers.	Silty, sand and sandy silt showing contorted layering over gentle sorted and layered rounded cobbles, gravel and sand.	Gentle	SW, SM, ML / GW, SP, SW SP, SM, ML	Frozen	Moderate	Shallow (perched) to Deep	Discontinuous	High	High	High when Frozen. Low when Thawed.	Low	Fine - Poor Coarse - Good
Cs-f / Bxu	Solifluction deposits (frozen) over bedrock	Smooth to lobate steplike topography on the flanks of some mountains, north and south of the Devil Canyon area.	Mixed gravels sands and silts with thin ice layers and faint contorted soil layering over bedrock.	Moderate to Steep	GW, GM SW, SM, ML / bedrock	Frozen	High	Shallow (perched)	Discontinuous	High	High	High	Low	Poor
Gtb-f / Bxu	Frozen basal till over bedrock	Rolling lowland areas and moderate to steeply sloping river canyon walls. Transitional to high mountains areas.	Gravels, silty sand and sandy silt with no layering or sorting, overlying bedrock.	Moderate to Steep	SP, SM, ML, / bedrock	Frozen	Moderate	Shallow (perched)	Discontinuous to Continuous	High	High	Low if Thawed. High when Frozen	Low	Poor
Gta / Bxu	Ablation till over un-weathered bedrock	Hummocky rolling surface transitional to higher mountains adjacent to Deadman Creek.	Rounded and striated cobbles, gravel and sand, no sorting or layering, over bedrock.	Gentle to Steep	GW, GM, SW, SM / bedrock	Good/ High	Moderate	Shallow to Moderately deep	Sporadic	Low to Moderate	Low to Moderate	Low if Thawed High when Frozen	Moderate	Fine - Poor Coarse - Fair
C / Bxu + Bxu	Colluvium over bedrock and bedrock exposures	Higher elevation mountain areas and steep slopes along the Susitna River and its major tributaries.	Angular blocks of rock with some sand and silt overlying bedrock.	Steep to Near Vertical	GP, GW, GM, SW, SM / Bedrock	Good/Low to High	Moderate to High	Deep	Sporadic	Low to High	Low to Moderate	Low to Very High	Moderate to High	Fine - Poor Coarse - Fair
C / Bxw + Bxw	Colluvium over weathered, poorly consolidated bedrock	Small cliffs cut into tertiary non-marine sediments along Watana Creek and tertiary volcanics in Fog Creek.	Angular rubble with silt and sand over poorly consolidated sand over poorly consolidated or highly weathered bedrock.	Steep to Near Vertical	GM, SM, ML, GW, SW	Good/Low to Moderate	Moderate	Deep	Sporadic to Discontinuous	Low to High	Low to Moderate	Low to Moderate	Moderate	Fine - Poor Coarse - Poor

TERRAIN UNIT PROPERTIES AND ENGINEERING INTERPRETATIONS

DATE	NO.	REVISIONS	CH.	APP.	APP.

ACRES

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

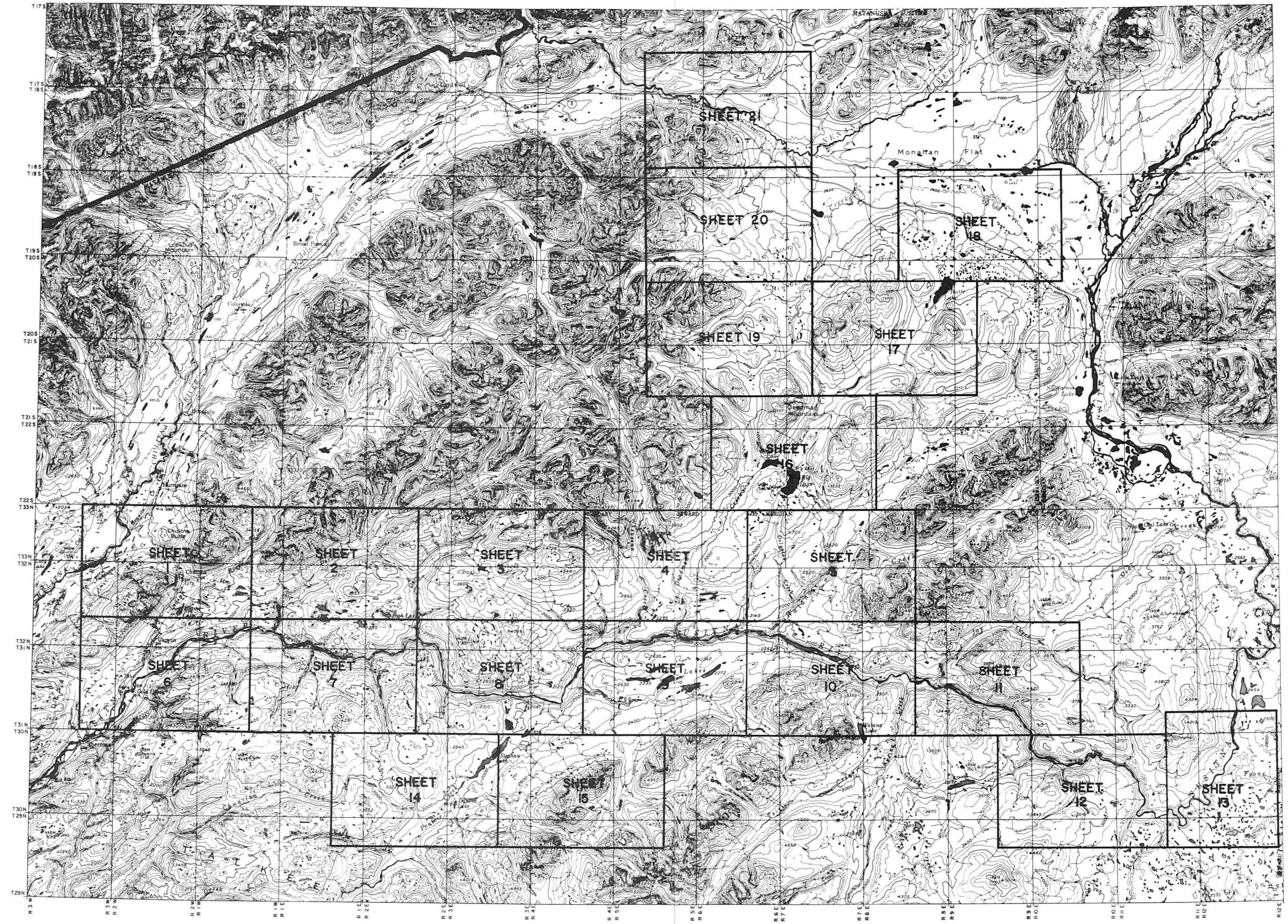
SUBTASK 5.02

PHOTO INTERPRETATION

R&M CONSULTANTS, INC.

DATE APRIL 1981

PROJECT 052502



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ACRES

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT INDEX MAP

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

DATE APRIL 1981

DEPARTMENT

PROJECT 052502

SCALE

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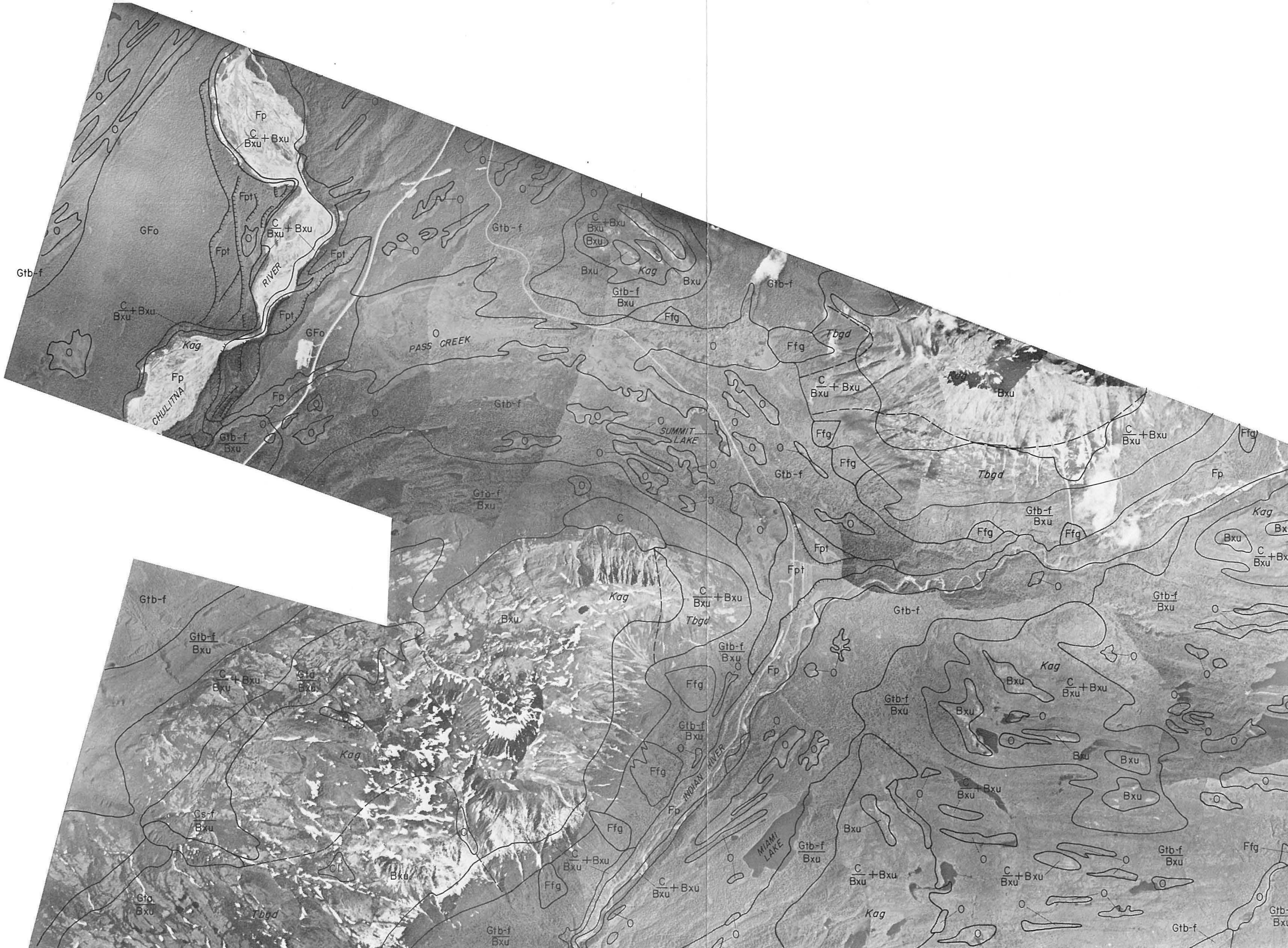

FOR CONTINUATION, SEE SHEET 2

FOR CONTINUATION, SEE SHEET 6

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
$\frac{L}{Gta}$	Lacustrine sediments over ablation till
$\frac{L}{Gtb\text{-}f}$	Lacustrine deposits over basal till (frozen)
$\frac{Cs\text{-}f}{Gtb\text{-}f}$	Solifluction deposits (frozen) over basal till (frozen)
$\frac{Cs\text{-}f}{Gta}$	Solifluction deposits (frozen) over ablation till
$\frac{Cs\text{-}f}{Fpt}$	Solifluction deposits (frozen) over terrace sediments
$\frac{Cs\text{-}f}{Bxu}$	Solifluction deposits (frozen) over bedrock
$\frac{Gtb\text{-}f}{Bxu}$	Frozen basal till over bedrock
$\frac{Gta}{Bxu}$	Ablation till over un-weathered bedrock
$\frac{C}{Bxu}$ + Bxu	Colluvium over bedrock and bedrock exposures
$\frac{C}{Bxw}$ + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*T̄Rv*	*Pzv (Pls)*	*Kag*	*T̄Rvs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

DEPARTMENT

PROJECT 052502

SCALE

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FOR CONTINUATION, SEE SHEET 1

FOR CONTINUATION, SEE SHEET 3

FOR CONTINUATION, SEE SHEET 7

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over un-weathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consoli-dated bedrock

Bedrock Mapping Units	Tv	Tsu	Tbgd	Tsmg	TKgr	Jam (Jtr)(Jgd)	R̄v	Pzv (Pls)	Kag	R̄vs
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

DATE	NO.	REVISIONS	CH.	APP.	APP.

ACRES

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

DEPARTMENT

PROJECT 052502

SCALE

DRAWING NO.

SHEET 2 OF 21

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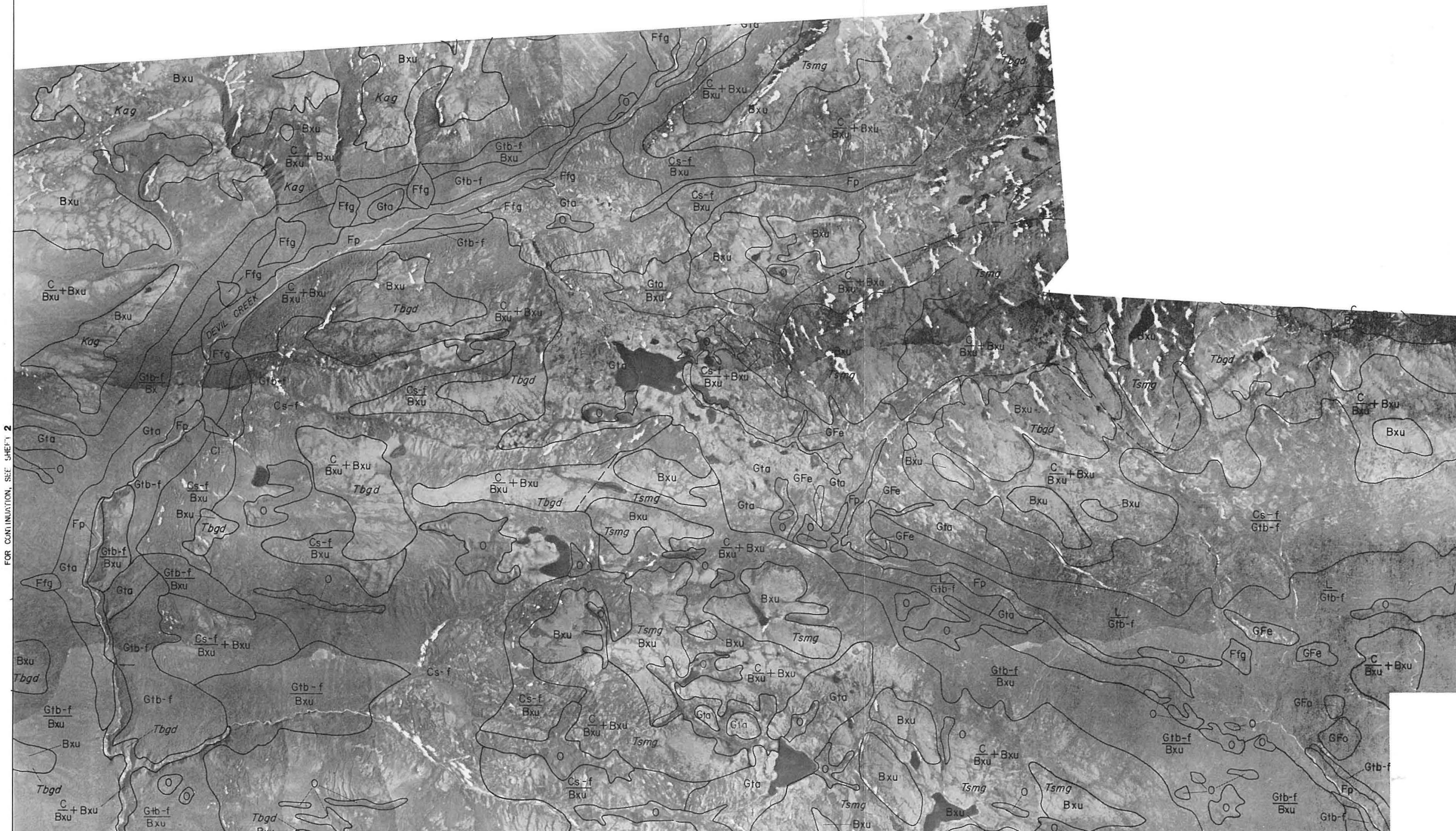
FOR CONTINUATION, SEE SHEET 2



FOR CONTINUATION, SEE SHEET 4

FOR CONTINUATION, SEE SHEET 8

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over un-weathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*R̄v*	*Pzv (Pls)*	*Kag*	*R̄vs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

DEPARTMENT

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SHEET 3 OF 21

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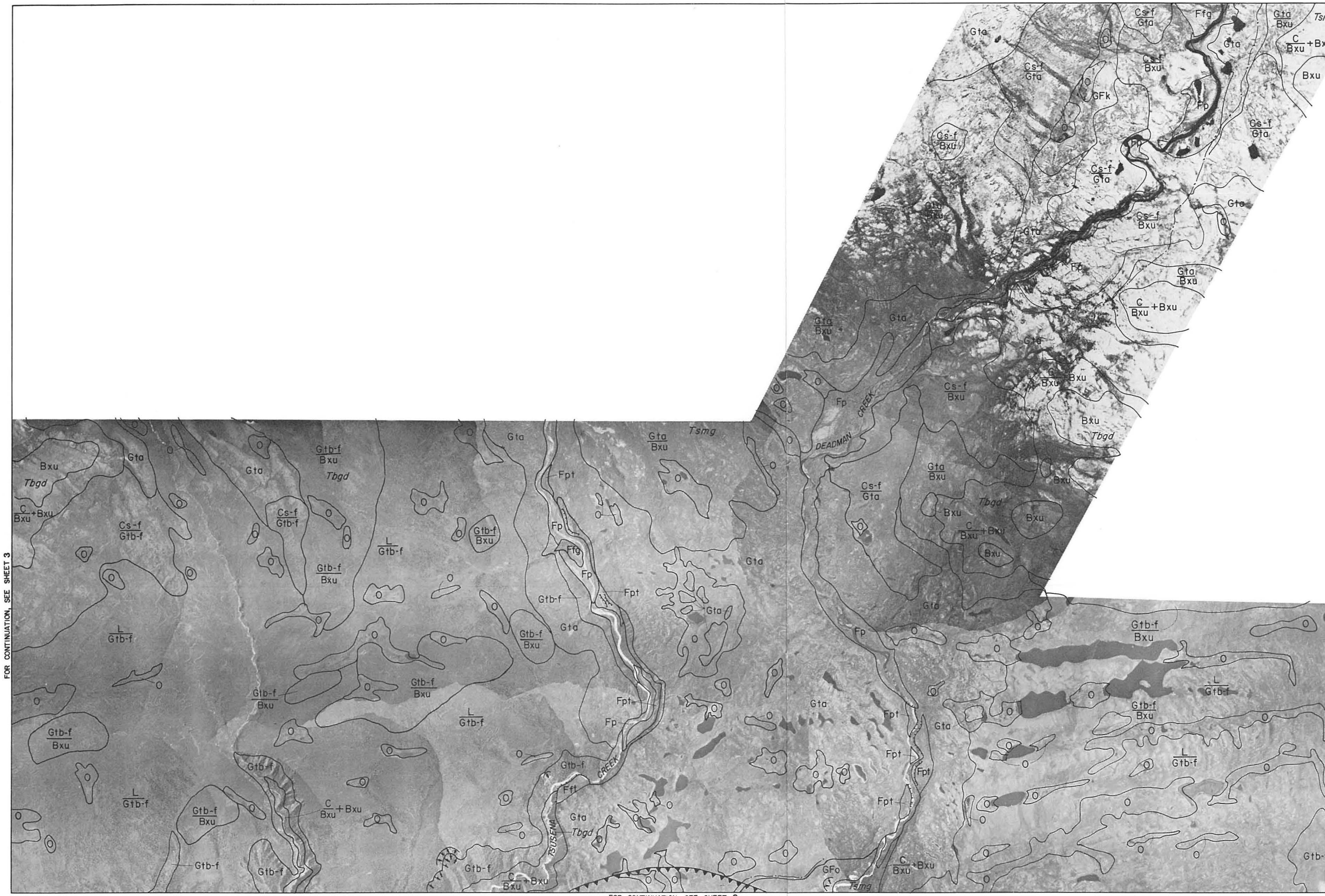

FOR CONTINUATION, SEE SHEET 3

FOR CONTINUATION, SEE SHEET 5

FOR CONTINUATION, SEE SHEET 9

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
$\frac{L}{Gta}$	Lacustrine sediments over ablation till
$\frac{L}{Gtb\text{-}f}$	Lacustrine deposits over basal till (frozen)
$\frac{Cs\text{-}f}{Gtb\text{-}f}$	Solifluction deposits (frozen) over basal till (frozen)
$\frac{Cs\text{-}f}{Gta}$	Solifluction deposits (frozen) over ablation till
$\frac{Cs\text{-}f}{Fpt}$	Solifluction deposits (frozen) over terrace sediments
$\frac{Cs\text{-}f}{Bxu}$	Solifluction deposits (frozen) over bedrock
$\frac{Gtb\text{-}f}{Bxu}$	Frozen basal till over bedrock
$\frac{Gta}{Bxu}$	Ablation till over un-weathered bedrock
$\frac{C}{Bxu}$+Bxu	Colluvium over bedrock and bedrock exposures
$\frac{C}{Bxw}$+Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*R̄v*	*Pzv (Pls)*	*Kag*	*R̄vs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

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PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

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PROJECT 052502

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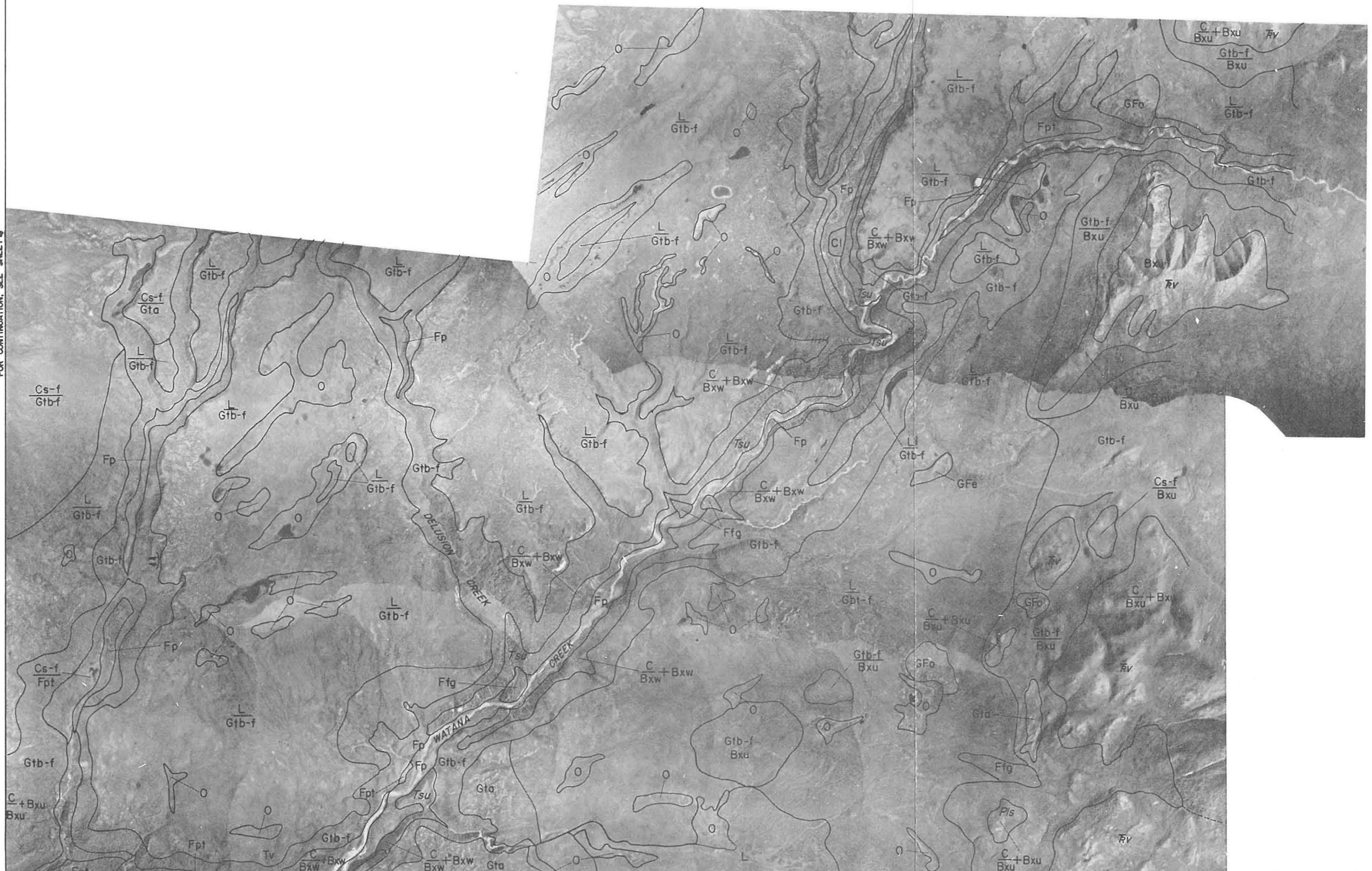

FOR CONTINUATION, SEE SHEET 10

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over unweathered bedrock
C/Bxu+Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw+Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*T̶Rv*	*Pzv (Pls)*	*Kag*	*T̶Rvs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp　Slide Scar　Buried Channel　Trail　Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

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FOR CONTINUATION, SEE SHEET 7

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over unweathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	Tv	Tsu	Tbgd	Tsmg	TKgr	Jam (Jtr)(Jgd)	₮v	Pzv (Pls)	Kag	₮vs
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

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TERRAIN UNIT MAPS

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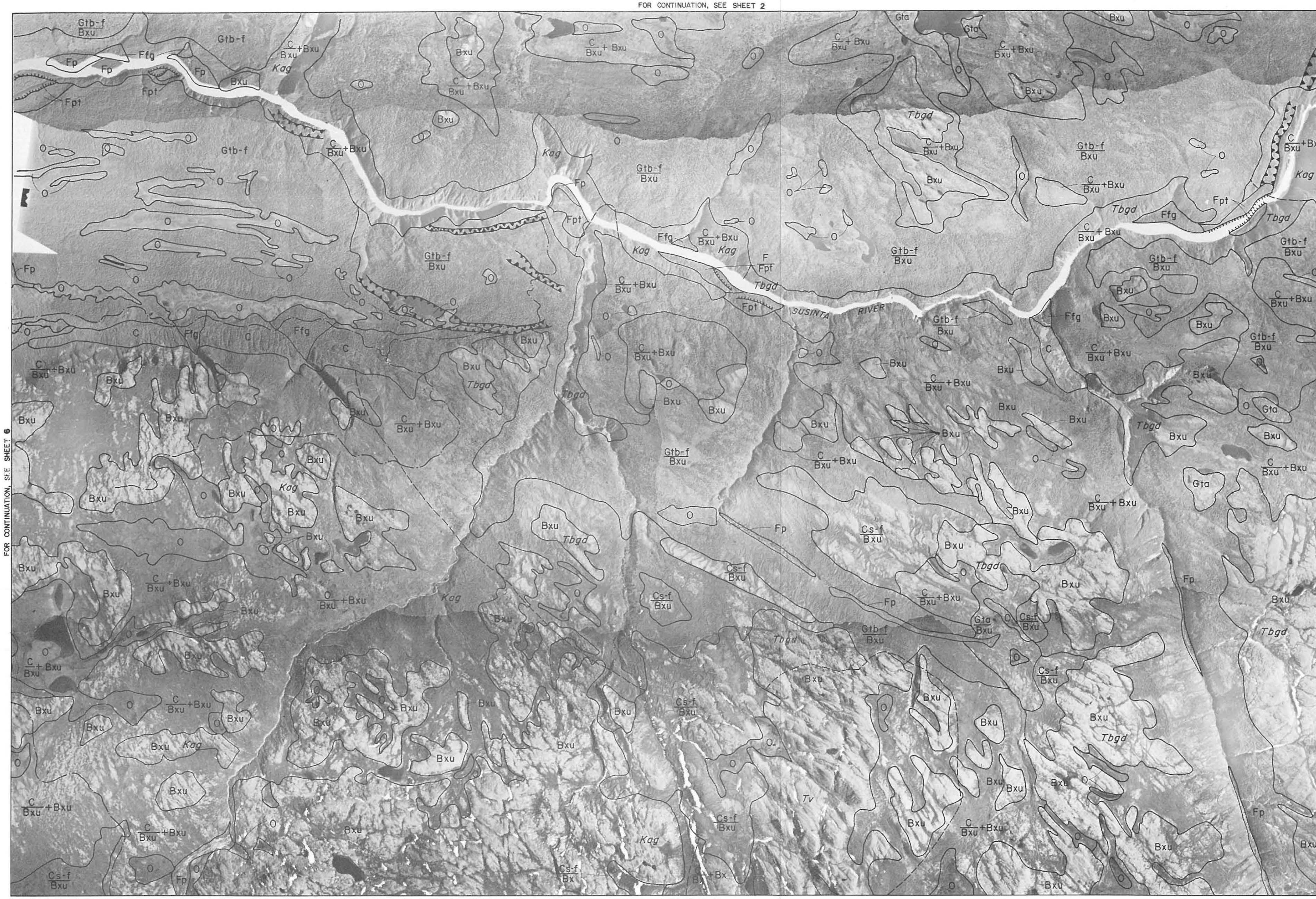

FOR CONTINUATION, SEE SHEET 8

FOR CONTINUATION, SEE SHEET 14

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over un-weathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consoli-dated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*T̄Rv*	*Pzv (Pls)*	*Kag*	*T̄Rvs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

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FOR CONTINUATION, SEE SHEET 14

FOR CONTINUATION, SEE SHEET 15

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L / Gta	Lacustrine sediments over ablation till
L / Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f / Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f / Gta	Solifluction deposits (frozen) over ablation till
Cs-f / Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f / Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f / Bxu	Frozen basal till over bedrock
Gta / Bxu	Ablation till over un-weathered bedrock
C / Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C / Bxw + Bxw	Colluvium over weathered or poorly consoli-dated bedrock

Bedrock Mapping Units	Tv	Tsu	Tbgd	Tsmg	TKgr	Jam (Jtr)(Jgd)	₹v	Pzv (Pls)	Kag	₹vs
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

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TERRAIN UNIT MAPS

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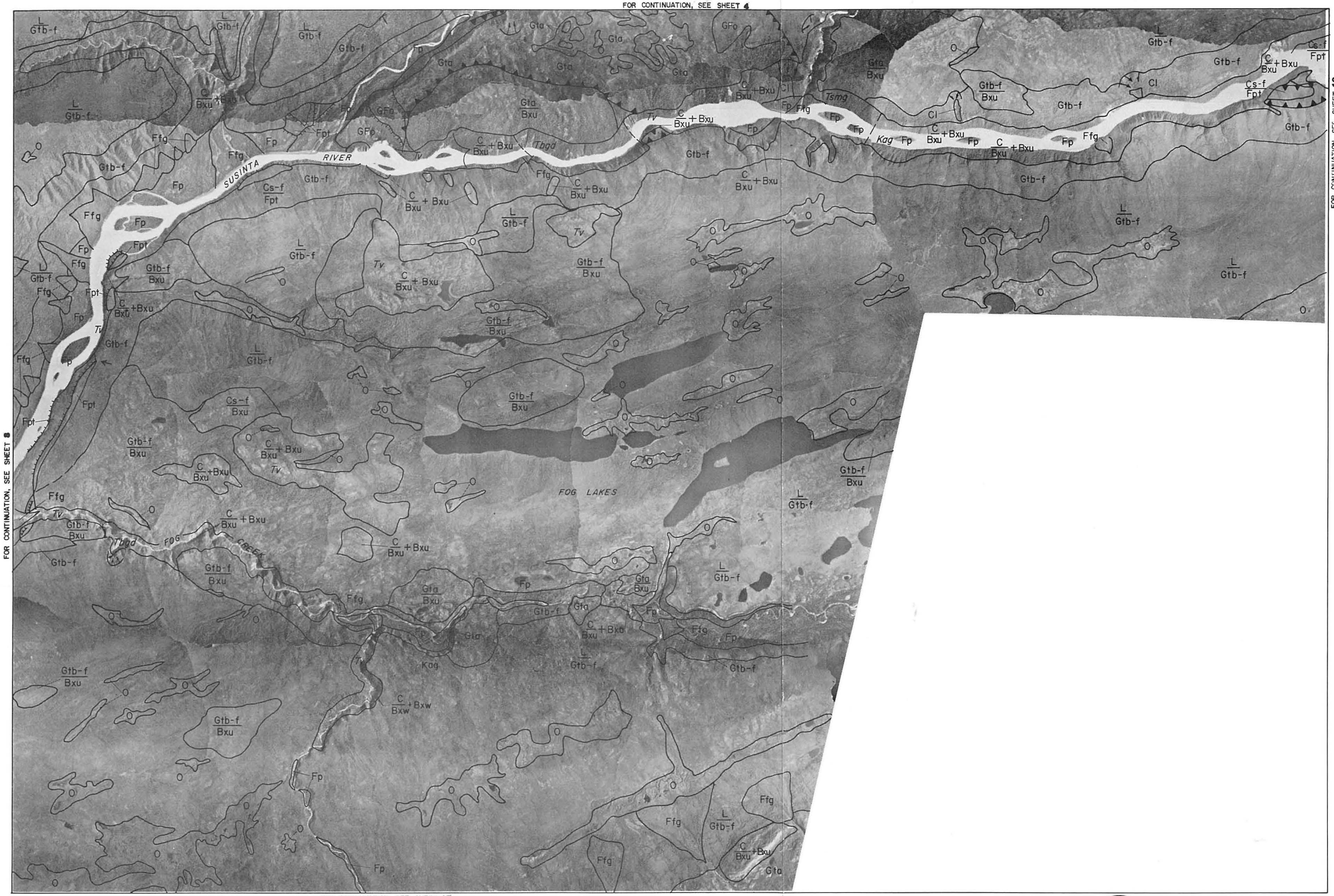

FOR CONTINUATION, SEE SHEET 10

FOR CONTINUATION, SEE SHEET 15

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
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Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over unweathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*TRv*	*Pzv (Pls)*	*Kag*	*TRvs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp · Slide Scar · Buried Channel · Trail · Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

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DEPARTMENT | DRAWING NO. | REV.
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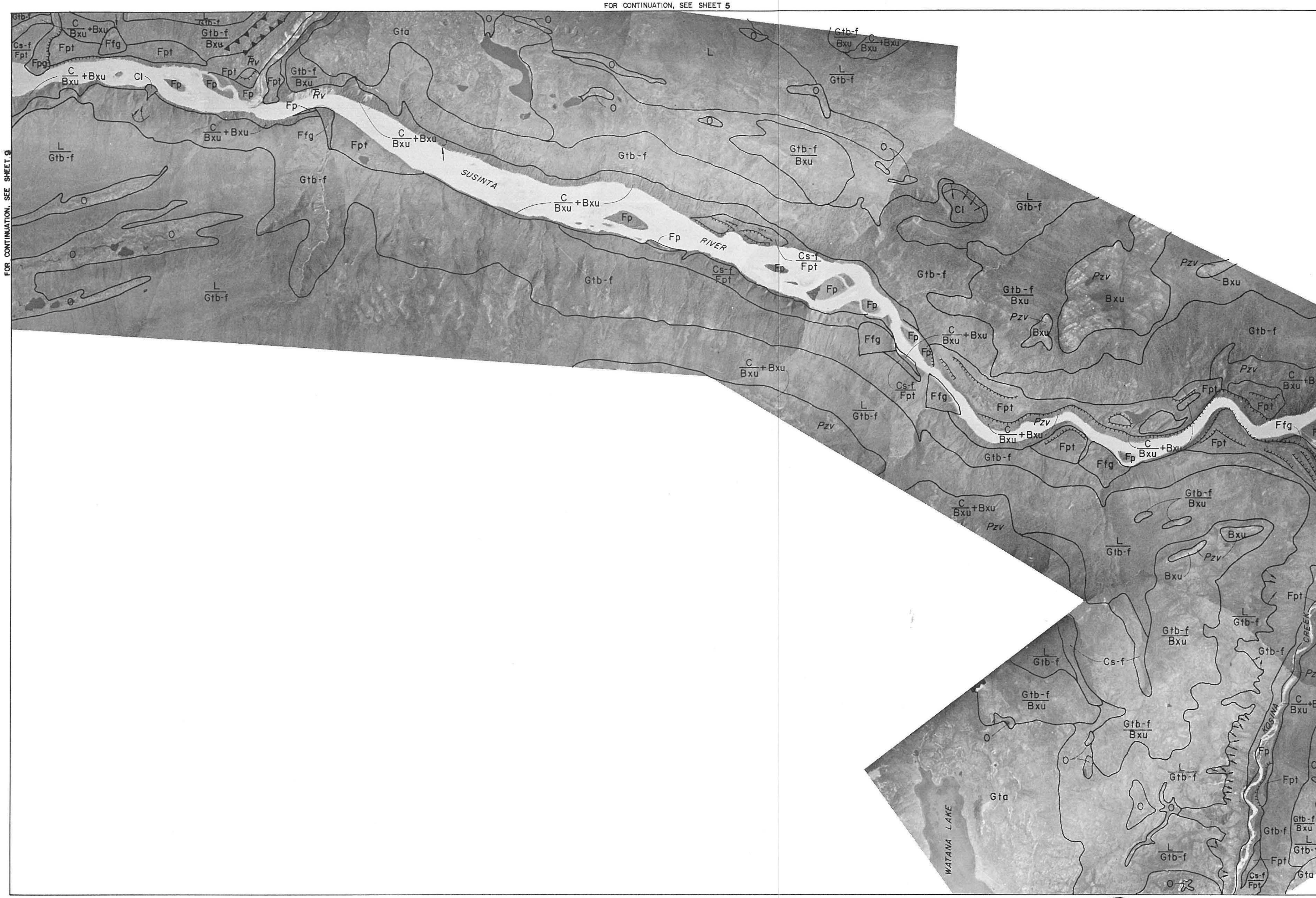

FOR CONTINUATION, SEE SHEET 11

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
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Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over unweathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
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Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*Ŧv*	*Pzv (Pls)*	*Kag*	*Ŧvs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981
DEPARTMENT
PROJECT 052502
SCALE
DRAWING NO.
SHEET 10 OF 21
REV.

FOR CONTINUATION, SEE SHEET 10

FOR CONTINUATION, SEE SHEET 12

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over unweathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	Tv	Tsu	Tbgd	Tsmg	TKgr	Jam (Jtr)(Jgd)	R̄v	Pzv (Pls)	Kag	R̄vs
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

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DRAWING NO.

SHEET 11 OF 21

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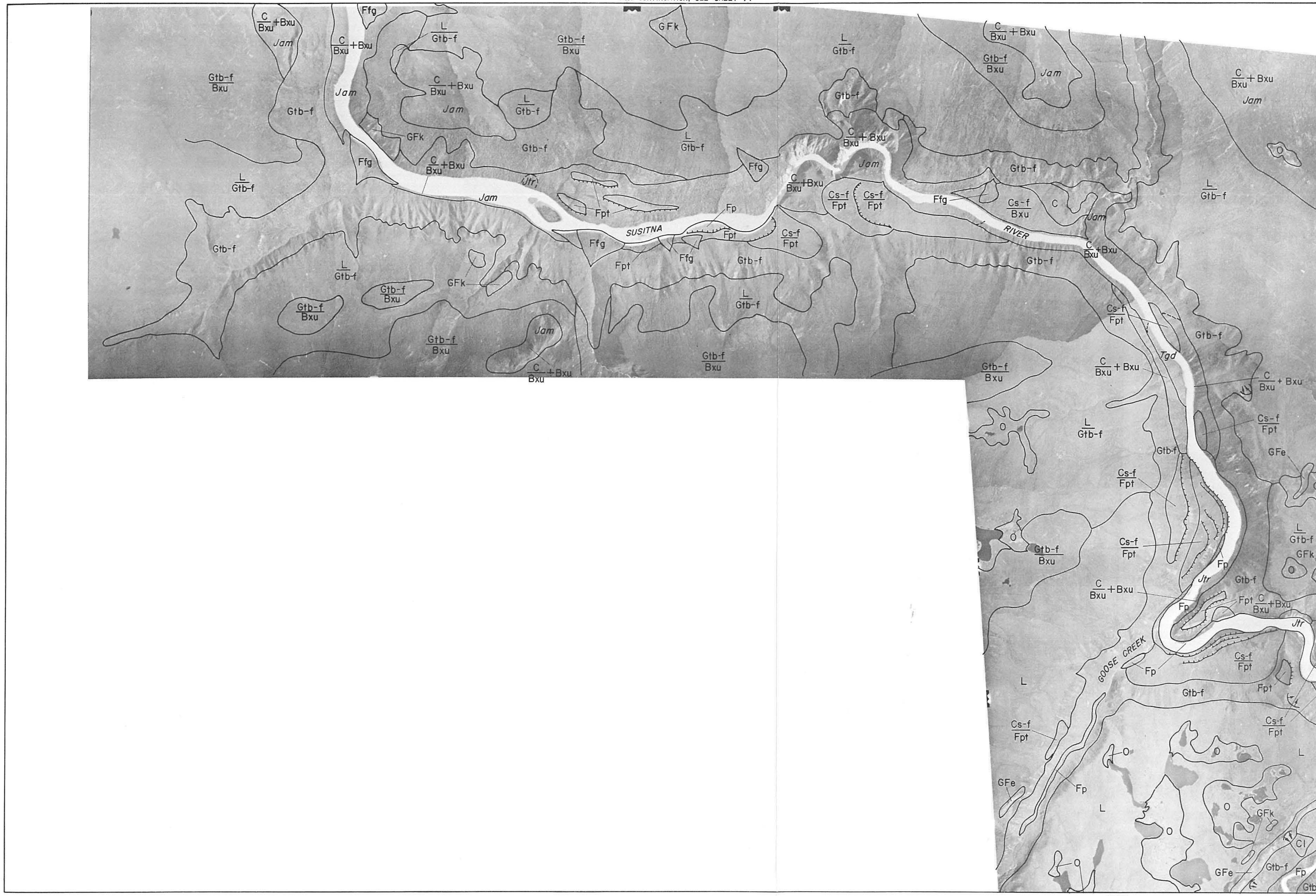
FOR CONTINUATION, SEE SHEET 11



FOR CONTINUATION, SEE SHEET 13

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over un-weathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consoli-dated bedrock

Bedrock Mapping Units	Tv	Tsu	Tbgd	Tsmg	TKgr	Jam (Jtr)(Jgd)	TRv	Pzv (Pls)	Kag	TRvs
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

DATE APRIL 1981

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PROJECT 052502

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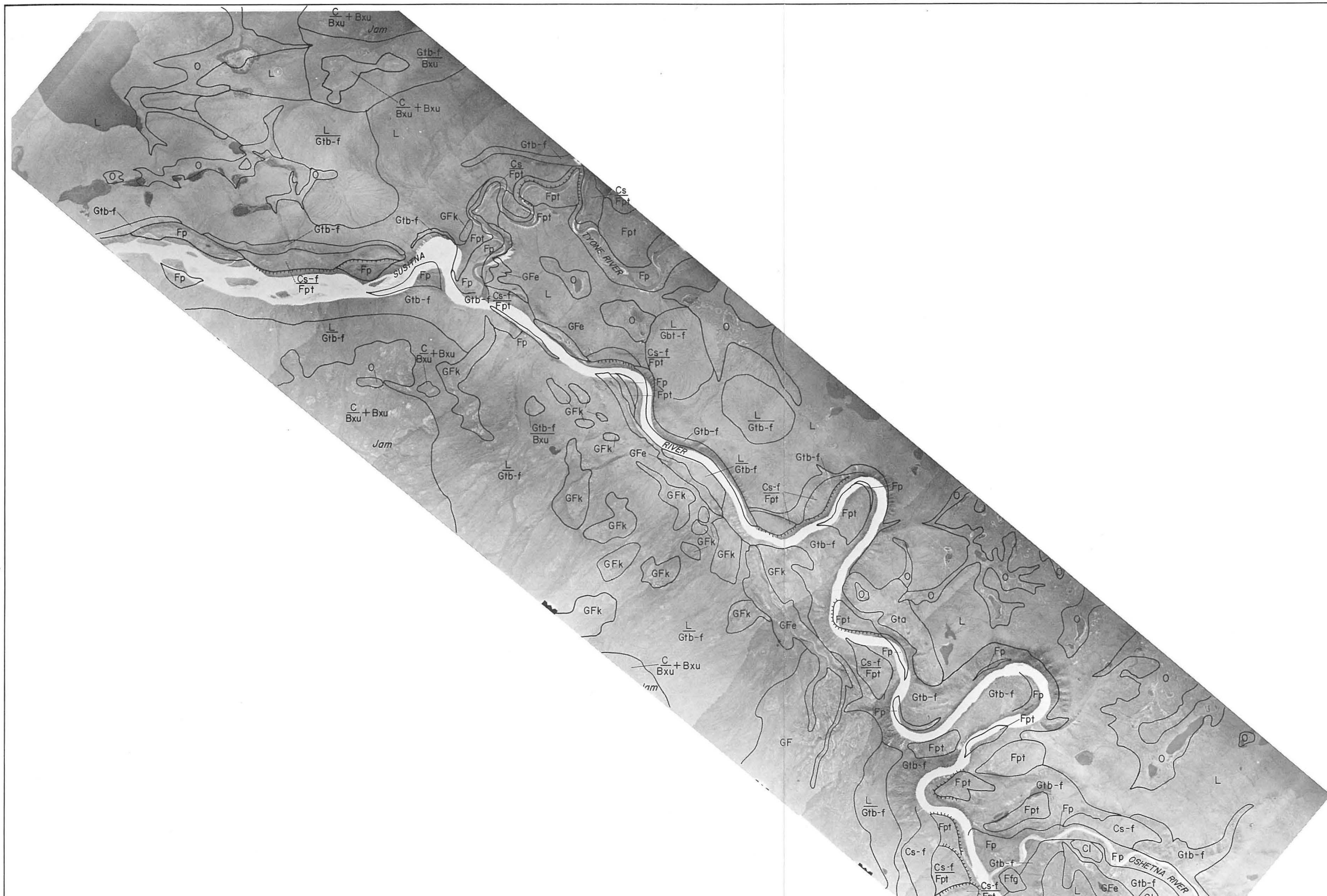

FOR CONTINUATION, SEE SHEET 12

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over unweathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*T̄v*	*Pzv (Pls)*	*Kag*	*T̄vs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp · Slide Scar · Buried Channel · Trail · Rock Contact

SCALE 0 2000 4000 FEET

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SUSITNA HYDROELECTRIC PROJECT

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PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

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FOR CONTINUATION, SEE SHEET 7

FOR CONTINUATION, SEE SHEET 8

FOR CONTINUATION, SEE SHEET 15

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L / Gta	Lacustrine sediments over ablation till
L / Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f / Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f / Gta	Solifluction deposits (frozen) over ablation till
Cs-f / Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f / Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f / Bxu	Frozen basal till over bedrock
Gta / Bxu	Ablation till over unweathered bedrock
C / Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C / Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	Tv	Tsu	Tbgd	Tsmg	TKgr	Jam (Jtr)(Jgd)	₮v	Pzv (Pls)	Kag	₮vs
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp | Slide Scar | Buried Channel | Trail | Rock Contact

SCALE 0 2000 4000 FEET

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SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

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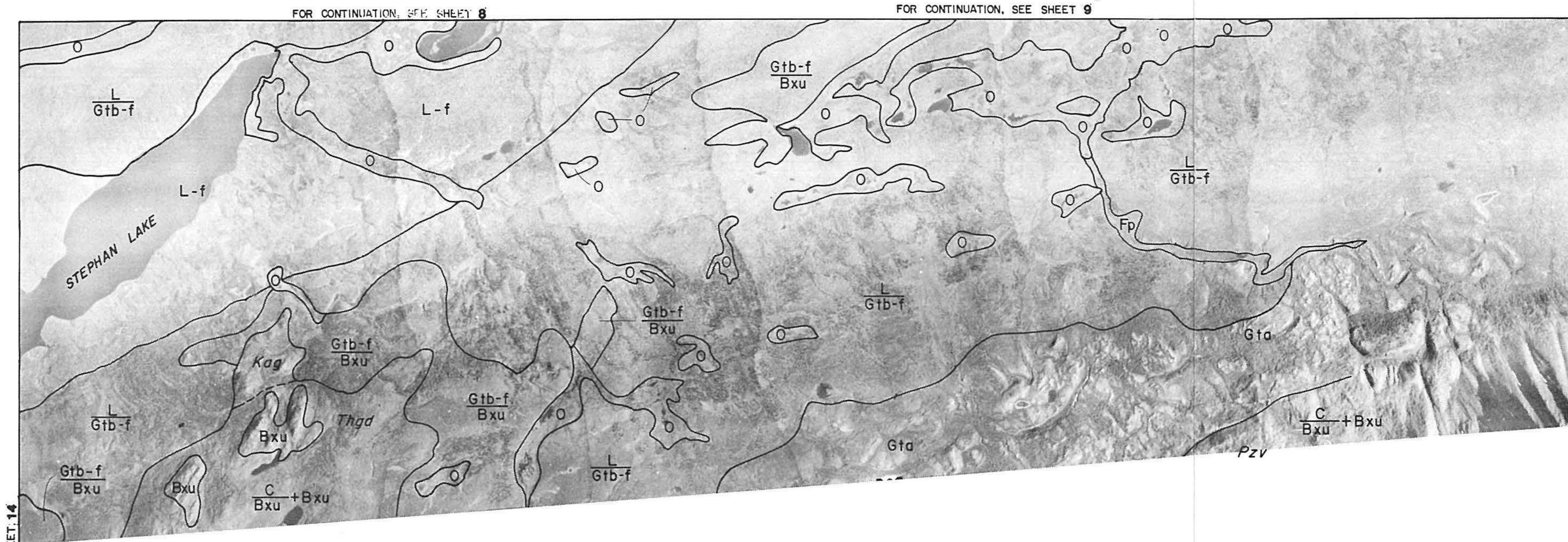
FOR CONTINUATION, SEE SHEET 8
FOR CONTINUATION, SEE SHEET 9
FOR CONTINUATION, SEE SHEET 14



Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L / Gta	Lacustrine sediments over ablation till
L / Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f / Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f / Gta	Solifluction deposits (frozen) over ablation till
Cs-f / Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f / Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f / Bxu	Frozen basal till over bedrock
Gta / Bxu	Ablation till over unweathered bedrock
C / Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C / Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	Tv	Tsu	Tbgd	Tsmg	TKgr	Jam (Jtr)(Jgd)	₸v	Pzv (Pls)	Kag	₸vs
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

DEPARTMENT

PROJECT 052502

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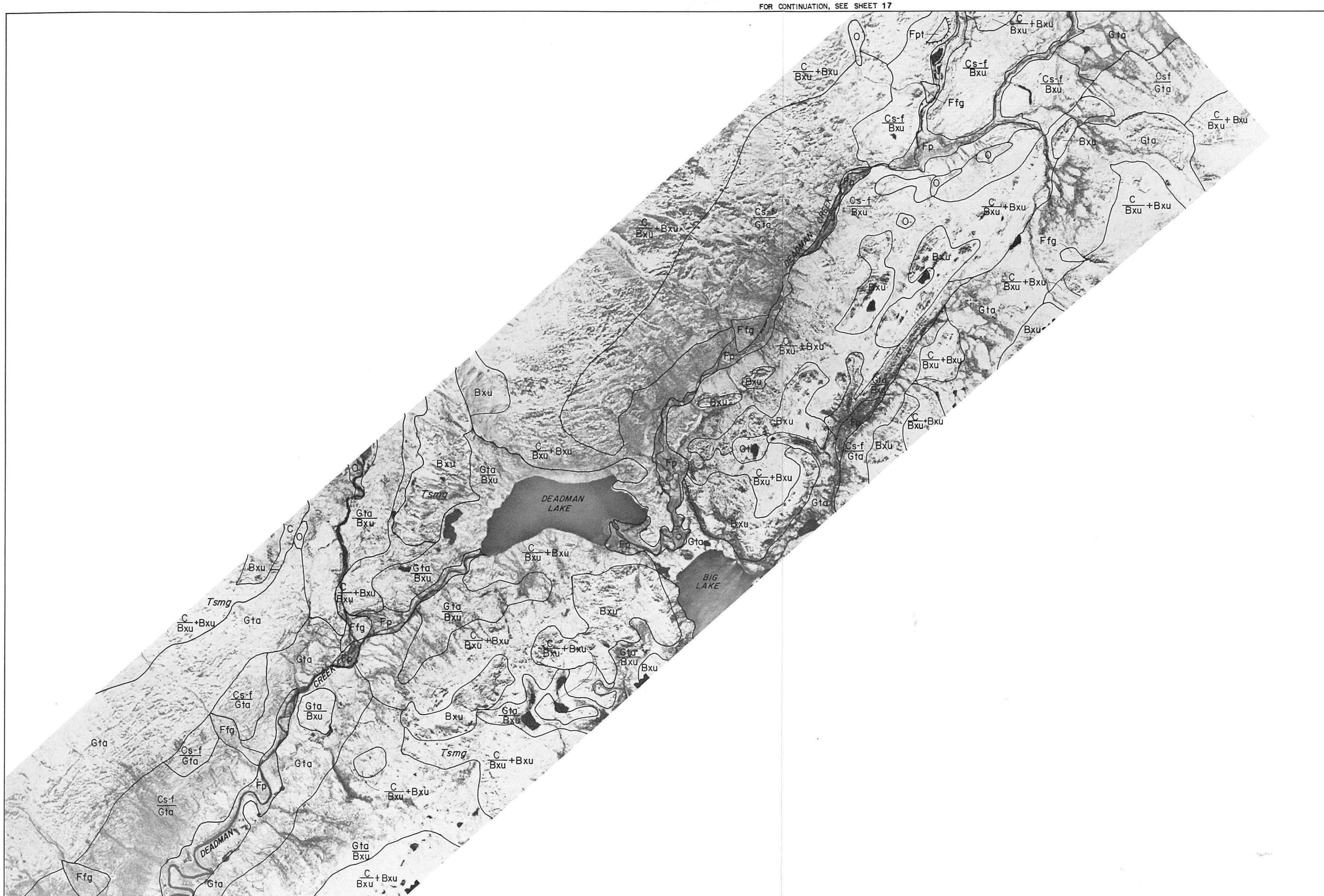

FOR CONTINUATION, SEE SHEET 9

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over un-weathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consoli-dated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*TRv*	*Pzv (Pls)*	*Kag*	*TRvs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

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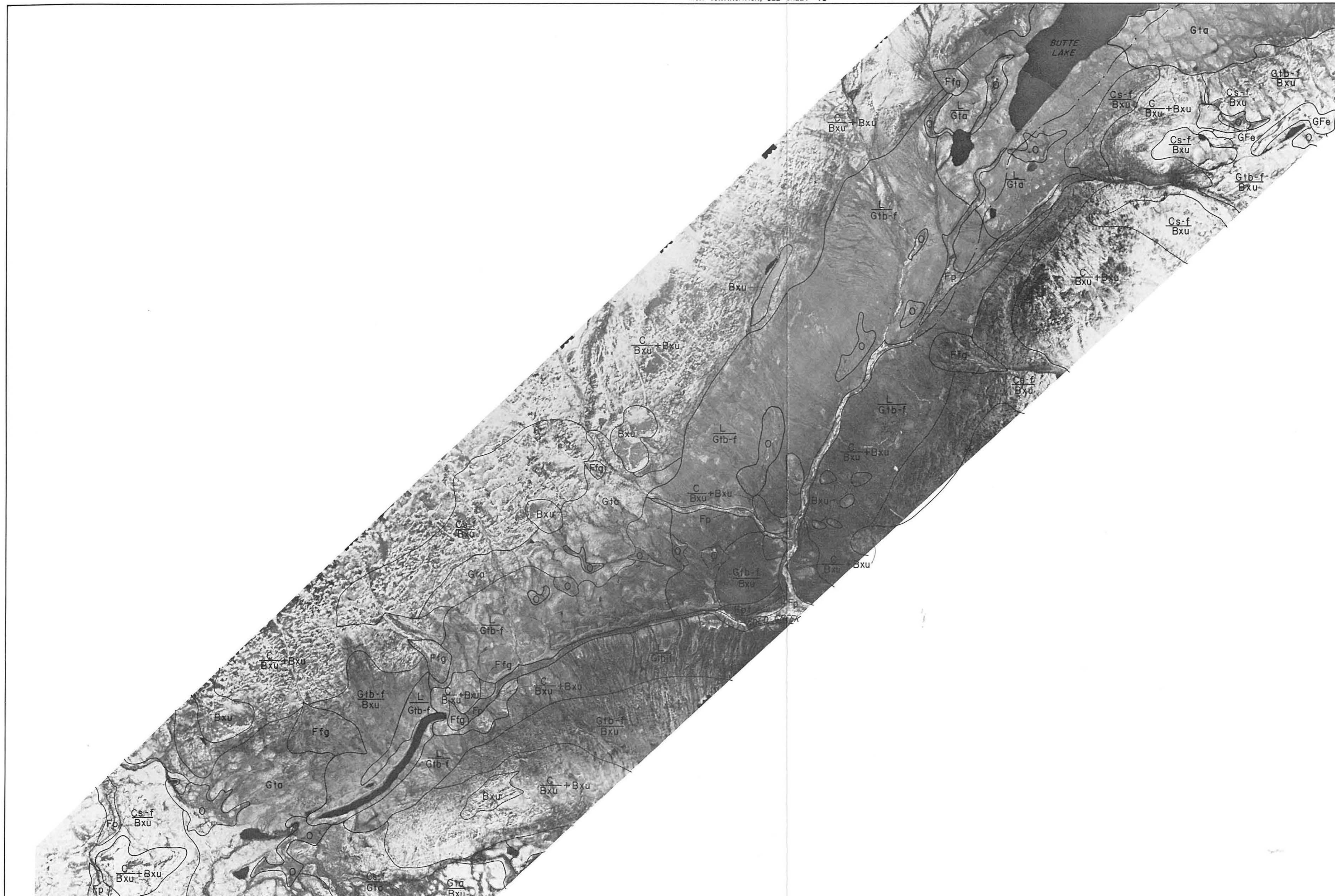
FOR CONTINUATION, SEE SHEET 18



FOR CONTINUATION, SEE SHEET 16

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over un-weathered bedrock
C/Bxu +Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw +Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*₸v*	*Pzv (Pls)*	*Kag*	*₸vs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

DEPARTMENT

PROJECT 052502

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DRAWING NO.

SHEET 17 OF 21

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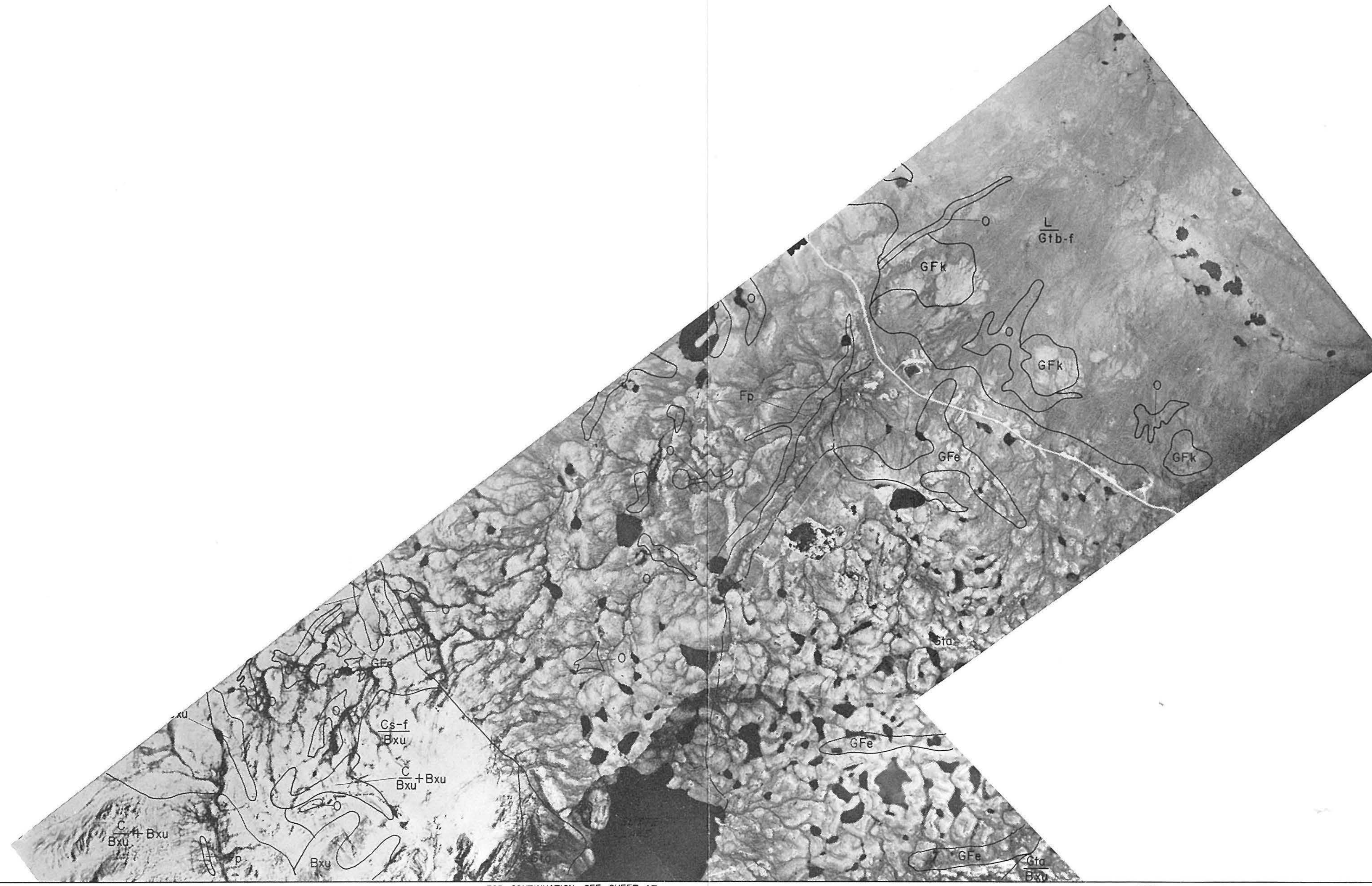

FOR CONTINUATION, SEE SHEET 17

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L / Gta	Lacustrine sediments over ablation till
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Cs-f / Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f / Gta	Solifluction deposits (frozen) over ablation till
Cs-f / Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f / Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f / Bxu	Frozen basal till over bedrock
Gta / Bxu	Ablation till over unweathered bedrock
C / Bxu +Bxu	Colluvium over bedrock and bedrock exposures
C / Bxw +Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*R̄v*	*Pzv (Pls)*	*Kag*	*R̄vs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp Slide Scar Buried Channel Trail Rock Contact

SCALE 0 2000 4000 FEET

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

R&M CONSULTANTS, INC.

DATE APRIL 1981

SCALE

DEPARTMENT

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REV.

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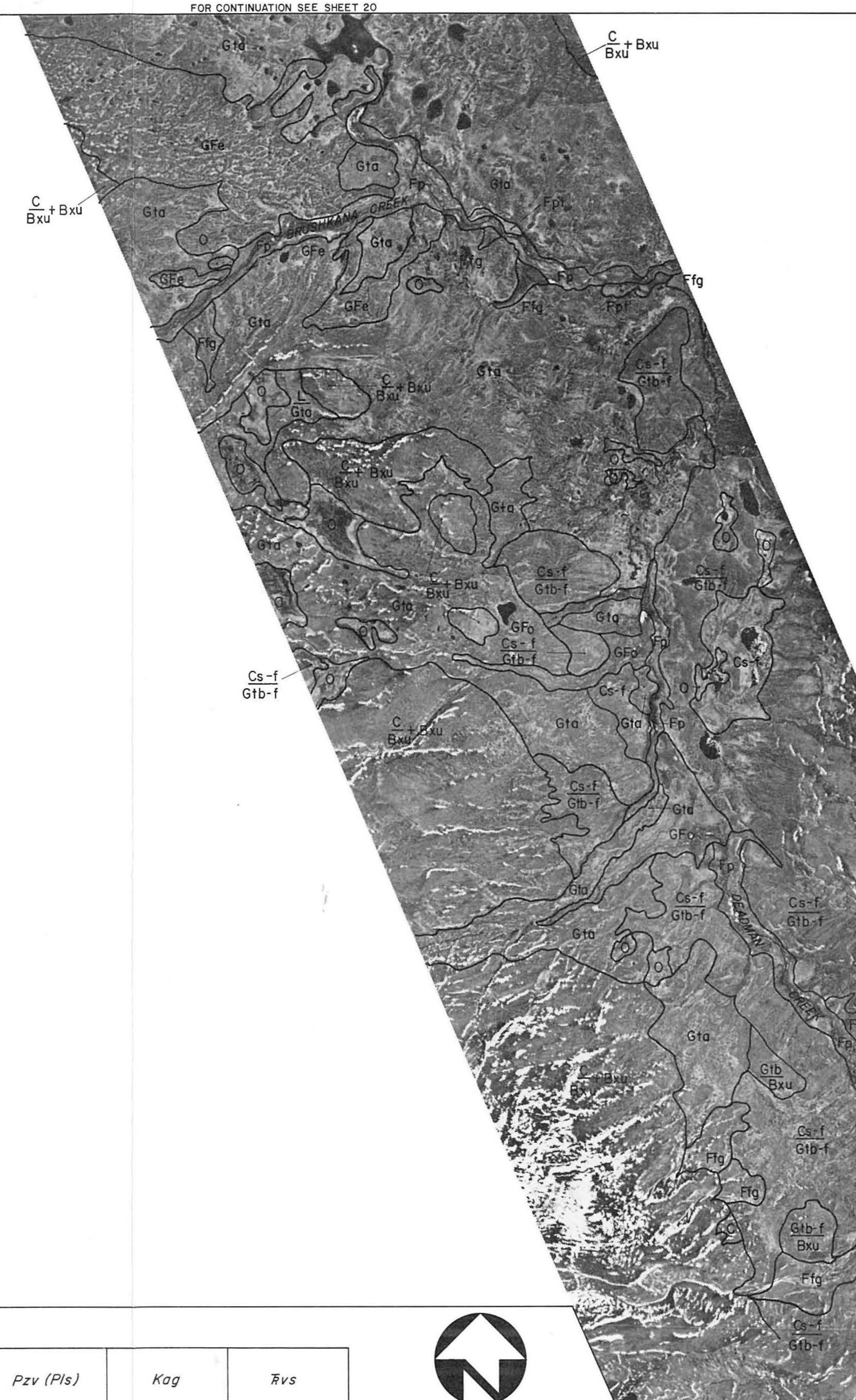

FOR CONTINUATION SEE SHEET 16

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
$\frac{L}{Gta}$	Lacustrine sediments over ablation till
$\frac{L}{Gtb-f}$	Lacustrine deposits over basal till (frozen)
$\frac{Cs-f}{Gtb-f}$	Solifluction deposits (frozen) over basal till (frozen)
$\frac{Cs-f}{Gta}$	Solifluction deposits (frozen) over ablation till
$\frac{Cs-f}{Fpt}$	Solifluction deposits (frozen) over terrace sediments
$\frac{Cs-f}{Bxu}$	Solifluction deposits (frozen) over bedrock
$\frac{Gtb-f}{Bxu}$	Frozen basal till over bedrock
$\frac{Gta}{Bxu}$	Ablation till over un-weathered bedrock
$\frac{C}{Bxu}$ + Bxu	Colluvium over bedrock and bedrock exposures
$\frac{C}{Bxw}$ + Bxw	Colluvium over weathered or poorly consoli-dated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*R̄v*	*Pzv (Pls)*	*Kag*	*R̄vs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

DATE	NO.	REVISIONS	CH.	APP.	APP.

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SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

DATE AUGUST 1981
SCALE
DEPARTMENT
DRAWING NO.
PROJECT 052502
SHEET 19 OF 21
REV.

FOR CONTINUATION SEE SHEET 21

FOR CONTINUATION SEE SHEET 19

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over unweathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*T̶Rv*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sandstone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of greenschist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.

Pzv (Pls)	*Kag*	*T̶Rvs*
Late Paleozoic basaltic and andesitic metavolcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

DATE	NO.	REVISIONS	CH.	APP.	APP.

ACRES

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

DATE AUGUST 1981
DEPARTMENT
PROJECT 052502
SCALE
DRAWING NO. 20
SHEET 20 OF 21
REV.

FOR CONTINUATION SEE SHEET 20

Terrain Unit Symbol	Terrain Unit Name
Bxu	Unweathered, consolidated bedrock
C	Colluvial deposits
Cl	Landslide
Cs-f	Solifluction deposits (frozen)
Ffg	Granular alluvial fan
Fp	Floodplain deposits
Fpt	Terrace
GFo	Outwash deposits
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
Gtb-f	Basal till (frozen)
O	Organic deposits
L-f	Lacustrines (frozen)
L/Gta	Lacustrine sediments over ablation till
L/Gtb-f	Lacustrine deposits over basal till (frozen)
Cs-f/Gtb-f	Solifluction deposits (frozen) over basal till (frozen)
Cs-f/Gta	Solifluction deposits (frozen) over ablation till
Cs-f/Fpt	Solifluction deposits (frozen) over terrace sediments
Cs-f/Bxu	Solifluction deposits (frozen) over bedrock
Gtb-f/Bxu	Frozen basal till over bedrock
Gta/Bxu	Ablation till over un-weathered bedrock
C/Bxu + Bxu	Colluvium over bedrock and bedrock exposures
C/Bxw + Bxw	Colluvium over weathered or poorly consolidated bedrock

Bedrock Mapping Units	*Tv*	*Tsu*	*Tbgd*	*Tsmg*	*TKgr*	*Jam (Jtr)(Jgd)*	*TRv*	*Pzv (Pls)*	*Kag*	*TRvs*
Abbreviated Descriptions	Tertiary Volcanic rocks; shallow intrusives, flows, and pyroclastics; rhyolitic to basaltic.	Tertiary non-marine sedimentary rocks; conglomerate, sand-stone, and claystone.	Tertiary biotite granodiorite; local hornblende granodiorite (Thgd).	Tertiary schist, migmatite and granite, representing the roof of a large stock.	Tertiary and/or Cretaceous granitics forming small plutons.	Jurassic amphibolite, inclusions of green-schist & marble; local trondjemite (Jtr) and granodiorite (Jgd).	Triassic basaltic metavolcanic rocks formed in shallow marine environment.	Late Paleozoic basaltic and andesitic meta-volcanogenic rocks, local meta-limestone (Pls).	Cretaceous argillite and graywacke, of a thick deformed turbidite sequence, lowgrade metamorphism.	Triassic metabasalt and slate, an interbedded shallow marine sequence.

Miscellaneous Map Symbols

Scarp — Slide Scar — Buried Channel — Trail — Rock Contact

SCALE 0 2000 4000 FEET

DATE	NO.	REVISIONS	CH.	APP.	APP.

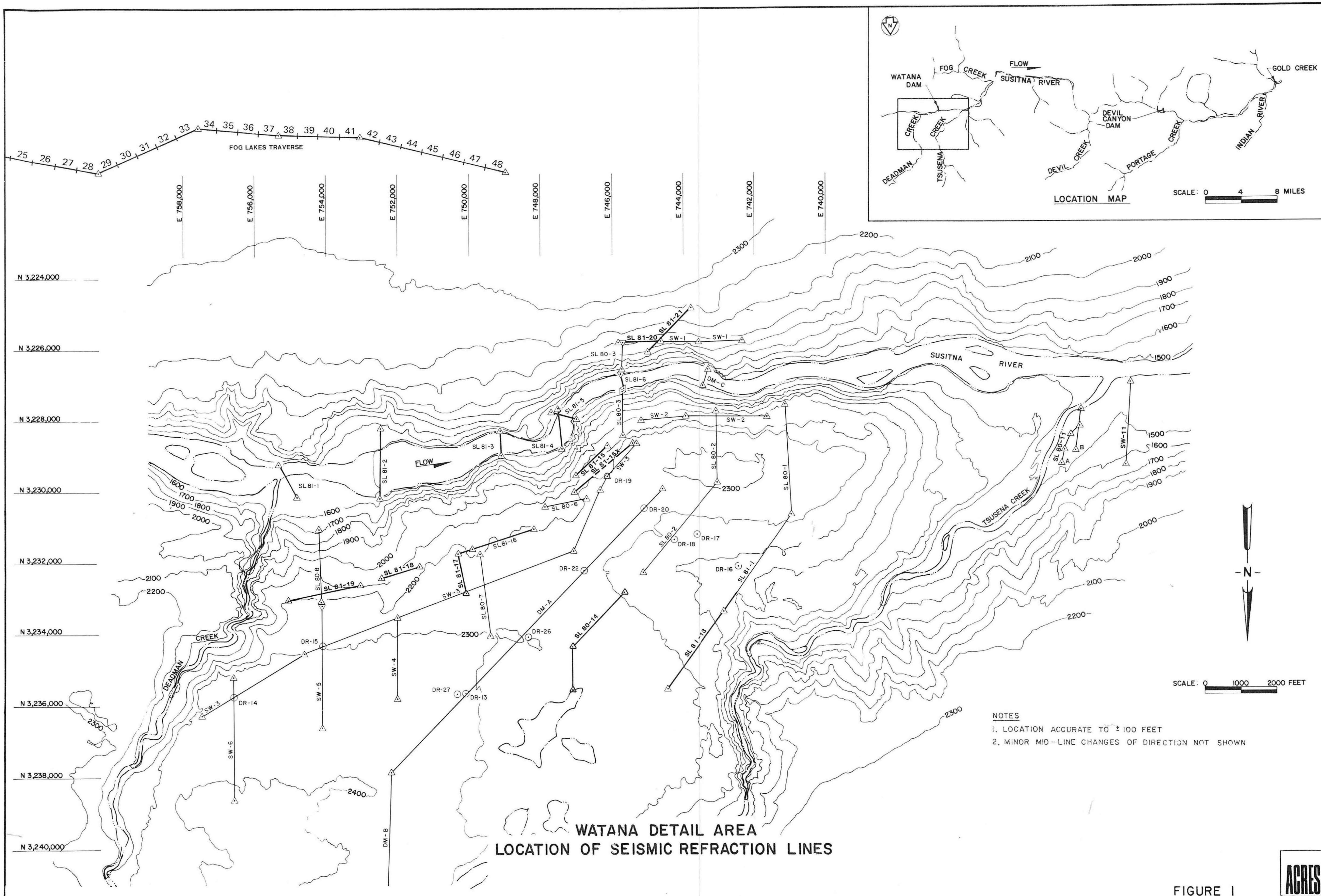
ACRES

SUBTASK 5.02

PHOTO INTERPRETATION

TERRAIN UNIT MAPS

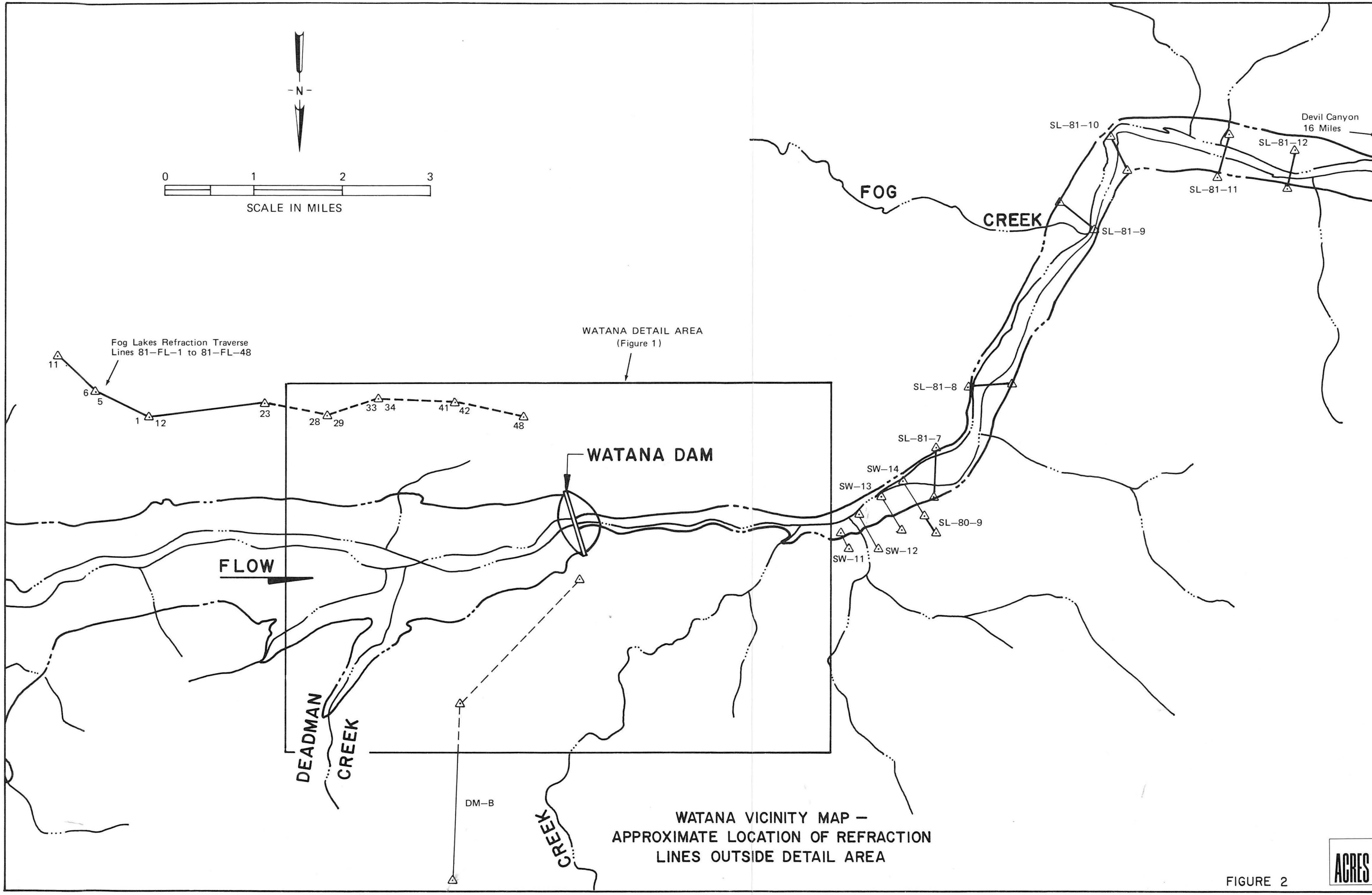
DATE AUGUST 1981 | SCALE
DEPARTMENT | DRAWING NO. 21 21 | REV.
PROJECT 052502 | SHEET OF



WATANA DETAIL AREA
LOCATION OF SEISMIC REFRACTION LINES

FIGURE 1

PREPARED BY WOODWARD-CLYDE CONSULTANTS

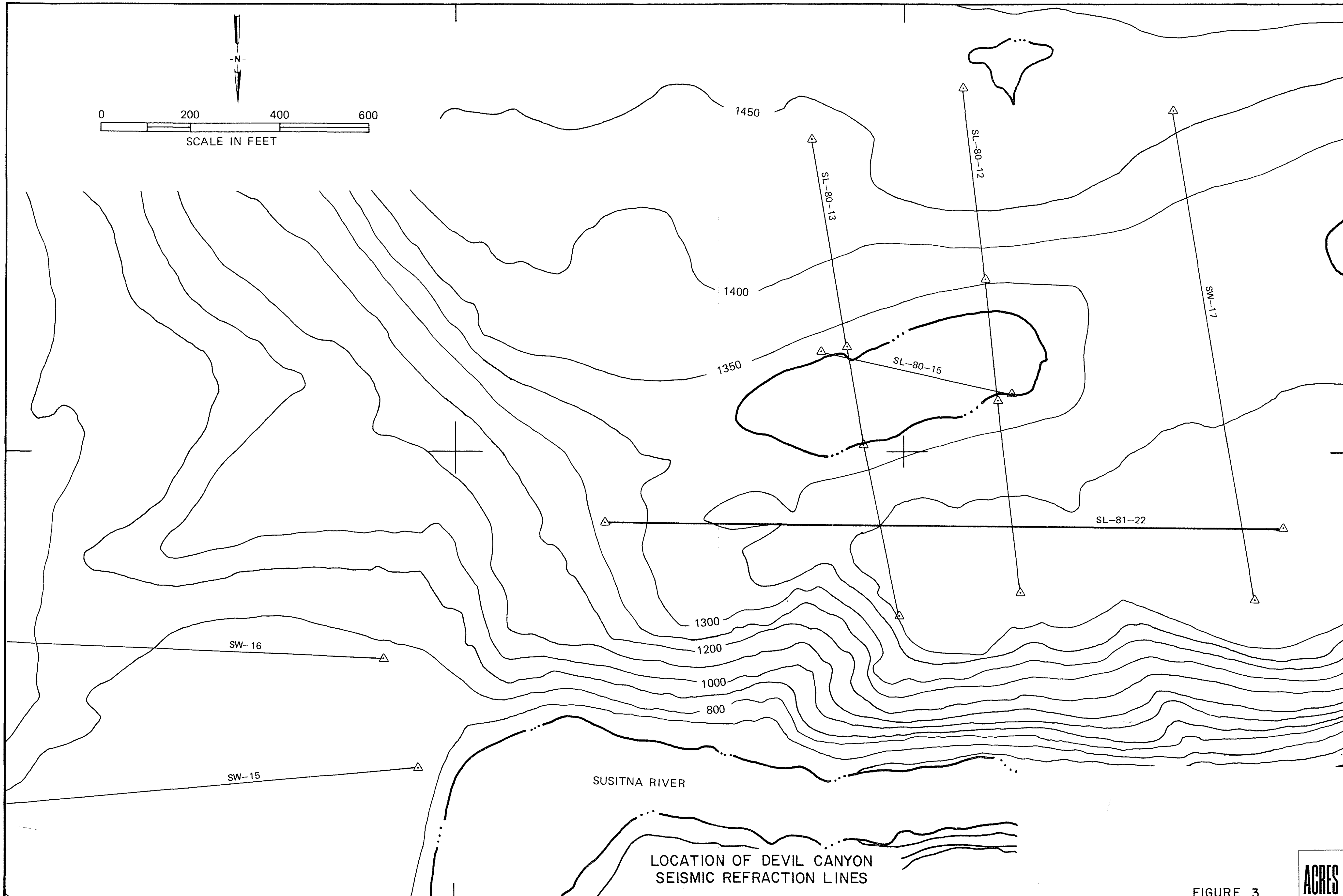


WATANA VICINITY MAP –
APPROXIMATE LOCATION OF REFRACTION
LINES OUTSIDE DETAIL AREA

FIGURE 2

ACRES

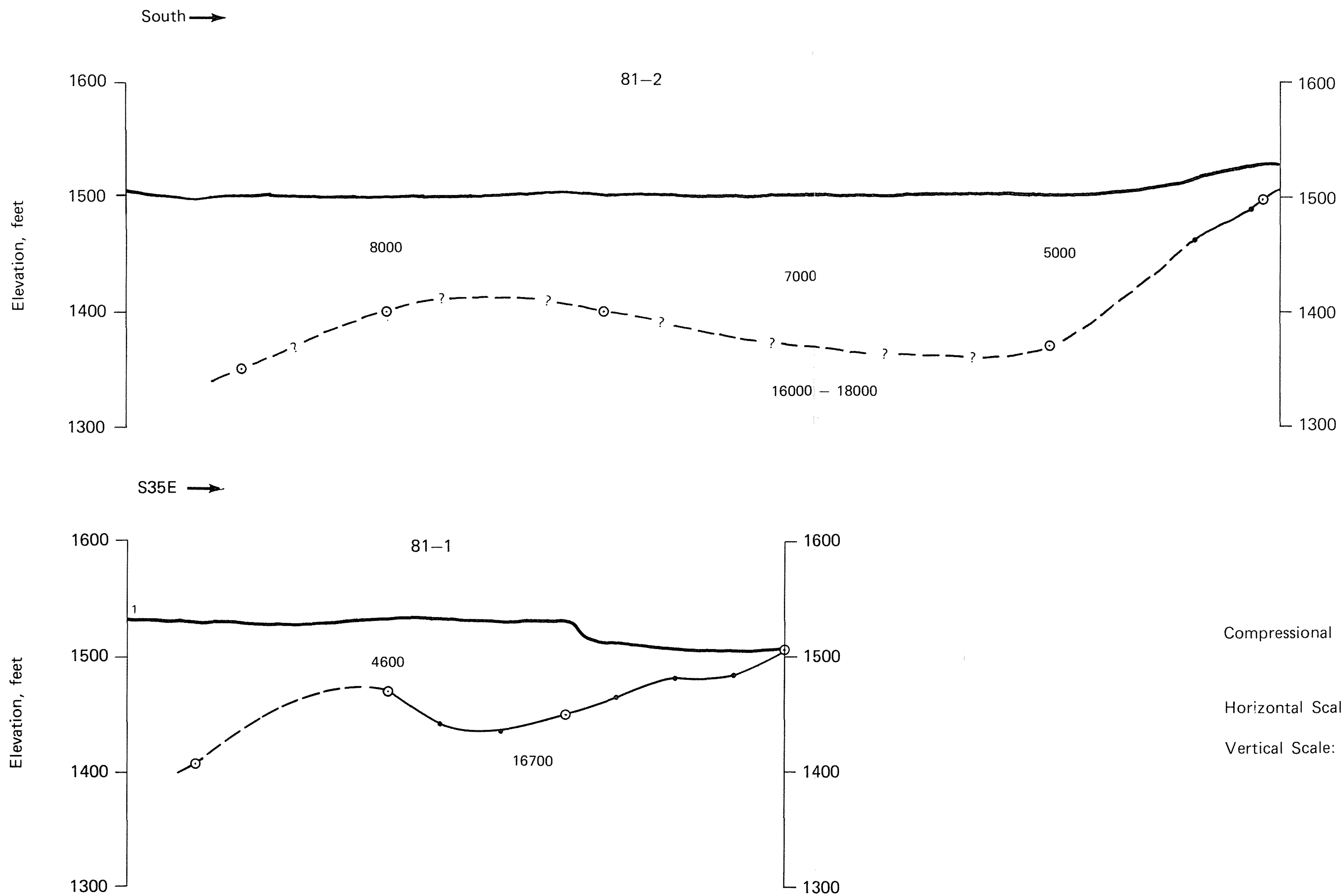
PREPARED BY WOODWARD – CLYDE CONSULTANTS



LOCATION OF DEVIL CANYON SEISMIC REFRACTION LINES

FIGURE 3

PREPARED BY WOODWARD - CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 200 feet

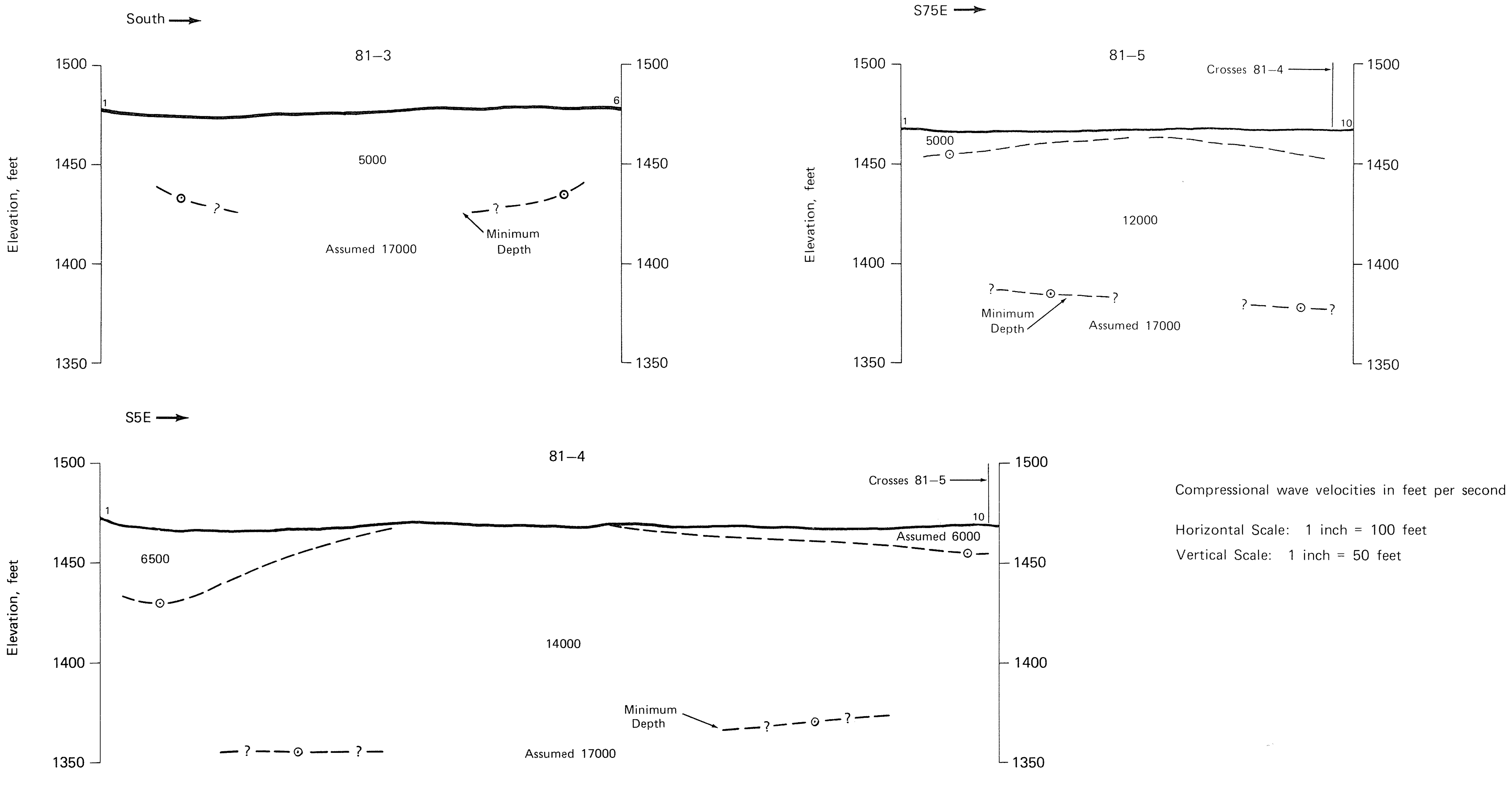
Vertical Scale: 1 inch = 100 feet

SEISMIC REFRACTION PROFILES
81-1 AND 81-2

FIGURE 4

ACRES

PREPARED BY WOODWARD — CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 100 feet

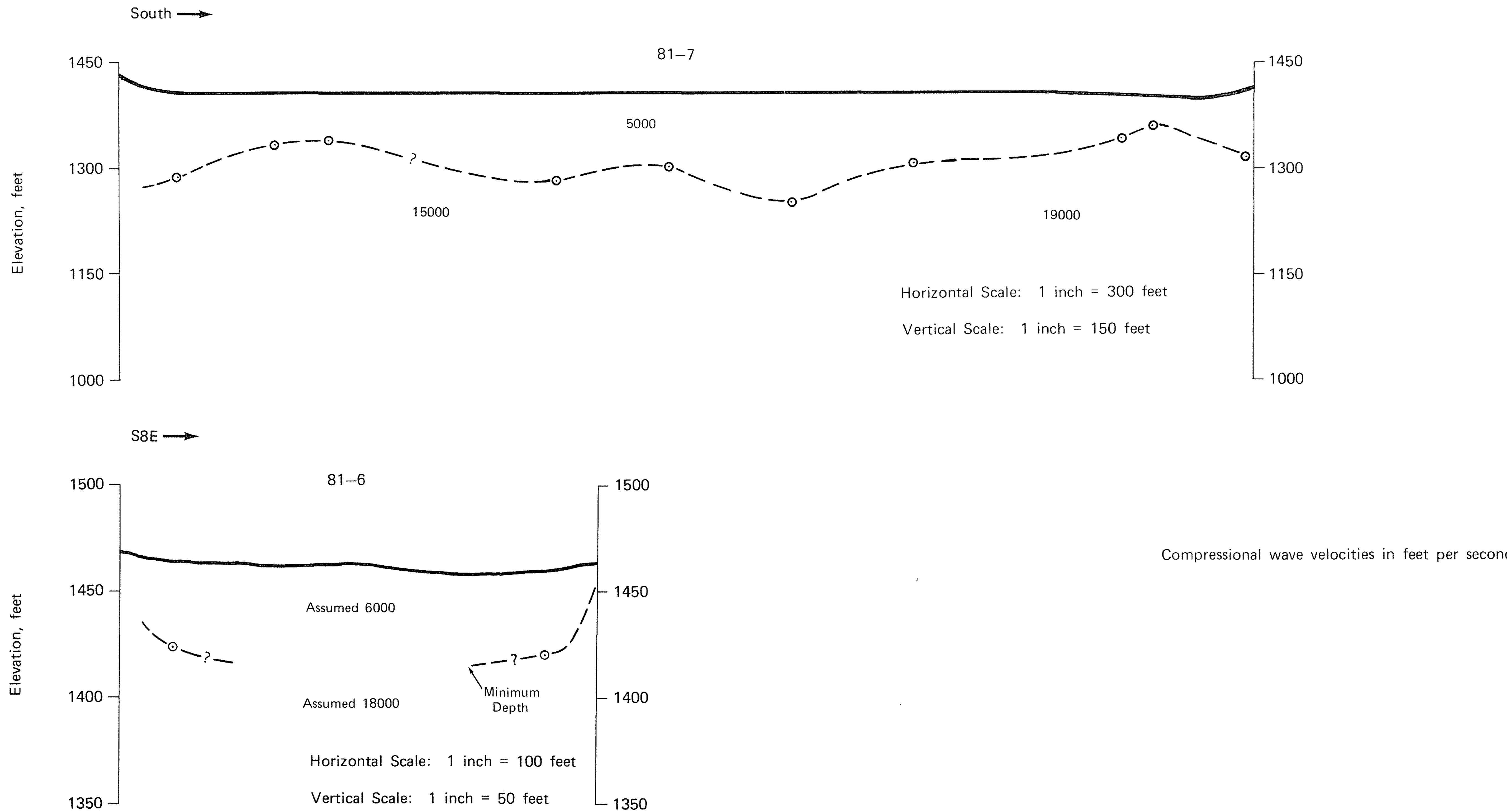
Vertical Scale: 1 inch = 50 feet

SEISMIC REFRACTION PROFILES
81-3, 81-4 AND 81-5

FIGURE 5

ACRES

PREPARED BY WOODWARD–CLYDE CONSULTANTS

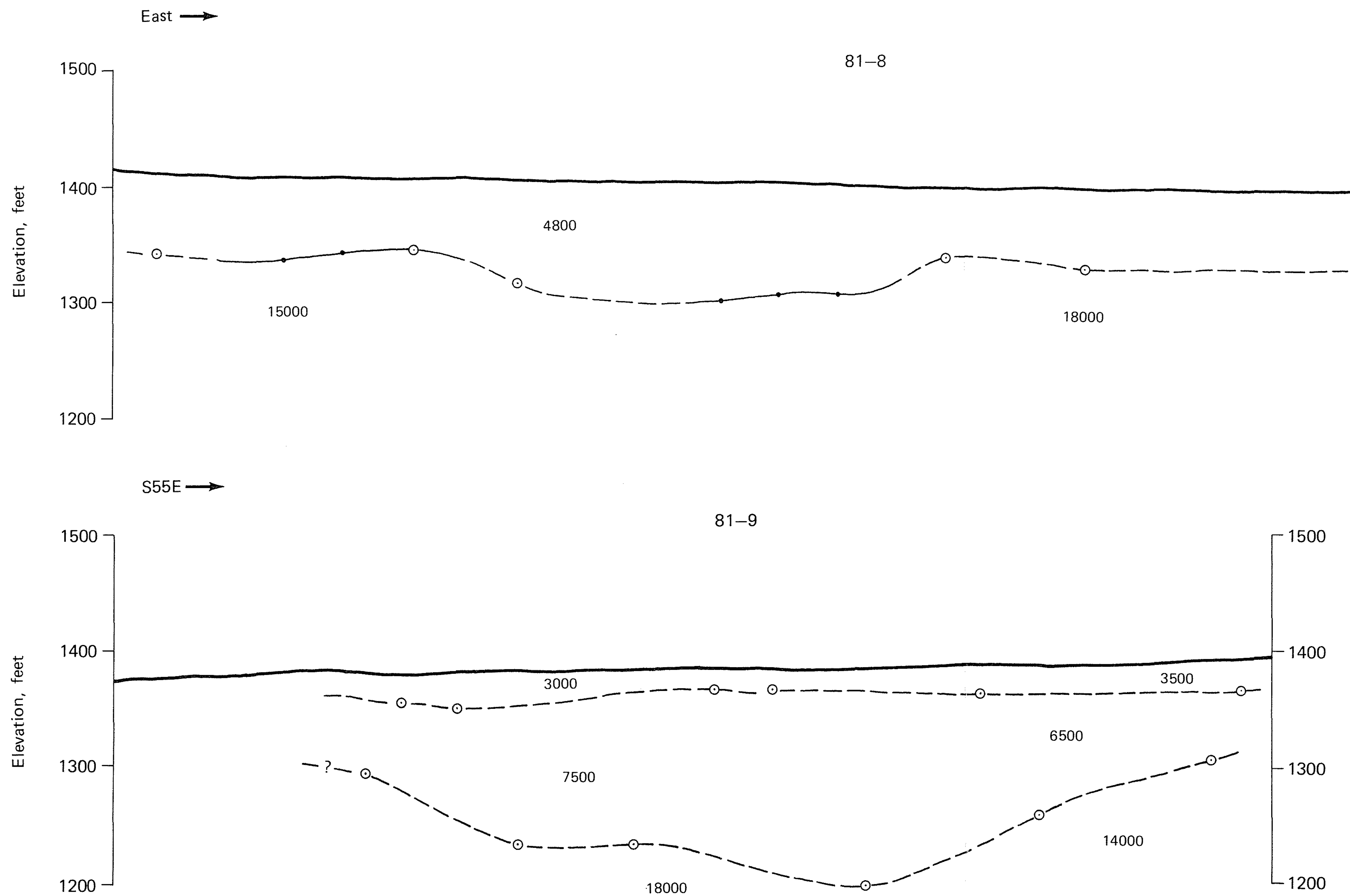


SEISMIC REFRACTION PROFILES
81-6 AND 81-7

FIGURE 6

ACRES

PREPARED BY WOODWARD – CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 200 feet

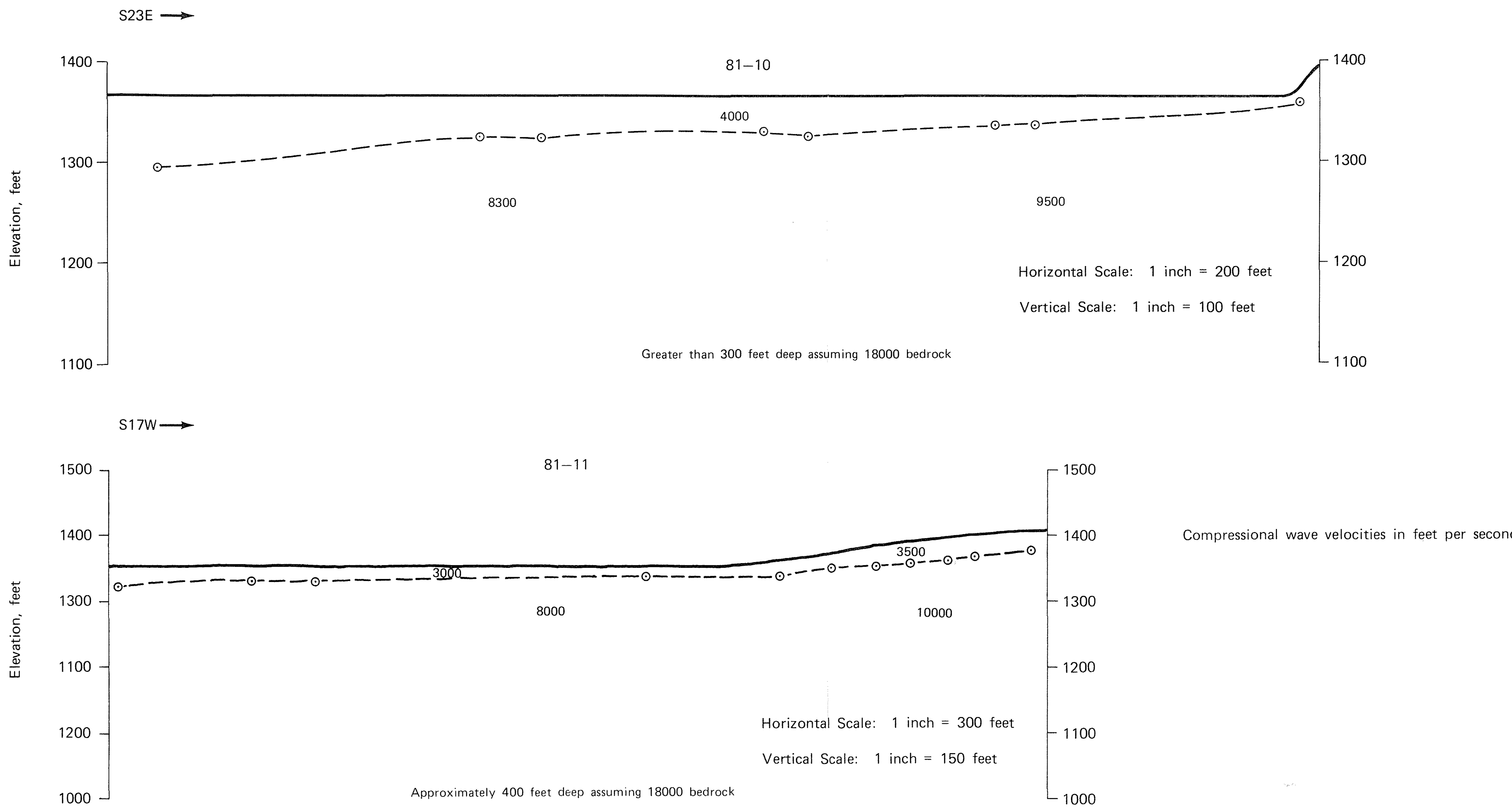
Vertical Scale: 1 inch = 100 feet

SEISMIC REFRACTION PROFILES
8l-8 AND 8l-9

FIGURE 7

ACRES

PREPARED BY WOODWARD – CLYDE CONSULTANTS

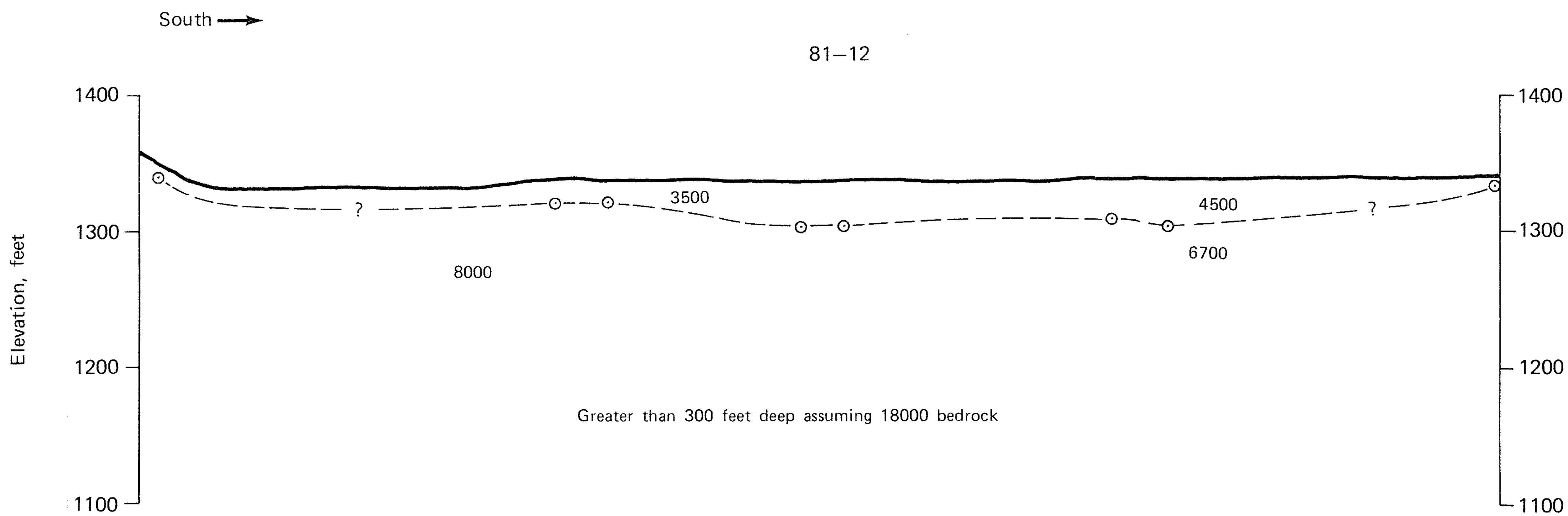


SEISMIC REFRACTION PROFILES
81-10 AND 81-11

ACRES

FIGURE 8

PREPARED BY WOODWARD – CLYDE CONSULTANTS



Compressional wave velocities in feet per second

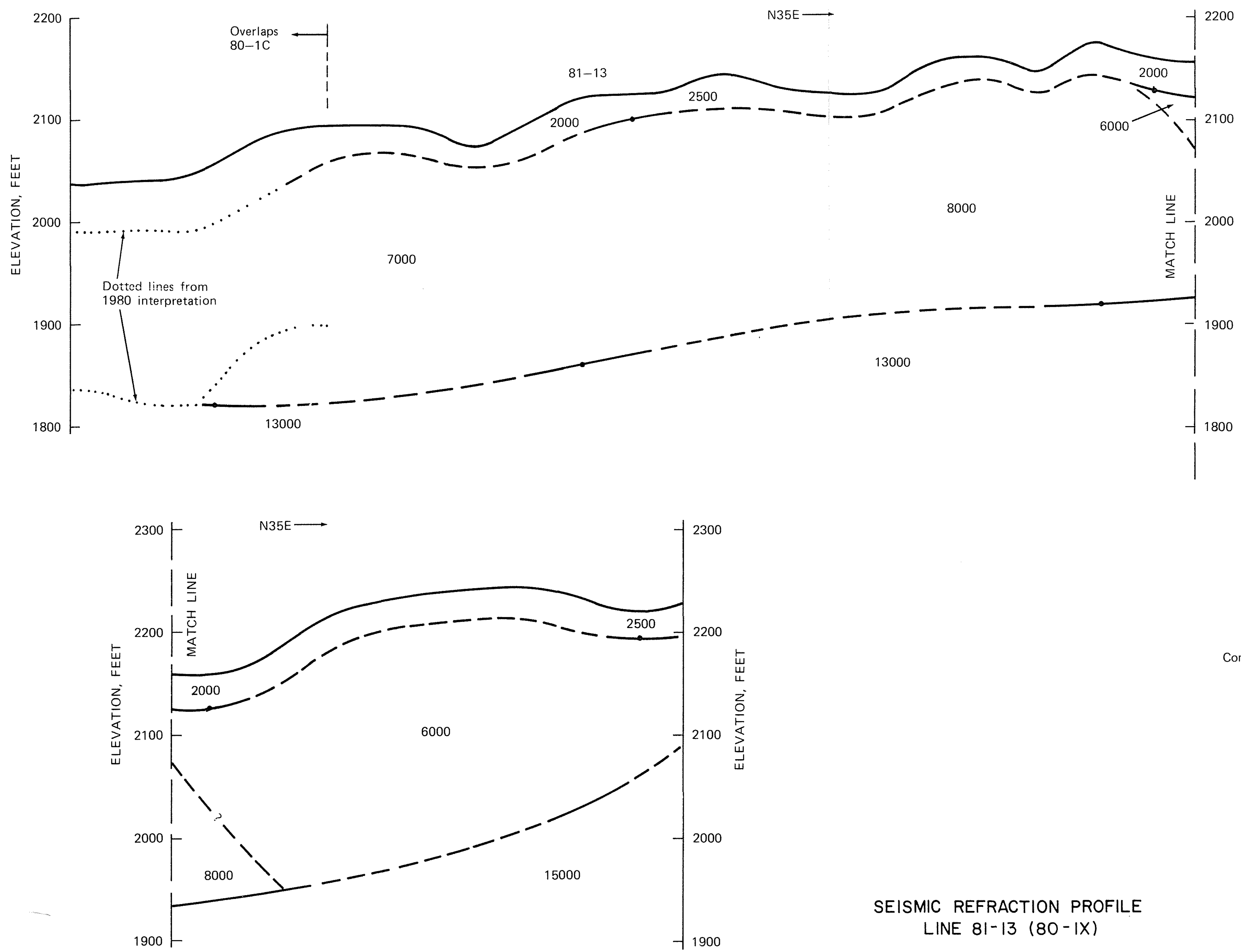
Horizontal Scale: 1 inch = 200 feet

Vertical Scale: 1 inch = 100 feet

SEISMIC REFRACTION PROFILE 81-12

FIGURE 9

PREPARED BY WOODWARD – CLYDE CONSULTANTS



Compressional velocities in feet per second

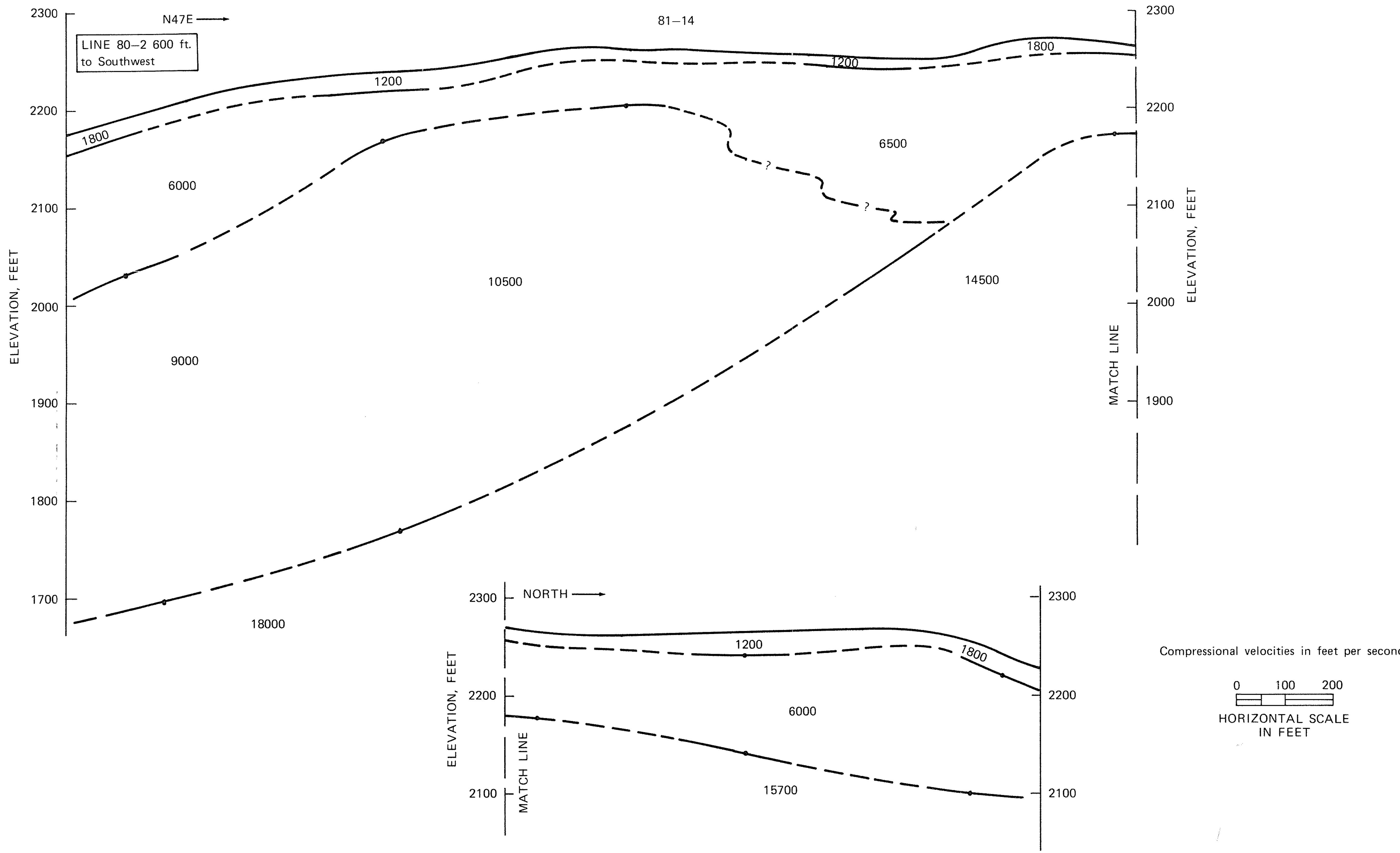
0 100 200

HORIZONTAL SCALE IN FEET

SEISMIC REFRACTION PROFILE
LINE 81-13 (80-IX)

FIGURE 10

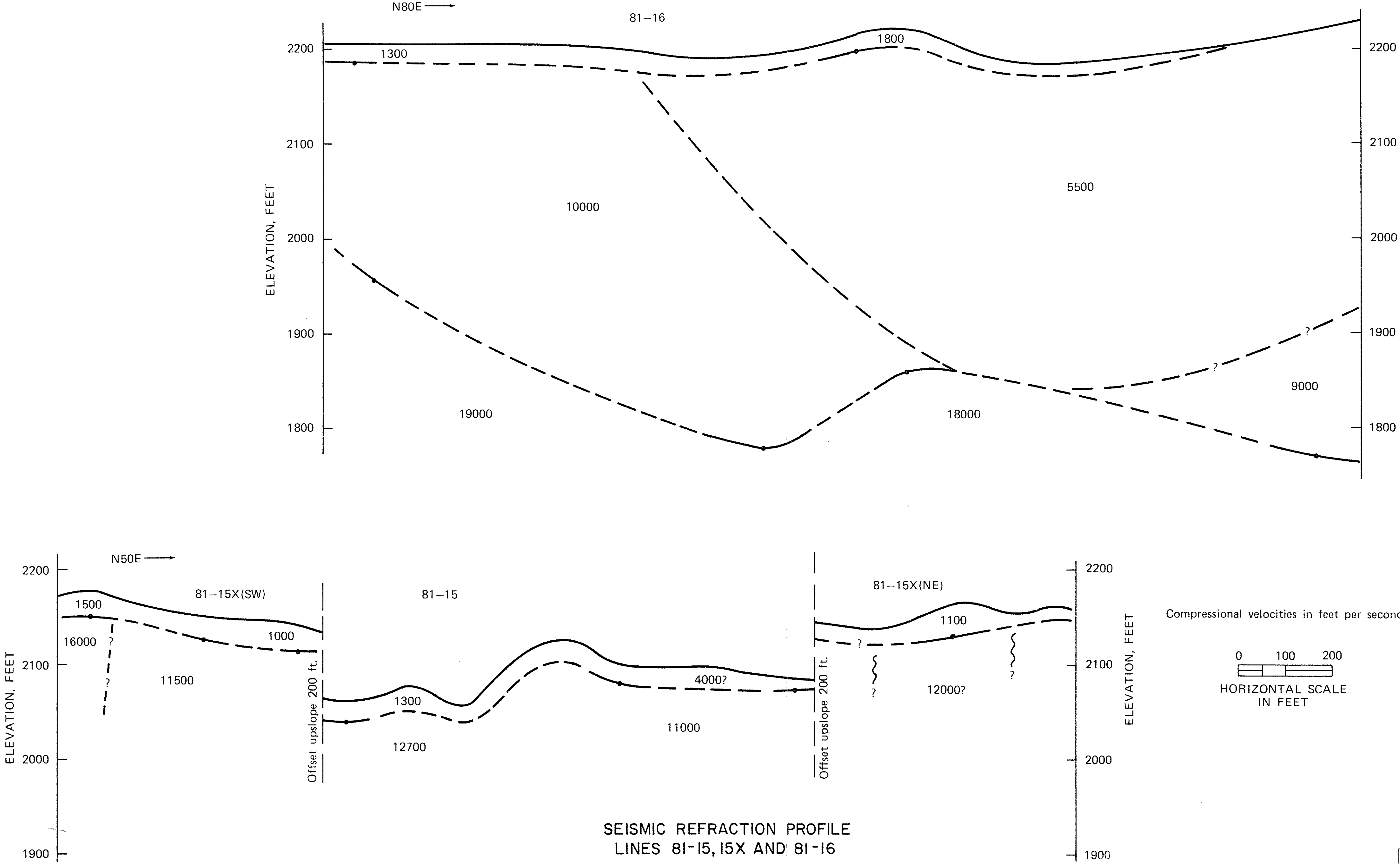
PREPARED BY WOODWARD — CLYDE CONSULTANTS



SEISMIC REFRACTION PROFILE
LINE 81-1 (80-2X)

FIGURE 11

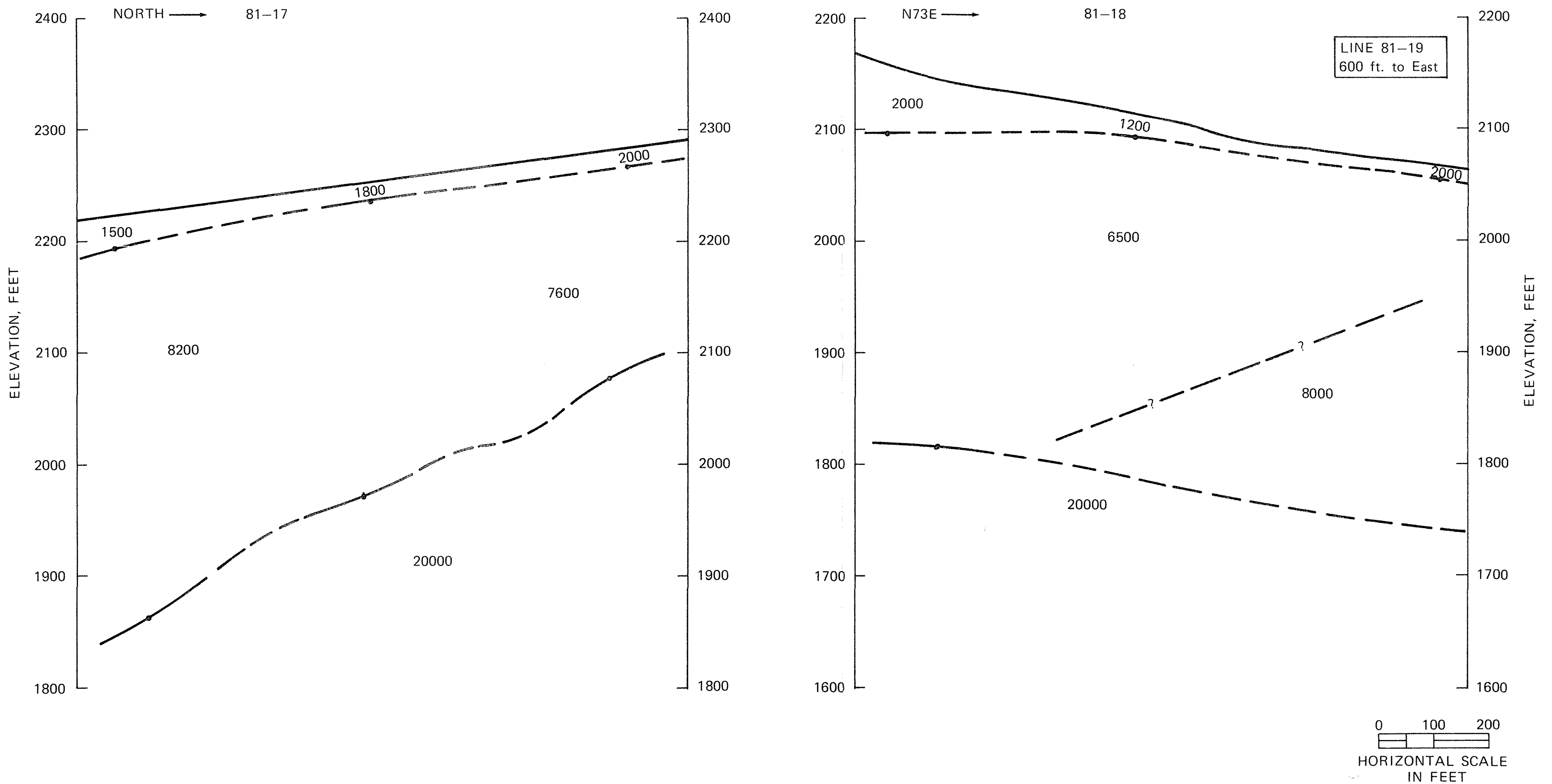
PREPARED BY WOODWARD–CLYDE CONSULTANTS



SEISMIC REFRACTION PROFILE
LINES 81-15, 15X AND 81-16

FIGURE 12

PREPARED BY WOODWARD – CLYDE CONSULTANTS

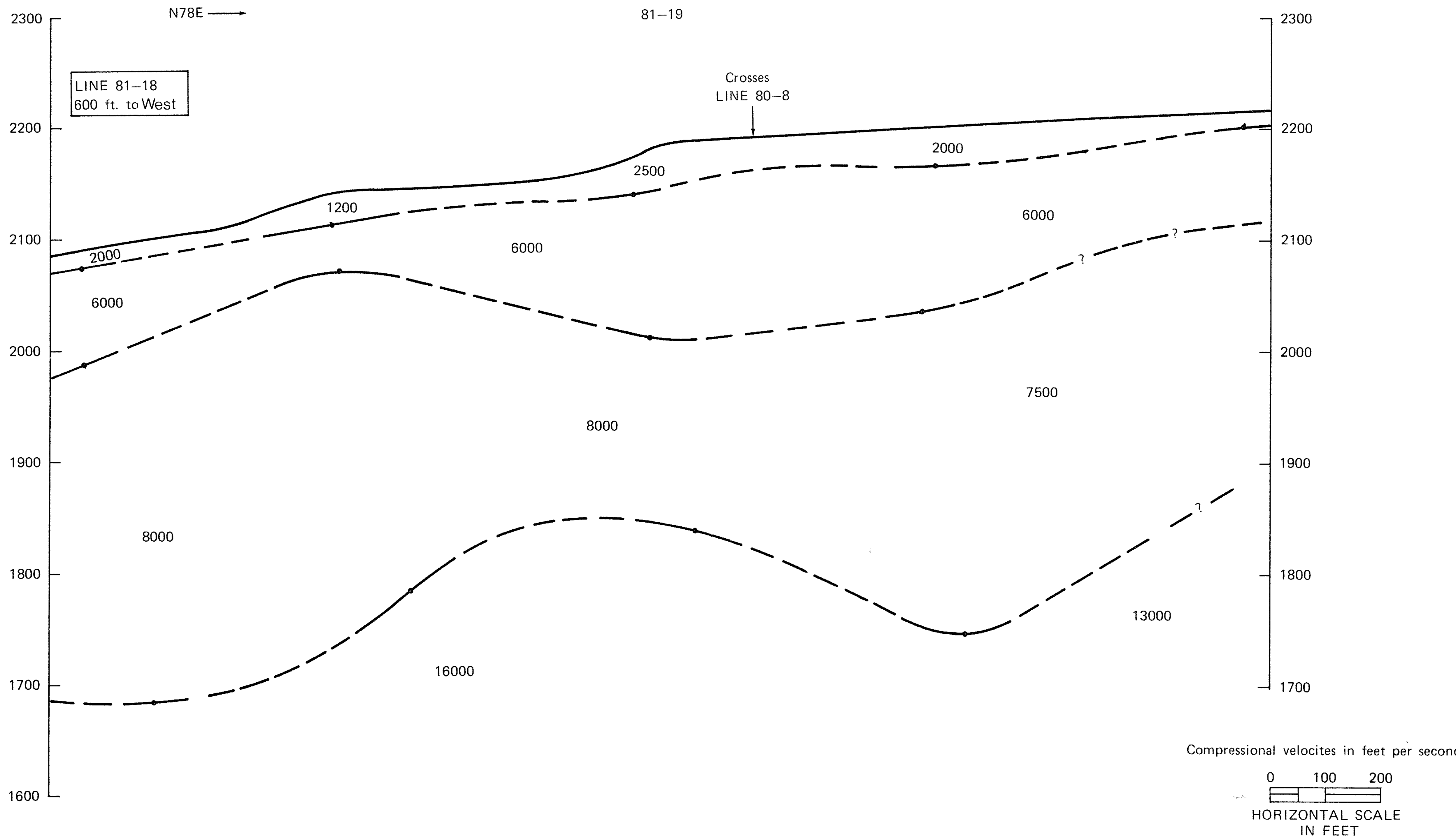


Compressional velocities in feet per second

SEISMIC REFRACTION PROFILE
LINES 81-17 AND 81-18

FIGURE 13

PREPARED BY WOODWARD – CLYDE CONSULTANTS

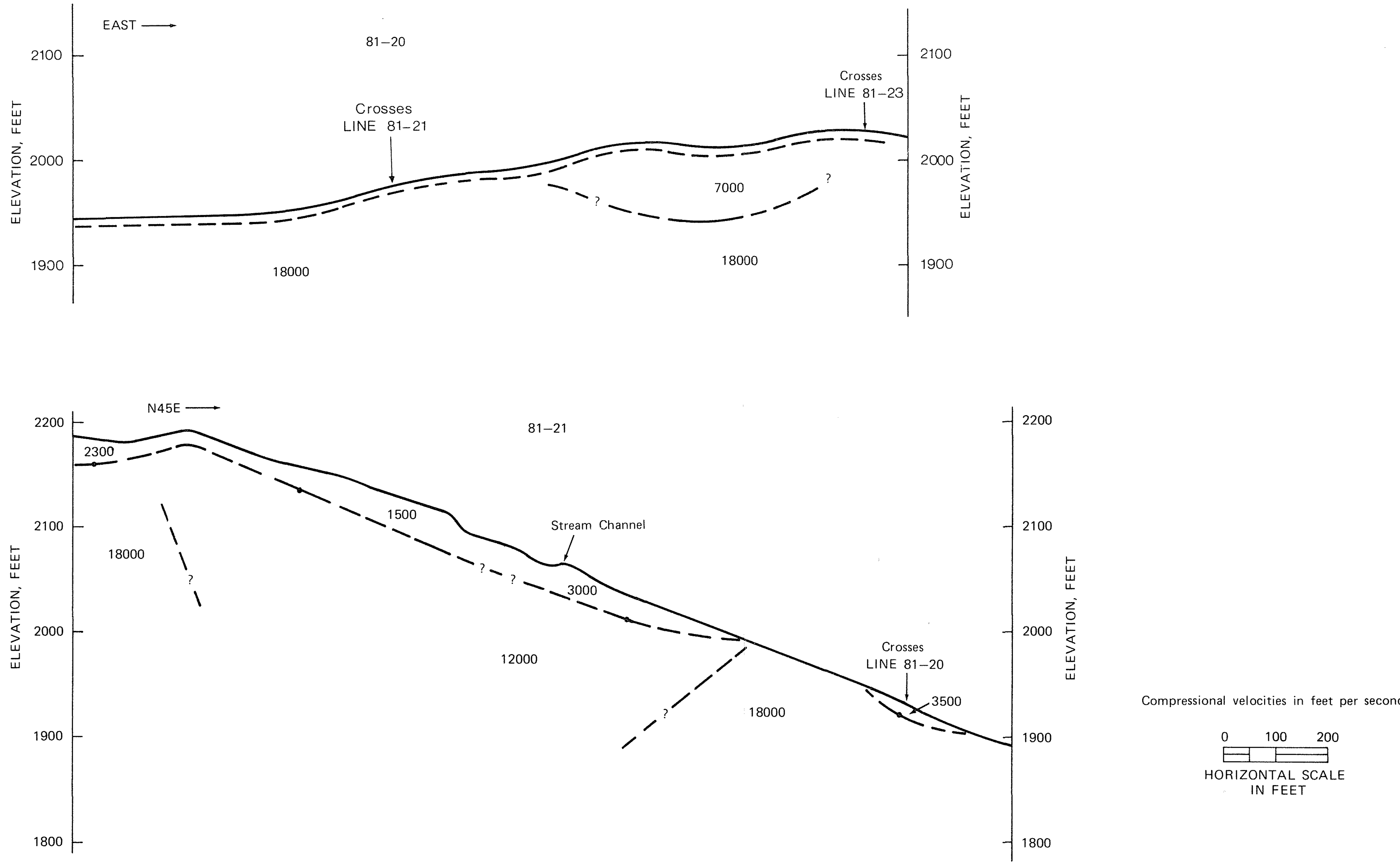


SEISMIC REFRACTION PROFILE
LINE 81-19 (QSB)

ACRES

FIGURE 14

PREPARED BY WOODWARD– CLYDE CONSULTANTS

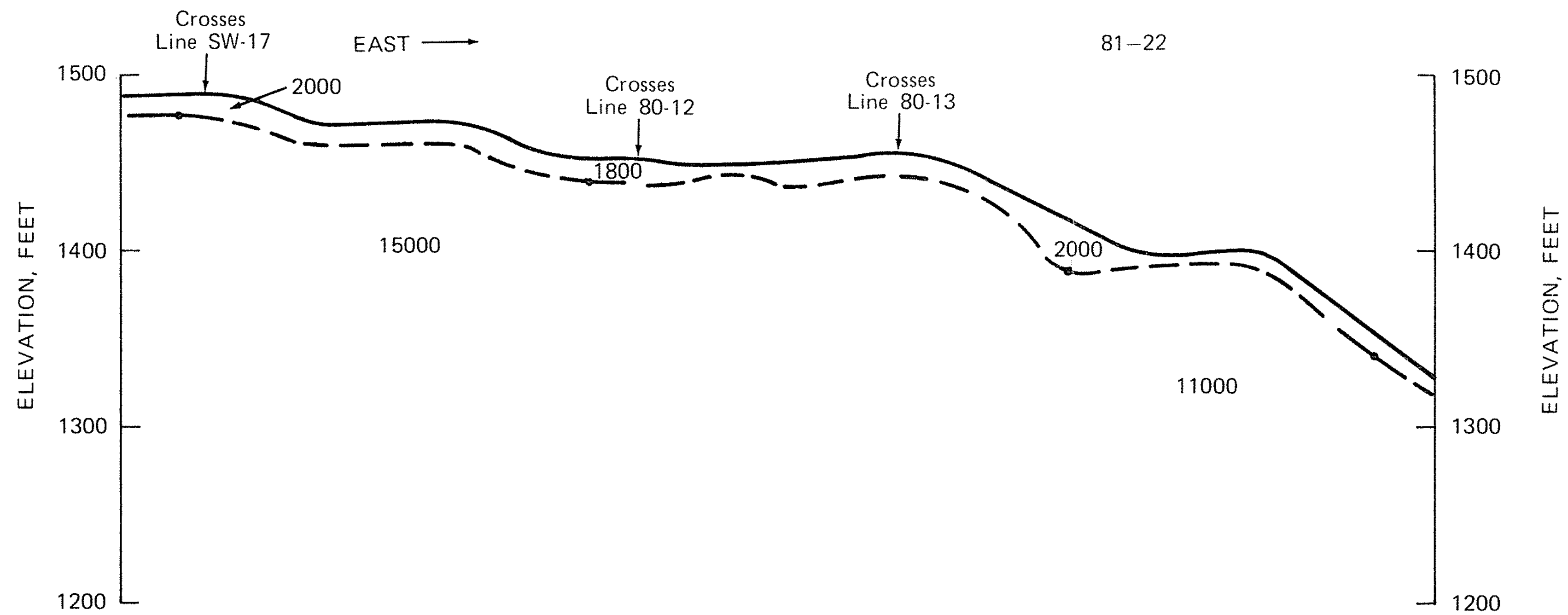


SEISMIC REFRACTION PROFILES
LINES 81-20 (SW-1X) AND
81-21 (BH-12)

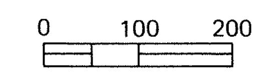
FIGURE 15

ACRES

PREPARED BY WOODWARD – CLYDE CONSULTANTS



Compressional velocities in feet per second



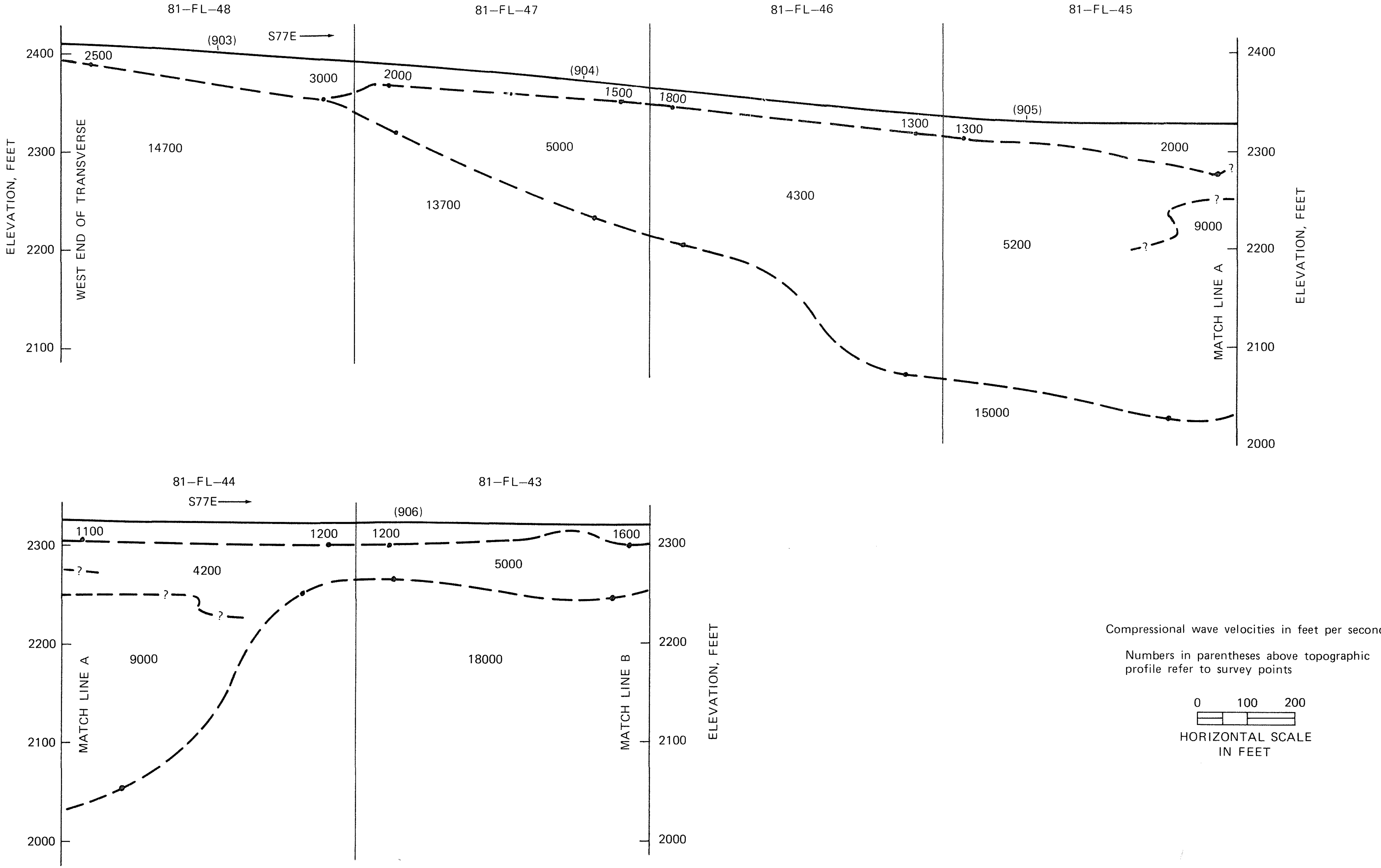
HORIZONTAL SCALE
IN FEET

FOG LAKES SEISMIC REFRACTION PROFILES
LINE 81-22 (R&M 81-17)

ACRES

FIGURE 16

PREPARED BY WOODWARD – CLYDE CONSULTANTS

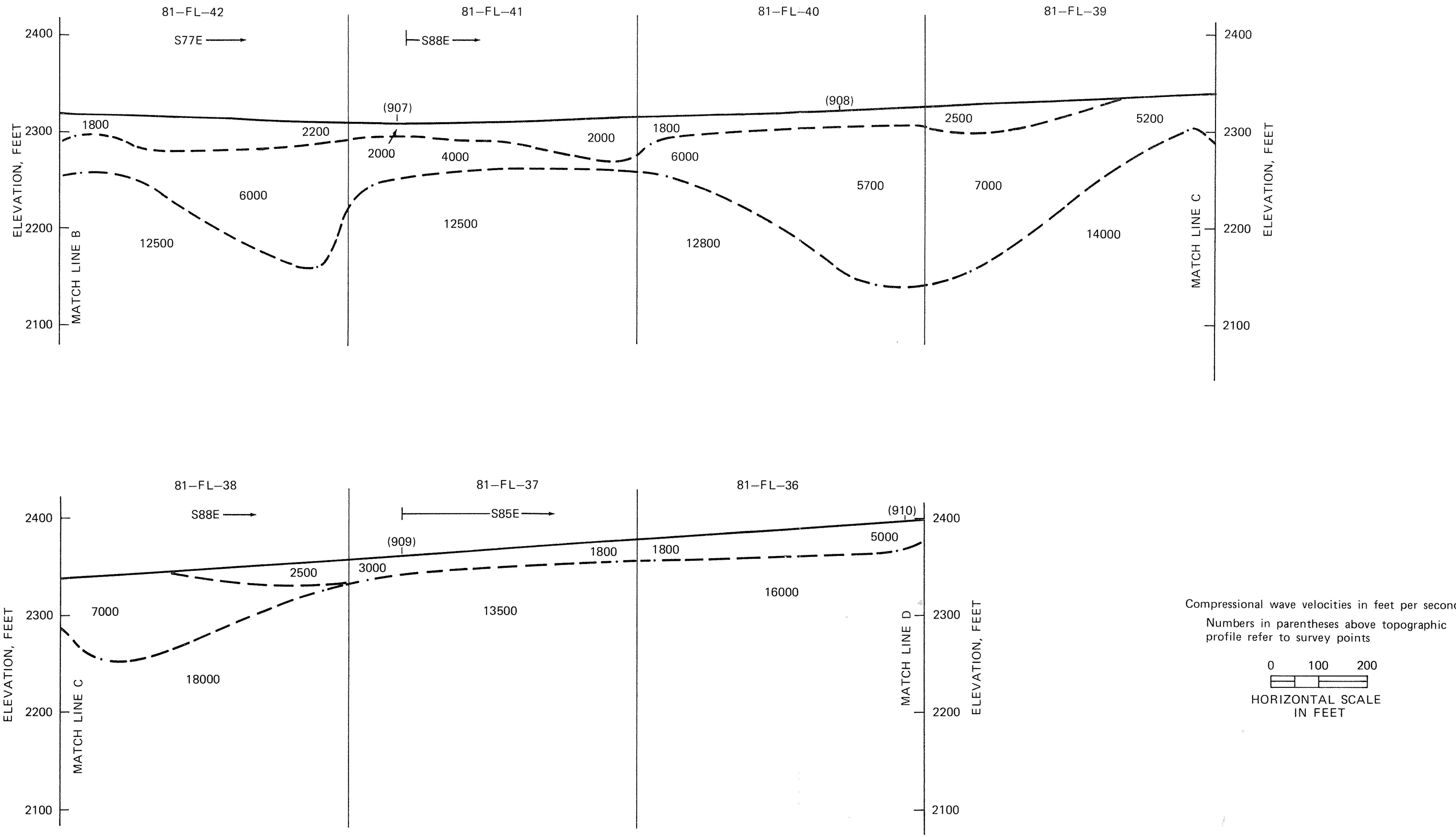


FOG LAKES SEISMIC REFRACTION PROFILES
SHEET 1 OF 7

FIGURE 17

ACRES

PREPARED BY WOODWARD – CLYDE CONSULTANTS

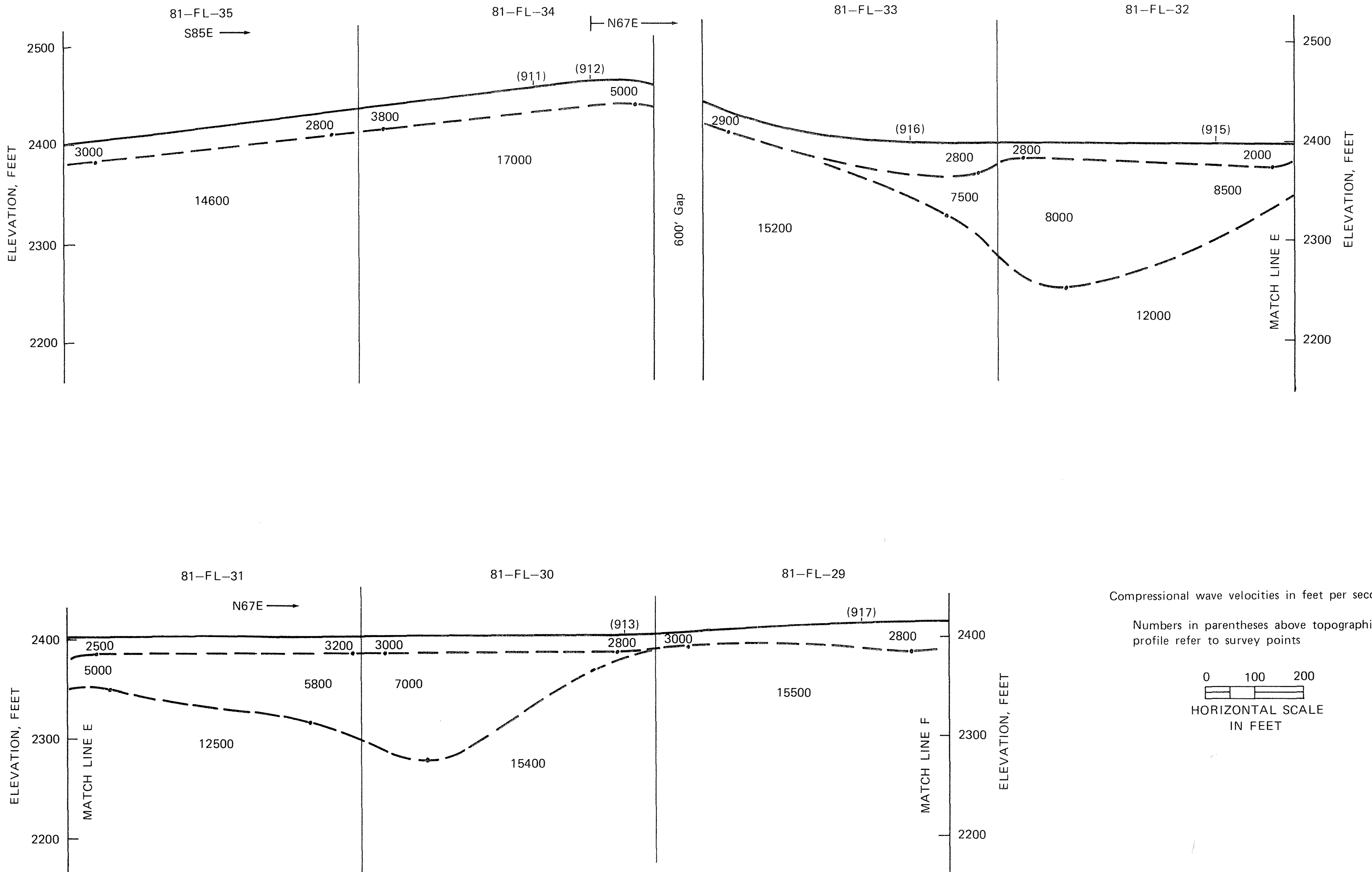


FOG LAKES SEISMIC REFRACTION PROFILES
SHEET 2 OF 7

ACRES

FIGURE 18

PREPARED BY WOODWARD – CLYDE CONSULTANTS



Compressional wave velocities in feet per second

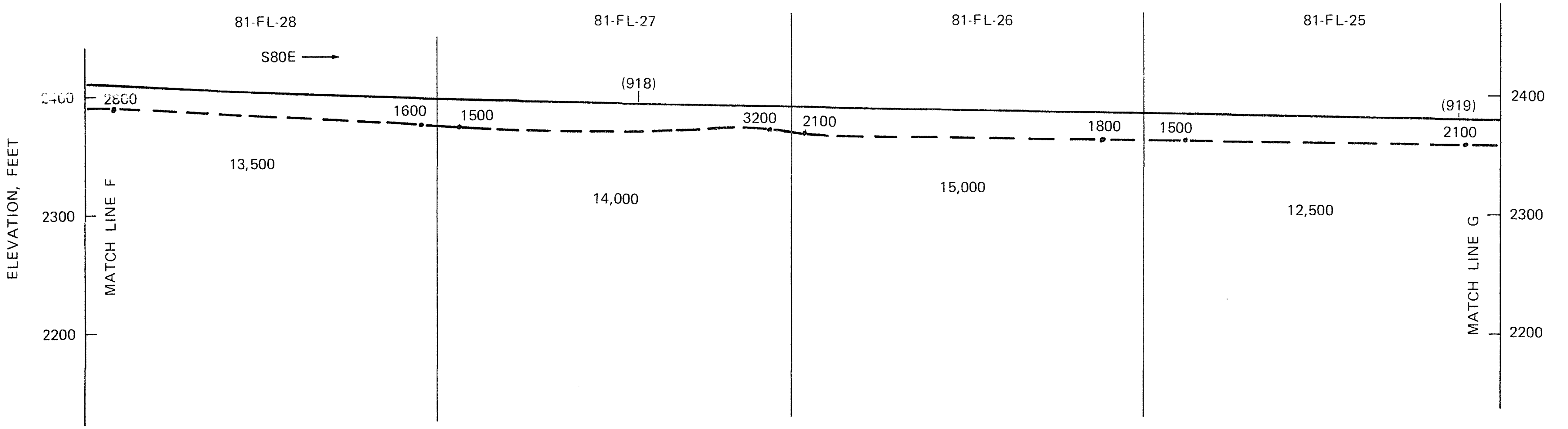
Numbers in parentheses above topographic profile refer to survey points

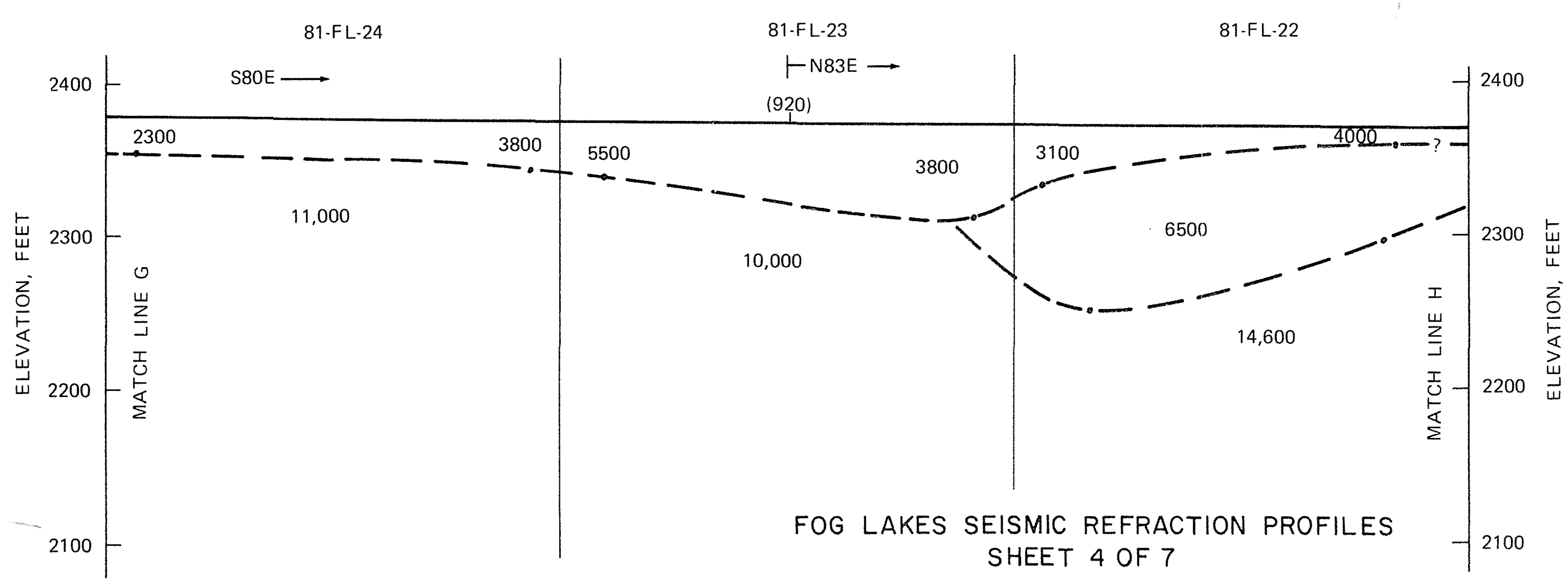
0 100 200
HORIZONTAL SCALE IN FEET

FOG LAKES SEISMIC REFRACTION PROFILES
SHEET 3 OF 7

FIGURE 19

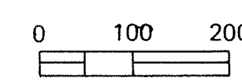
PREPARED BY WOODWARD – CLYDE CONSULTANTS





Compressional wave velocities in feet per second

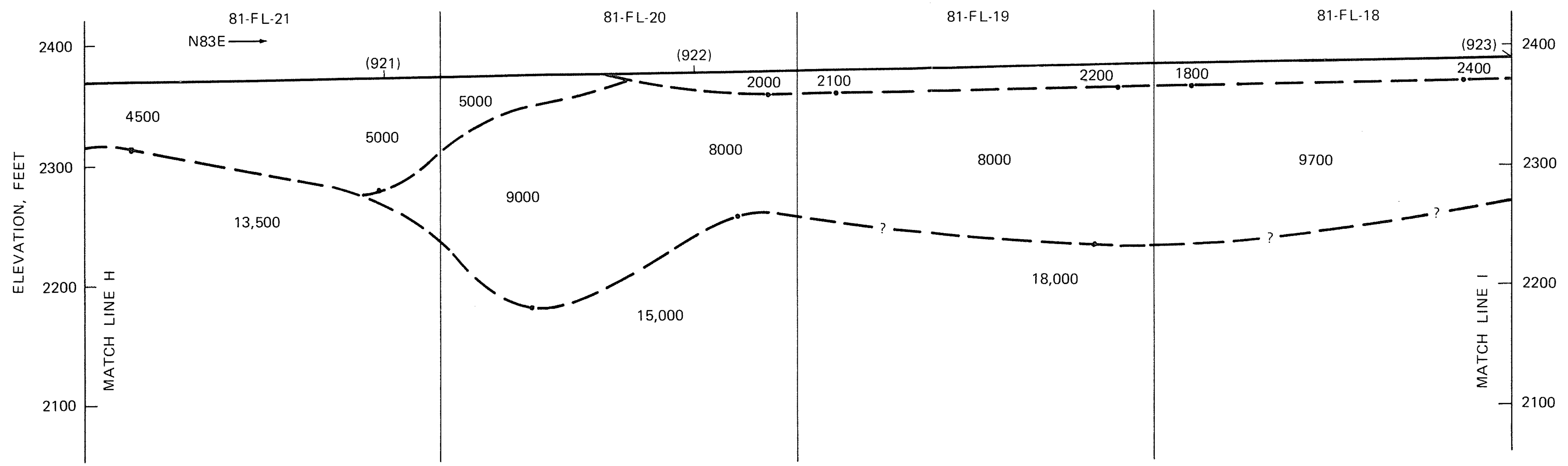
Numbers in parentheses above totographic profile refer to survey points

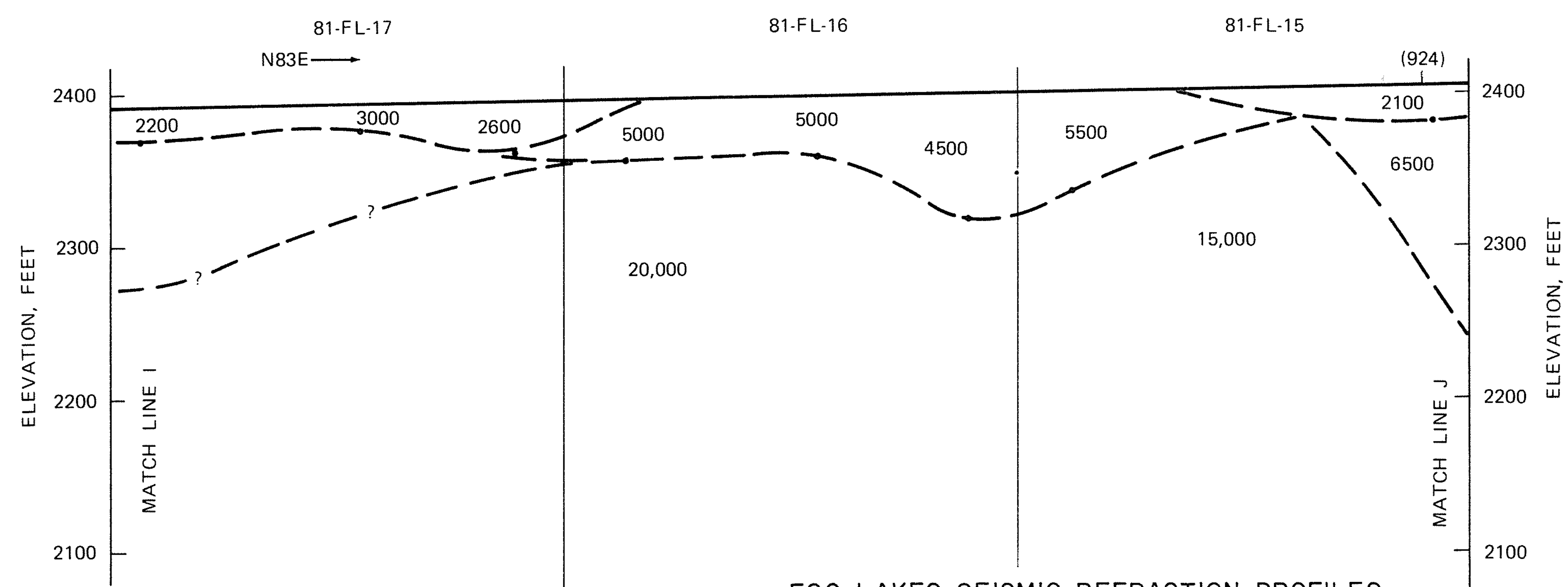


FOG LAKES SEISMIC REFRACTION PROFILES
SHEET 4 OF 7

FIGURE 20

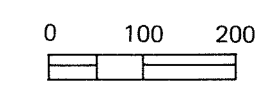
PREPARED BY WOODWARD — CLYDE CONSULTANTS





Compressional wave velocities in feet per second

Numbers in parentheses above topographic profile refer to survey points



HORIZONTAL SCALE IN FEET

FOG LAKES SEISMIC REFRACTION PROFILES
SHEET 5 OF 7

FIGURE 21

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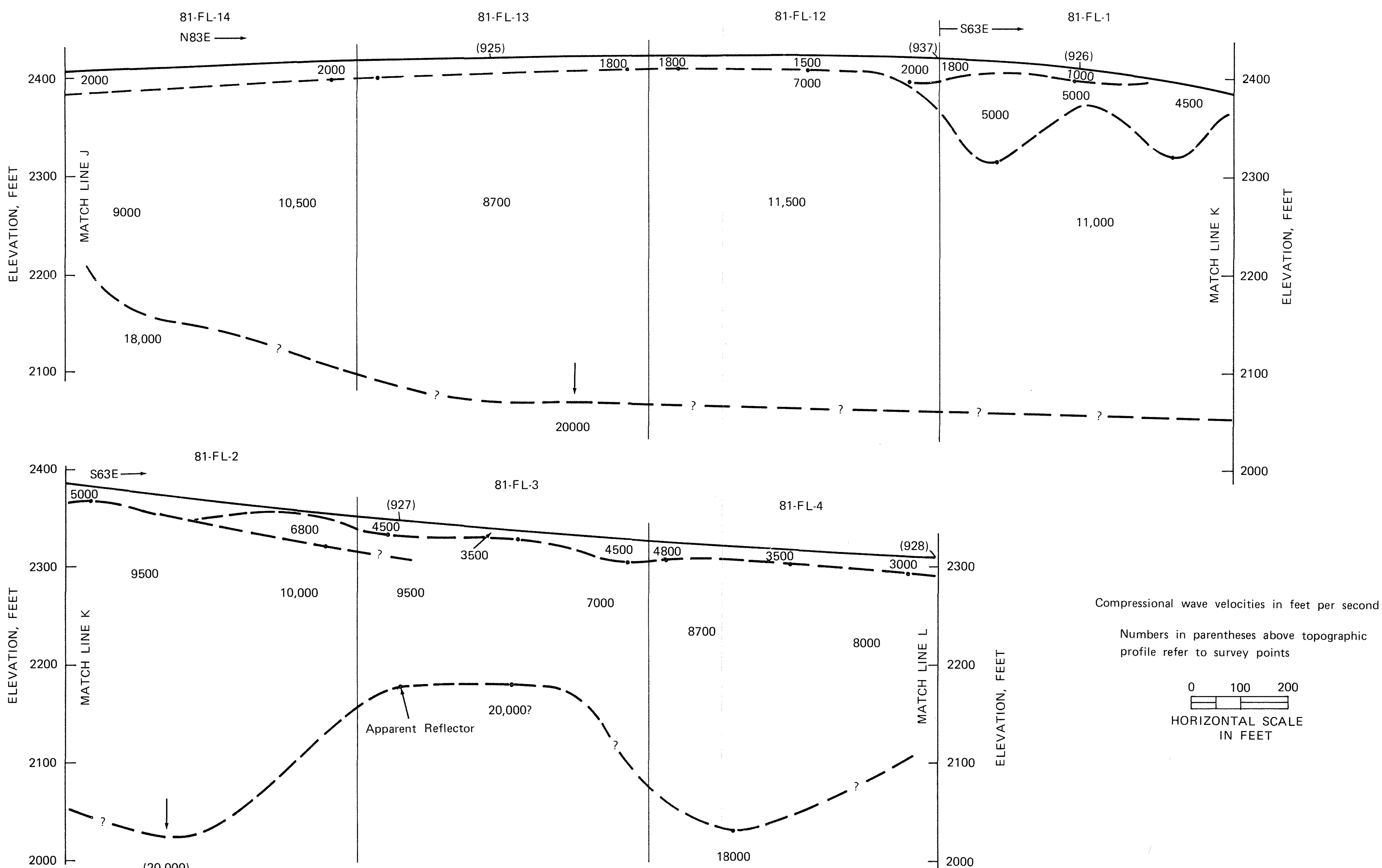
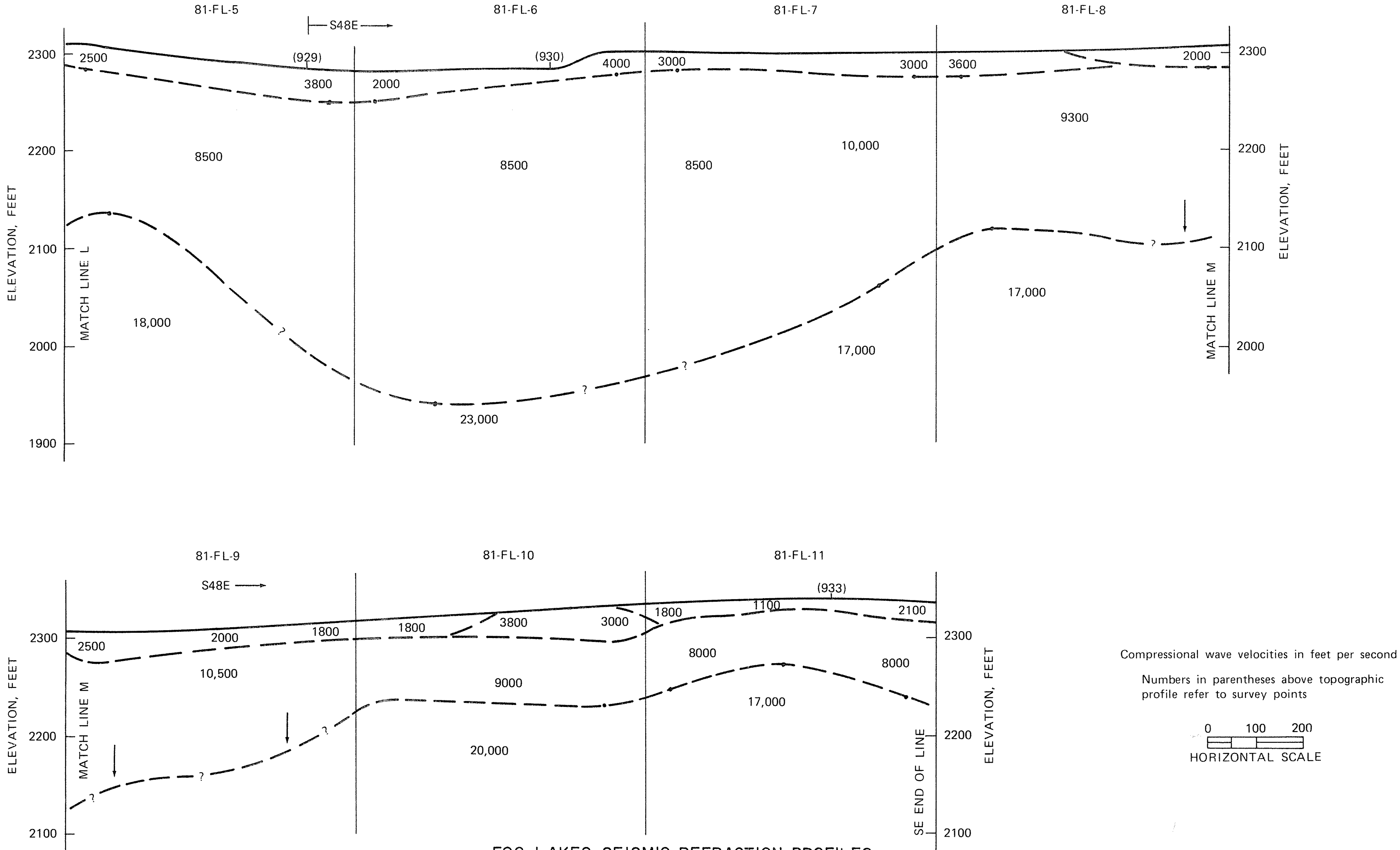
PREPARED BY WOODWARD – CLYDE CONSULTANTS



FOG LAKES SEISMIC REFRACTION PROFILES
SHEET 6 OF 7

FIGURE 22

PREPARED BY WOODWARD – CLYDE CONSULTANTS



FOG LAKES SEISMIC REFRACTION PROFILES
SHEET 7 OF 7

ACRES

FIGURE 23

PREPARED BY WOODWARD–CLYDE CONSULTANTS

APPENDIX K
RESERVOIR GEOLOGY

APPENDIX K

RESERVOIR SLOPE STABILITY

1 - INTRODUCTION

1.1 - General

Impounding of the Susitna River valley and its tributaries will influence the slope stability of both the Devil Canyon and Watana Reservoirs. Currently on the slopes above river elevation there is evidence of shallow landslides and discontinuous permafrost. Impounding of water will result in raising the groundwater table and thawing the permafrost which will likely cause slope instability and failures within certain areas of the reservoirs.

Because of the complexity and uncertainties of analyzing slope stabilities in a thawing permafrost environment, a "best estimate" has been made in this study to identify those areas in the reservoir that may be subject to future beaching, erosion, and slope failures.

The following sections discuss slope stability as it relates to the Watana and Devil Canyon reservoirs. Section 2 briefly discusses the type and causes for slope instability while Section 3 and 4 evaluate the type of instability that may occur after impoundment at Watana and Devil Canyon. The last two sections provide a summary and conclusions with recommendations.

2 - TYPES AND CAUSES OF SLOPE INSTABILITY

2.1 - General

Shoreline erosions will occur as a result of two geologic process: (1) beaching and (2) mass movements. The types of mass movement encountered in a permafrost terrain and which are pertinent to this study are described below (4,5,12):

(a) Bimodal Flow - A slide that consists of a steep headwall containing ice or ice-rich sediment, which retreats in a retrogressive fashion through melting forming a debris flow which slides down the face of the headwall to its base.

(b) Block Slide - Movement of a large block that has moved out and down with varying degrees of back tilting, most often along a preexisting plane of weakness such as bedding, joints, and faults.

(c) Flows - A broad type of movement that exhibits the characteristics of a viscous fluid in its downslope motion.

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(d) Multiple Regressive Flow - Forms a series of arcuate, concave downslope ridges as it retains some portion of the prefailure relief.

(e) Multiple Retrogressive Flow/Slide - Series of arcuate blocks concave towards the toe that step backward higher and higher towards the headwall.

(f) Rotational Slides - A landslide in which shearing takes place on a well defined, curved shear surface, concave upward in cross section, producing a backward rotation in the displaced mass.

(g) Skin Flows - The detachment of a thin veneer of vegetation and mineral soil with subsequent movement over a planar, inclined surface, usually indicative of thawing fine-grained overburden over permafrost.

(h) Slides - Landslides exhibiting a more coherent displacement; a greater appearance of rigid-body motion.

(i) Solifluction Flow - Ground movements restricted to the active layer and generally requires fine-grained soils caused by melting and saturated soils.

Aside from the formation of beaches due to erosion, instability along the reservoir slopes can result from two principal causes: a change in the groundwater regime and the thawing of permafrost. Beach erosion can give rise to general instability through the sloughing or failure of an oversteepened backslope, thereby enlarging the beach area.

2.2 - Changes in Groundwater Regime

As a reservoir fills, the groundwater table in the adjacent slope also rises as shown in Figure 2.1. This may result in a previously stable slope above the groundwater table to become unstable due to increased pore pressures and seepage acting on the slope. The slope shown in Figure 2.1, whether in soil or rock, is less stable after filling than it was prior to the existence of the reservoir. This is not to say that this slope will necessarily fail, since failure is dependent on the strength parameters of the soil or the rock.

Rapid drawdown of a reservoir may also result in increased instability of susceptible slopes.

2.3 - Thawing of Permafrost

The instability of thawing slopes in permafrost is addressed by McRoberts and Morgenstern (4). They indicate that the characteristic features of solifluction slopes, skin flows and the lobes of bimodul flows are caused by instability on low angle slopes resulting from thawing of permafrost. Mobility is often substantial and rapid as the movements are generally distributed throughout the mass.

2.4 - Stability During Earthquakes

There are certain conditions which can exist after reservoir filling which will cause slides to occur during earthquakes. This section will address only those situations which may exist after reservoir filling in which slopes are more susceptible to sliding under earthquake loading than they are in their present condition.

Submerged slopes in granular materials, particularly uniform fine sands, may be susceptible to liquefaction during earthquakes. This is one example where a small slide could occur below the reservoir level. In addition, areas above the reservoir rim in which the groundwater table has re-established itself could have a greater potential for sliding during an earthquake due to the increased pore water pressures.

Thawing permafrost could generate excess pore pressures in some soils. In cases where this situation exists in liquefiable soils, small slides on flat lying slopes could occur. The existence of fine-grained sands, coarse silts and other liquefaction susceptible material is not extensive in the reservoir areas. Therefore, it is considered that the extent of failures due to liquefaction during earthquakes will be small and primarily limited to areas of permafrost thaw. Some slides could occur above the reservoir level in previously unfrozen soils due to the earthquake shaking.

2.5 - Slope Stability Models for Watana and Devil Canyon Reservoirs

Following a detailed evaluation of the Watana and Devil Canyon reservoir geology, four general slope stability models were defined for this study. These models are shown in Figures 2.2 and 2.3 and consist of several types of beaching, flows and slides that could occur in the reservoir during and after impoundment. Based on aerial photo interpretation and limited field reconnaissance, potentially unstable slopes in the reservoir were classified by one or more of these models as to the type of failure that may occur in specific areas. In addition to identifying potential slope instability models around the reservoir, attempts were made to delineate areas of existing slope failures, and permafrost regions. These maps are shown in Figures 2.4 through 2.28. Table K.1 provides a summary of soil types as they relate to the type of slope instability. As stated above, these maps have been constructed using photo interpretation and limited field reconnaissance and are intended to be preliminary and subject to verification in subsequent studies.

3 - DEVIL CANYON RESERVOIR

3.1 - Surficial and Bedrock Geology

The topography in and around the Devil Canyon reservoir is bedrock controlled. Overburden is thin to absent, except in the upper reaches of the proposed reservoir where alluvial deposits cover the valley floor.

ACRES

A large intrusive plutonic body composed predominantly of biotite granodiorite with local areas of quartz diorite and diorite, underlies most of the reservoir and adjacent slopes. The rock is light gray to pink, medium grained and composed of quartz, feldspar, biotite and hornblende. The most common mafic mineral is biotite. Where weathered, the rock has a light yellow-gray or pinkish yellow-gray color, except where it is highly oxidized and iron stained. The granodiorite is generally massive, competent, and hard with the exception of the rock exposed on the upland north of the Susitna River where the biotite granodiorite has been badly decomposed as a result of mechanical weathering.

The other principal rock types in the reservoir area are the argillite and graywacke, which are exposed at the Devil Canyon damsite. The argillite has been intruded by the massive granodiorite and as a result, large isolated roof pendants of argillite and graywacke are found locally throughout the reservior and surrounding areas. The argillite/graywacke varies locally to a phyllite of low metamorphic grade, with possible isolated schist outcrops.

The rock has been isoclinally folded into steeply dipping structures which generally strike northeast-southwest. The contact between the argillite and the biotite granodiorite crosses the Susitna River just upstream of the Devil Canyon damsite. It is non-conformable and is characterized by an aphanitic texture with a wide chilled zone. The trend of the contact is roughly northeast-southwest where it crosses the river. Several large outcrops of the argillite completely surrounded by the biotite granodiorite are found within the Devil Creek area.

A general discussion of the regional geology is presented in Section 4.1 of the main text.

3.2 - Slope Stability and Erosion

The Devil Canyon reservoir will be entirely confined within the walls of the present river valley. This reservoir will be a narrow and deep with minimal seasonal drawdown. From Devil Canyon Creek downstream to the damsite, the slopes of the reservoir and its shoreline consist primarily of bedrock with localized areas of thin vaneer of colluvium or till. Upstream of Devil Canyon Creek, the slopes of the reservoir are covered with increasing amounts of unconsolidated materials, especially on the south abutment. These materials are principally basal tills, coarse-grained floodplain deposits, and alluvial fan deposits (see Appendix J).

Existing slope failures in this area of the Susitna River, as defined by photogrammetry and limited field reconnaissance, are skin and bimodal flows in soil and block slides and rotational slides in rock. The basal tills are the primary materials susceptible to mass movements. On the south abutment there is a possibility of sporadic permafrost existing within the delineated areas. Upstream of this area the basal till is nearly continuously frozen as evidenced by field information in Borrow Area H.

Downstream of the Devil Creek area, instability is largely reserved to small rock falls. Beaching will be the primary process acting on the shoreline in this area (Figures 3.1 and 3.2). Although this area is mapped as a basal till, the material is coarser grained than that which is found in the Watana Reservoir and is therefore more susceptible to beaching.

In areas where the shoreline will be in contact with steep bedrock cliffs, the fluctuation of the reservoir may contribute to rockfalls. Fluctuation of the reservoir and therefore the groundwater table, accompanied by seasonal freezing and thawing, will encourage frost heaving as an erosive agent to accelerate degradation of the slope and beaching. These rock falls will be limited in extent and will not have the capacity to produce a large wave which could affect dam stability. In Devil Creek, a potential small block slide may occur after reservoir or dam.

Above Devil Creek up to about river mile 180, beaching will be the most common erosive agent. Present slope instability above reservoir normal pool level will continue to occur, with primary beaching occurring at the shoreline. At approximate river mile 175, there is an old landslide on the south abutment. This large rotational slide is composed of basal till which, for the most part, is frozen. A large bimodal flow exists within this block headed by a large block of ground ice. Yearly ablation of the ice results in flowage of saturated material downslope. The landslide has an arcuate back scarp which has become completely vegetated since its last movement. However, this landslide, which has an estimated volume of 3.4 mcy, could possibly be reactivated due to continued thawing or change in the groundwater regime brought about with reservoir filling.

Since the maximum pool elevation extends only to the toe of this slide, it is unlikely that a large catastrophic slide could result from normal reservoir impoundment (See Figure 3.3). However, potential for an earthquake-induced landslide is possible. A mass slide in this area could result in temporary blockage of river flow.

The distance from the dam, the meandering of the river valley, and the shallow depth of the reservoir in this area makes the potential of a wave induced by a massive landslide that could affect the dam stability very remote.

In general, the following conclusions can be drawn about the slope conditions of the Devil Canyon Reservoir after impoundment:

- Minimal drawdown of the reservoir is conducive to stable slope conditions.

- The lack of significant depths of unconsolidated materials along the lower slopes of the reservoir and the existence of stable bedrock conditions is indicative of stable slope conditions after reservoir impounding.

- An old large landslide in the upper reservoir has the potential for instability, which, if failed, could conceivably create a temporary blockage of the river in this area.

- The probability of a landslide-induced wave in the reservoir overtopping the dam is remote.

4 - WATANA RESERVOIR

4.1 - General

Preliminary reconnaissance mapping of the Watana Reservoir was performed during this study and principal rock types and general types of surficial material were identified.

The topography of the Watana Reservoir and adjacent slopes is characterized by a narrow V-shaped stream-cut valley superimposed on a broad U-shaped glacial valley. Surficial deposits mask much of the bedrock in the area, especially in the lower and uppermost reaches of the reservoir. A surficial geology map of the reservoir, prepared by the COE, and airphoto interpretation performed during this study (Appendix J), identifies tills, lacustrine and alluvial deposits, as well as predominant rock types (11).

4.2 - Surficial Deposits

Generally, the lower section of the Watana Reservoir and adjacent slopes are covered by a vaneer of glacial till and lacustrine deposits. Two main types of till have been identified in this area; ablation and basal tills. The basal till is predominately over-consolidated, with a fine-grain matrix (more silt and clay) and low permeability. The ablation till has less fines and a somewhat higher permeability. Lacustrine deposits consist primarily of poorly-graded fine sands and silts with lesser amounts of gravel and clay, and exhibits a crude stratification.

On the south side of the Susitna River, the Fog Lake area is characteristic of a fluted ground moraine surface. Upstream in the Watana Creek area, glaciolacustrine material forms a broad, flat plain which mantles the underlying glacial till and the partially lithified Tertiary sediments. Significant alluvial and outwash deposits exist in the river valley. Ice disintegration features such as kames and eskers have been observed adjacent to the river valley.

Permafrost exists in the area, as evidenced by ground ice, patterned ground stone nets and slumping of the glacial till overlying permafrost. Numerous slumps have been identified in the Watana Reservoir area, especially in sediments comprised of basal till. Additional details regarding this subject will be given in subsequent sections. In addition, numerous areas of frozen alluvium and interstitial ice crystals have been observed in outcrops and identified from drill hole drive samples.

4.3 - Bedrock Geology

As discussed in Section 6 (Main Report), the Watana damsite is underlain by a diorite pluton. Approximately three miles upstream of the Watana damsite, a non-conformable contact between argillite and the dioritic pluton crosses the Susitna River. An approximate location of this contact has also been delineated on Fog Creek, four miles to the south of the damsite. Just downstream of the confluence of Watana Creek and the Susitna River, the bedrock consists of semi-consolidated, Tertiary sediments (8) and volcanics of Triassic age. These Triassic volcanics consist of metavolcaniclastic rocks and marble (3). From just upstream of Watana Creek to Jay Creek, the rock consists of a metavolcanogenic sequence dominantly composed of metamorphosed flows and tuffs of basaltic to andesitic composition. From Jay Creek to just downstream of the Oshetna River, the reservoir is underlain by a metamorphic terrain of amphibolite and minor amounts of greenschist and foliated diorite. To the east of the Oshetna River, glacial deposits are predominant.

The main structural feature within the Watana Reservoir is the Talkeetna Thrust fault, which trends northeast-southwest (3) and crosses the Susitna River approximately eight miles upstream of the Watana damsite (Figure 4.1 - Main Text). Csejtey and others (2) have interpreted this to have a southeast dip, while Turner and Smith (10) suggest a northwest dip. The southwest end of the fault is overlain by unfaulted Tertiary volcanics (2). A detailed discussion of this fault is presented in Woodward-Clyde Consultant's Task 4 Report. A general discussion of regional geology is presented in Section 4 of the main text.

4.4 - Slope Stability and Erosion

Most of the slopes within the reservoir are composed of unconsolidated materials. As a generalization, permafrost is nearly continuous in the basal tills and sporatic to continuous in the lacustrine deposits. In Figures 2.12 through 2.28, the distribution of permafrost has been delineated primarily on the flatter slopes below elevation 2300 feet. Inclined slopes may be underlain by permafrost, but based on photogrametric characteristics, the active layer is much thicker indicating that permafrost soils are thawing, and/or that permafrost does not exist. Existing slope instability within the reservoir (as defined by aerial photographic interpretation (Appendix J) and limited field reconnaissance), indicate that the types of mass movement are primarily solifluction, skin flows, bimodal flows, and small rotational slides. These types of failure occur predominantly in the basal till or areas where the basal till is overlain by lacustrine deposits (Appendix J). In some cases, solifluction, which originated in the basal till has proceeded downslope over some of the floodplain terraces.

Three major factors which will contribute significantly to slope instability in the Watana Reservoir are changes in the groundwater regime, large seasonal fluctuation of the reservoir level (estimated at 60 feet), and thawing of permafrost. These factors were analyzed to determine their effects on typical conditions in the reservoir. From this, four basic models of shoreline conditions were developed (Figures 2.2 and 2.3). The two processes affecting the shoreline of the reservoirs are beaching and slope stability. These models were applied to selected reaches of the reservoir shoreline and evaluated for conditions at or near normal pool levels. It should be noted that the slope stability of the Watana Reservoir was evaluated for the "worst" case which considered the maximum and minimum pool levels. In cases where sliding will occur, it will not be uncommon for some flows or possibly beaching to occur over the same reach. Slope instability during and after reservoir impounding will be addressed below.

It is estimated that filling of the reservoir to normal pool level will take approximately three years. Due to the relatively slow rate of impounding, the potential for slope instability occurring during flooding of the reservoir will be minimal and confined to shallow surface flows and possibly some sliding. Slopes will be more susceptible to slope instability after impoundment when thawing of the permafrost soils occurs and the groundwater regime has reestablished itself in the frozen soils.

Near the damsite, assuming that the present contours will remain unchanged, the north abutment will primarily be subject to beaching except for some small flows and slides, which may occur adjacent to Deadman Creek. On the south abutment, thawing of the frozen basal tills will result in numerous skin and bimodal flows. There is also a potential for small rotational sliding to occur primarily opposite Deadman Creek.

On the south abutment between the Watana damsite and Vee Canyon, the shoreline of the reservoir has a high potential for flows and shallow rotational slides (Figures 4.1 and 4.2). In contrast to the north abutment, the shoreline is almost exclusively in contact with frozen basal tills, overburden is relatively thick, and steeper slopes are present. Thermal erosion, resulting from the erosion and thawing of the ice-rich fine grained soils, will be the key factor influencing their stability. On the north abutment below Vee Canyon and on both abutments upstream of Vee Canyon, the geological and topographic conditions are more variable and therefore have a potential for varying slope conditions. In the Watana Creek drainage area, there is a thick sequence of lacustrine material overlying the basal till (Figure 4.3).

Unlike the till, it appears that the lacustrine material is largely unfrozen. All four types of slope instability could develop here, depending on where the seasonal drawdown zone is in contact with the aforementioned stratigraphy. In addition, slope instability resulting from potential liquefaction of the lacustrine material during earthquakes may occur. Overall, slopes on the north abutment, in contrast with the south abutment, are less steep and slightly better drained, which may be indicative of less continuous permafrost and/or slightly coarse material at the surface with a deeper active layer.

In general, the potential for beaching is high due to: (a) the wide seasonal drawdown zone that will be in contact with a thin vaneer of colluvium over bedrock; and, (b) the large areas around the reservoir with low slopes (Figure 4.4). In the Oshetna-Goose Creeks area, there is a thick sequence of lacustrine material. Permafrost appears to be nearly continuous in this area based on the presence of unsorted polygonal ground and potential thermokarst activity around some of the many small ponds (thaw lakes/kettles). The reservoir in this area will be primarily confined within the floodplain and therefore little modification of the slopes is expected. Where the slopes are steep, there could be some thermal niche erosion resulting in small rotational slides.

The potential for a large block slide occurring, and generating a wave which could overtop the dam is very remote. For this to occur, a very high, steep slope with a potentially unstable block of large volume would need to exist adjacent to the reservoir. This condition was not observed within the limits of the reservoir. In approximately the first 16 miles upstream of the dam, the shoreline will be in contact with the low slopes of the broad U-shaped valley. Between 16 and 30 miles upstream of the dam, no potentially large landslides were observed. Beyond 30 miles upstream, the reservoir begins to meander and narrows, therefore any wave induced in this area by a large landslide would, in all likelihood, dissipate prior to reaching the dam.

In general, the following conclusions can be drawn about the slope conditions of the Watana reservoir after impounding:

- The principal factors influencing slope instability are the large seasonal drawdown of the reservoir and the thawing of permafrost soils. Other factors are the change in the groundwater regime, the steepness of the slopes, coarseness of the material, thermal toe erosion, and the fetch available to generate wave action;

- The potential for beaching is much greater on the north abutment of the reservoir;

- A large portion of the reservoir slopes are susceptible to shallow slides, mainly skin and bimodal flows, and shallow rotational slides;

- The potential for a large block slide which might generate a wave that could overtop the dam is remote; and

- The period in which restabilization of the slopes adjacent to the reservoir will occur is largely unknown.

In general, most of the reservoir slopes will be totally submerged. Areas where the filling is above the break in slope will exhibit less stability problems than those in which the reservoir is at an intermediate or low level. Flow slides induced by thawing permafrost can be expected to occur over very flat-lying surfaces.

5 - SUMMARY

Some amount of slope instability will be generated in the Watana and Devil Canyon reservoirs due to reservoir filling. These areas will primarily be in locations where the water level will be at an intermediate level relative to the valley depth.

Slope failure will be more common in the Watana reservoir due to the existence of permafrost soil throughout the reservoir. The Devil Canyon reservoir is generally in more stable rock and the relatively thin overburden is unfrozen in the reach of the river upstream from the dam.

Although skin flows, minor slides and beaching will be common in parts of the reservoirs, it will present only a visual concern and poses no threat to the project. Many areas in which sliding does occur will stabilize into beaches with a steep backslope.

Tree root systems left from reservoir clearing will tend to hold shallow surface slides and in cases where permafrost exists may have a stabilizing influence since the mat will hold the soil in place until excess pore pressure have dissipated.

6 - RECOMMENDATIONS

It is recommended that typical slope conditions outlined in this report be further investigated during subsequent phases of the project in order to determine:

- The magnitude of the potential for instability at a given location; and
- Whether beaching or sliding will exist at major migrating herd crossing sites.

This investigation should include drilling, instrumentation and laboratory analysis to confirm the findings in this study. Since only one significant existing landslide has been identified in this study, it is also recommended that further study be directed to this site to determine the potential for future sliding in this area.

TABLE K.1: CHARACTERISTICS OF SLOPE MATERIALS

Unit	Terrain Unit Symbol*	Material	Permafrost Conditions	Current Slope Stability	Slope Conditions After Reservoir Filling Low	Steep
Bedrock	Bxu	Consolidated bedrock	unfrozen	stable	Beaching (I)**	
Colluvium, over bedrock and bedrock exposures	C + Bxu / Bxu	Angular blocks of rock with some sand and silt overlying bedrock	unfrozen	stable	Beaching (I)	
Floodplain	Fp	Rounded cobbles, gravel and sand sorted and layered with or without silt cover	unfrozen	stable	Beaching	
Floodplain Terraces	Fpt	Rounded cobbles, gravel and sand with some silt covered by thin silt layers. Sorted, layered	unfrozen	stable	Beaching (I)	
Granular Alluvial Fan	Ffg	Rounded cobbles, gravel, with sand and some silt. Some sorting and layering of materials	unfrozen	stables	Beaching (I)	
Kame Deposits	GFK	Rounded and striated cobbles and sand. Crudely sorted and layered	unfrozen	stable	Beaching (I)	
Lacustrine	L	Fine sand to sandy silt with occasional pebbles. Sorted and layered	unfrozen frozen	stable stable	Beaching (I) Flows (II)	Sliding (III) Sliding (IV)
Basal Till	Gtb-f	Gravelly silty sand and gravelly, sandy silt cobbles and boulders poorly rounded and striated. No layering, poorly graded	frozen	unstable	Flows (II)	Sliding (IV)
Ablation Till	Gta	Rounded and striated cobbles, gravel and sand, no layering, well graded. Boulder and cobble, lag covers surface	unfrozen frozen	stable stable	Beaching (I) Flow (II)	Sliding (IV) Sliding (IV)
Ablation till over unweathered layer	Gta / Bru	Rounded and striated cobbles, gravel and sand, no layering, well graded over bedrock	unfrozen	stable	Beaching (I)	

*See Appendix J for mapped terrain unit symbols.
**I, II, III, IV - refer to Figures 2.2 and 2.3.

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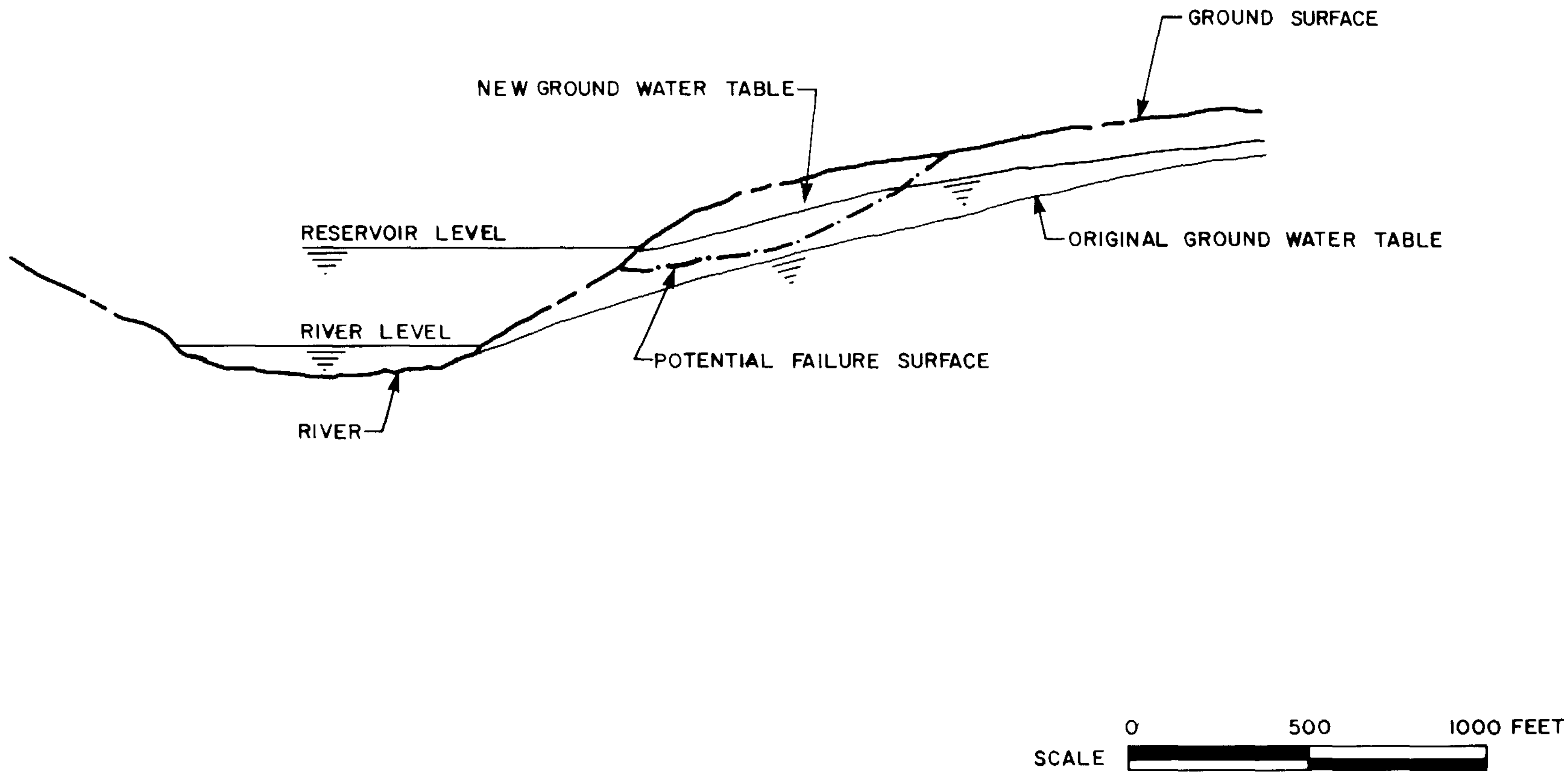
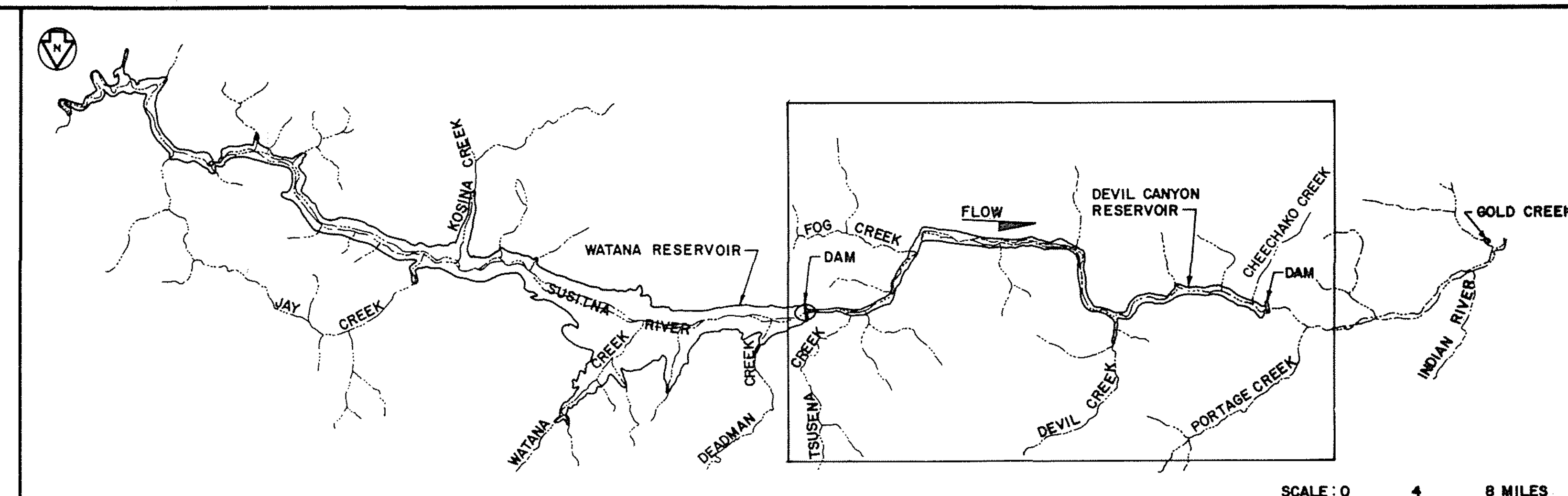
ACRES



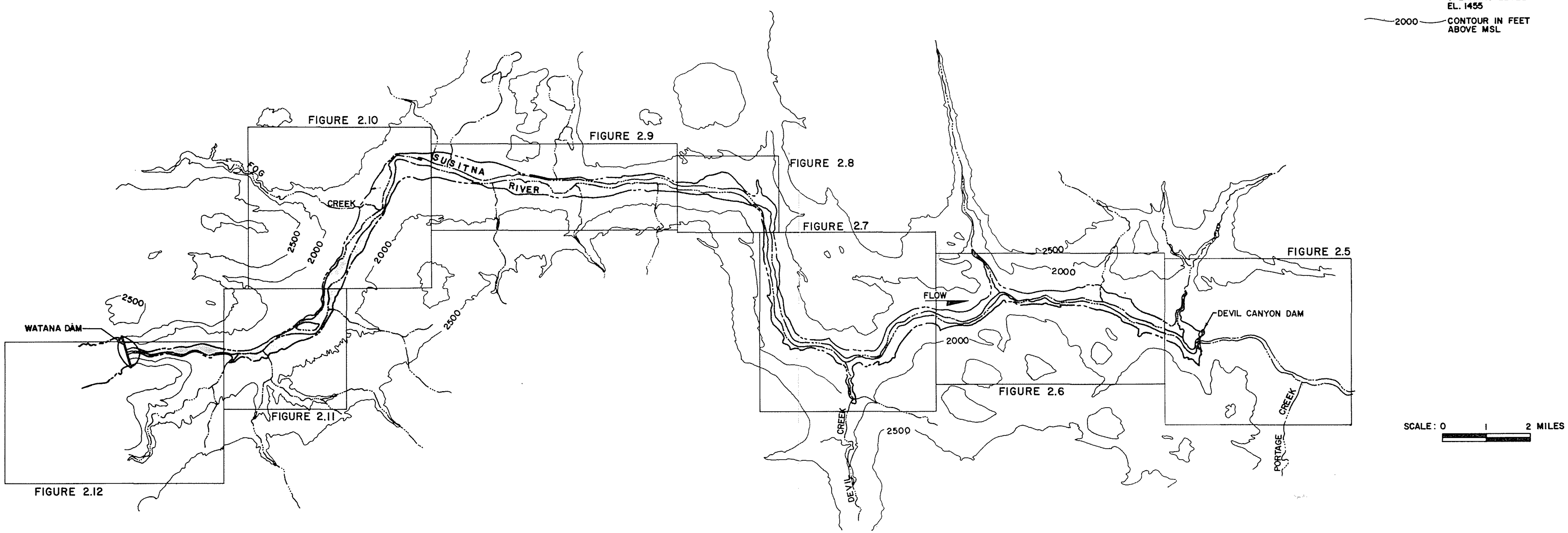
TYPICAL SLOPE FAILURE

ACRES

FIGURE 2.1



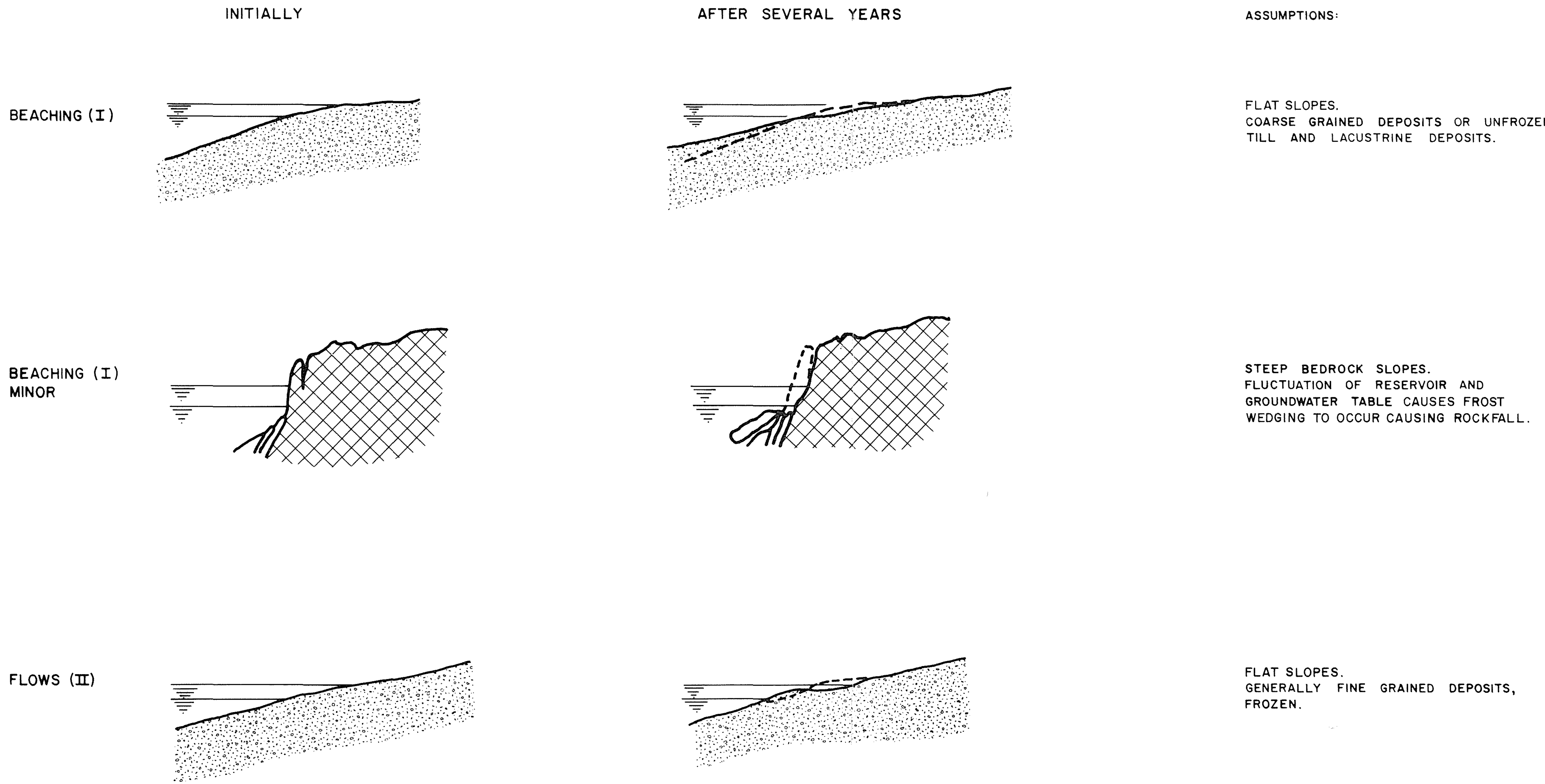
LOCATION MAP



DEVIL CANYON RESERVOIR
INDEX MAP

FIGURE 2.4

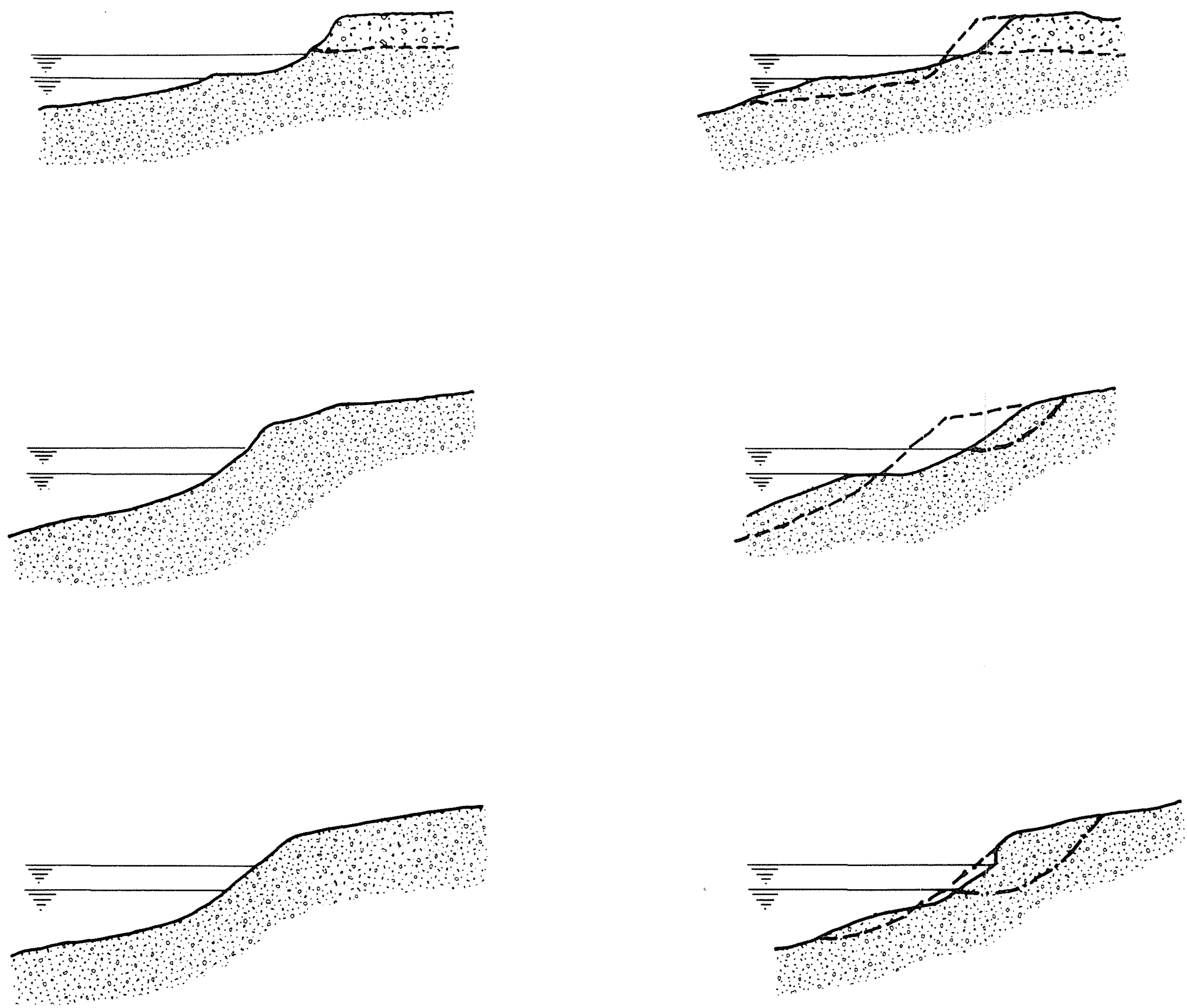
ACRES



SLOPE MODELS FOR THE WATANA AND DEVIL CANYON RESERVOIRS

FIGURE 2.2

INITIALLY | AFTER SEVERAL YEARS | ASSUMPTIONS:



SLIDING (III)
STEEP SLOPES.
TWO LAYER CASE, LOWER LAYER IS FINE GRAINED AND FROZEN. UPPER LAYER IS COARSER GRAINED, PARTLY TO COMPLETELY FROZEN.
FLOWS IN LOWER LAYER ACCOMPANY SLOPE DEGRADATION

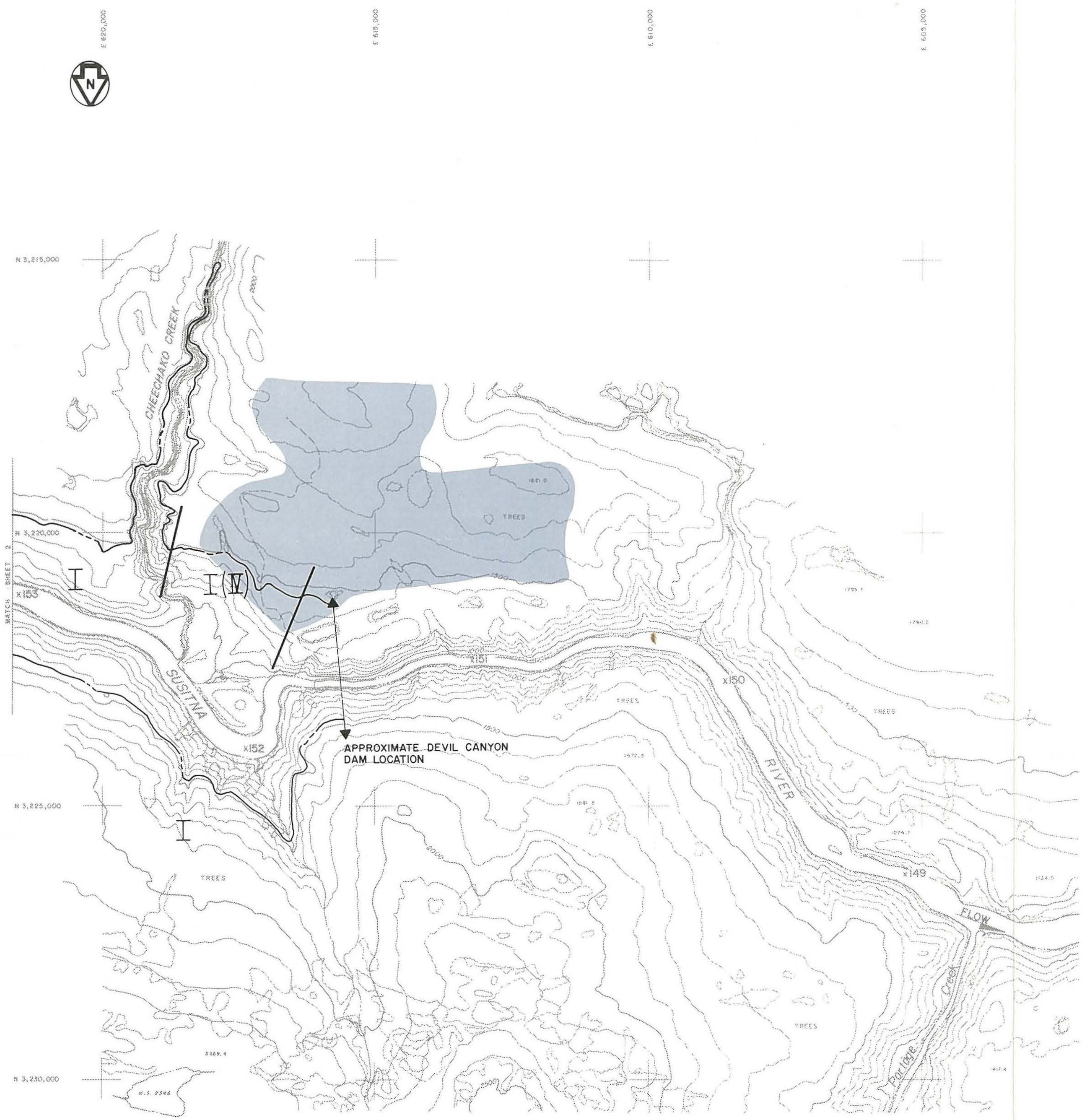
SLIDING (IV)
STEEP SLOPES.
FINE GRAINED AND UNFROZEN.

(IV)
STEEP SLOPES.
FINE GRAINED AND UNFROZEN.
NOTE: POSSIBLE FURTHER SLIDING IF THAW BULB EXTENDS INTO SLOPE WITH TIME.

SLOPE MODELS FOR THE WATANA AND DEVIL CANYON RESERVOIRS

FIGURE 2.3

ACRES



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I - II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- x RIVER MILES
- A A SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION.

SCALE 0 1000 2000 FEET

Date of Photography : 7 - 19 - 81
Scale : 1" = 1000' Contour Interval 100'

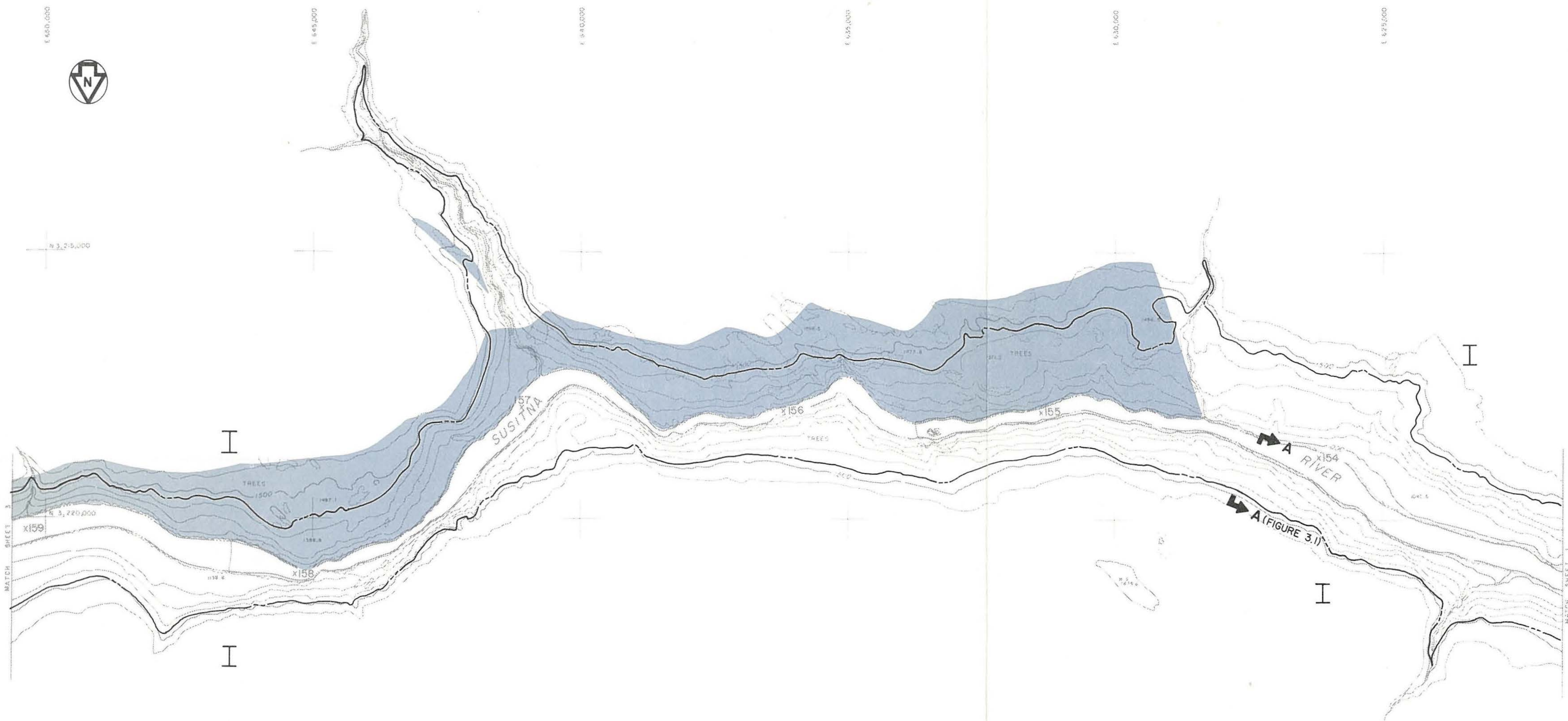
SHEET INDEX

		4		
7	5			
8	6	3	2	

DEVIL CANYON
SLOPE STABILITY MAP

FIGURE 2.5

ACRES



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- RIVER MILES
- A A — SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

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Date of Photography 7-19-81
Scale 1:1000 Contour Interval 100'

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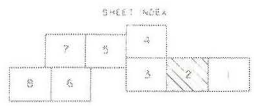
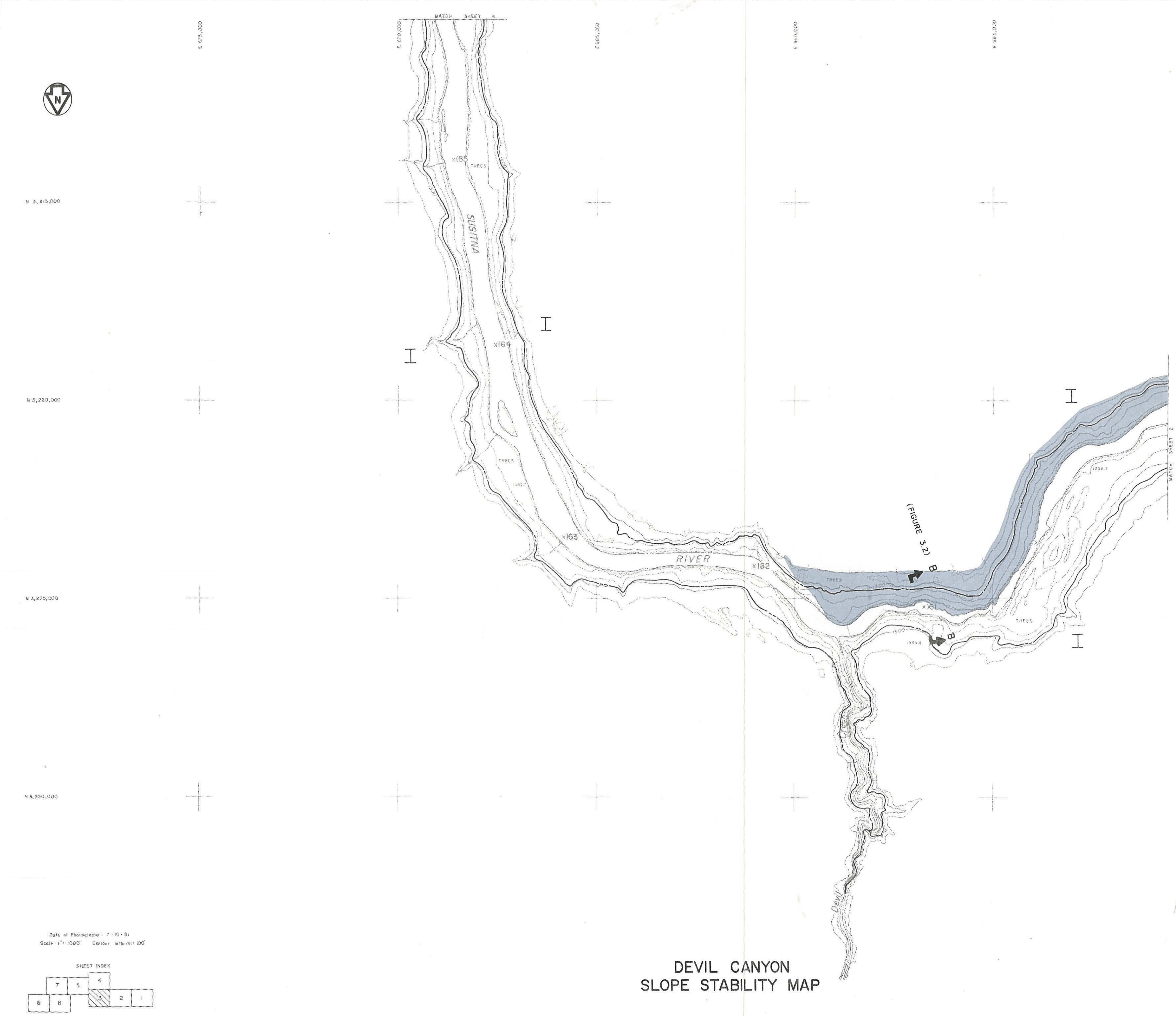


DEVIL CANYON SLOPE STABILITY MAP

ACRES

FIGURE 2.6



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- x RIVER MILES
- A A SECTION LOCATION

AREA OF POTENTIAL PERMAFROST

NOTES

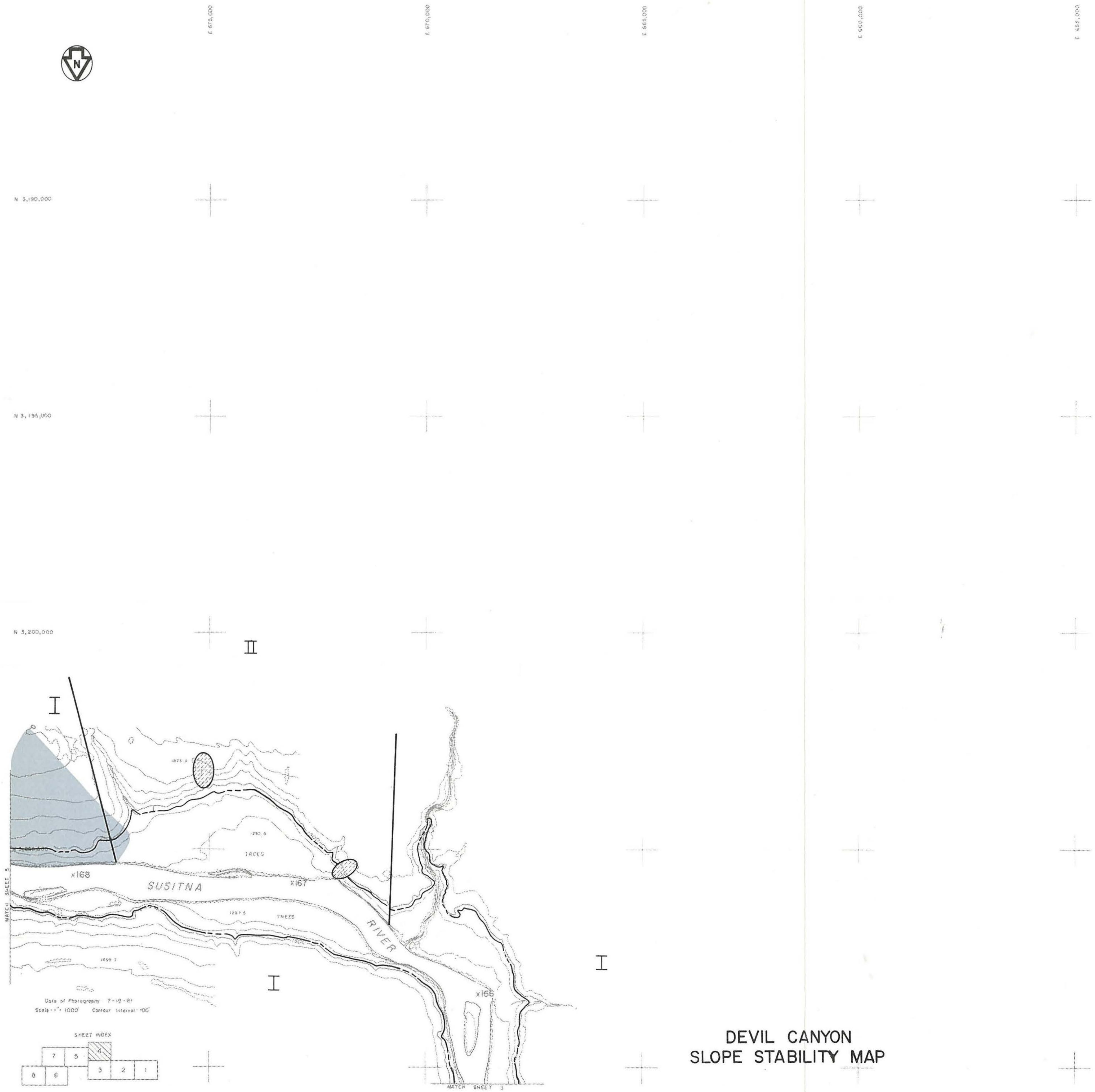
1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

DEVIL CANYON SLOPE STABILITY MAP

FIGURE 2.7

ACRES



DEVIL CANYON
SLOPE STABILITY MAP

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I (IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
	NORMAL MAXIMUM OPERATING LEVEL
x	RIVER MILES
A A	SECTION LOCATION
	AREA OF POTENTIAL PERMAFROST

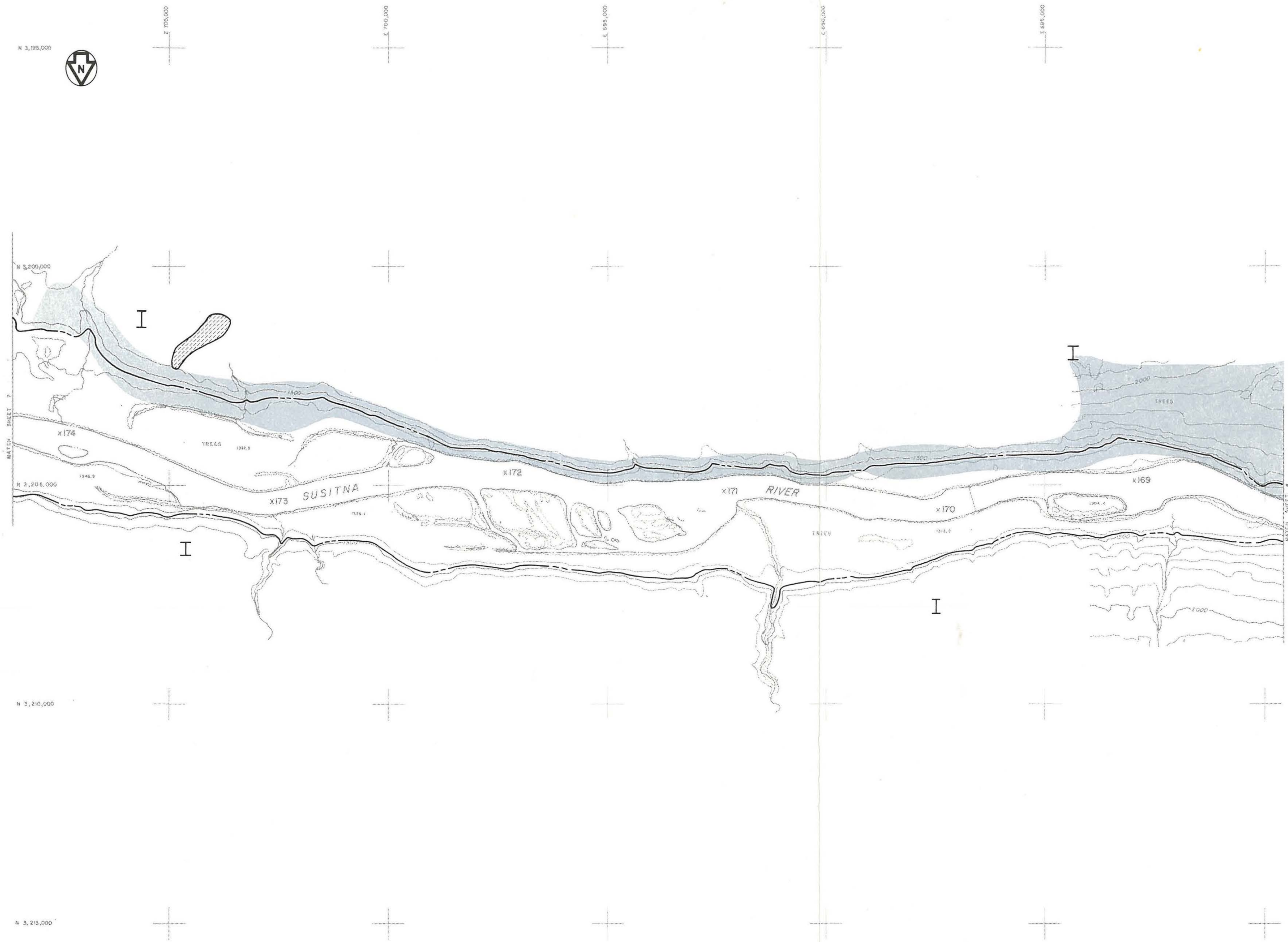
NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

FIGURE 2.8

ACRES



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I - II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- x RIVER MILES
- A A SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

Date of Photography: 7-19-81
Scale 1"=1000' Contour Interval 100'

SHEET INDEX

8 6 7 5 4 3 2 1

DEVIL CANYON
SLOPE STABILITY MAP

ACRES

FIGURE 2.9

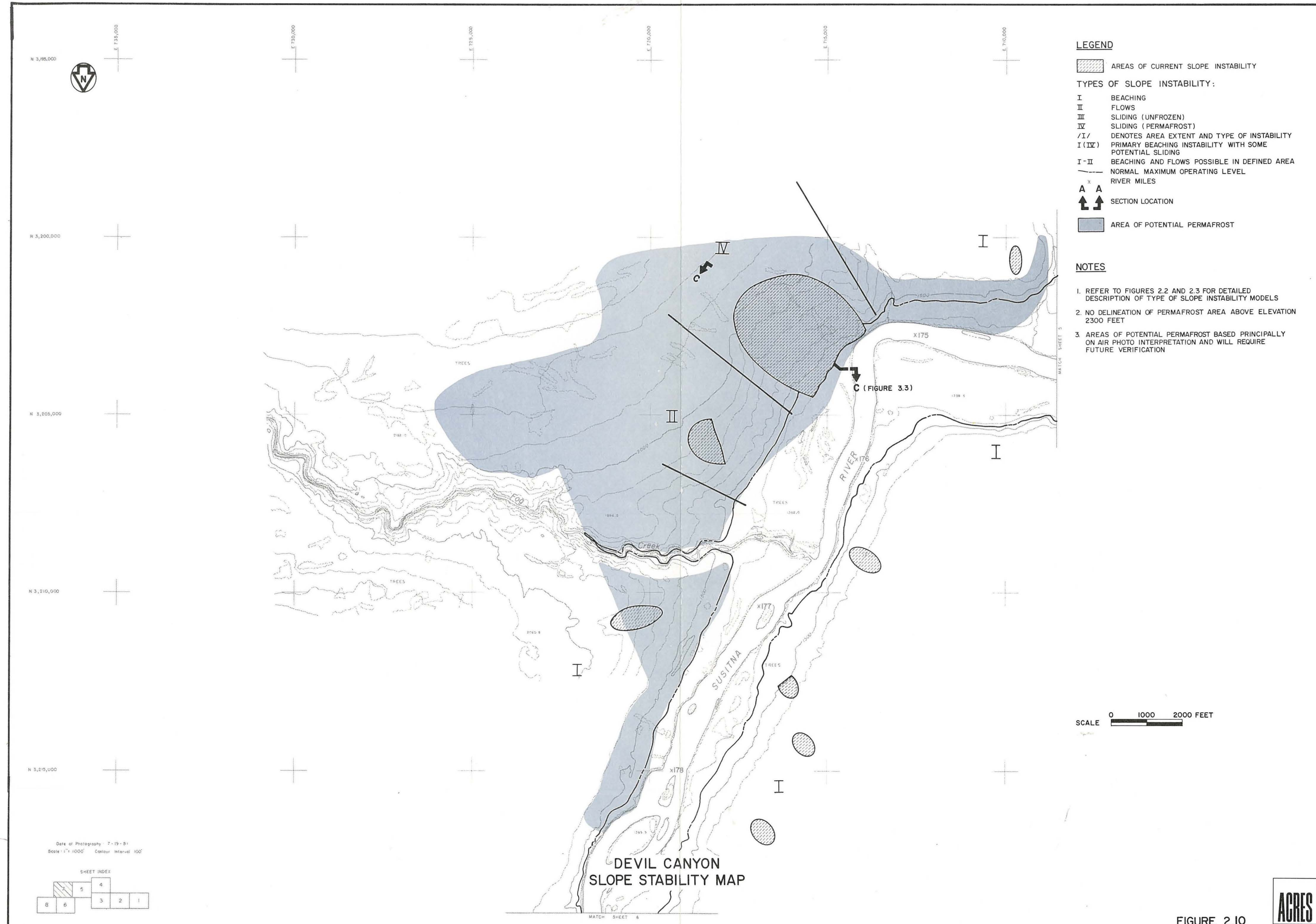
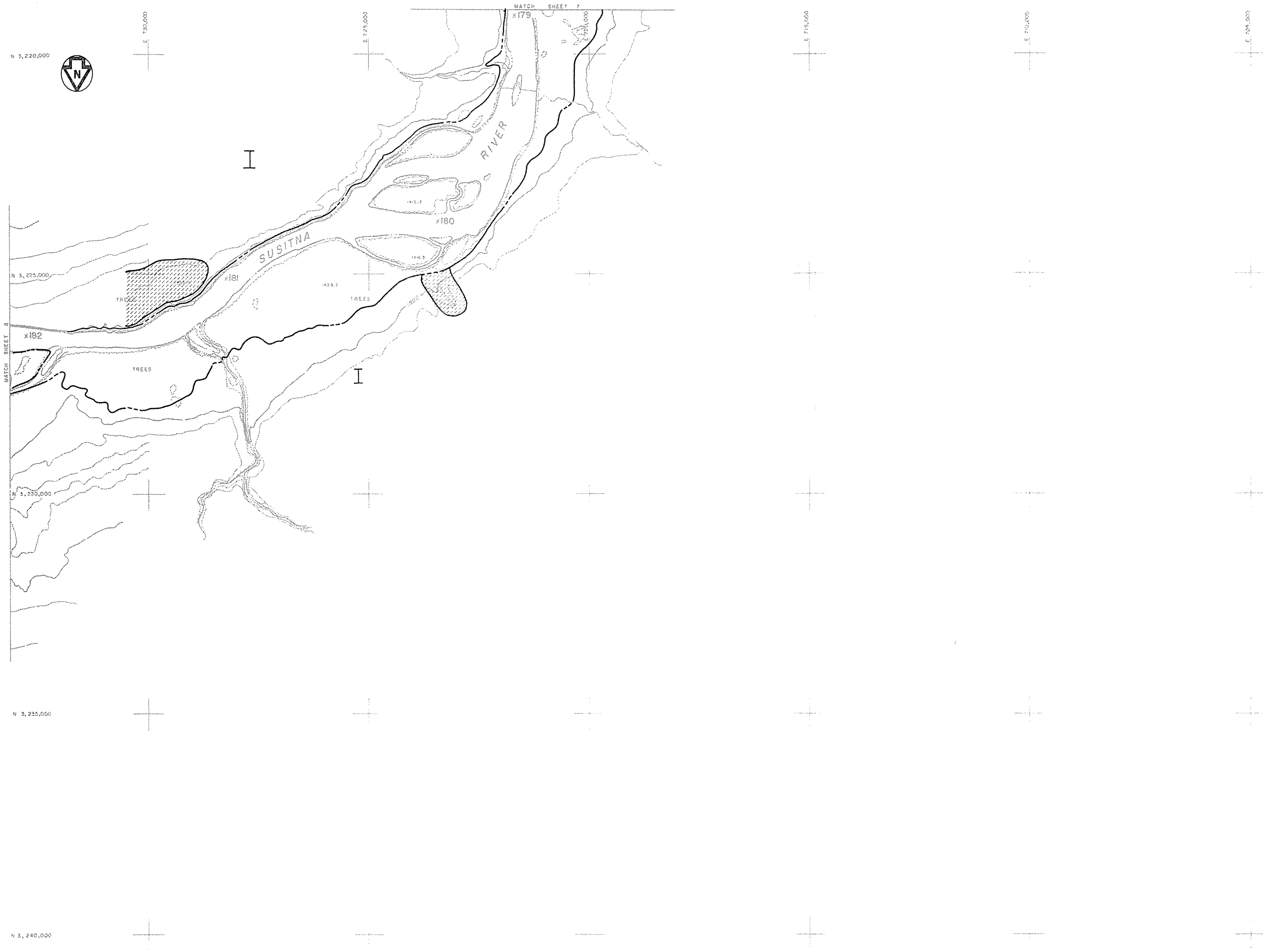

LEGEND
AREAS OF CURRENT SLOPE INSTABILITY
TYPES OF SLOPE INSTABILITY:
I BEACHING
II FLOWS
III SLIDING (UNFROZEN)
IV SLIDING (PERMAFROST)
/I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I (IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I - II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
NORMAL MAXIMUM OPERATING LEVEL
RIVER MILES
A A SECTION LOCATION
AREA OF POTENTIAL PERMAFROST
NOTES
1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION
SCALE 0 1000 2000 FEET
C (FIGURE 3.3)
x175
x176
x177
x178
RIVER
SUSITNA
Fog Creek
TREES
MATCH SHEET 5
MATCH SHEET 6
Date of Photography 7-19-81
Scale 1" = 1000' Contour Interval 100'
SHEET INDEX
DEVIL CANYON
SLOPE STABILITY MAP
ACRES

FIGURE 2.10



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I - II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- RIVER MILES
- A A — SECTION LOCATION

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

Date of Photography 7-19-81
Scale 1"=1000' Contour Interval 100'

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7	5	4		
8	6	3	2	1

DEVIL CANYON SLOPE STABILITY MAP

ACRES

FIGURE 2.11

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

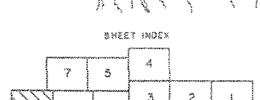
TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
	NORMAL MAXIMUM OPERATING LEVEL
	NORMAL MINIMUM OPERATING LEVEL
x	RIVER MILES
A A	SECTION LOCATION

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

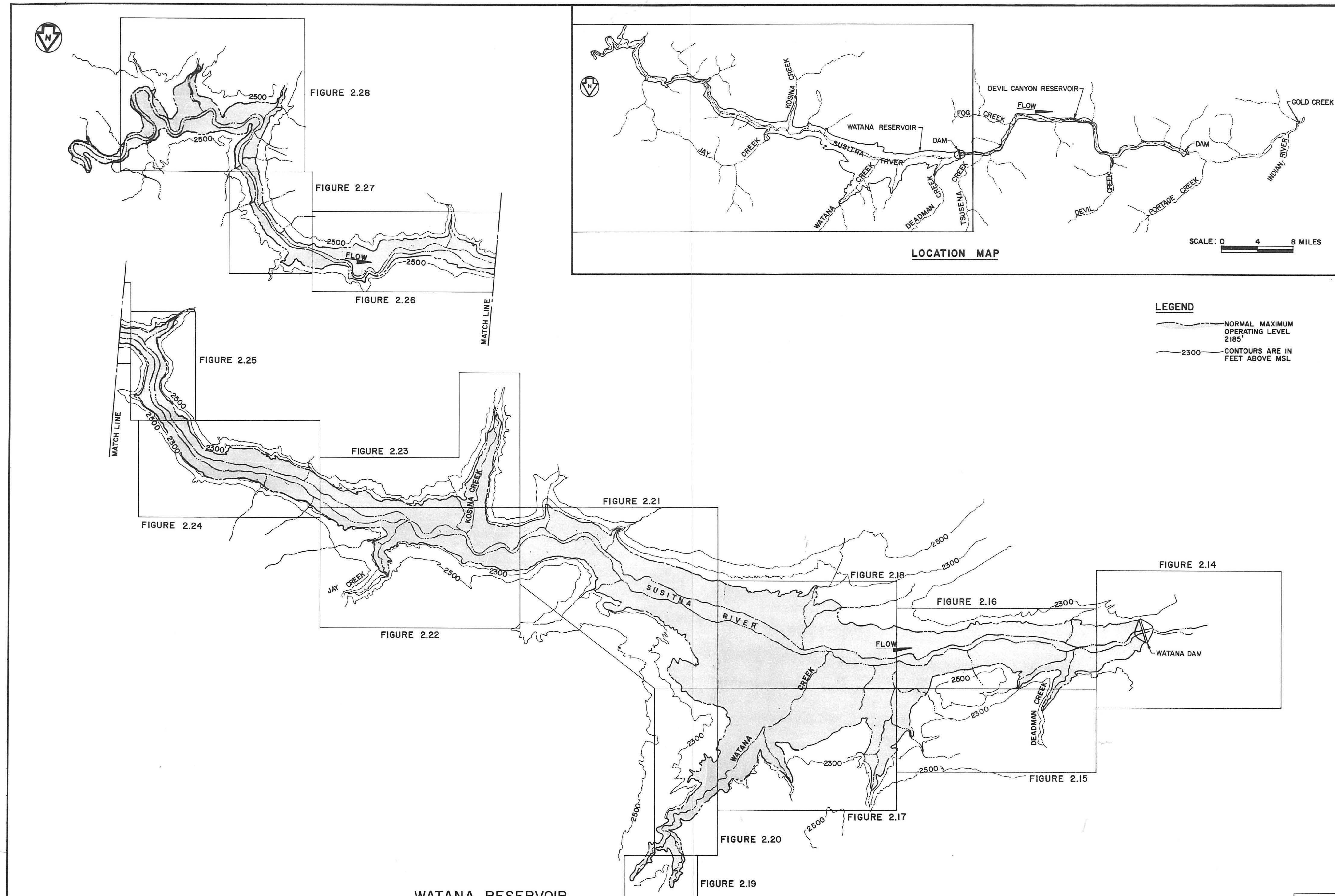
SCALE 0 1000 2000 FEET



DEVIL CANYON
SLOPE STABILITY MAP

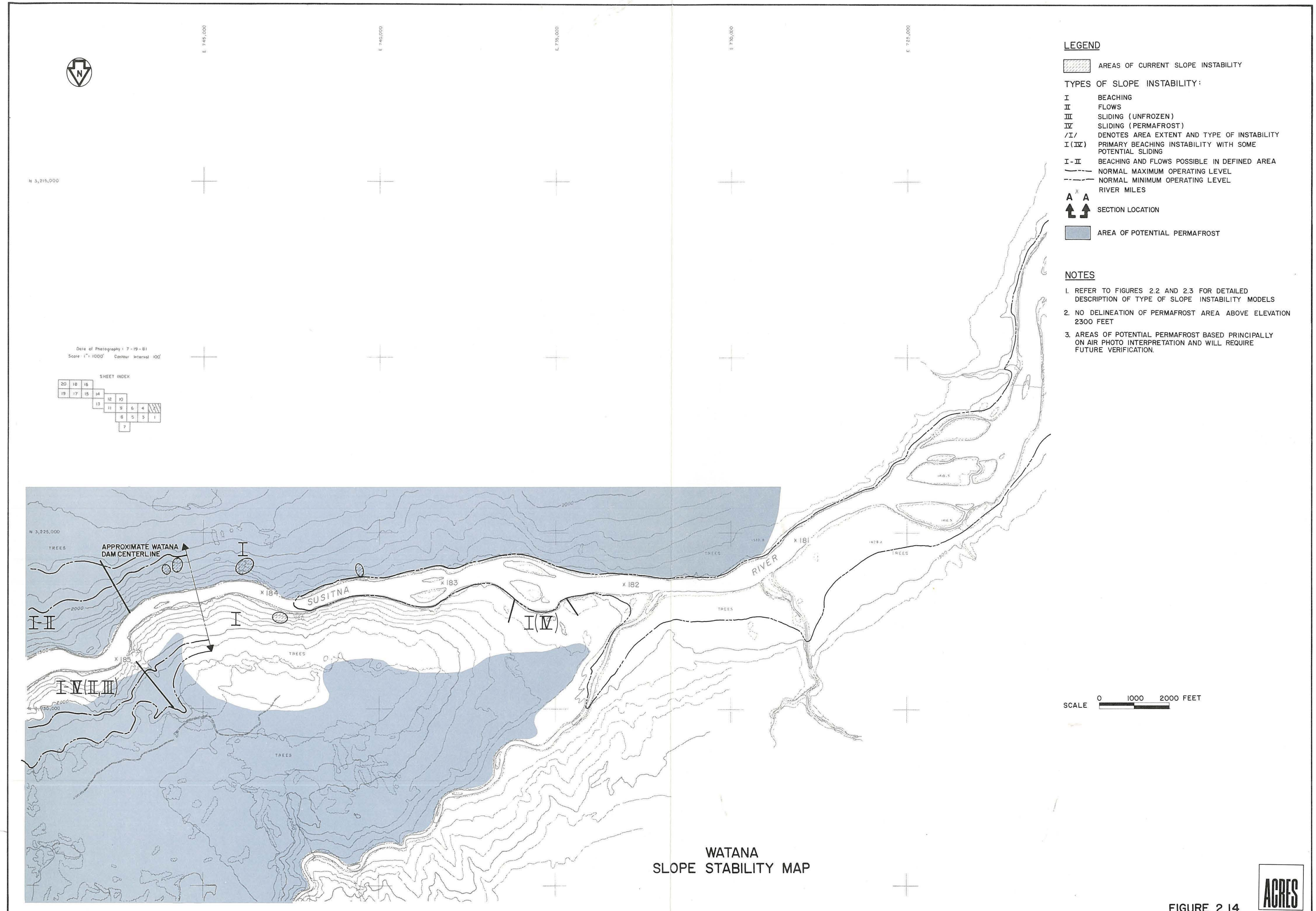
ACRES

FIGURE 2.12



WATANA RESERVOIR
INDEX MAP

FIGURE 2.13



WATANA
SLOPE STABILITY MAP

FIGURE 2.14

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
	NORMAL MAXIMUM OPERATING LEVEL
	NORMAL MINIMUM OPERATING LEVEL
A A	SECTION LOCATION
	AREA OF POTENTIAL PERMAFROST

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

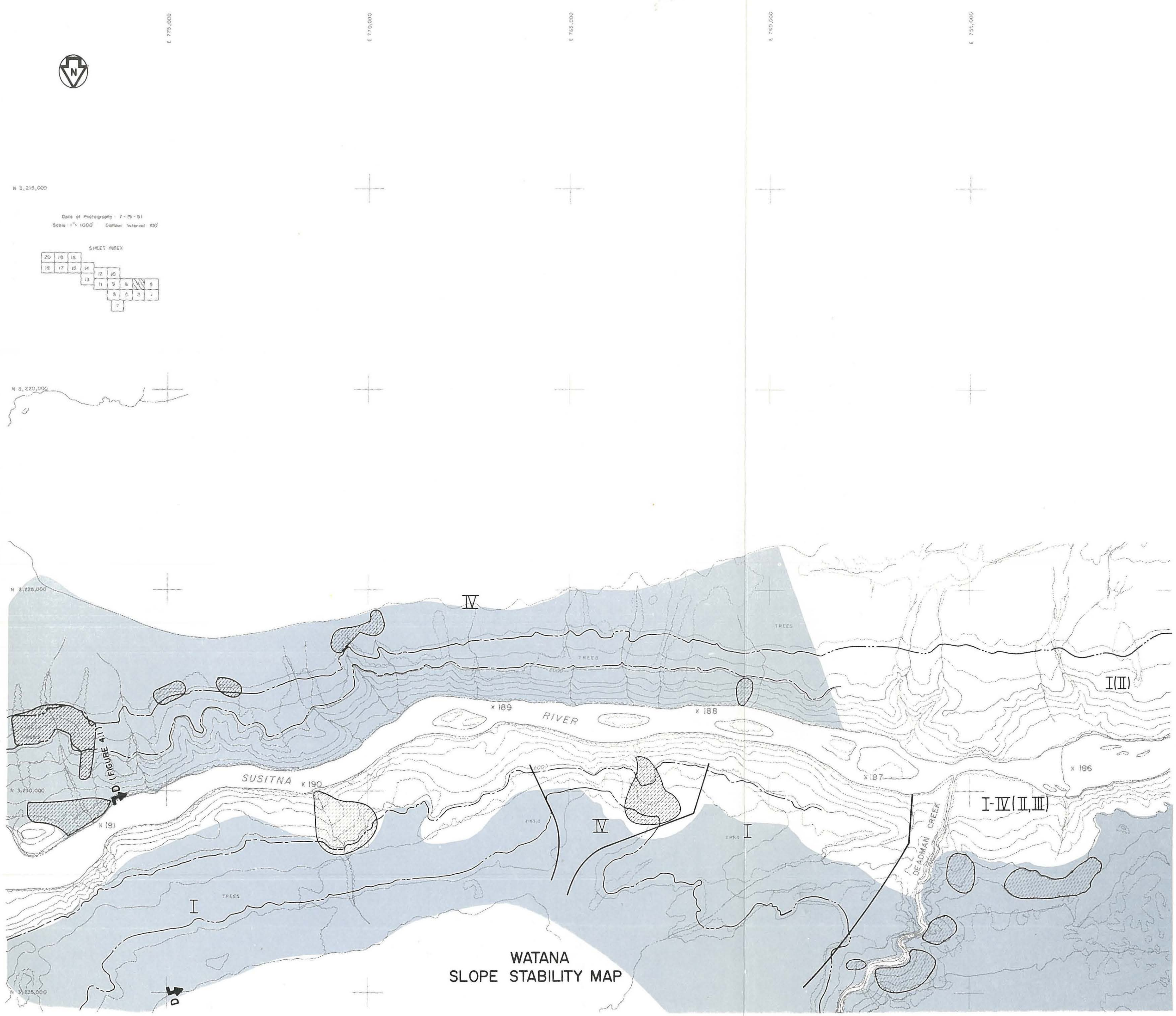
Date of Photography 7-15-81
Scale: 1" = 1000' Contour Interval 100'

SHEET INDEX

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.15



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- x RIVER MILES
- A A SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

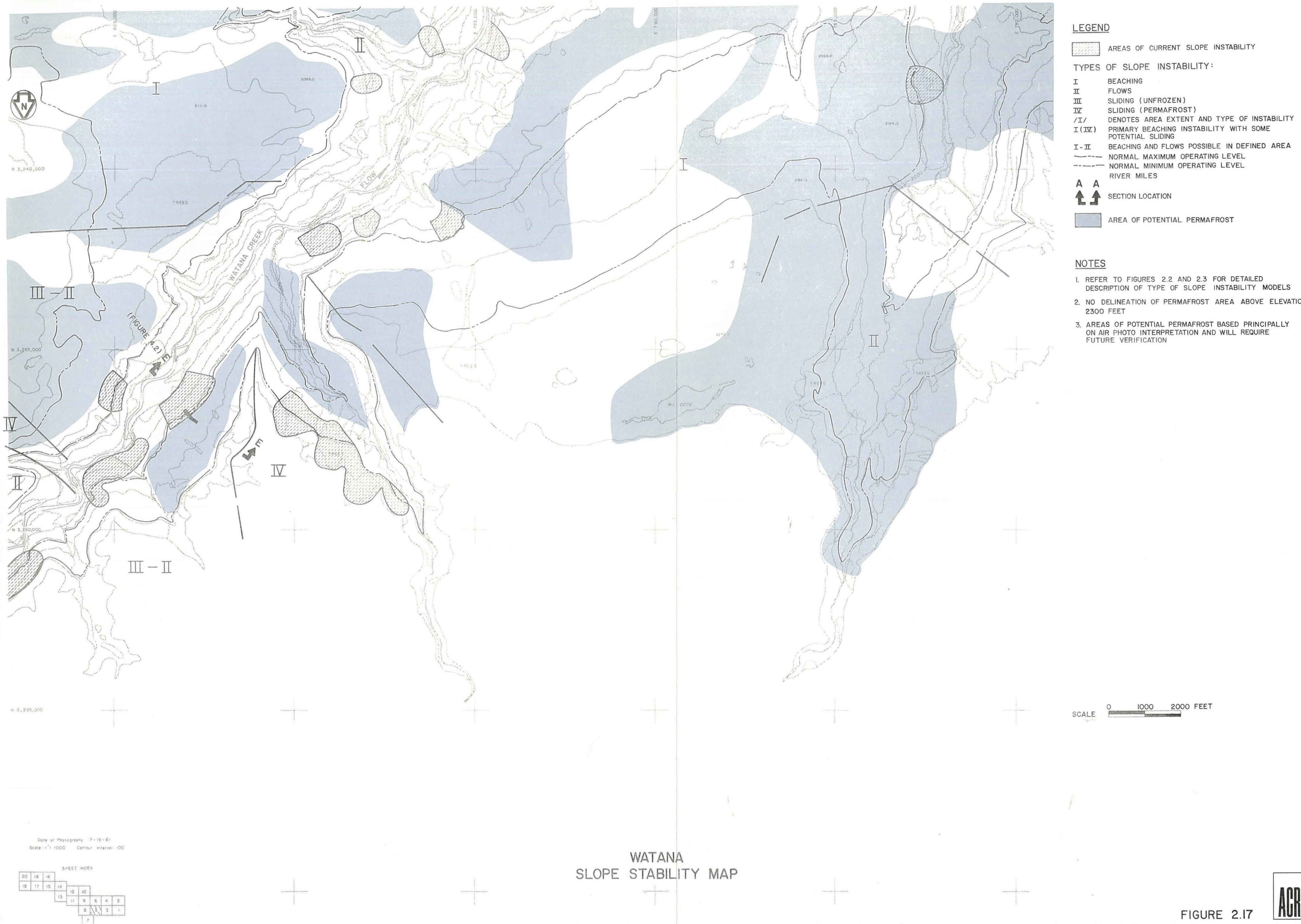
1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

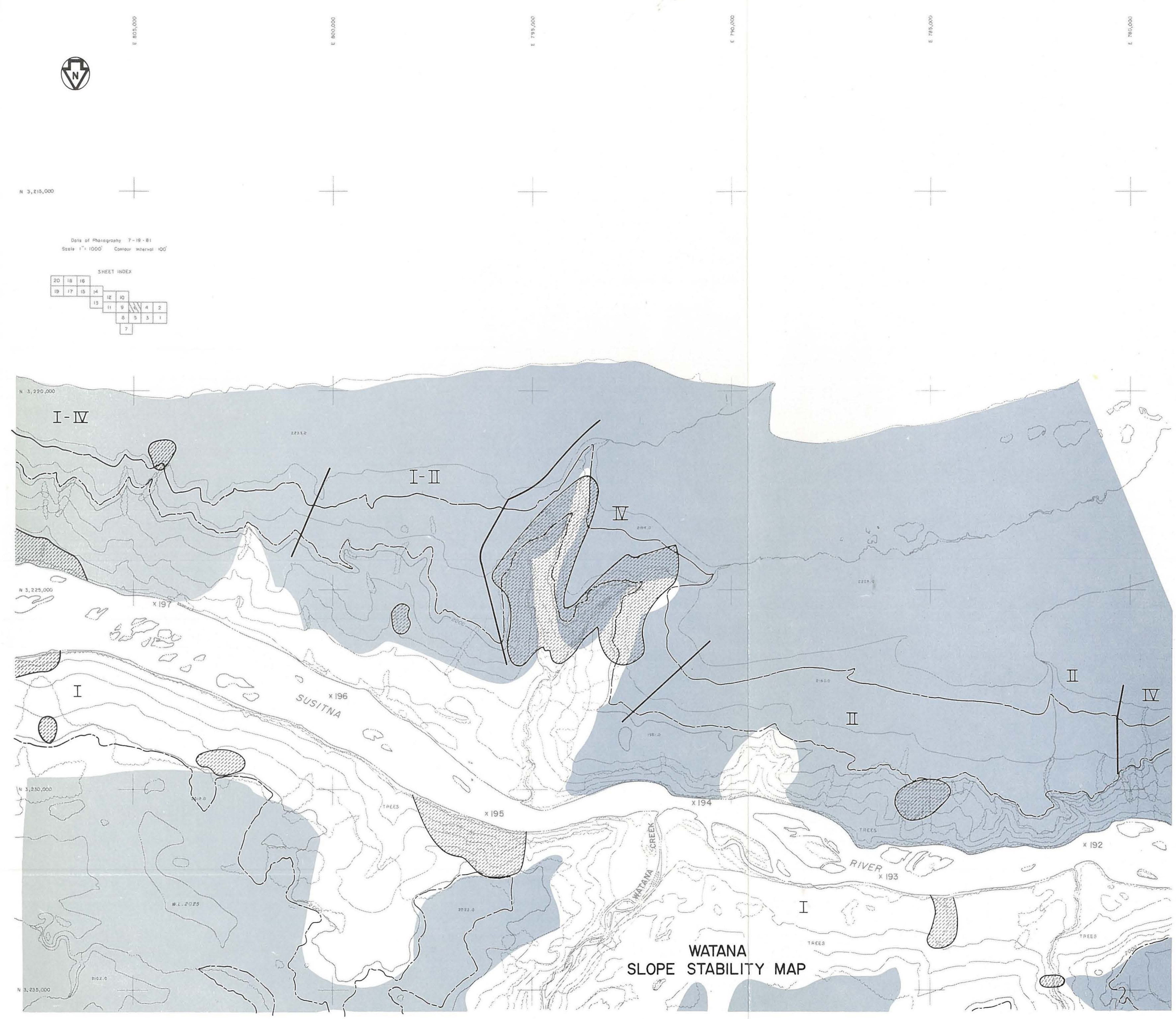
FIGURE 2.16

ACRES



WATANA
SLOPE STABILITY MAP

FIGURE 2.17



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

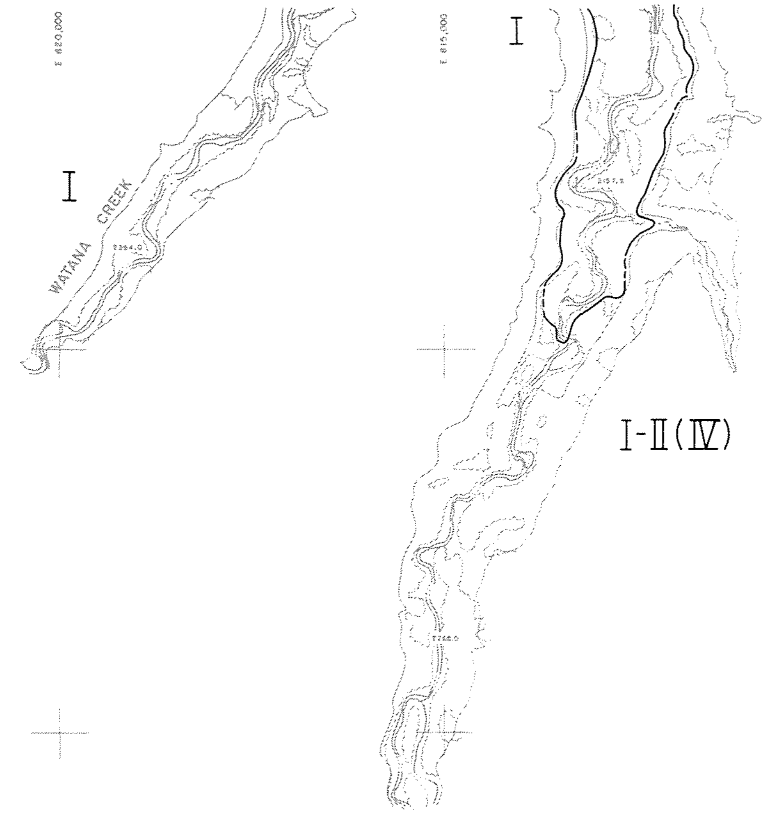
I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
	NORMAL MAXIMUM OPERATING LEVEL
	NORMAL MINIMUM OPERATING LEVEL
x	RIVER MILES
A A	SECTION LOCATION
	AREA OF POTENTIAL PERMAFROST

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

FIGURE 2.18



N 3,265,000

N 3,270,000

N 3,275,000

N 3,280,000

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
——-——	NORMAL MAXIMUM OPERATING LEVEL
—·—·—	NORMAL MINIMUM OPERATING LEVEL
	RIVER MILES
A A	SECTION LOCATION

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

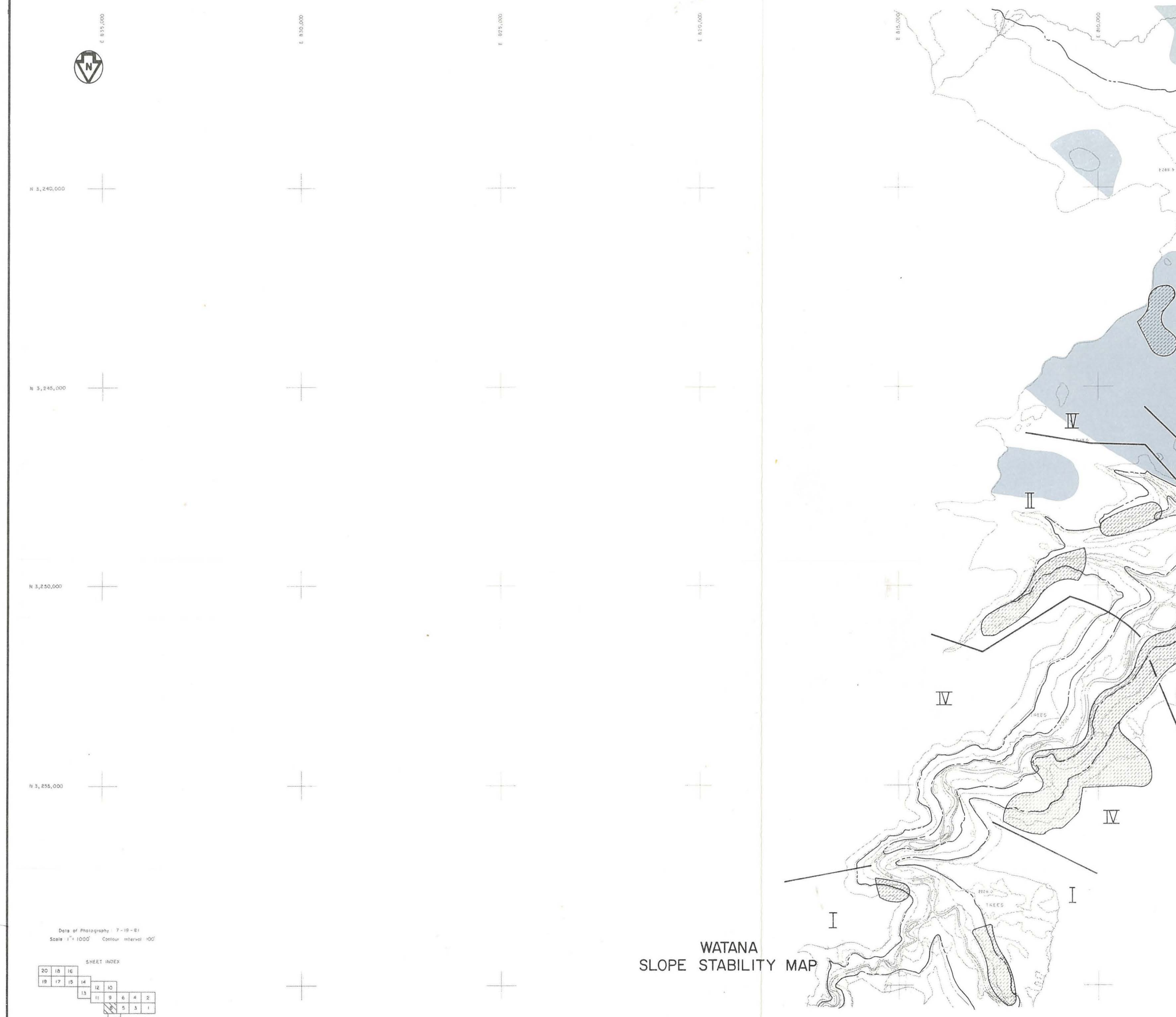
Date of Photography 7-19-81
Scale 1" = 1000' Contour Interval 100'

SHEET INDEX

WATANA SLOPE STABILITY MAP

FIGURE 2.19

ACRES



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- RIVER MILES
- A A SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

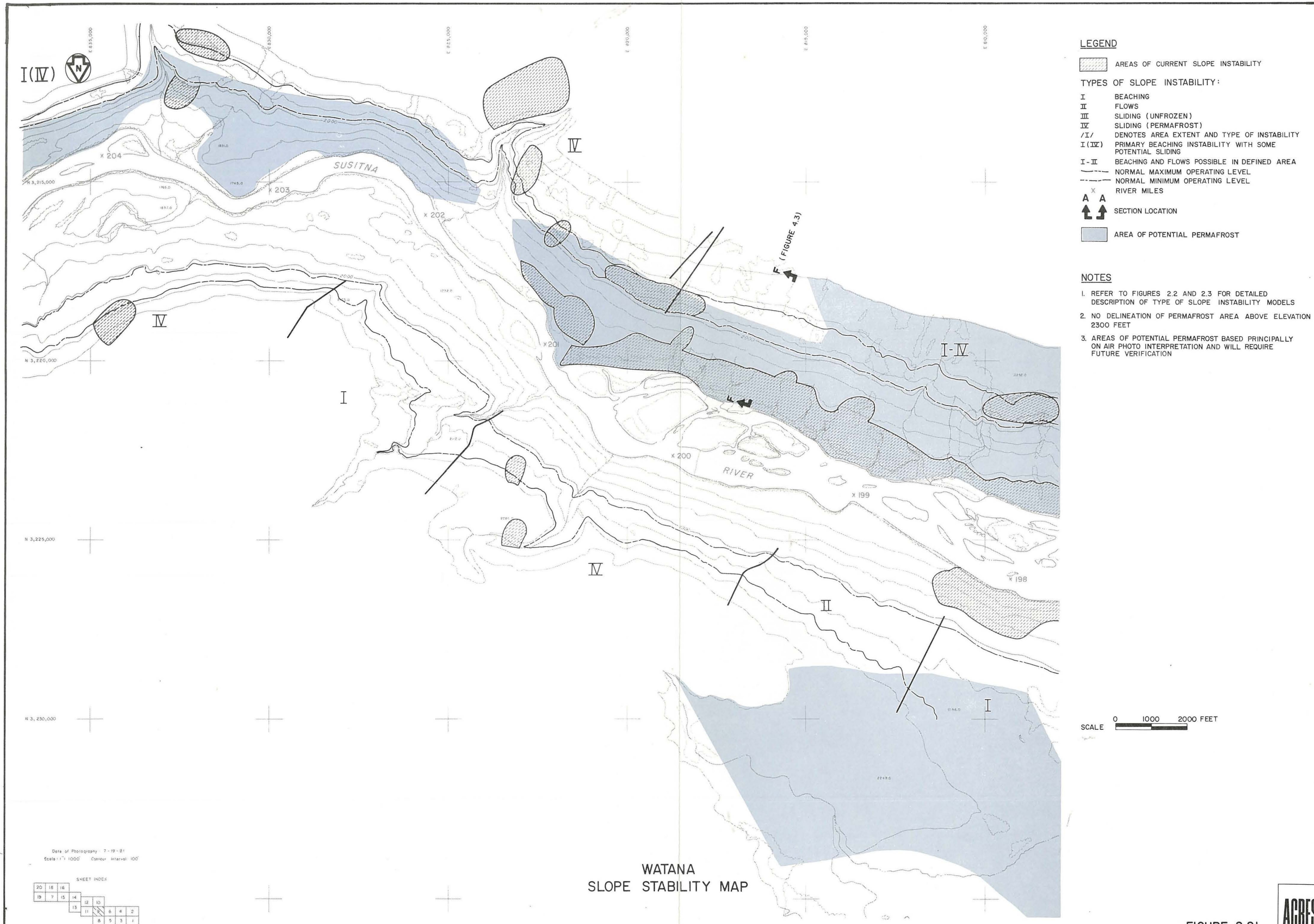
1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

FIGURE 2.20

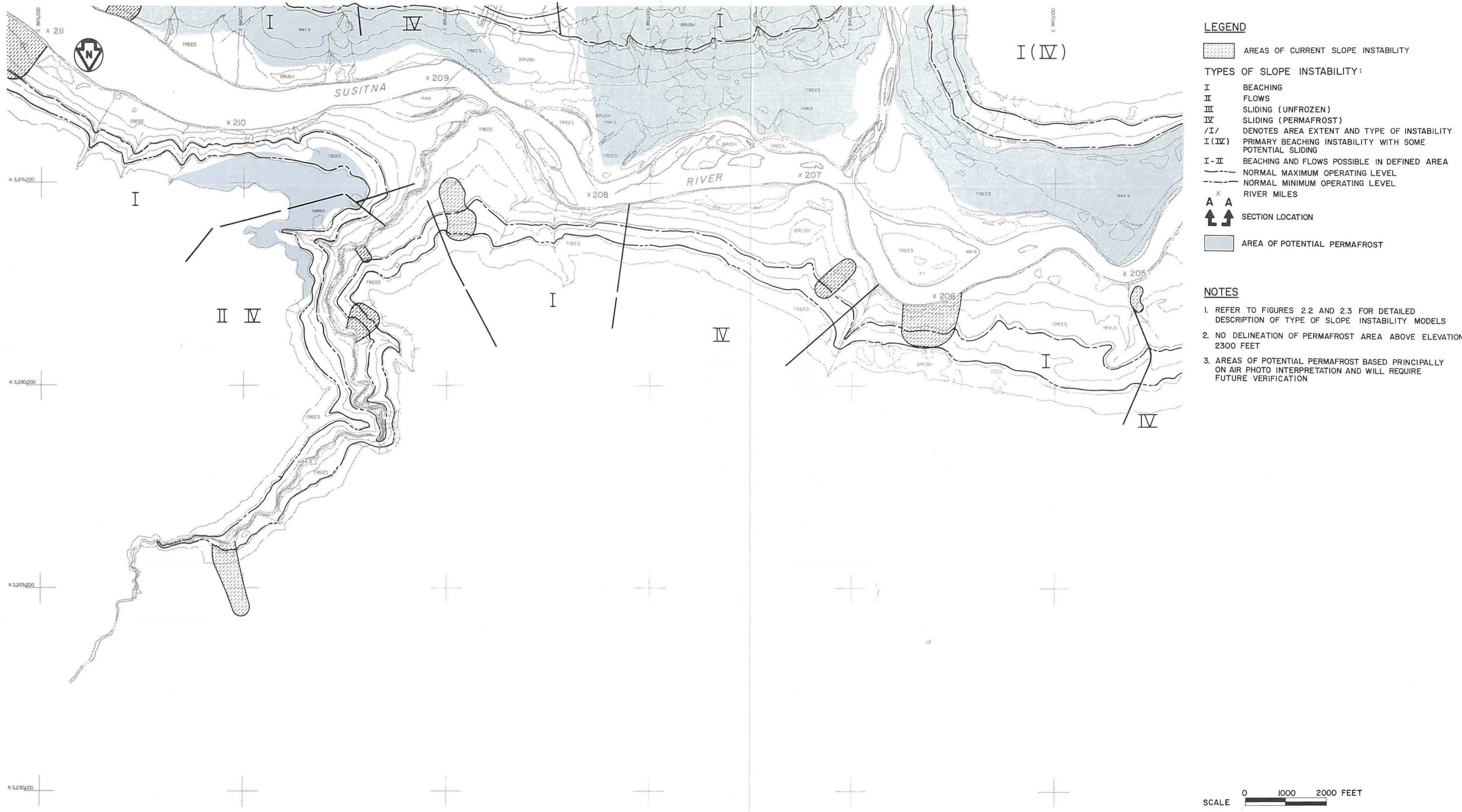
ACRES



WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.21



Date of Photography: 7-19-81
Scale: 1" = 1000' Contour Interval: 100'

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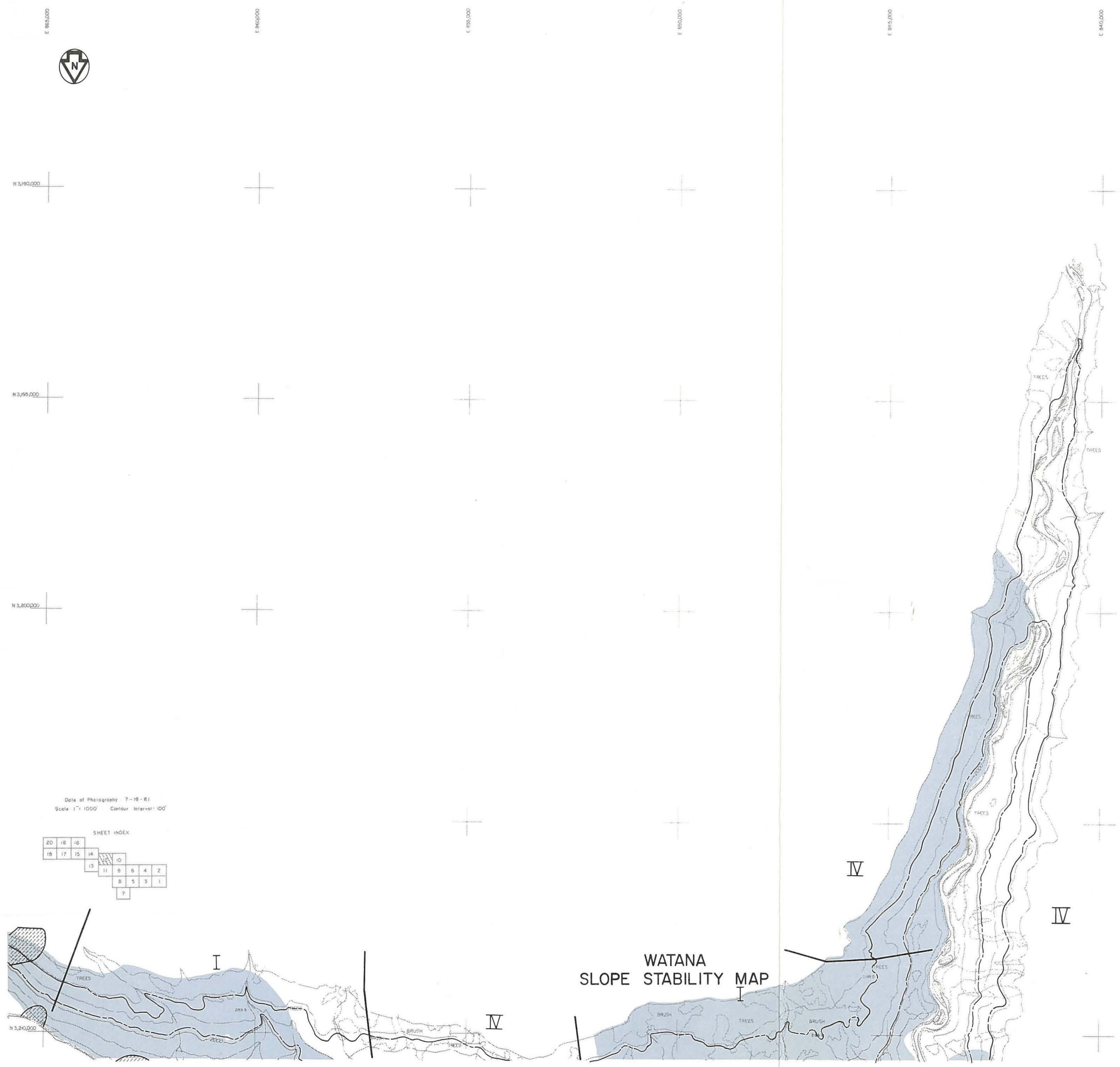
19	17	15	14					
			13	12	10			
				11	9	6	4	2
					8	5	3	1
					7			

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.22



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I (IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I - II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
———	NORMAL MAXIMUM OPERATING LEVEL
—·—·—	NORMAL MINIMUM OPERATING LEVEL
	RIVER MILES
A A	SECTION LOCATION
	AREA OF POTENTIAL PERMAFROST

NOTES

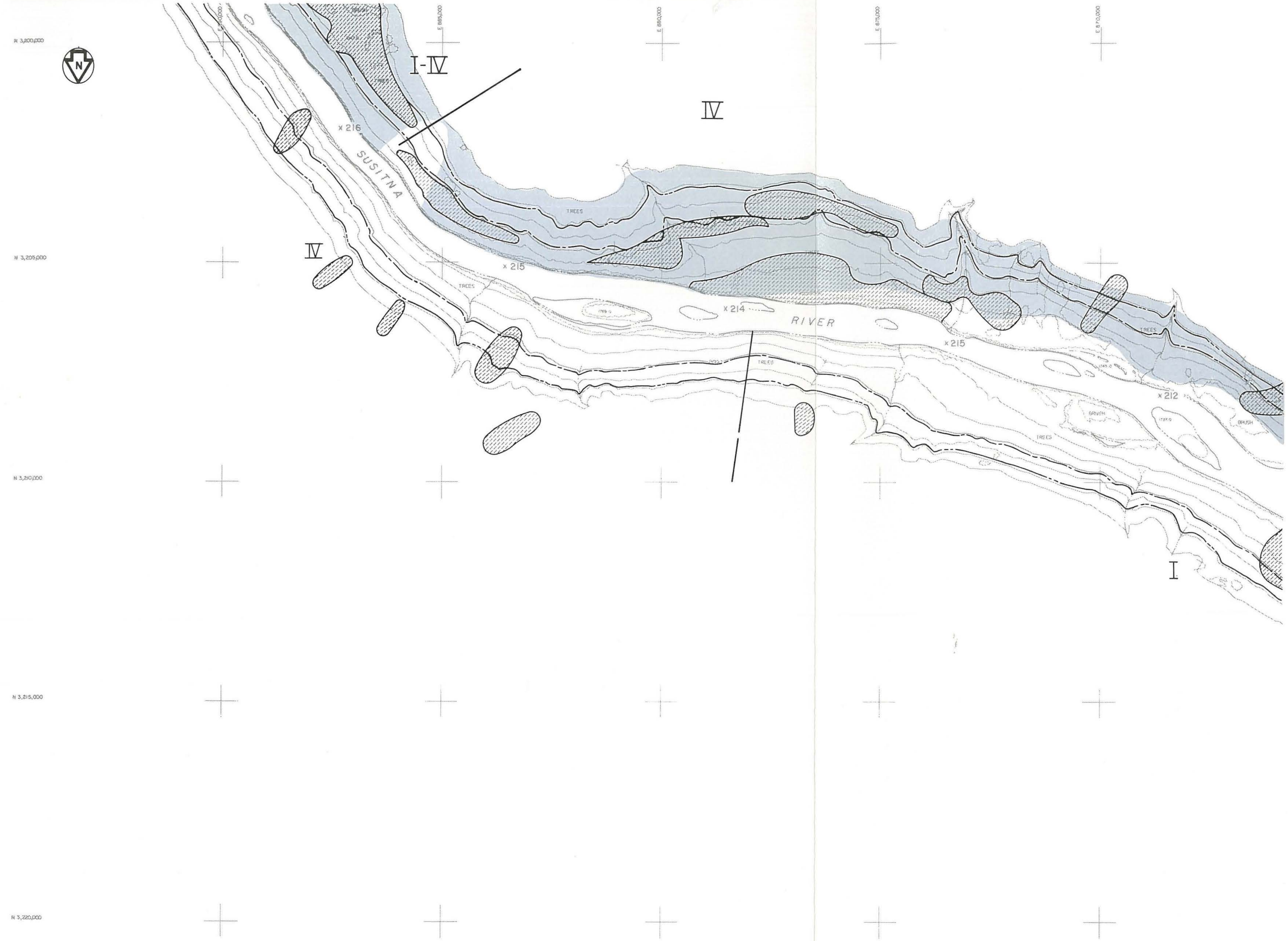
1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.23



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- x RIVER MILES
- A A SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

Date of Photography: 7-19-81
Scale: 1" = 1000' Contour Interval 100'

SHEET INDEX

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.24

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
——---	NORMAL MAXIMUM OPERATING LEVEL
--·—·—	NORMAL MINIMUM OPERATING LEVEL
x	RIVER MILES
A A	SECTION LOCATION
	AREA OF POTENTIAL PERMAFROST

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.25

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- RIVER MILES
- A A — SECTION LOCATION

NOTES

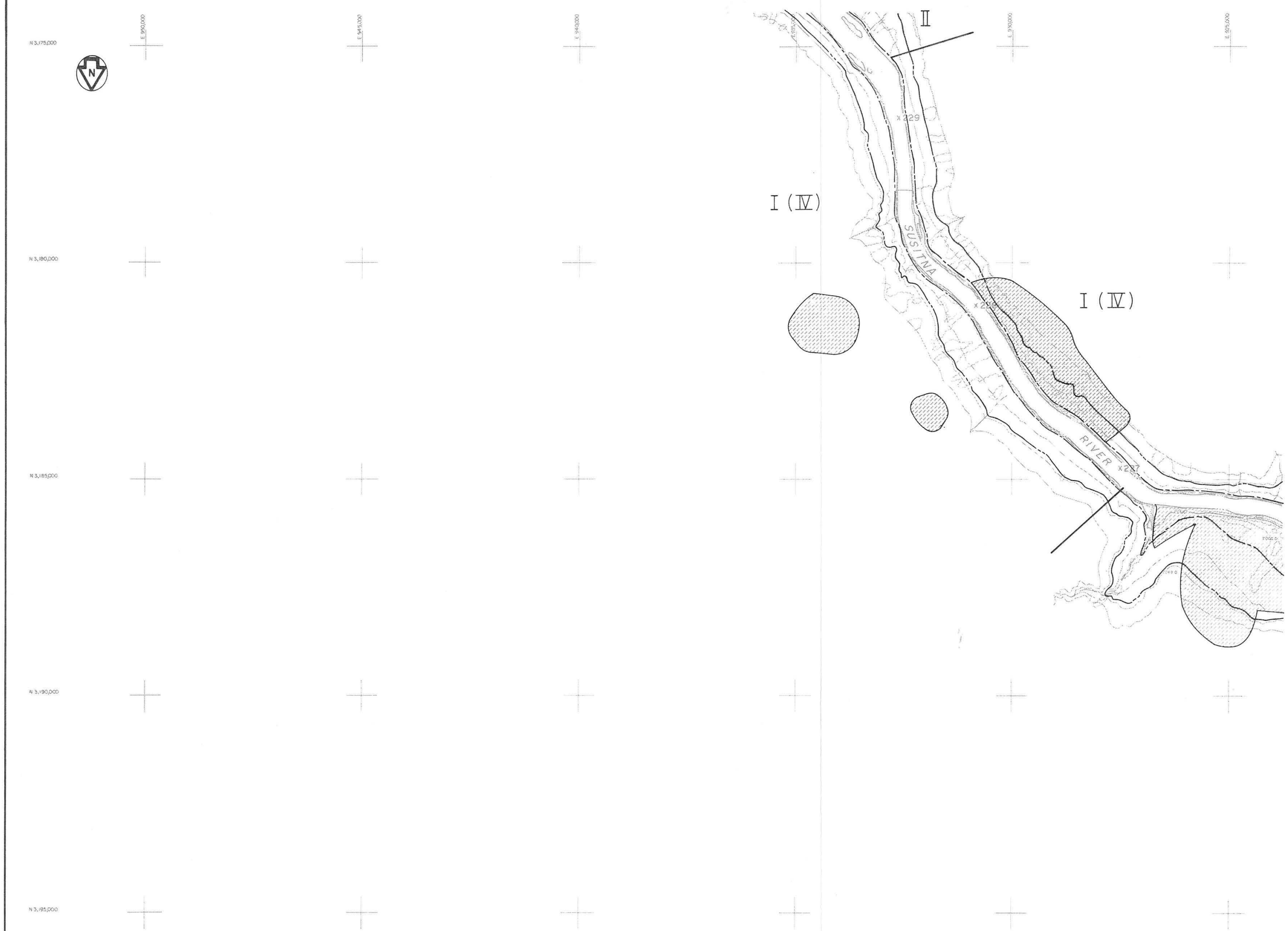
1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.26



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I - II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- x RIVER MILES
- A A SECTION LOCATION

NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

Date of Photography 7-19-81
Scale 1" = 1000' Contour interval 100'

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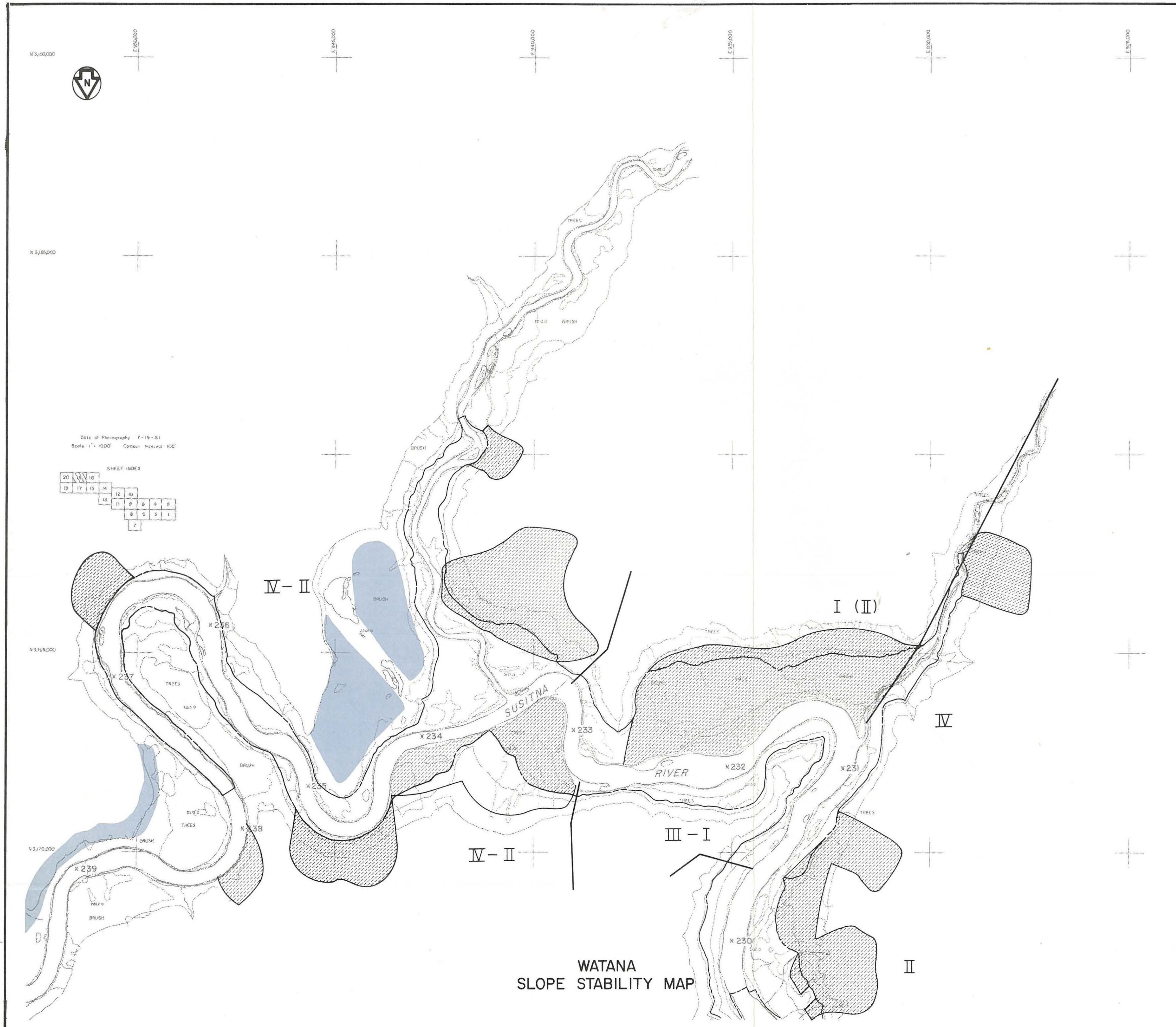
				12	10			
			13	11	9	6	4	2
					8	5	3	1
					7			

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.27



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- RIVER MILES
- SECTION LOCATION

AREA OF POTENTIAL PERMAFROST

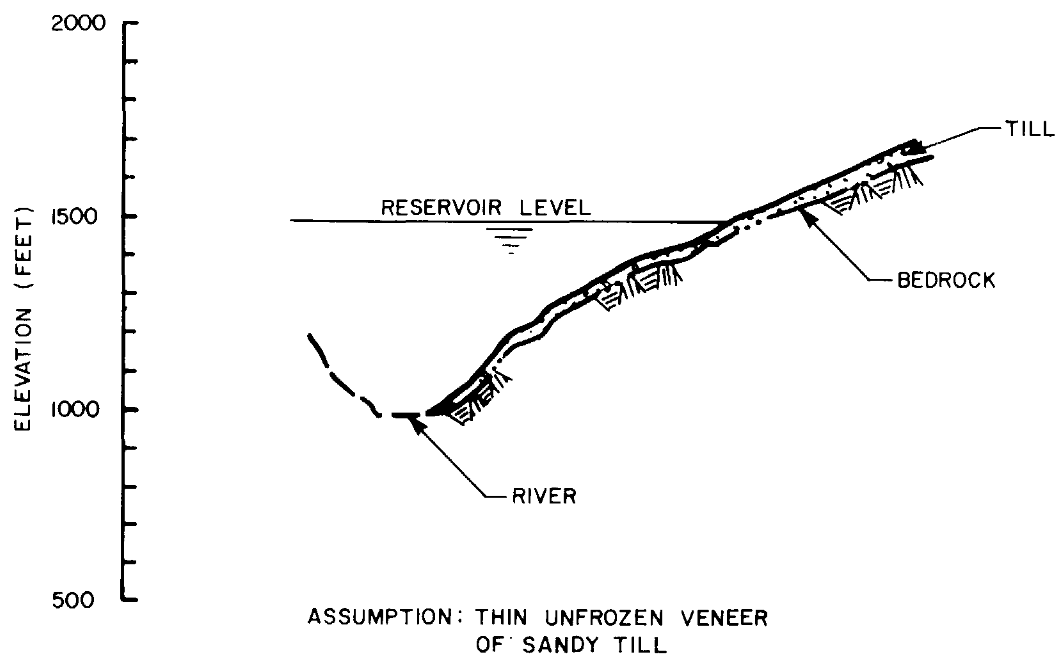
NOTES

1. REFER TO FIGURES 2.2 AND 2.3 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION.

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 2.28



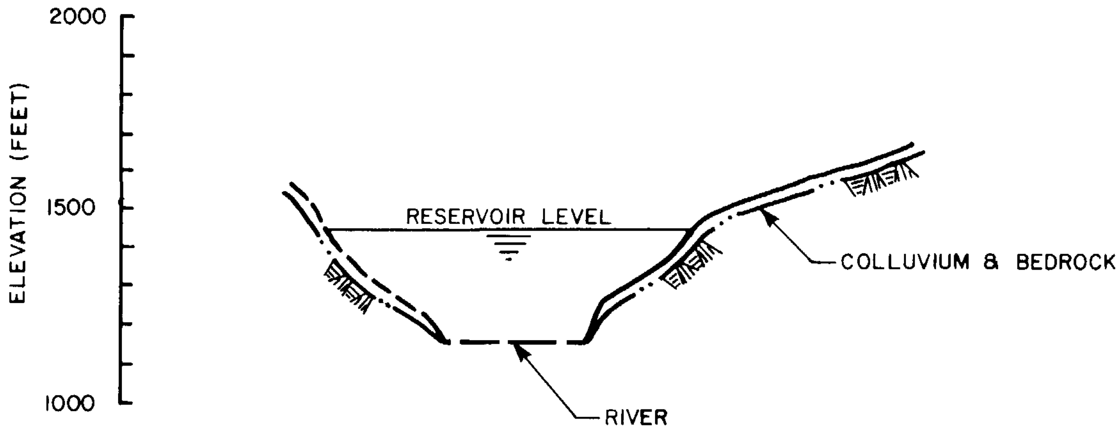
NOTE: SEE FIGURE 2.6 FOR
SECTION LOCATION

SCALE 0 500 1000 FEET

SECTION A-A
DEVIL CANYON RESERVOIR
POTENTIAL MINOR BEACHING

ACRES

FIGURE 3.1



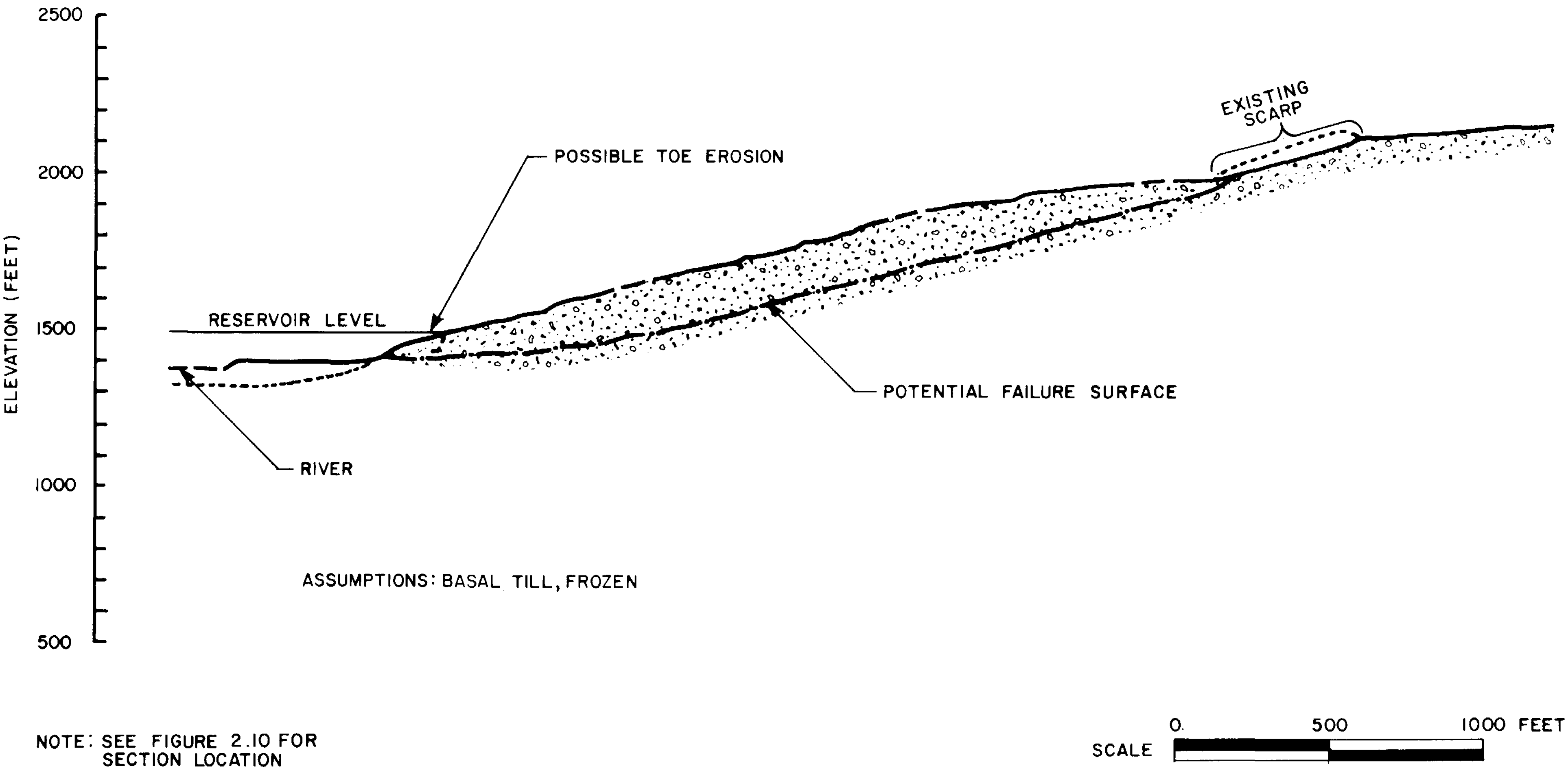
ASSUMPTIONS: COLLUVIUM, UNFROZEN BEDROCK PROBABLY IN CONTACT WITH THE RESERVOIR LEVEL

NOTE: SEE FIGURE 2.7 FOR SECTION LOCATION

SECTION B-B
DEVIL CANYON RESERVOIR
POTENTIAL MINOR BEACHING

ACRES

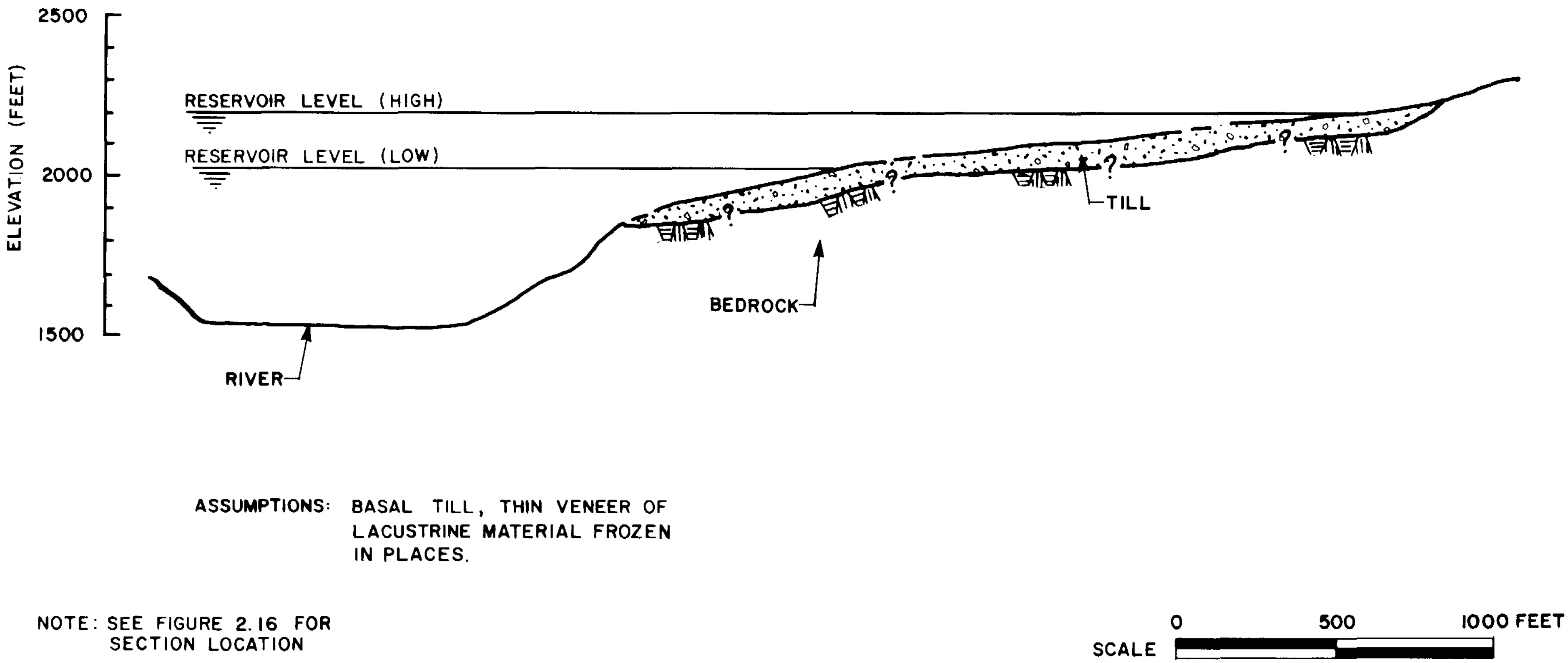
FIGURE 3.2



SECTION C-C
DEVIL CANYON RESERVOIR
POTENTIAL LARGE SLIDE

ACRES

FIGURE 3.3



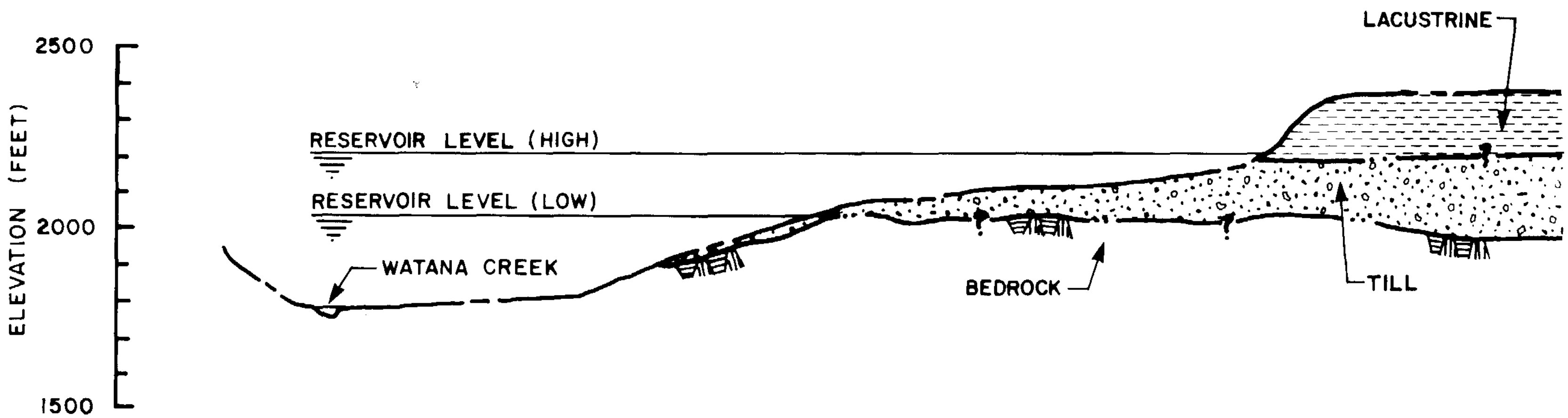
ASSUMPTIONS: BASAL TILL, THIN VENEER OF LACUSTRINE MATERIAL FROZEN IN PLACES.

NOTE: SEE FIGURE 2.16 FOR SECTION LOCATION

SECTION D-D
WATANA RESERVOIR
POTENTIAL BEACHING

ACRES

FIGURE 4.1



ASSUMPTIONS: STRATIGRAPHY CONSISTS OF GLACIO-LACUSTRINE SANDS AND SILTS, TILL. TILL IS FROZEN, LACUSTRINE MAY BE PARTLY FROZEN.

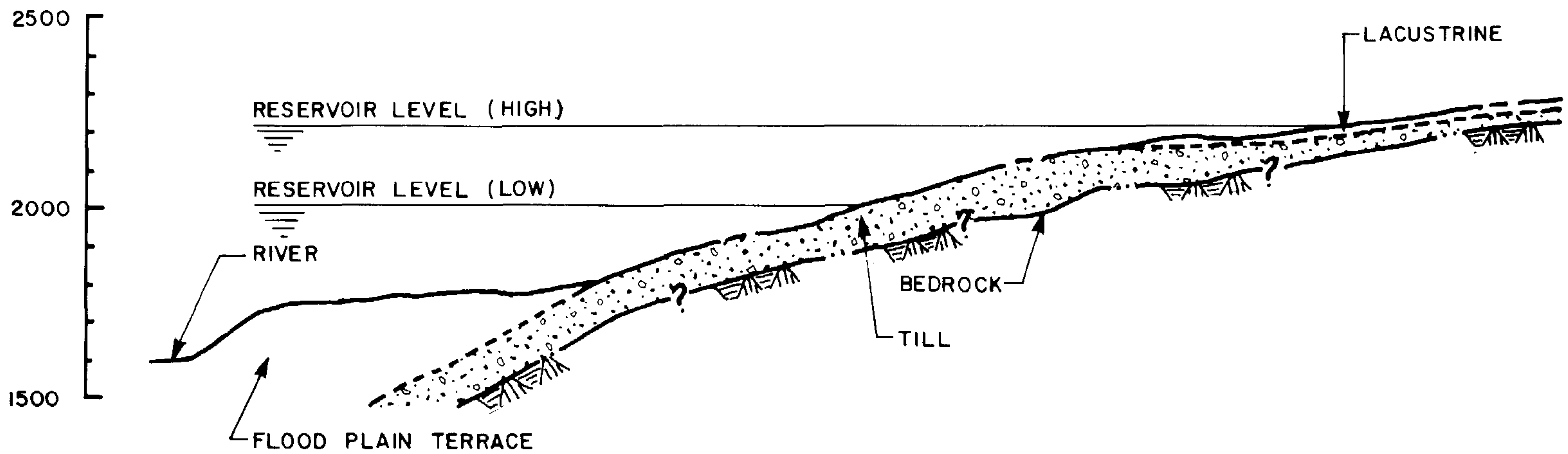
NOTE: SEE FIGURE 2.17 FOR SECTION LOCATION

SCALE 0 500 1000 FEET

SECTION E-E
WATANA RESERVOIR
AREA OF POTENTIAL FLOWS

ACRES

FIGURE 4.2



ASSUMPTIONS: BASAL TILL, PRIMARILY FROZEN

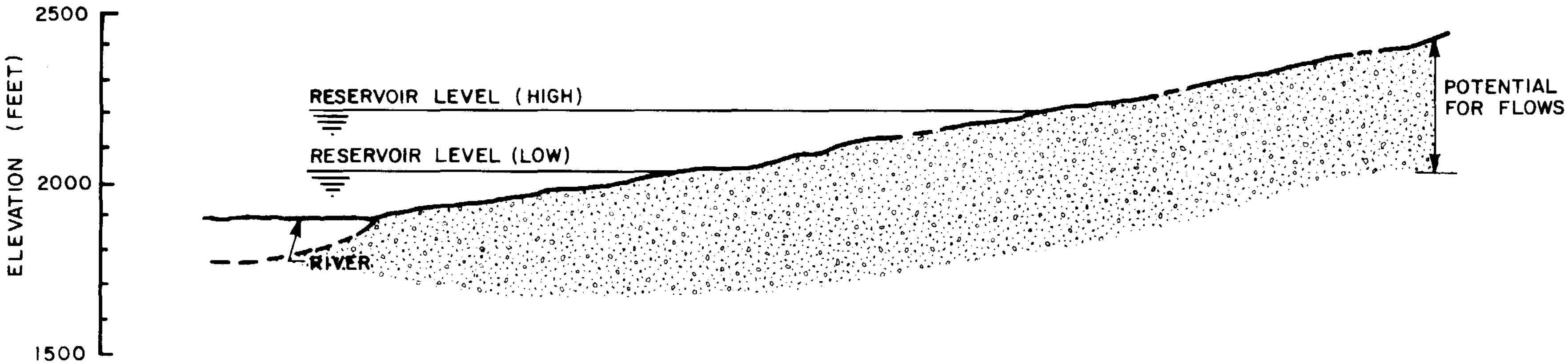
NOTE: SEE FIGURE 2.21 FOR SECTION LOCATION

SCALE 0 500 1000 FEET

SECTION F-F
WATANA RESERVOIR
POTENTIAL ROTATIONAL SLIDES AND FLOWS

ACRES

FIGURE 4.3



ASSUMPTIONS: SANDY MATERIAL, FROZEN

NOTE: SEE FIGURE 2.26 FOR SECTION LOCATION

SCALE 0 500 1000 FEET

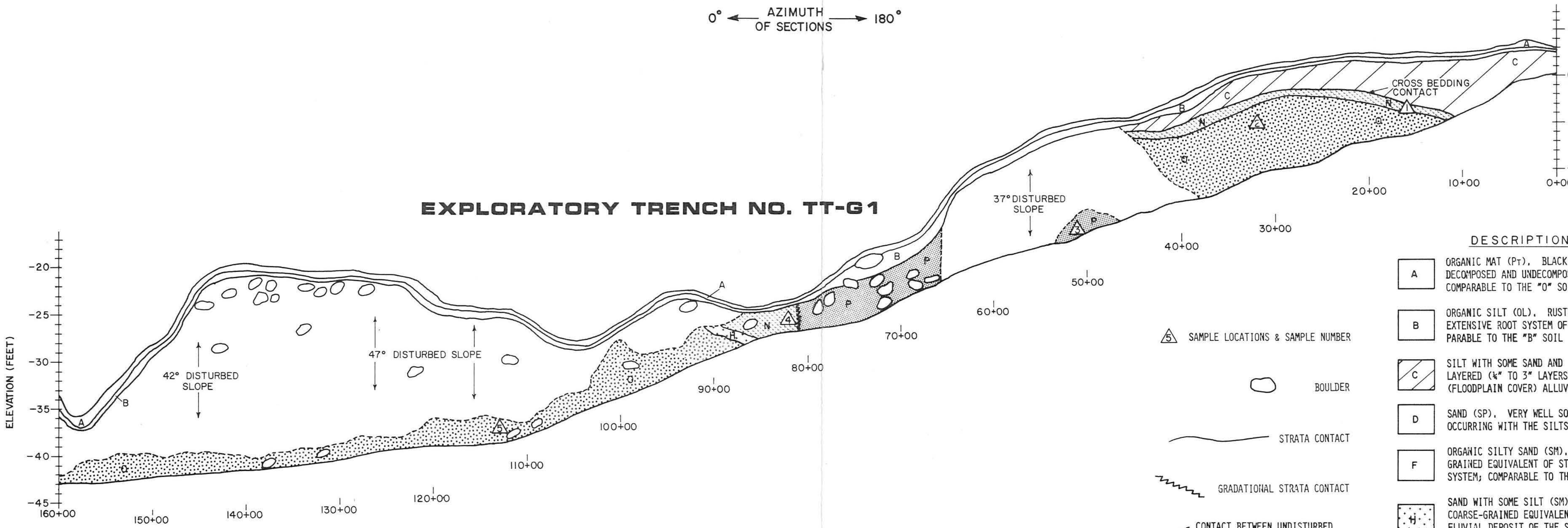
SECTION G-G
WATANA RESERVOIR
AREA OF FLOW FAILURES

ACRES

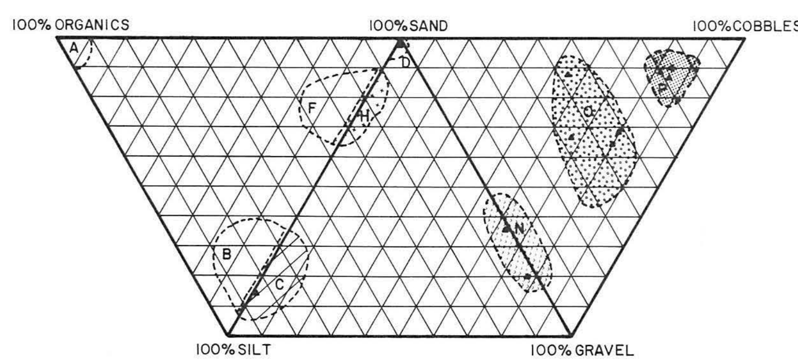
FIGURE 4.4

TABLE 1 (Continued)

WCC Line No.	R & M Survey No.	Location Figure	Profile Figure	Time-Distance Plot Figure	Line Length (ft)	Number of Segments/Shots	Comments
81-5	81-5	2	5	A-1	450	1/3	Run Over River Ice, 0.5 Miles Upstream from Proposed Watana Dam Centerline.
81-6	81-6	2	6	A-1	450	1/2	Run Over River Ice, 0.1 Miles Upstream from Proposed Watana Dam Centerline.
81-7	81-7	1	6	A-2	3,200	3/9	Run Over River Ice, 4.0 Miles Downstream from Proposed Watana Dam Centerline.
81-8	81-8	1	7	A-2	2,500	3/6	Run Over River Ice, 5.2 Miles Downstream from Proposed Watana Dam Centerline.
81-9	81-9	1	7	A-2	2,000	2/6	Run Over River Ice, 7.3 Miles Downstream from Proposed Watana Dam Centerline.
81-10	81-10	1	8	A-3	2,100	2/6	Run Over River Ice, 8.2 Miles Downstream from Proposed Watana Dam Centerline.
81-11	81-11	1	8	A-3	2,800	3/9	Run Over River Ice, 9.3 Miles Downstream from Proposed Watana Dam Centerline.
81-12	81-12	1	9	A-3	2,000	2/7	Run Over River Ice, 10.1 Miles Downstream from Proposed Watana Dam Centerline.
81-13	80-1X	2	10	B-1	3,200	3/10	Watana Relict Channel Area--Extends 80-1 to NE
81-14	80-2X	2	11	B-2	3,300	3/5	Watana Relict Channel Area--Extends 80-2 to NE--North Extension Not Surveyed
81-15 & 15X	BH-11	2	12	B-3	2,100	4/11	Watana Rt Abutment--Fins Area
81-16	16-81	2	12	B-3	2,200	2/8	Watana Relict Channel Area
81-17	---	2	13	B-4	1,100	1/5	Watana Relict Channel Area--Not Surveyed
81-18	QSB	2	13	B-4	2,200	2/10	Watana Relict Channel Area--N of Quarry Source B
81-19	QSB	2	14	B-5	1,100	1/6	Watana Relict Channel Area--N of Quarry Source B
81-20	SW-1X	2	15	B-6	1,600	5/11	Watana Left Abutment--Extends SW-1 East
81-21	BH-12	2	15	B-6	1,850	5/19	Watana Left Abutment--Crosses 81-20
81-22	17	3	16	B-6	1,500	3/6	Devil Canyon Left Abutment--Crosses 80-12 and 80-13
81-FL-1 to 81-FL-48	Fog Lakes	1 & 2	17 - 23	C1 - C7	28,800	48/138	Watana Fog Lakes Area--Continuous Profile

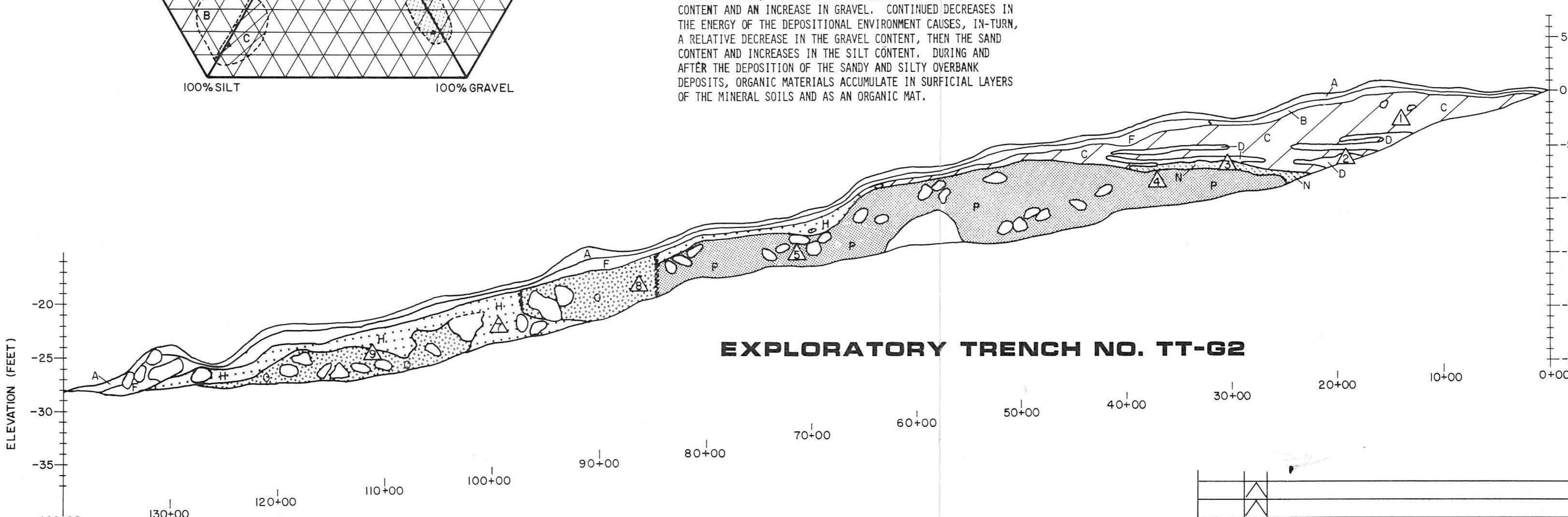


GRAIN SIZE ANALYSIS DATA



LABORATORY AND FIELD ESTIMATED GRAIN SIZE DATA, FOR EACH SOIL STRATA, HAVE BEEN PLOTTED ON THE ADJACENT TRIANGULAR DIAGRAMS. INDIVIDUAL SAMPLES APPEAR AS SMALL TRIANGLES AND THE DASHED LINE AREAS ARE USED TO ESTIMATE THE RANGE OF TEXTURES THAT MAY OCCUR WITHIN EACH STRATA. THE DIAGRAM PROVIDES A BASIS FOR GROUPING THE SOILS AND REVEALS THE SIGNIFICANCE OF DIFFERENCES BETWEEN GROUPS.

AS THE ENERGY OF THE FLUVIAL ENVIRONMENT DECREASES (FROM A RIVERBED TO OVERBANK DEPOSITION) THE SOILS FOLLOW A "W" SHAPED PATTERN, INITIATED BY A DECREASE IN THE COBBLE CONTENT AND AN INCREASE IN GRAVEL. CONTINUED DECREASES IN THE ENERGY OF THE DEPOSITIONAL ENVIRONMENT CAUSES, IN-TURN, A RELATIVE DECREASE IN THE GRAVEL CONTENT, THEN THE SAND CONTENT AND INCREASES IN THE SILT CONTENT. DURING AND AFTER THE DEPOSITION OF THE SANDY AND SILTY OVERBANK DEPOSITS, ORGANIC MATERIALS ACCUMULATE IN SURFICIAL LAYERS OF THE MINERAL SOILS AND AS AN ORGANIC MAT.



SAMPLE LOCATIONS & SAMPLE NUMBER

BOULDER

STRATA CONTACT

GRADATIONAL STRATA CONTACT

CONTACT BETWEEN UNDISTURBED STRATA AND DISTURBED (FAILING) TRENCH WALL-DOES NOT CORRESPOND TO A STRATA CHANGE.

DESCRIPTION

A	ORGANIC MAT (PT). BLACK TO DARK BROWN PARTIALLY DECOMPOSED AND UNDECOMPOSED VEGETATIVE MATTER; COMPARABLE TO THE "O" SOIL HORIZON.
B	ORGANIC SILT (OL). RUSTY BROWN SILT CONTAINING THE EXTENSIVE ROOT SYSTEM OF THE SURFACE BRUSH; COMPARABLE TO THE "B" SOIL HORIZON.
C	SILT WITH SOME SAND AND SANDY SILT (ML). INTER-LAYERED (¼" TO 3" LAYERS) WITH BROWN OVERBANK (FLOODPLAIN COVER) ALLUVIAL DEPOSITS.
D	SAND (SP). VERY WELL SORTED, GRAY, SAND LENSES OCCURRING WITH THE SILTS OF STRATA C.
F	ORGANIC SILTY SAND (SM). SLIGHTLY MORE COARSE-GRAINED EQUIVALENT OF STRATA B, CONTAINING A ROOT SYSTEM; COMPARABLE TO THE "B" SOIL HORIZON.
H	SAND WITH SOME SILT (SM). BROWN, SLIGHTLY MORE COARSE-GRAINED EQUIVALENT OF STRATA C, AND OVERBANK FLUVIAL DEPOSIT OF THE SUSTTNA AND CHEECHAKO STREAM SYSTEMS.
N	SANDY GRAVEL (GP-GW). BROWN TO GRAY SANDY AND GRAVELLY FLUVIAL DEPOSITS, PROBABLY GRADATIONAL BETWEEN THE RIVERBED AND OVERBANK DEPOSITS OF THE SUSITNA AND CHEECHAKO STREAM SYSTEMS.
O	SANDY GRAVEL WITH SCATTERED TO NUMEROUS COBBLES AND SCATTERED BOULDERS (GP, GW, SP, SW), VERY COARSE-GRAINED (UP TO ABOUT 50% COBBLES AND BOULDERS) RIVER-BED AND/OR ALLUVIAL FAN DEPOSITS OF THE SUSITNA AND CHEECHAKO STREAM SYSTEMS.
P	SANDY GRAVEL AND GRAVELLY SAND WITH TRACE SILT AND NUMEROUS COBBLES AND SCATTERED BOULDERS (SW, SP, GP, GW), EXTREMELY COARSE GRAINED (OVER 60% COBBLES AND BOULDERS) RIVERBED AND/OR ALLUVIAL FAN DEPOSITS OF THE SUSITNA AND CHEECHAKO STREAM SYSTEM: SIMILAR TO STRATA O.

NOTES:

1. REFERENCE ELEVATIONS FOR EACH TRENCH ARE ARBITRARY AND INDEPENDENT (0.0 FT. ELEVATION IN TT-G1 DOES NOT CORRESPOND TO THE 0.0 FT. ELEVATION IN TT-G2).
2. THE UNIFIED SOIL CALL-OUTS ARE BASED ON THE MINUS 3-INCH FRACTION, AND WHERE APPROPRIATE ARE AUGMENTED BY DESCRIPTIONS (I.E. SCATTERED & NUMEROUS) OF THE PLUS 3-INCH FRACTION. THE TERM SCATTERED IS USED WHEN LESS THAN 40% OF THE SOIL IS COMPOSED OF COBBLES OR BOULDERS, WHILE NUMEROUS IS USED FOR COBBLE AND BOULDER CONCENTRATIONS ABOVE 40%.

SCALE 0 5 10 FEET

DATE	NO.	REVISIONS	CH.	APP.	APP.

ACRES

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

EXPLORATORY TRENCH GEOLOGIC-SECTIONS BORROW AREA G DEVIL CANYON

PREPARED BY: R&M CONSULTANTS, INC.

DATE JAN. 1982

DEPARTMENT

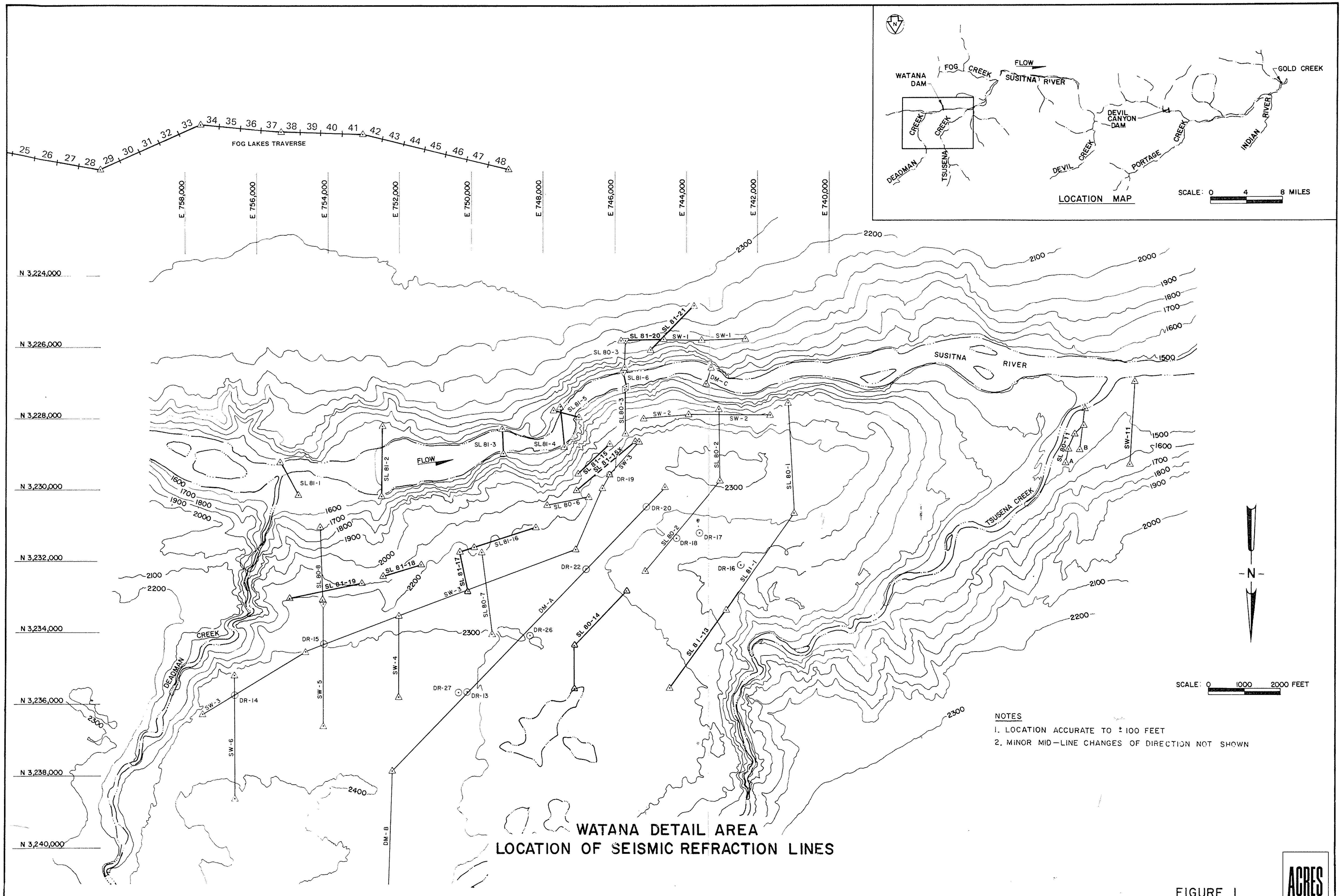
PROJECT 052506

SCALE

DRAWING NO.

SHEET OF

REV.

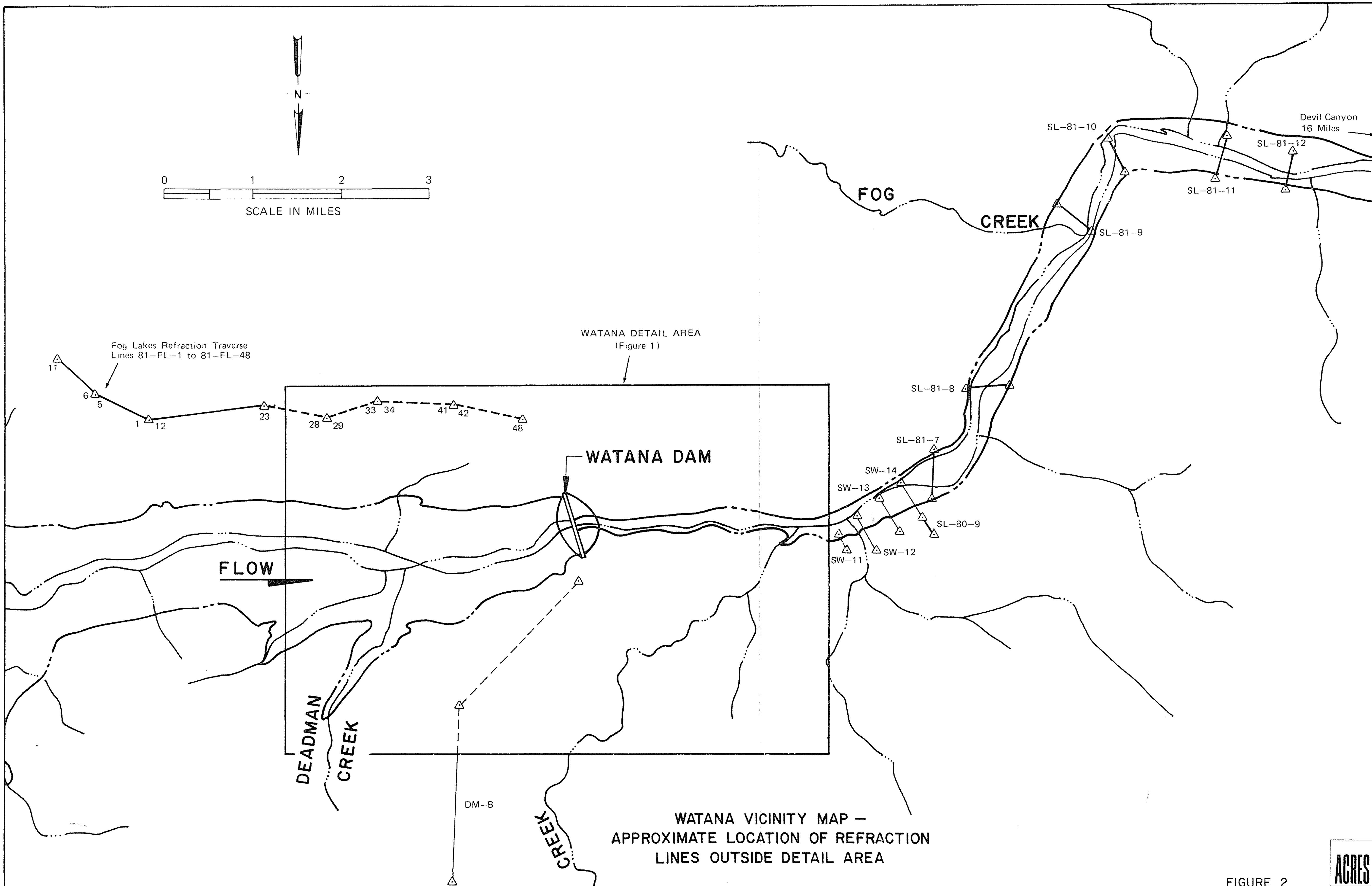


WATANA DETAIL AREA
LOCATION OF SEISMIC REFRACTION LINES

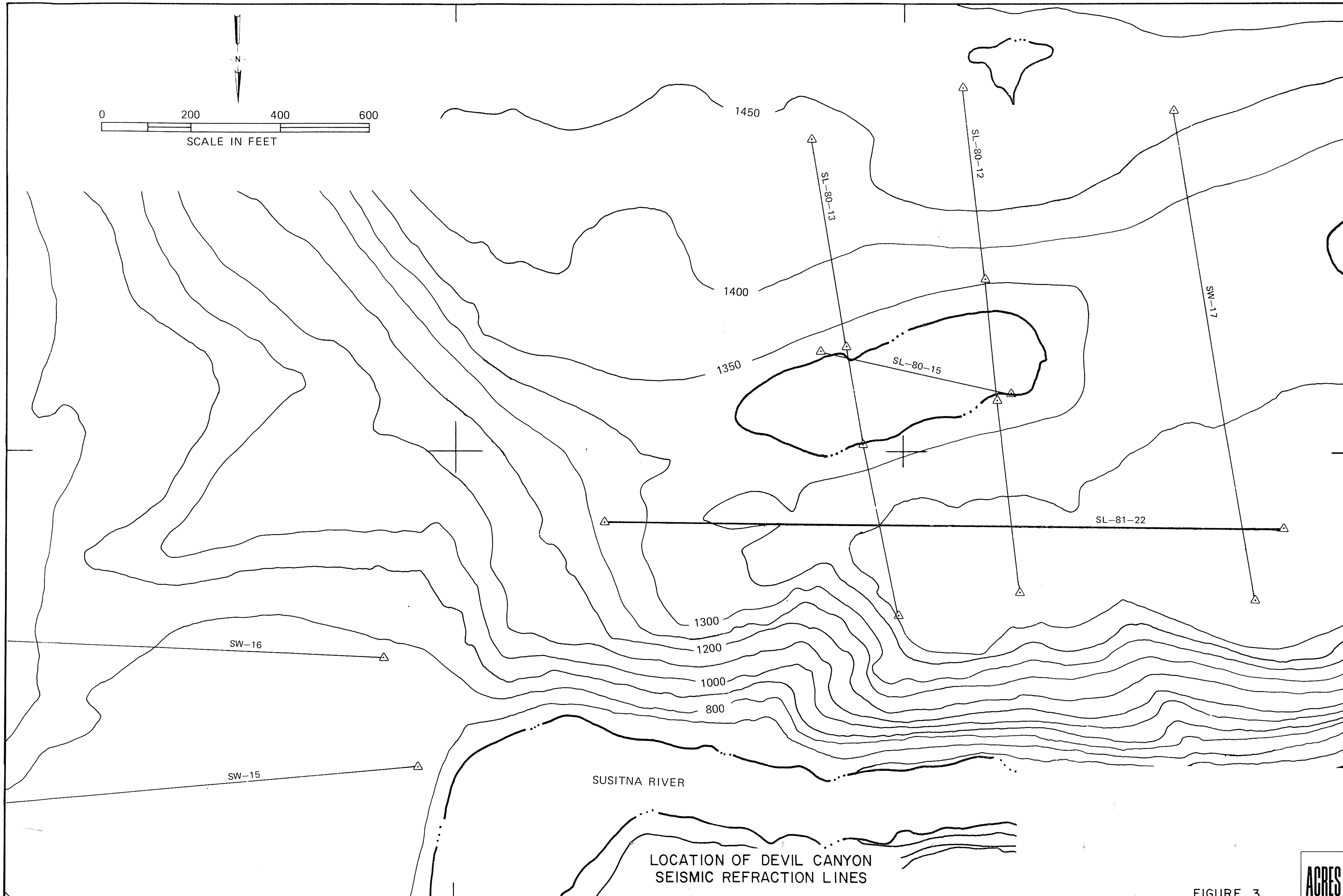
ACRES

FIGURE 1

PREPARED BY WOODWARD - CLYDE CONSULTANTS



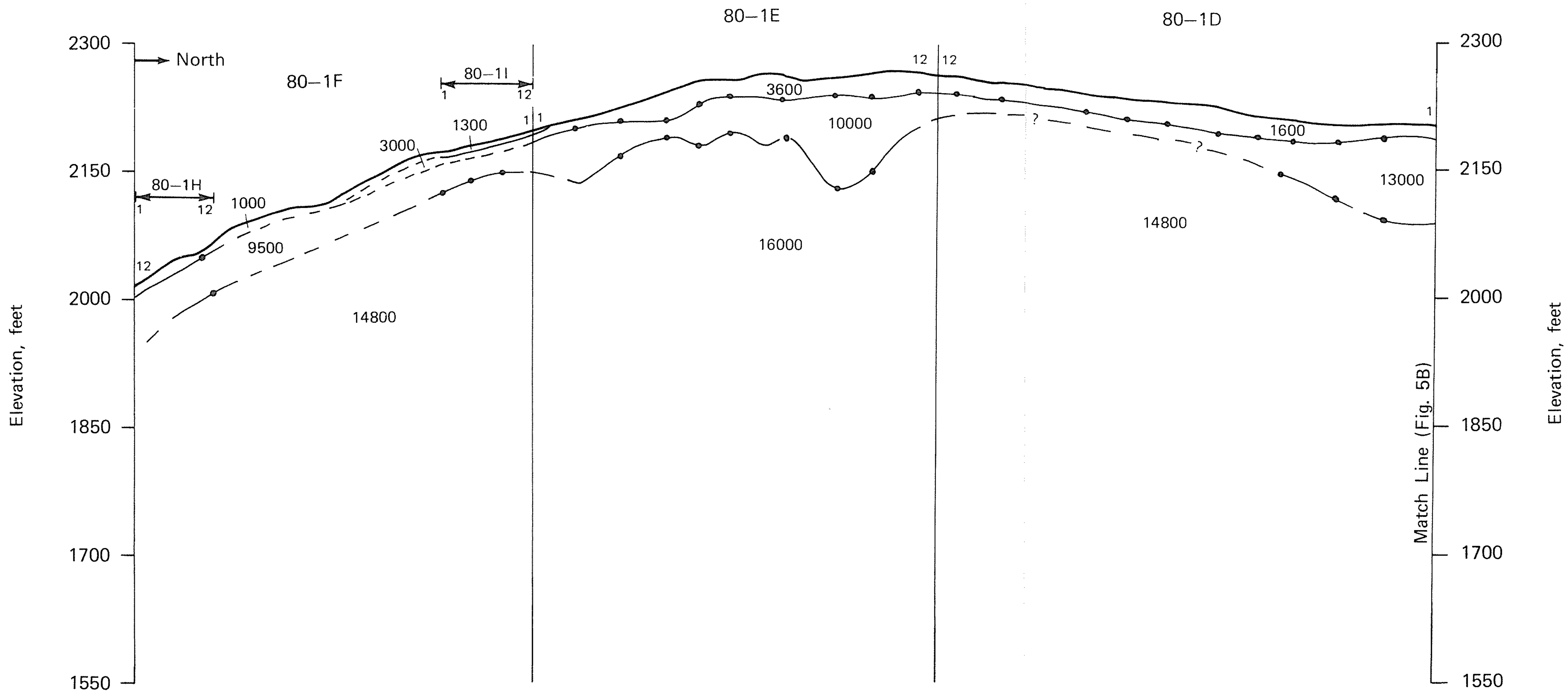
PREPARED BY WOODWARD-CLYDE CONSULTANTS



LOCATION OF DEVIL CANYON
SEISMIC REFRACTION LINES

FIGURE 3

PREPARED BY WOODWARD - CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 300 feet
Vertical Scale: 1 inch = 150 feet

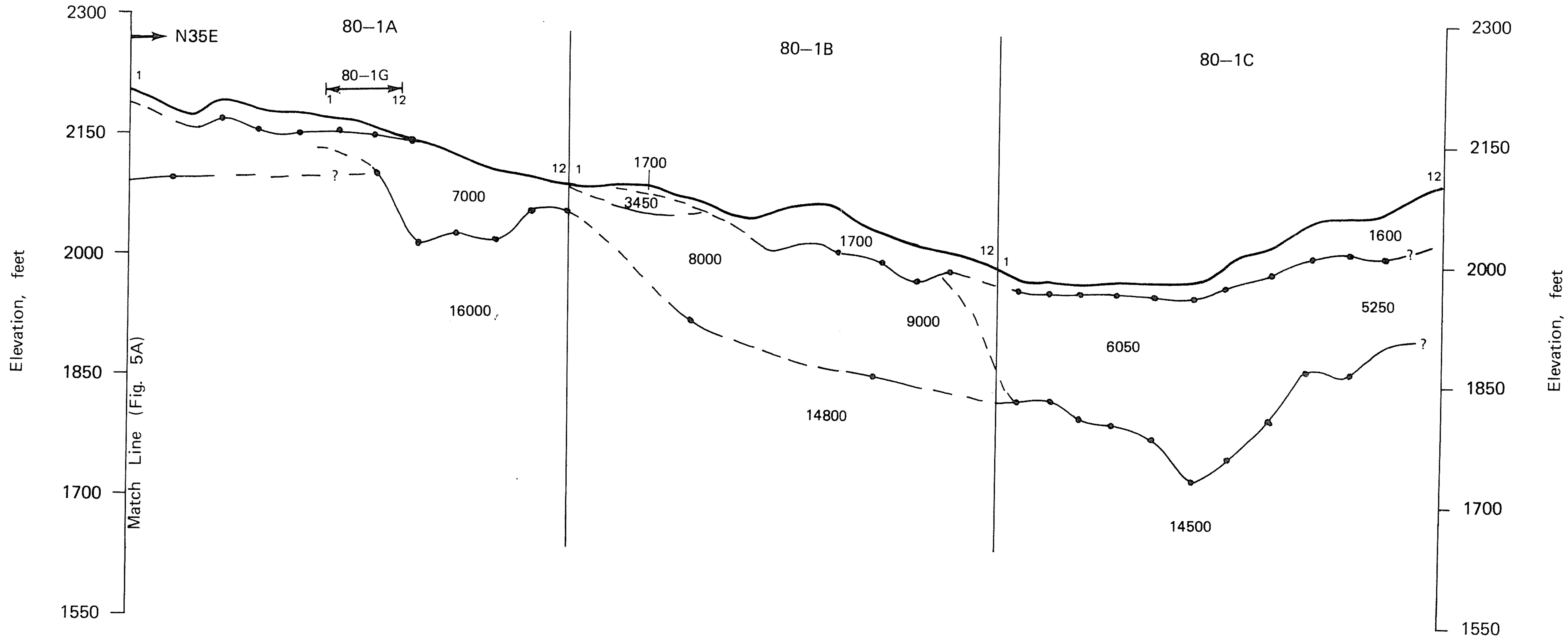
NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R&M CONSULTANTS, 3/19/81.

SEISMIC REFRACTION PROFILE 80-1
SHEET 1 OF 2

ACRES

FIGURE 4a

PREPARED BY WOODWARD-CLYDE CONSULTANTS



Compressional wave velocities in feet per second

NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R&M CONSULTANTS, 3/19/81.

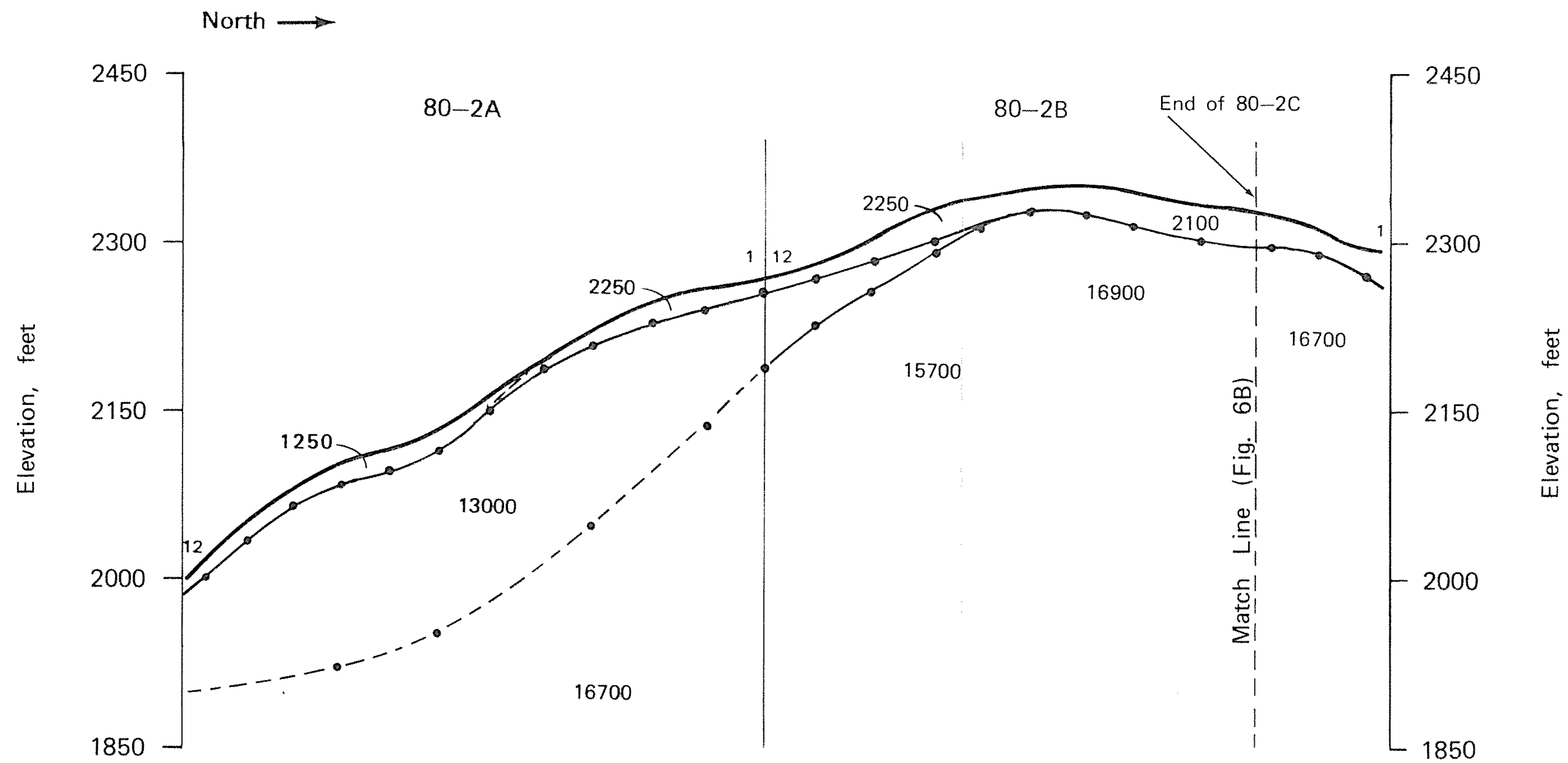
Horizontal Scale: 1 inch = 300 feet
Vertical Scale: 1 inch = 150 feet

SEISMIC REFRACTION PROFILE 80-I
SHEET 2 OF 2

FIGURE 4b

ACRES

PREPARED BY WOODWARD-CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 300 feet
Vertical Scale: 1 inch = 150 feet

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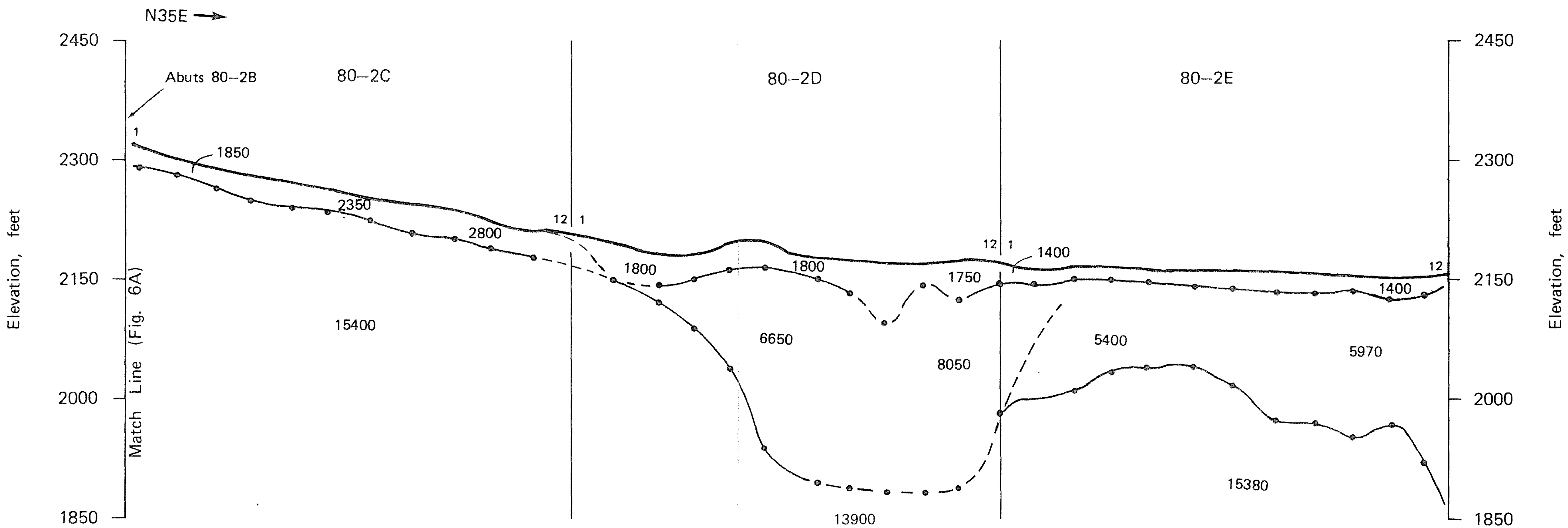
SEISMIC REFRACTION PROFILE 80-2
SHEET I OF 2

FIGURE 5a

ACRES

PREPARED BY WOODWARD-CLYDE CONSULTANTS



Compressional wave velocities in feet per second

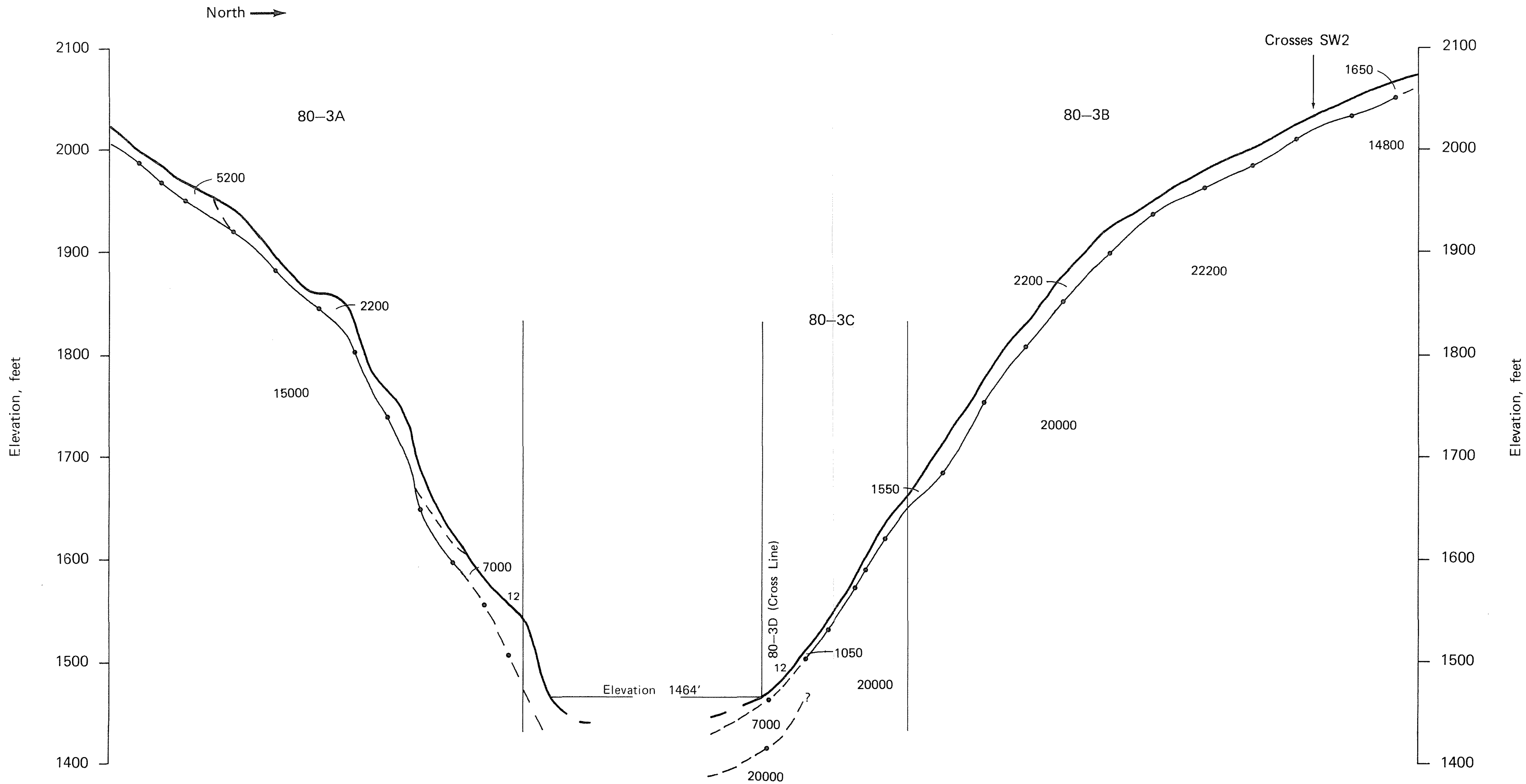
Horizontal Scale: 1 inch = 300 feet
Vertical Scale: 1 inch = 150 feet

NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R & M CONSULTANTS, 3/19/81.

SEISMIC REFRACTION PROFILE 80-2
SHEET 2 OF 2

FIGURE 5b

PREPARED BY WOODWARD-CLYDE CONSULTANTS



NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R&M CONSULTANTS, 3/19/81.

Compressional wave velocities in feet per second

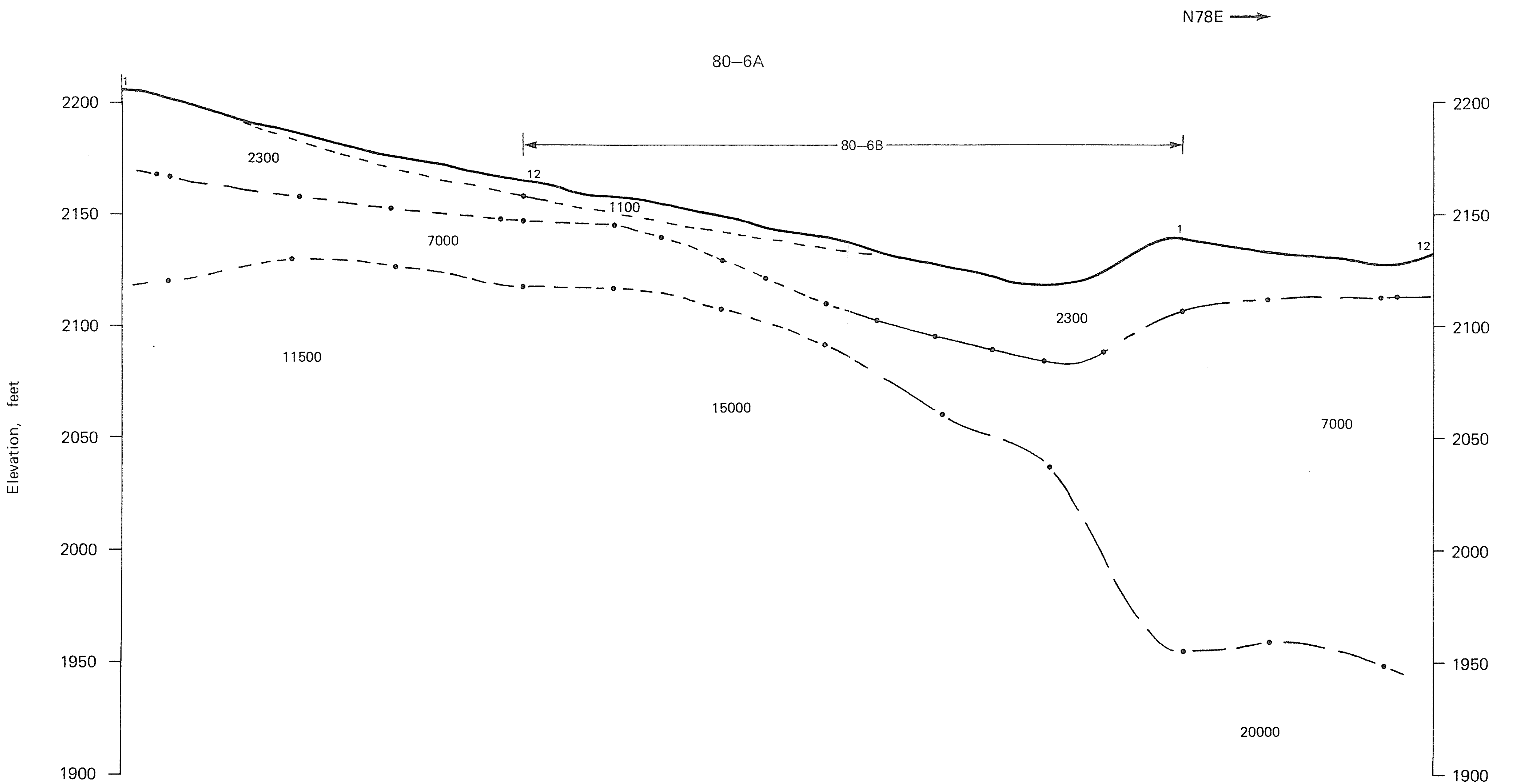
Horizontal Scale: 1 inch = 200 feet
Vertical Scale: 1 inch = 100 feet

SEISMIC REFRACTION PROFILE 80-3

ACRES

FIGURE 6

PREPARED BY WOODWARD-CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 100 feet

Vertical Scale: 1 inch = 50 feet

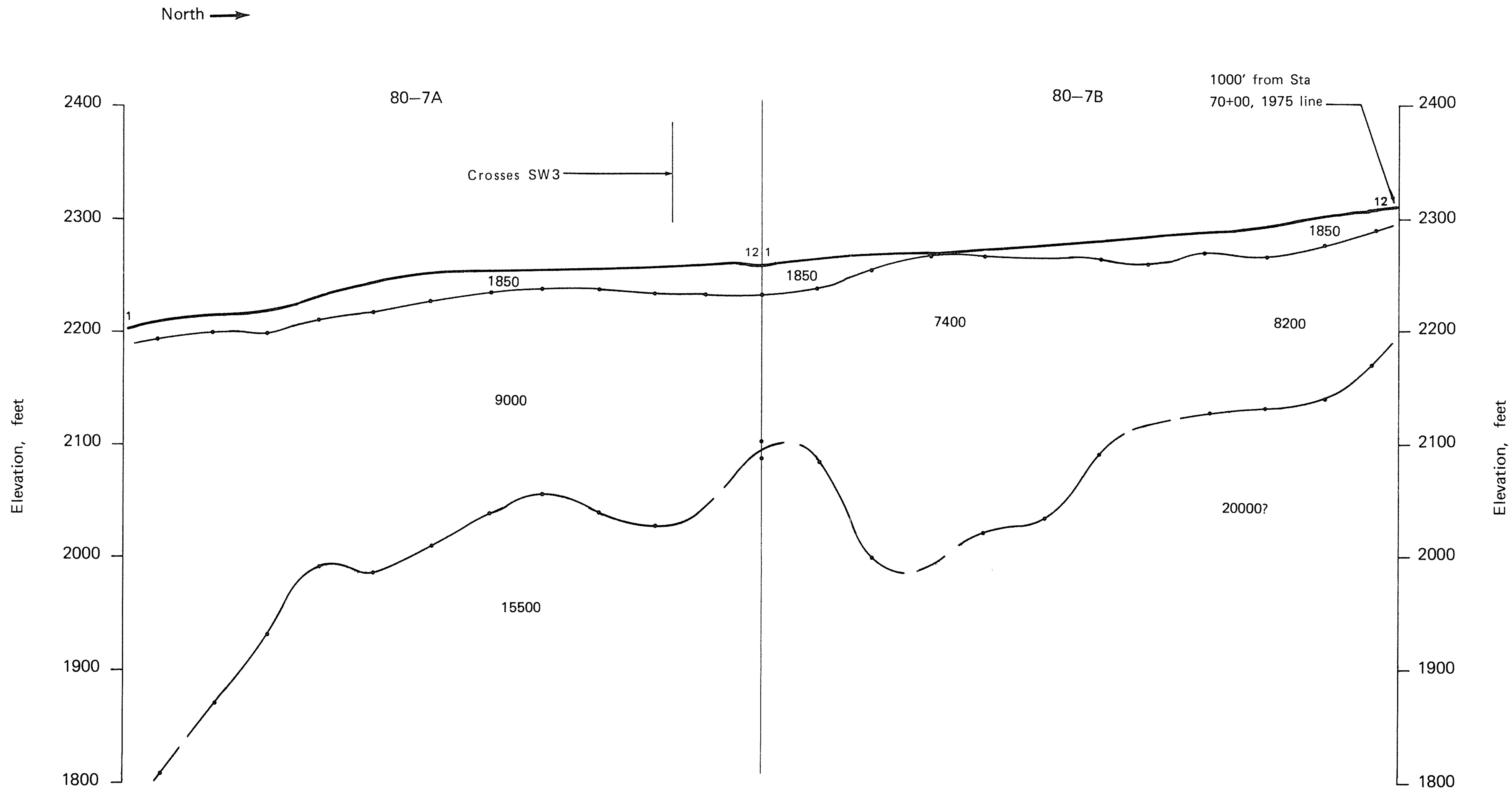
NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R&M CONSULTANTS, 3/19/81.

SEISMIC REFRACTION PROFILE 80-6

FIGURE 7

ACRES

PREPARED BY WOODWARD-CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 200 feet
Vertical Scale: 1 inch = 100 feet

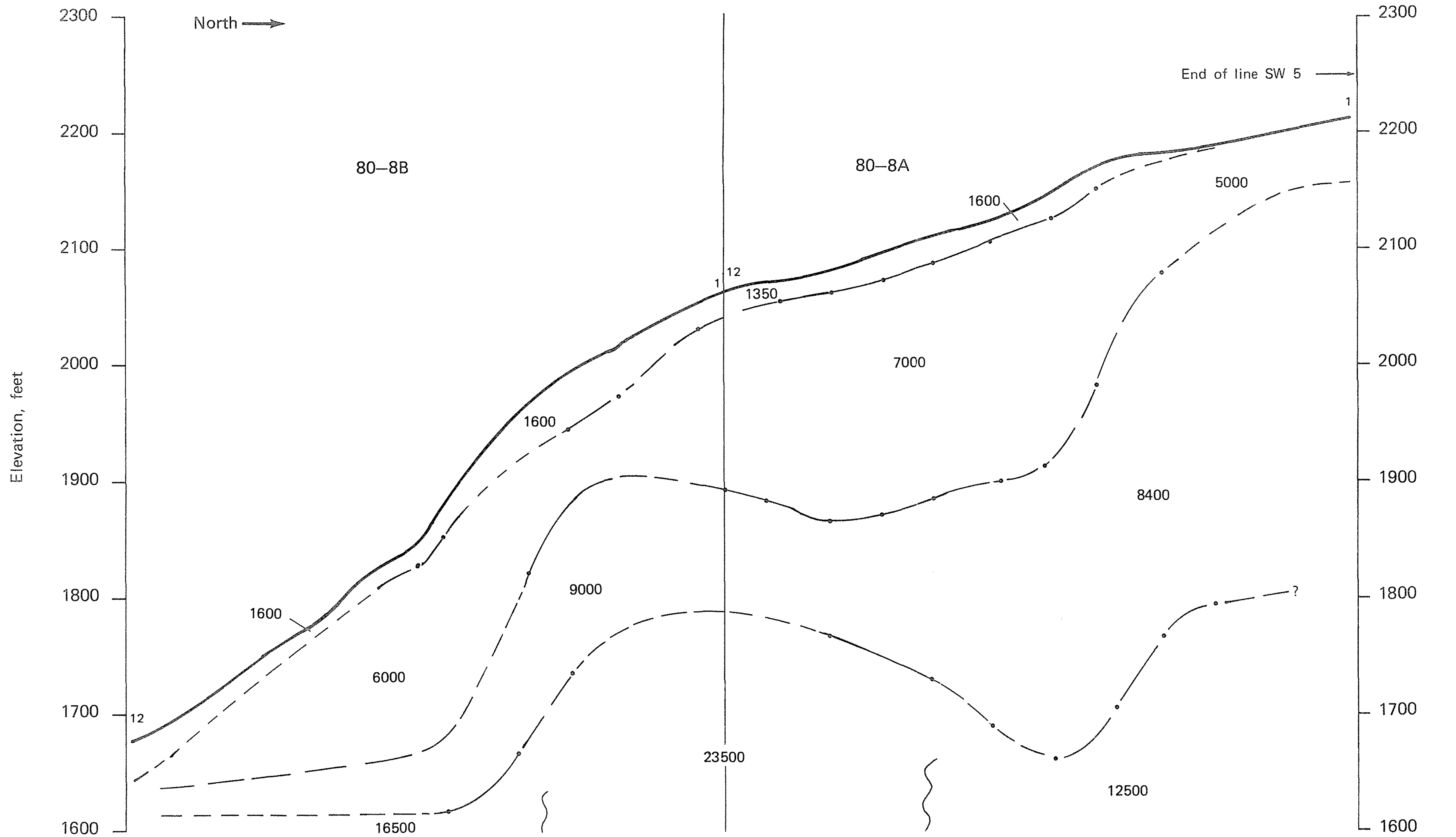
SEISMIC REFRACTION PROFILE 80-7

NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R&M CONSULTANTS, 3/19/81.

ACRES

FIGURE 8

PREPARED BY WOODWARD-CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 200 feet

Vertical Scale: 1 inch = 100 feet

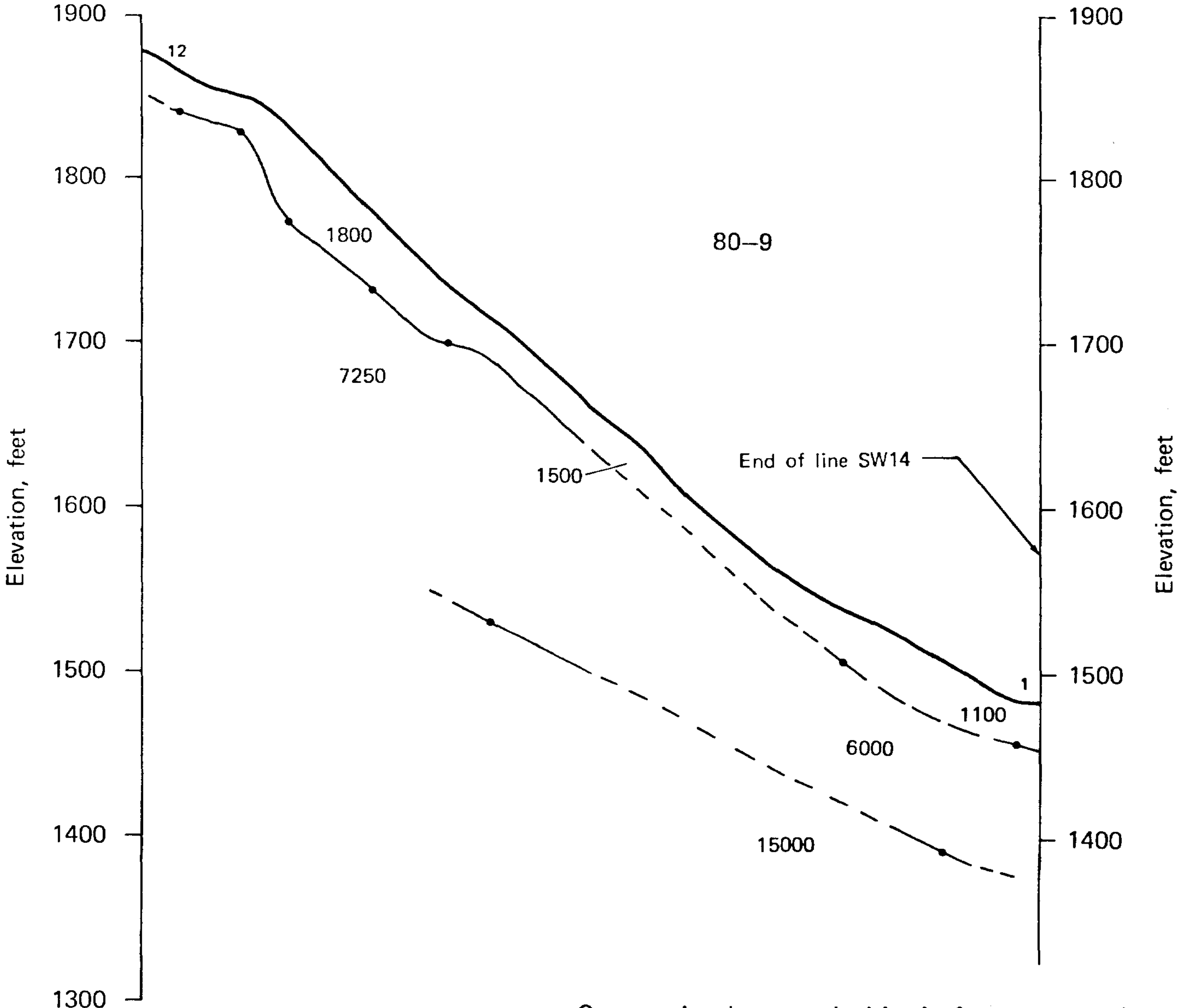
NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R&M CONSULTANTS, 3/19/81.

SEISMIC REFRACTION PROFILE 80-8

FIGURE 9

ACRES

PREPARED BY WOODWARD-CLYDE CONSULTANTS



Compressional wave velocities in feet per second

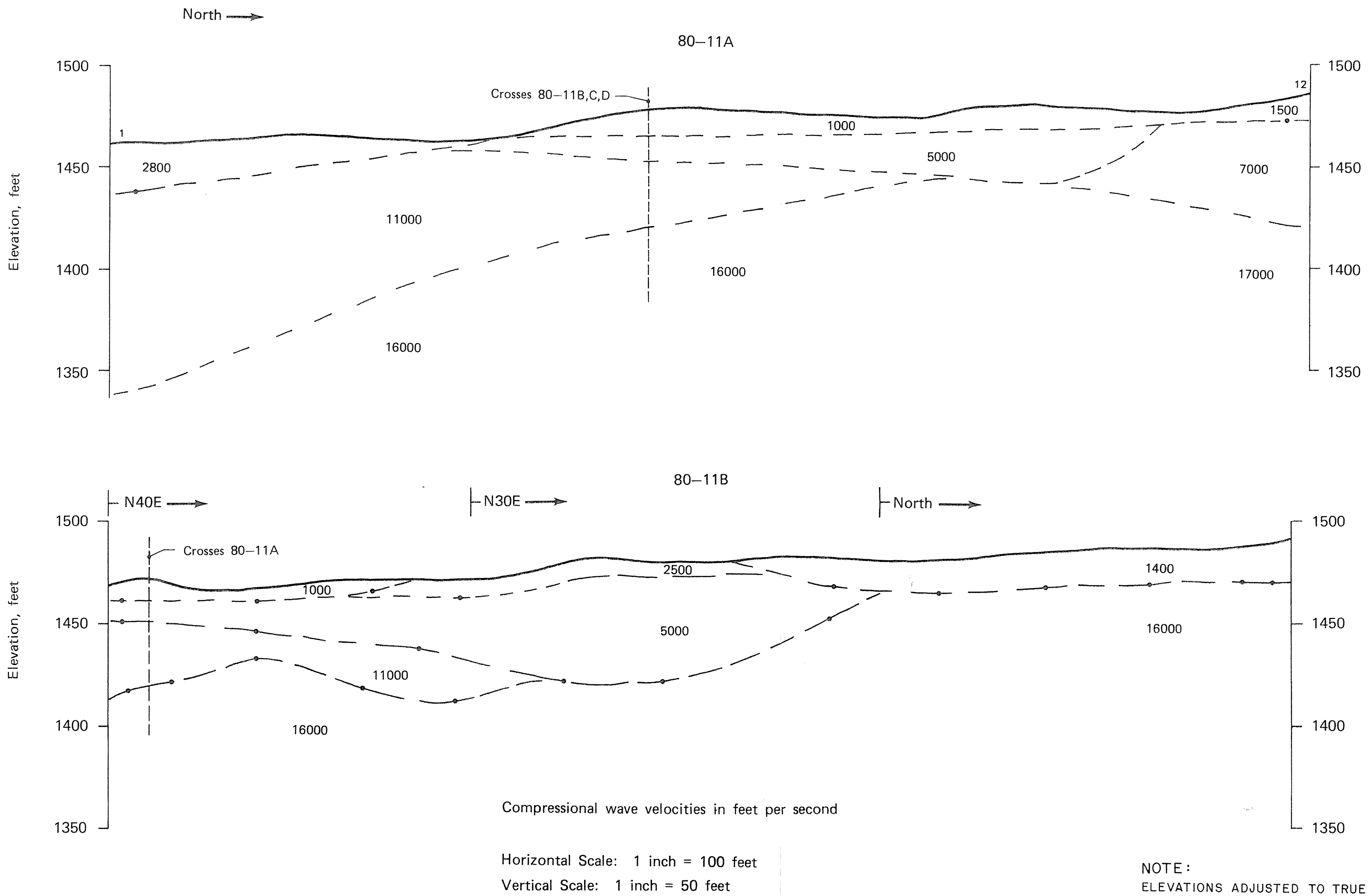
Horizontal Scale: 1 inch = 200 feet
Vertical Scale: 1 inch = 100 feet

Note: Elevations adjusted to true values according to R&M Consultants, 3/19/81

SEISMIC REFRACTION PROFILE 80-9

FIGURE 10

ACRES



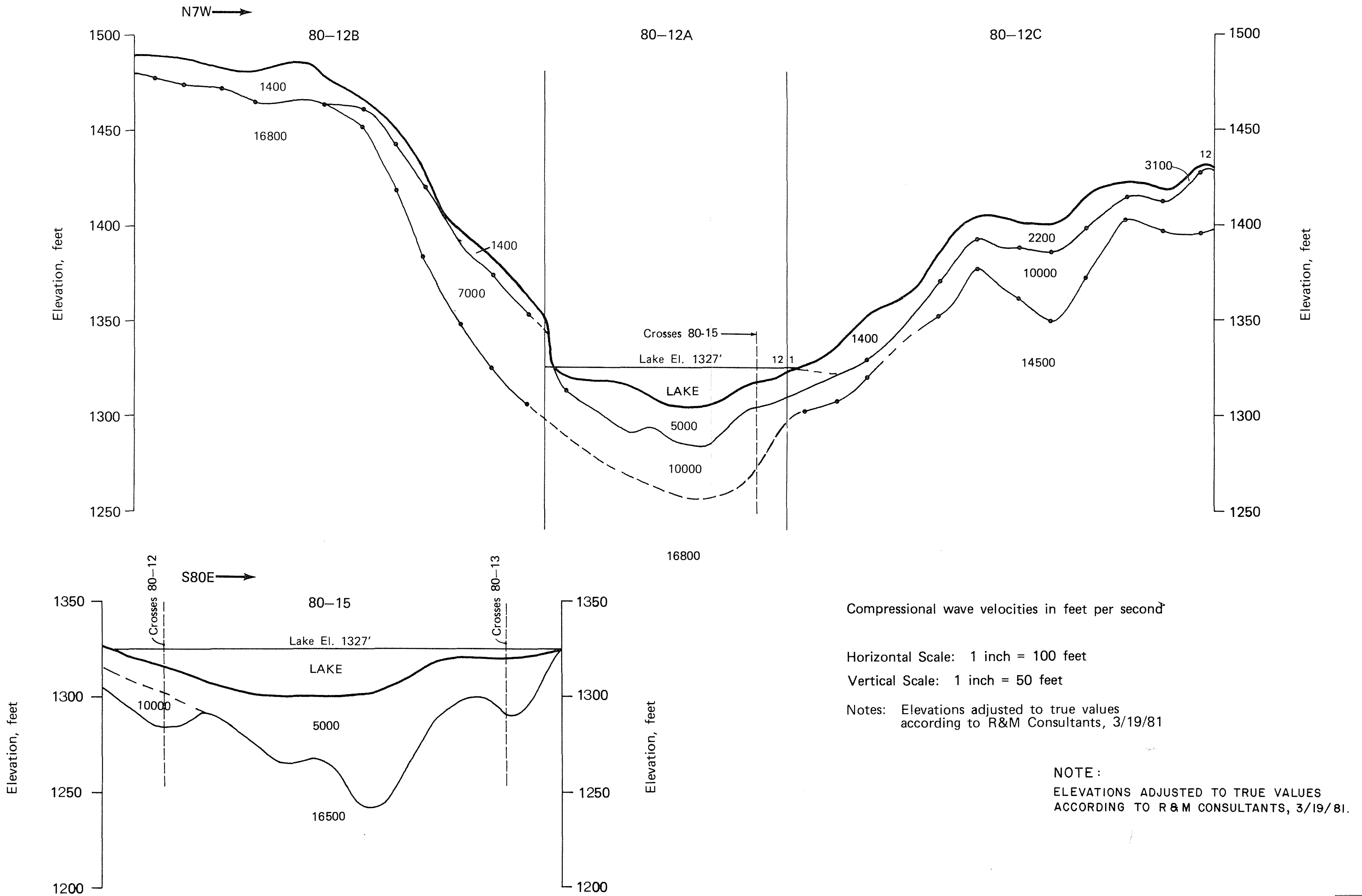
NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R&M CONSULTANTS, 3/19/81.

SEISMIC REFRACTION PROFILE 80-11

FIGURE 11

ACRES

PREPARED BY WOODWARD-CLYDE CONSULTANTS

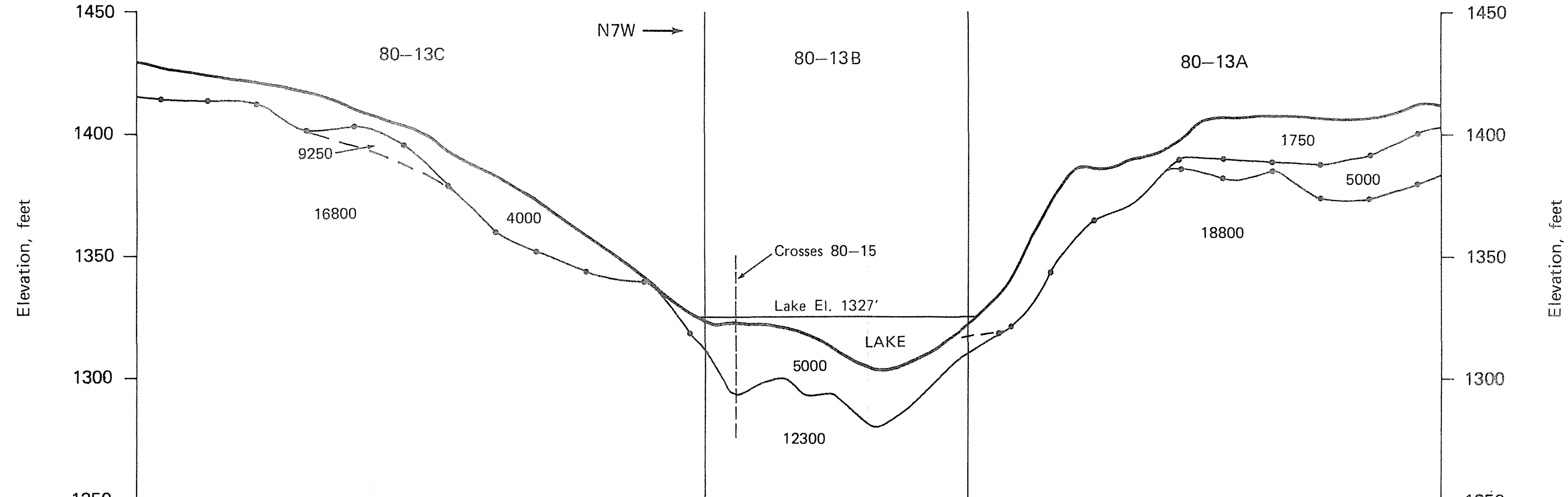


SEISMIC REFRACTION PROFILES 80-12 & 80-15

FIGURE 12

ACRES

PREPARED BY WOODWARD-CLYDE CONSULTANTS



Compressional wave velocities in feet per second

Horizontal Scale: 1 inch = 100 feet
Vertical Scale: 1 inch = 50 feet

NOTE:
ELEVATIONS ADJUSTED TO TRUE VALUES ACCORDING TO R&M CONSULTANTS, 3/19/81.

SEISMIC REFRACTION PROFILE 80-13

FIGURE 13

ACRES

PREPARED BY WOODWARD-CLYDE CONSULTANTS