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Record No. 1971/121

Musa River Hydroelectric Scheme, Eastern Papua: Geophysical Investigations 1970.

by

F. J. Taylor

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Report 1971/121

MUSA RIVER HYDRO-ELECTRIC SCHEME, EASTERN PAPUA: GEOPHYSICAL INVESTIGATIONS 1970

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CONTENTS

SUMMARY

A seismic refraction survey was carried out for the Commonwealth Department of Works (whose client is the Papua New Guinea Electricity Commission), to investigate five possible dam sites in the Musa Gorge. The aim of the survey was to determine the depth to bedrock and nature of the overburden on each of the dam sites, and as far as possible the physical properties of the bedrock.

The depth of weathering is generally less than 33 metres and up to 40 metres. Bedrock velocity ranges between 2100 m/sec (7000 ft/sec) and 5500 m/sec (18,000 ft/sec); the lower bedrock velocities occur at higher elevations. The results indicate strong bedrock.

One major anomaly exists in depth to bedrock on dam site 5 on the western bank. The structural change is also clearly visible on the aerial photographs and suggests either a fault or a dyke.

CORRECTED

INTRODUCTION

Approximately 4300 m (14,000 ft) of seismic refraction work was carried out at Musa Gorge to investigate five possible dam sites proposed for the upper part of the gorge. The Musa Gorge is situated on the Musa River approximately 160 km (100 miles) east of Port Moresby (Plate 1), and lies north of the Musa Valley, through which several large tributaries of the Musa River flow. Their catchment area is about 3000 sq km (1200 square miles). A 150 m (500 foot) high dam across the gorge would impound water in a reservoir some 640 sq km (250 square miles) in surface area, which would be used to generate hydro-electric power.

Access to the area is by aircraft to Safia airstrip and then by boat down the Adau River to the entrance of the gorge. A semi-permanent camp was established at this point by the Commonwealth Department of Works and it served as a base for the geophysical survey as well as a geological survey. Access to the individual dam sites, designated 1, 2, 3, 4, and 5 (Plate 2), is by walking tracks only. No roads have been built: the terrain is so rugged that extensive blasting and heavy machinery would be needed. A flying fox was erected across the river between dam sites 1 and 2 to allow easier access to dam sites 2, 3, 4, and 5 on the eastern bank. All the sites have slopes in excess of 35°, and many slopes end as vertical cliffs, about 60 m (200 feet) high, at the edge of the river. In general, seismic work was not undertaken in areas where the slope exceeded 50°. The river elevation is approximately 120 m (400 feet) A.S.L., and the banks of the gorge about 360 m (1200 feet) A.S.L.

Trig stations established on major peaks for the purpose of aerial mapping have been given names by the Commonwealth Department of Works. Three such peaks shown in Plate 2 are named 'Rebel', 'Damyl', and 'Bev'.

Current maps differ in their delineation of the start of the Musa River: for this Record and for the geological reports at present being compiled, the Musa River commences approximately one-quarter of a mile upstream from the entrance of the gorge at the junction of the Adau and Moni Rivers; or, in other words the major river which joins the Adau River just before the entrance of the gorge is called the Moni River. The river below the junction is called the Musa River.

The survey was carried out during October and November 1970, by a party comprising F.J. Taylor (party leader), M.J. Dickson (technical assistant), and M. Pounder (technical officer). The supervising geophysicist, Dr E.J. Polak, assisted during the early part of the survey.

The term 'bedrock' used in this Record refers to the deepest refractor detected and the term 'overburden' refers to soil, alluvium, and weathered rock above it.

Concurrently with the geophysical investigation, regional geological mapping was carried out by G.P. Robinson and detailed geological mapping by D.F. Macias and J. Harris, all geologists of the P.N.G. Geological Survey. The results of their work are being issued by the P N.G. Geological Survey as two Notes on Investigation.

GEOLOGY

The geology of the Musa River area is reported in Smith & Green (1961). A more recent report on the Musa Gorge area was written by G. Robinson in 1970 and will appear in 1971 in P.N.G. Geological Survey Note on Investigation Series (Robinson, 1970). Low level aerial photographs were also flown in 1970, and the results of further geological work in 1970 are being compiled by the Government Geological Office in Port Moresby and will appear in the same series (Macias, 1971).

The geology is briefly summarized here, but the reader is referred to the geological reports for a more detailed description. Two rock units have been recognized in the gorge area: the Domara River Beds (Pleistocene), and basic and ultrabasic rocks forming the Didana Range (late Cretaceous). The latter unit has been called the Didana Ultramafic Complex. The two units in the region of the gorge are roughly divided by a southeast-trending fault close to the entrance of the gorge, which also marks the boundary between the Didana Range and the Musa Valley.

Inside the gorge the principal rock unit is the Didana Ultramafic Complex, with thin erosional remnants of the Domara River Beds occupying the occassional ridge. It is the basic and ultrabasic rocks of the Didana Ultramafic Complex which have been investigated during this survey.

METHODS AND EQUIPMENT

The seismic results were obtained using 24-channel SIE PSU-19 refraction equipment with TIC 20 Hz geophones. The reciprocal geophone method (Heiland, 1946) was used to obtain vertical travel times under each geophone station, and average vertical velocities were obtained from short weathering spreads. Three-dimensional geophones were used to measure the relation between the velocities of transverse and longitudinal waves. Poisson's Ratio and Modulus of Elasticity were deduced from this relation.

The layout of traverses and the location of the individual dam sites are shown on Plate 2. Although the traverse lines are accurately surveyed the elevation contours are approximate only; they were obtained from aerial photographs with only limited ground control. For this reason the map must be considered a sketch map only. A more accurate map is at present being compiled by the Commonwealth Department of Works in Port Moresby.

The traverses covering the individual dam sites are listed below. 'A' refers to the east bank and 'B' to the west bank.

Site	Traverse Number
1	A1, B1
2	A2, B2
3	A3, A6, B3
4	A4, B4
5	A5, B5

Traverses A7, A8, A9, and A10 were undertaken in order to obtain information on the bedrock around river level.

Hydrophone equipment was taken on the survey in order to obtain depths under the river. However, the current was far too fast to attempt to place cables and hydrophones in the stream.

In addition to these traverses covering the dam sites several other traverses were undertaken in areas of particular interest. These areas are:

1. Landslide Area. Four traverses designated LS1, LS2, LS3, and LS4 were undertaken on a major landslide between dam sites 2 and 3 on the western bank.

2. Safia Airstrip. A traverse 335 m (1100 feet) long was sited alongside the airstrip in order to determine the thickness of sediments in the Musa valley.

3. Stream Gauge Station. A short traverse was sited at this point on the Domara River Beds in order to determine the depth to bedrock and the velocity of bedrock.

4. Accelerograph Site. A short weathering spread was placed at the proposed accelerograph site, which is situated on alluvium flats at river level on the west bank near the flying fox.

RESULTS

Three groups of velocities were observed over the area:

300 - 760 m/s	(1000 - 2500 ft/sec)	- soil
900 - 1500 m/s	(3000 - 5000 ft/sec)	- clays and extensively *weathered rock
2100 - 5500 m/s	(7000 - 18,000 ft/sec)	- slightly weathered to fresh rock (ultrabasic) showing varying degrees of jointing.

The depth to 'bedrock' is less than 40 m (130 feet) along all traverses. This is not an exceptionally large depth, but the low velocities recorded for the overburden suggest that the material above bedrock is highly weathered. The variation in bedrock velocities may be caused by different degrees of jointing or slight weathering or a combination of both. Lower velocities are present on the upper sections of the banks of the gorge. Jointing is probably loose and more extensive in those areas.

The cross-sections along the seismic traverses are shown in Plates 3 to 8. In general the depth of weathering on the upper slopes lies between 17 m (50 feet) and 40 m (130 feet), whereas traverses A7, A8, A9, and A10 along the river bed show fairly shallow weathering around river level. Faults may exist on traverse lines B2 and B5. The apparent fault on B5 would have a fairly large displacement of 18 m (60 feet) and is clearly visible on the aerial photographs as an apparent 'cleared' line running north-south from the river. However, both the aerial photographs and the seismic cross-section also suggest the possibility of a dyke about

* Standard BMR classifications of weathering are not used since specimens of rock at depth were not available.

45 m (150 feet) in width instead of a fault (Plate 7). If the anomaly is a dyke then the depth of weathering on the western side is approximately 18 m (60 feet) greater than that on the eastern side. Weathering velocities also indicate that the depth of soil is greater on the western end of the traverse line.

Traverse A4 shows a very low bedrock velocity (1800 m/sec; 6000 ft/sec). Unfortunately, the traverse line is too short to decide whether this condition is localized at the peak of 'Rebel' or extends for a considerable distance. Both north-south traverse lines on 'Rebel' show lower bedrock velocities than the east-west traverse lines. This may indicate that the strongest jointing runs generally east-west. The saddle on the eastern side of 'Rebel' has approximately 24 m (80 feet) of weathered material. Hence the bedrock (elevation of 295 m, 970 feet) would have to be excavated to a depth of 45 m (150 feet) if the saddle is to be used as a natural spillway.

Site 3 on the western side of the gorge is not considered ideal because of the relatively low velocity of bedrock located at an elevation of 253 m (830 feet) (Traverse B3, Plate 7). Site 2 on this bank also has low velocities (Traverse B2, Plate 7) but these are recorded at an elevation of 335 m (1100 feet). It is expected that higher velocities would be recorded lower down in the gorge.

Both sides of site 1 (Traverse A1 and B1, Plate 6) show reasonably high velocities. This site appears to be the most stable of the five investigated. Cumming & Carter (1969) in their report on the area indicated several areas of instability: site 5 (west), site 2 (east), site 2-3 (west), and upstream from site 1 on the eastern bank. The report concludes that the most stable region in the upper part of the gorge is around site 1, which is confirmed by the geophysical work. The length of the top of a dam wall sited at site 1 would be approximately 610 m (2000 feet). This compares with 520 m (1700 feet) for sites 2, 3, and 4, and 580 m (1900 feet) for site 5.

Possible shear zones have been indicated on both sections covering site 1 (Plate 6). A shear zone may be evident as either an increase in the depth of weathering or a decrease in the measured bedrock velocity. In the latter case the shear zone would have to extend over several geophone stations for this change to be detected.

In section A1 station 275 has a much greater recorded weathering time than the adjacent stations. In section B1 there are two zones which give rise to anomalies in the measured bedrock velocity. All three of these anomalies could be produced by shear zones and are marked on the sections as possible shear zones. Any further investigations in this area should consider these particular zones in detail.

Traverses A7, A8, A9, and A10 located at river level show high bedrock velocities and shallow weathering depths. The irregular bedrock boundary shown for A10 (Plate 4) is probably produced by near-surface floating boulders of considerable size as well as changes in weathering depth. It was not possible to determine the depth to bedrock under the river because of the fast current; but it would probably be comparable to that found along the four traverses A7, A8, A9, and A10.

Poisson's Ratio and Modulus of Elasticity

Table 1 gives the values of Poisson's Ratio (μ) and modulus of elasticity (E) calculated from longitudinal and transverse wave velocities recorded on 10 locations. Poisson's Ratio (μ) is derived from:

$$\left(\frac{V_L}{V_T}\right)^2 = \frac{(\mu - 1)}{(\mu - \frac{1}{2})}$$

and modulus of elasticity (E) from

$$V_L = \left[\frac{E\,(1 - \mu)}{\rho\,(1 + \mu)\,(1 - 2\mu)}\right]^{\frac{1}{2}}$$

where ρ is rock density

Transverse waves are greatly affected by the overburden, and as overburden thickness increases the quality of the record decreases; therefore the values of the Poisson's ratio may be up to 2 percent in error, resulting in a corresponding error in modulus of elasticity. For computation an average in situ density of 2.65 was assumed for bedrock. The figure is conservative, since the density of a solid specimen of bedrock (ultramafics) is probably in excess of 2.9. An error of one percent in density will result in a one percent error in modulus of elasticity.

The regression line equation for the relation of the seismic velocity to modulus of elasticity (E) for this particular set of measurements is: $E = 2.26 \times 10^{-2} (V_L)^2$ kg/cm^2

TABLE 1

Traverse	V_L / V_T	Poisson's Ratio	Longitudinal Velocity (V_L) m/sec	ft/sec	Modulus of Elasticity (E) x 10^5 kg/cm^2	x 10^6 lb/sq in
A1	1.77	.27	3350	11000	2.45	3.49
A3	1.80	.28	2740	9000	1.60	2.28
A3	1.77	.27	3050	10000	2.03	2.89
A3	1.71	.24	4570	15000	4.80	6.81
A4	1.66	.22	1830	6000	0.80	1.14
A6	1.72	.24	3810	12500	3.30	4.70
A6	1.80	.28	3810	12500	3.09	4.40
A8	1.80	.28	3960	13000	3.34	4.75
B2	1.55	.14	2590	8500	1.73	2.46
B3	1.9	.31	2740	9000	1.47	2.09

Landslide Area

In the vicinity of LS4 the depth of overburden attains a maximum thickness of 42 m (140 feet). Plate 8 shows the cross-sections of this traverse as well as the results of further probes on this landslide. Bedrock velocities are relatively low. Very weak seismic signals were recorded from comparatively large charges and some geological explanation is necessary for this rapid attenuation of energy. One of the charges was placed in a natural hole at least 3.5 m (12 feet) deep situated under a large boulder. Perhaps the possibility of similar cavities underground should be considered.

No end off-set shots were possible for spreads LS1 and LS2 because of the topography, and profiles for these spreads are not available.

Safia Airstrip

A 335 m (1100 feet) spread alongside the Safia airstrip gave velocities and depths as shown in Plate 8. The profile consists of:

0 - 1.5	metres (0 - 5 feet)	soil	(300 m/sec)
1.5 - 30	metres (5 - 100 feet),	clays and gravels	(1200 m/sec)
30 - ?	metres (100 - ? feet),	unconsolidated sediments	(1800 m/sec)

Dip is zero along the entire 335 m (1100 feet).

Bedrock was not detected by this spread. Theoretical calculations show that bedrock must be more than 150 m (500 feet) below ground level. From geological considerations the sediments in the area could be many hundreds of metres thick. For sediments of thickness 300 m (1000 feet) the minimum shot-geophone distance required to detect bedrock is 1050 m (3500 feet) and for sediments of thickness 600 m (2000 feet) this distance is 2100 m (7000 feet). Such large shot-geophone distances would require charges in the order of 20 kg placed at a depth of 30 m to give good signals.

Stream-Gauge Station (Domara River Beds)

A short east-west weathering spread at this point revealed a bedrock velocity of 2700 m/sec (9000 ft/sec) with an average depth to bedrock of 17 m (50 feet). The bedrock shows a slight dip to the east.

Accelerograph Site

A short north-south weathering spread was placed at the proposed site for an accelerograph on the west bank of the gorge near the flying fox. Plate 8 shows the velocities and depths recorded. Bedrock dips slightly to the north. A small fault is suggested on this section. The depth to bedrock varies from 10 to 18 m (35 - 60 feet) and the maximum velocity recorded is 5500 m/sec (18,000 ft/sec). This velocity indicates that bedrock at river level is exceptionally strong.

CONCLUSIONS AND RECOMMENDATIONS

The seismic work completed has given a reasonable coverage of the upper part of the gorge. The depth of weathering varies greatly but is generally less than 33 m (100 feet) and up to about 40 m (130 feet) to 'bedrock' with velocities from 2100 m/sec (7,000 ft/sec) to 5500 m/sec (18,000 ft/sec). The higher velocities and the value of modulus of elasticity indicate strong rock suitable for a dam site.

An important outcome of the seismic work is that the lower bedrock velocities are recorded near the peaks. However, these areas are substantially more elevated than any abutments required.

Except on the western side of site 3, the overburden is probably too weathered (about 1200 m/sec) to be useful as rockfill for the dam, but is probably rippable and may be suitable as core material.

Of all the dam sites, it is suggested on the basis of the seismic work that sites 1 and 2 be given more attention. However, whichever sites are selected it is considered that detailed seismic work should be carried out in order to give complete coverage from peaks to river level and to indicate bedrock irregularities which may be due to shear zones or weathered joints.

Seismic work in the area is difficult and may necessitate the use of climbing ropes on the steeper slopes. The work could possibly be made easier by working on cross traverses where elevation changes are small. A thorough survey would also require the use of a small boat and outboard motor for use in the gorge. Depth of bedrock under the river could possibly be determined in the dry season by placing geophones on the large rocks which are exposed at low water level. Because of these difficulties and the detailed coverage which may be necessary it is considered that the number of sites should be restricted as far as possible by the latest geological and other considerations before further geophysical work is undertaken.

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PLATE I

LOCALITY MAP SHOWING SURVEY SITE IN RELATION TO GENERAL PLAN OF GEOLOGY OF MUSA SCHEME

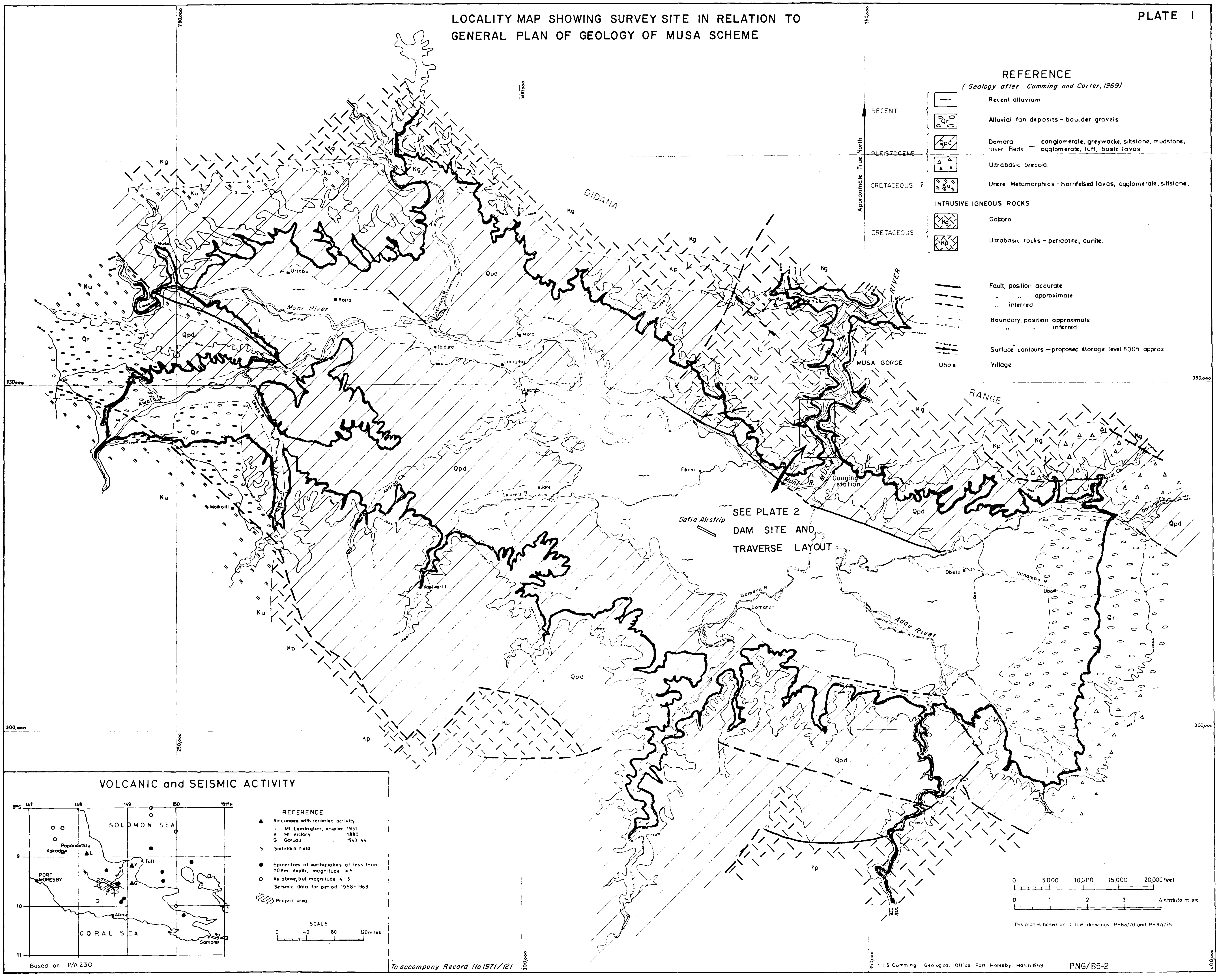
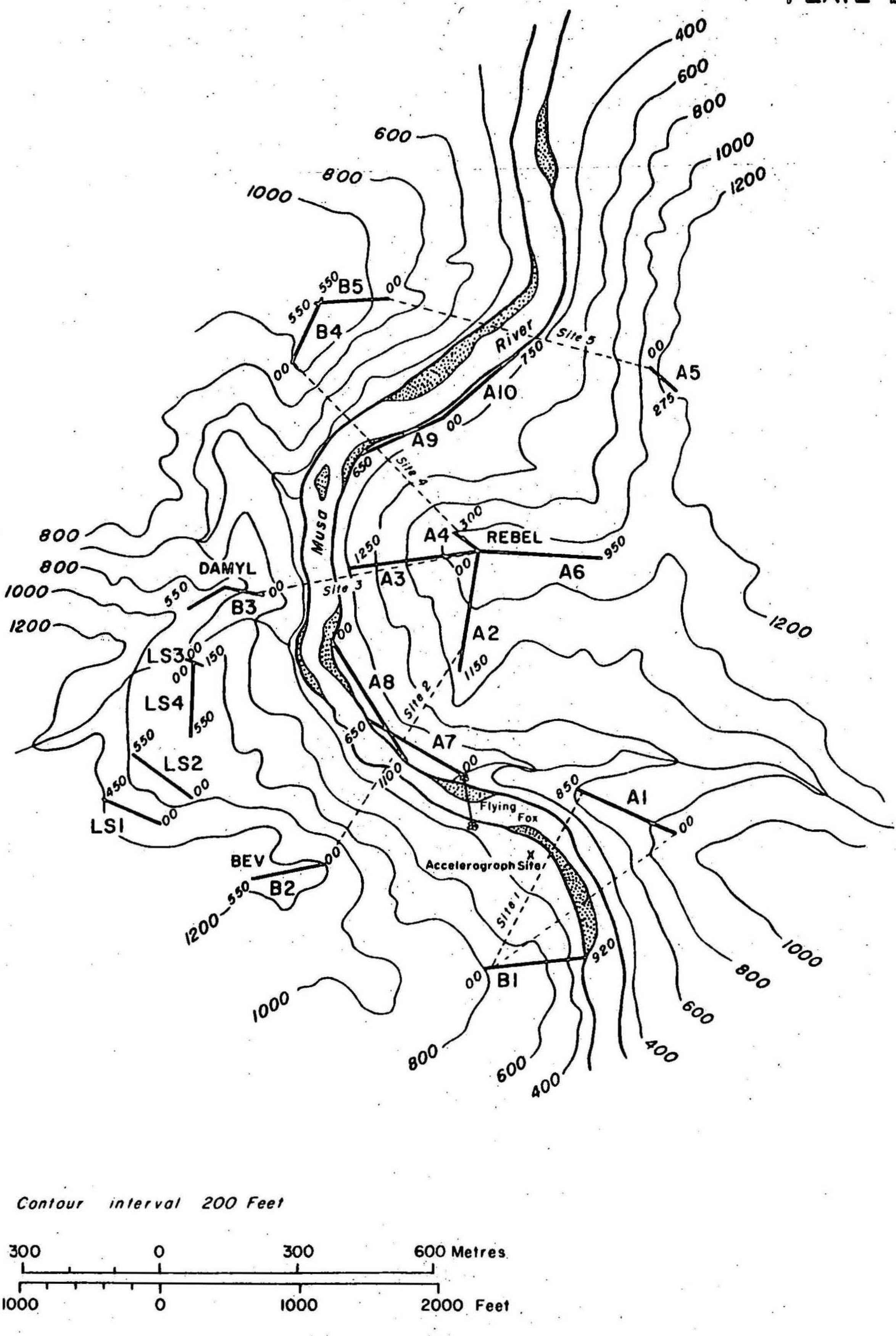


PLATE 2

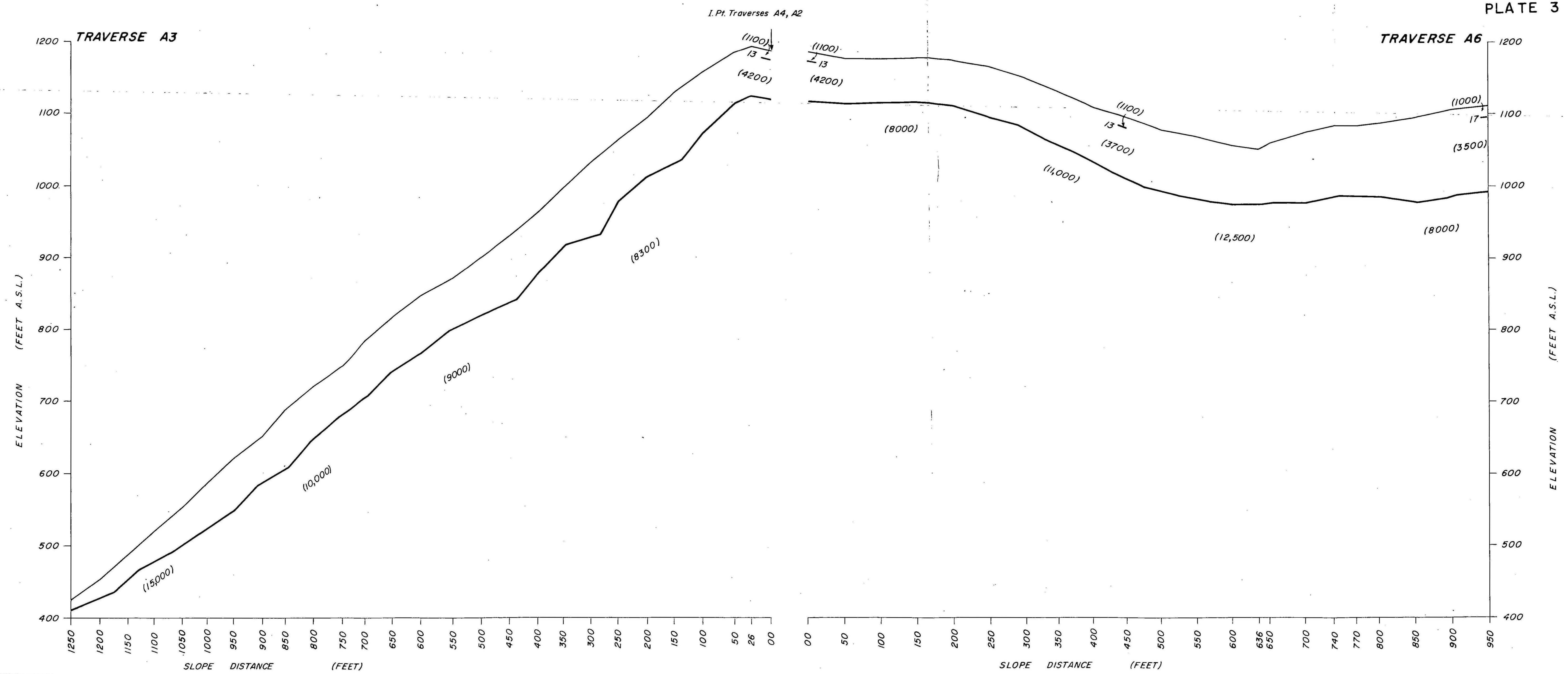


MUSA RIVER DAMSITE PNG

TOPOGRAPHY AND TRAVERSE LAYOUT

To accompany Record No 1971/121

C55/B5-1A



SEIMIC CROSS SECTIONS

TRAVERSES A3 AND A6

LEGEND

———	Bedrock boundary
(5900)	Seismic velocity in formation (ft/s)
23 —	Depth in feet to formation with different seismic velocity
I. Pt.	Intersection point

25 0 25 50 75 100 Metres

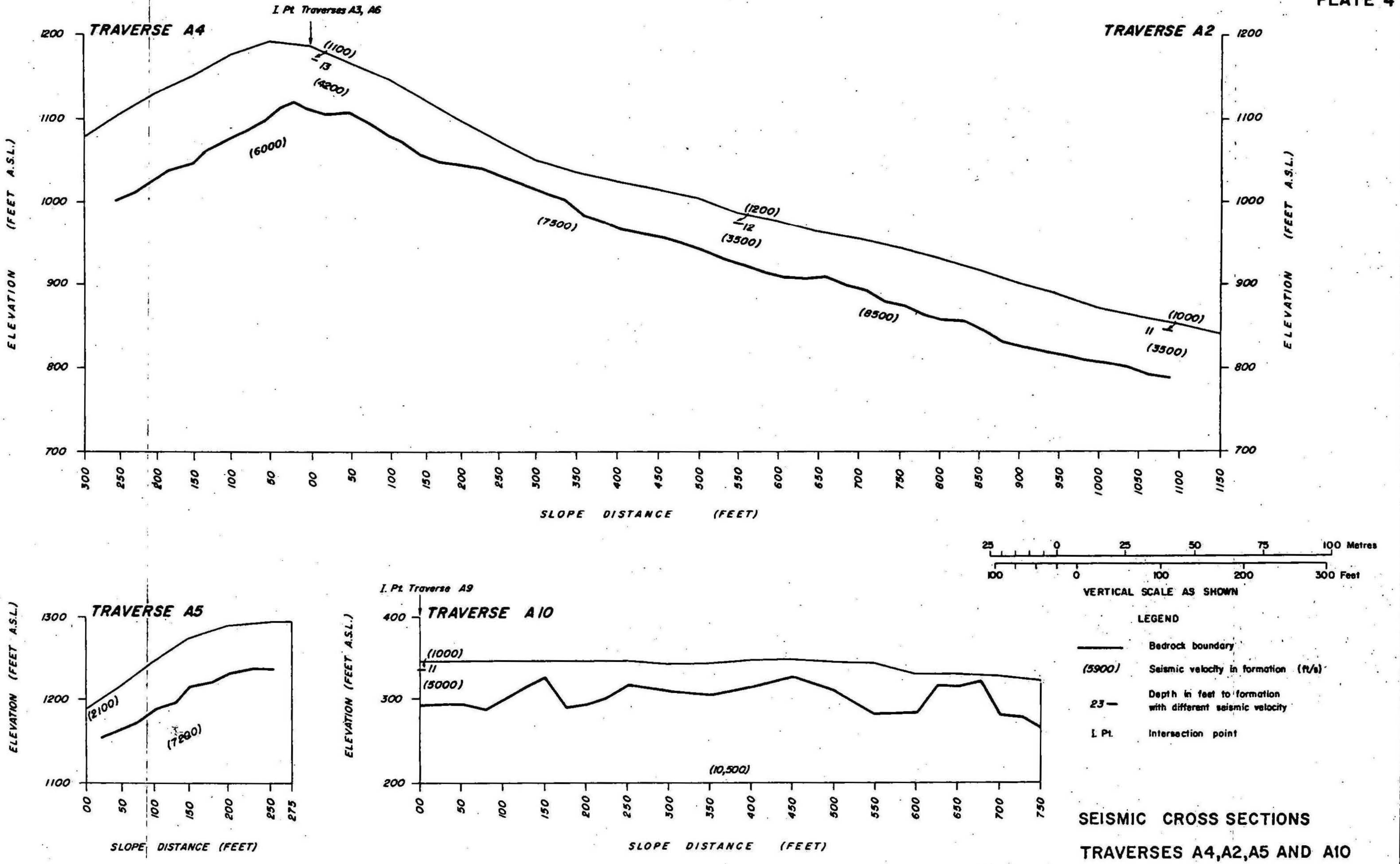
100 0 100 200 300 Feet

VERTICAL SCALE AS SHOWN

To accompany Record No. 1971/121

C55/B5-5

PLATE 4



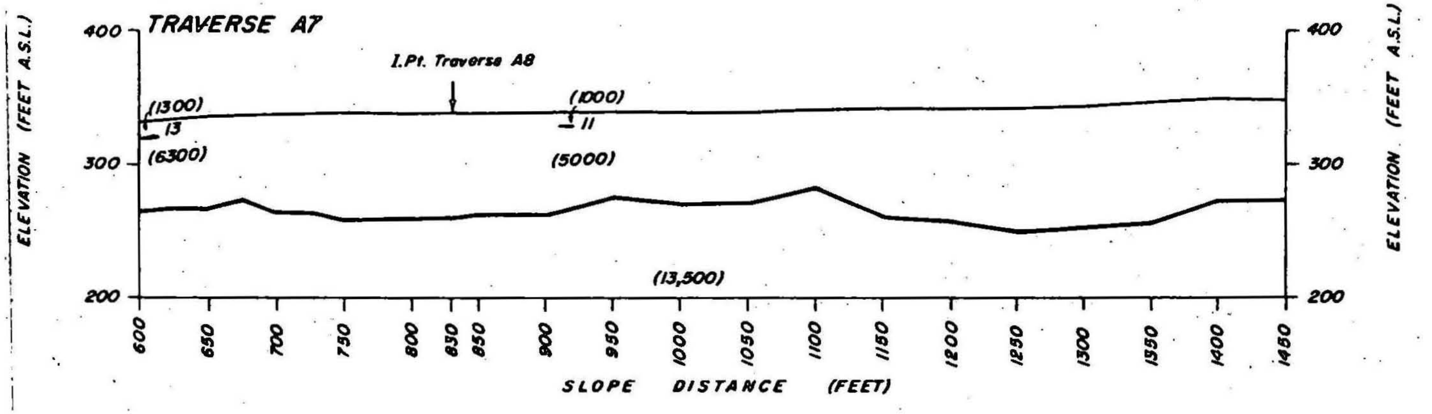
SEISMIC CROSS SECTIONS

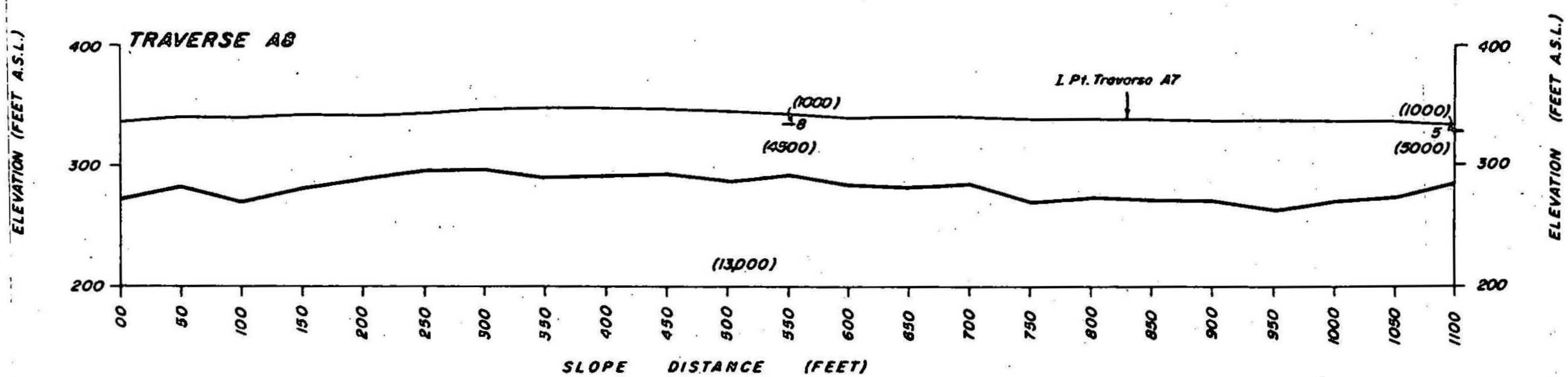
TRAVERSES A4, A2, A5 AND A10

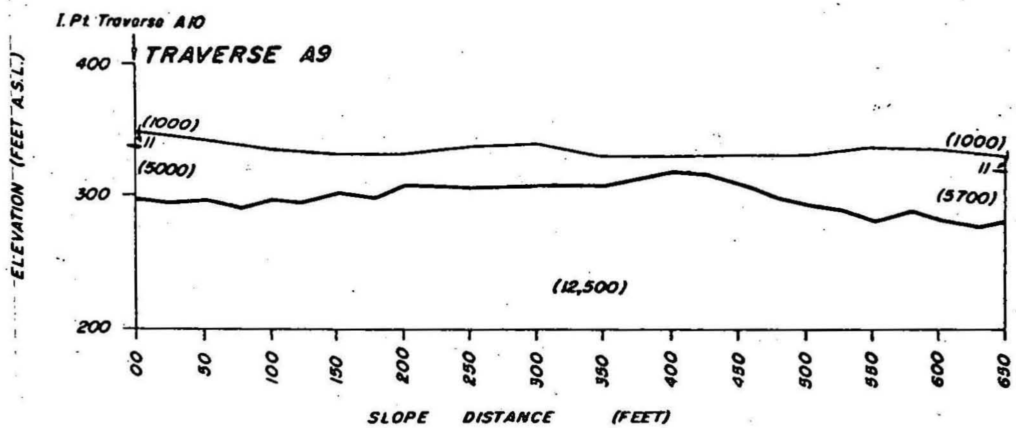
To accompany Record No. 1971/121

C55/B5-3

PLATE 5



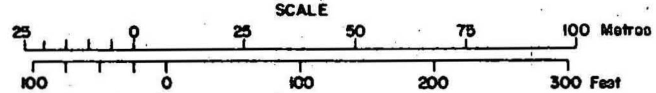




LEGEND

———	Bedrock boundary
23 —	Depth in feet to formation with different seismic velocity
(5900)	Seismic velocity in formation (ft/s)
I. Pt.	Intersection point

SCALE



VERTICAL SCALE AS SHOWN

SEISMIC CROSS-SECTIONS
TRAVERSES A7, A8, AND A9

To accompany Record No. 1971/121

C55/B5-4

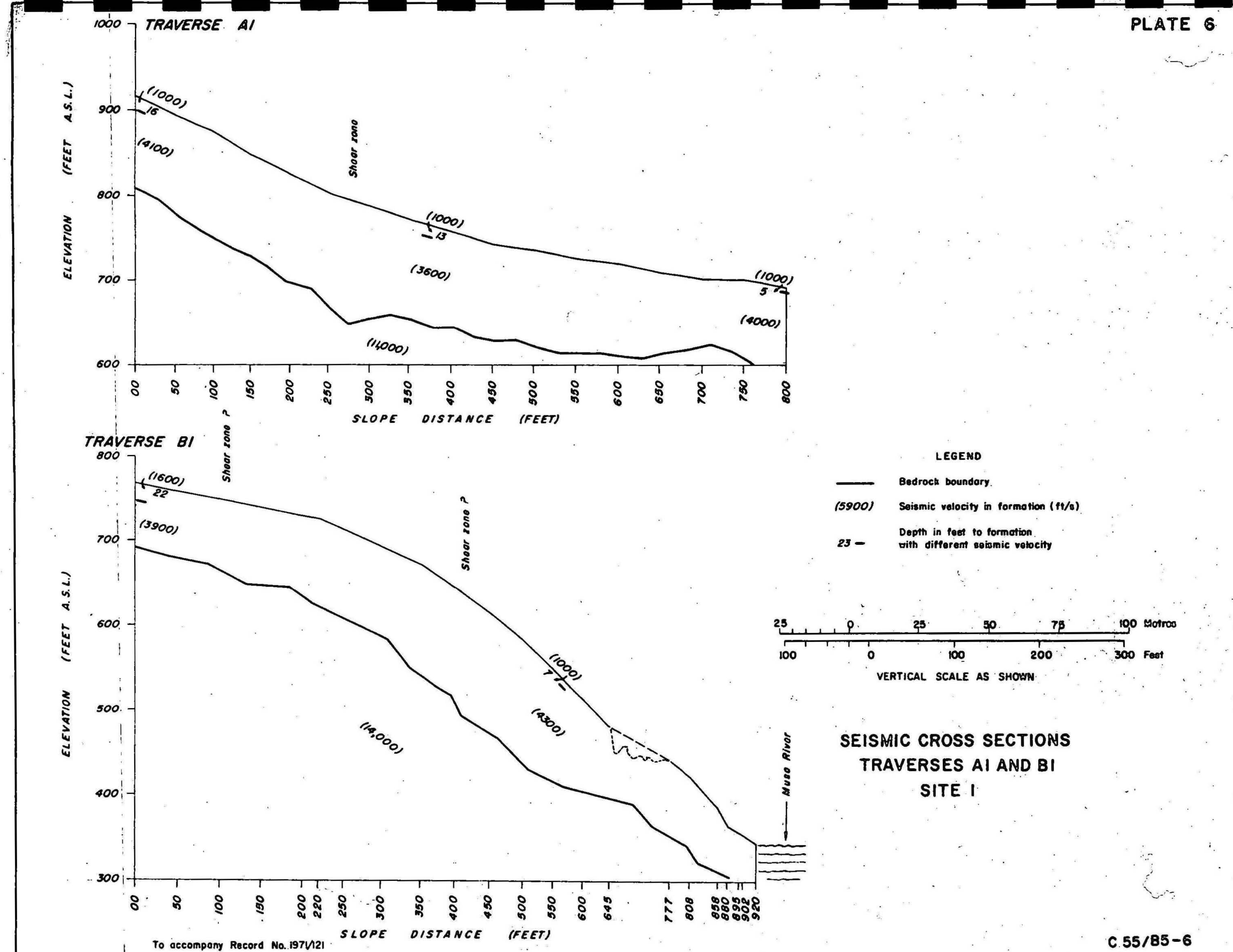
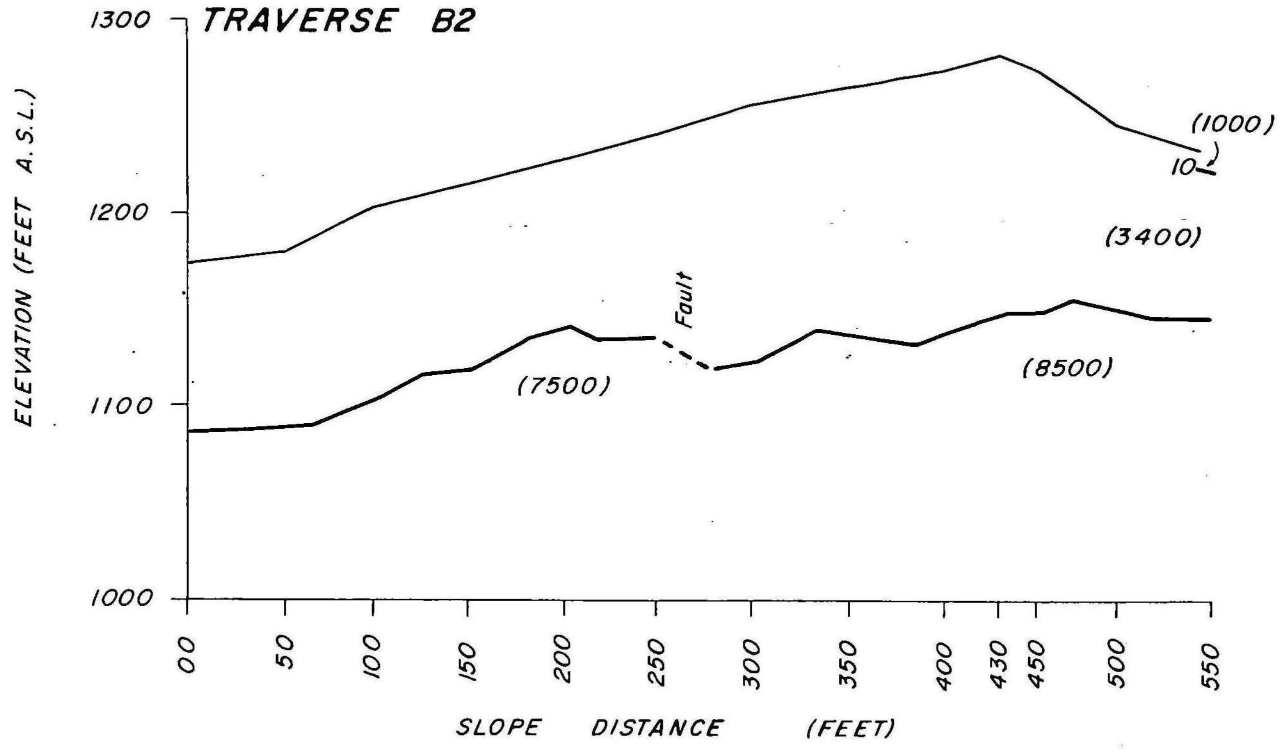
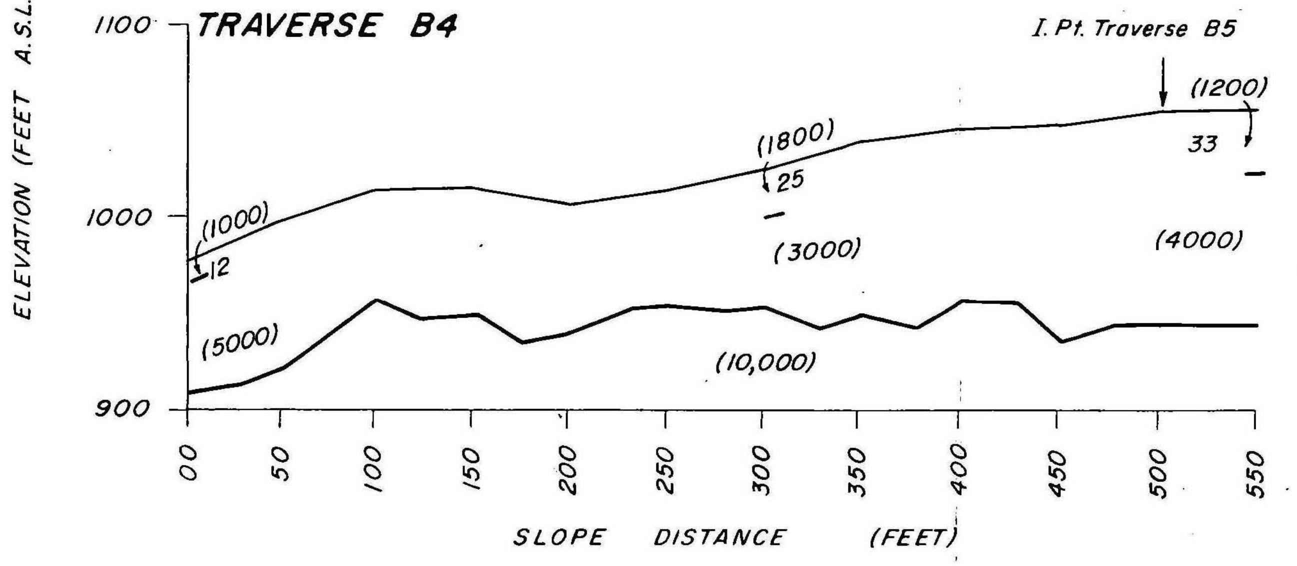
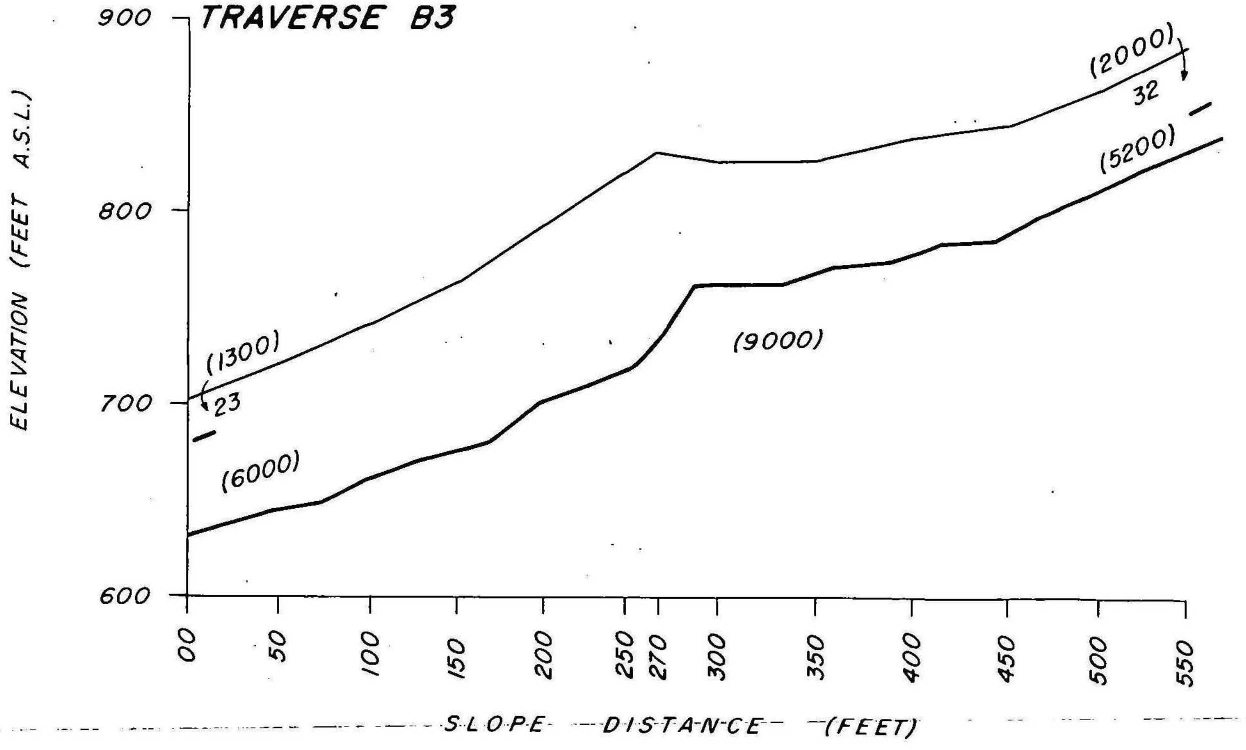


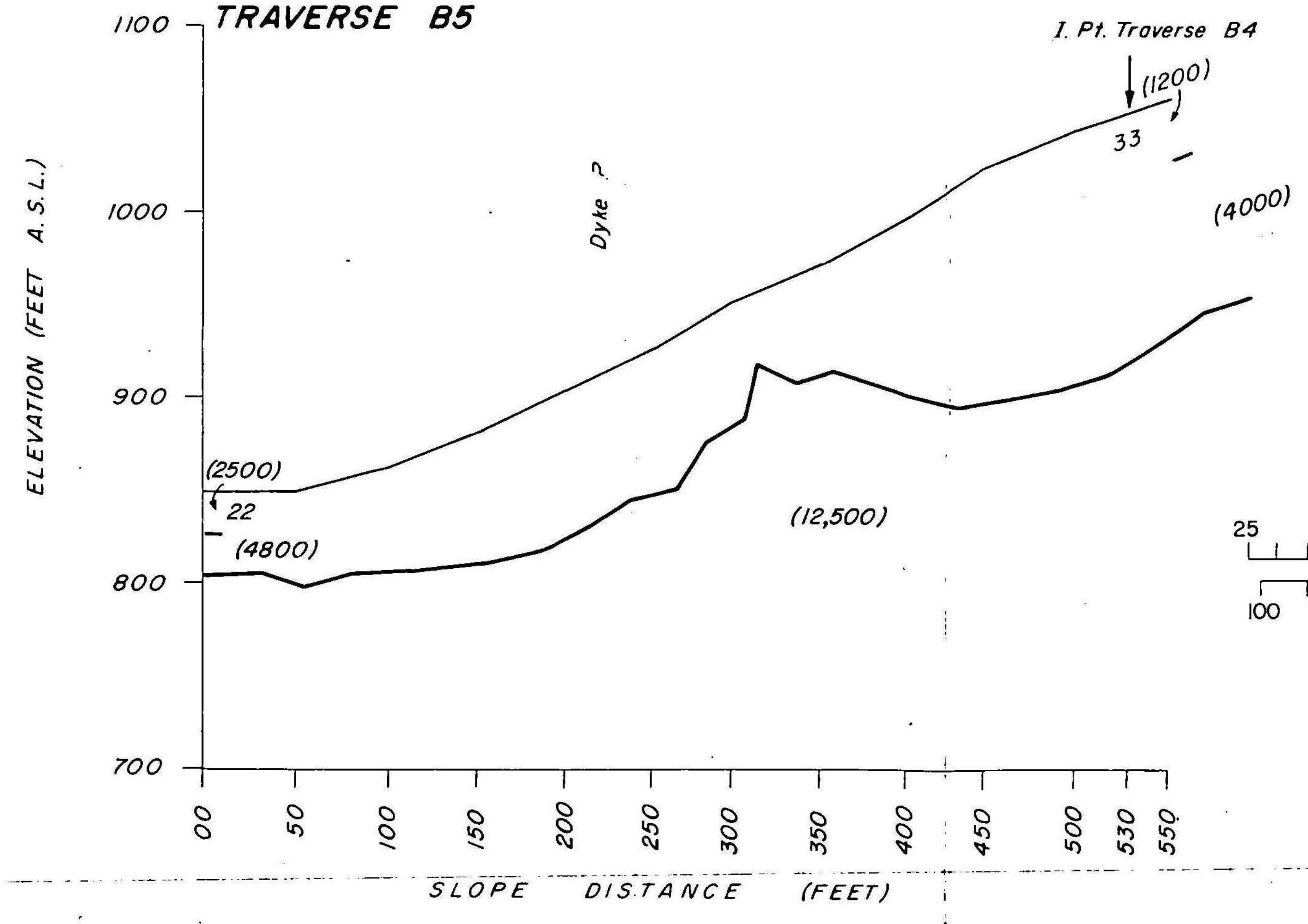
PLATE 6
TRAVERSE A1
ELEVATION (FEET A.S.L.)
1000
900
800
700
600
(1000)
16
(4100)
Shear zone
(1000)
13
(3600)
(1000)
5
(4000)
(11,000)
00 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800
SLOPE DISTANCE (FEET)
TRAVERSE B1
Shear zone ?
ELEVATION (FEET A.S.L.)
800
700
600
500
400
300
(1600)
22
(3900)
Shear zone ?
(1000)
7
(4300)
(14,000)
Musa River
00 50 100 150 200 220 250 300 350 400 450 500 550 600 645 777 808 858 880 895 902 920
SLOPE DISTANCE (FEET)
LEGEND
Bedrock boundary
(5900) Seismic velocity in formation (ft/s)
23 — Depth in feet to formation with different seismic velocity
25 0 25 50 75 100 Metres
100 0 100 200 300 Feet
VERTICAL SCALE AS SHOWN
SEISMIC CROSS SECTIONS
TRAVERSES A1 AND B1
SITE 1
To accompany Record No. 1971/121
C 55/B5-6

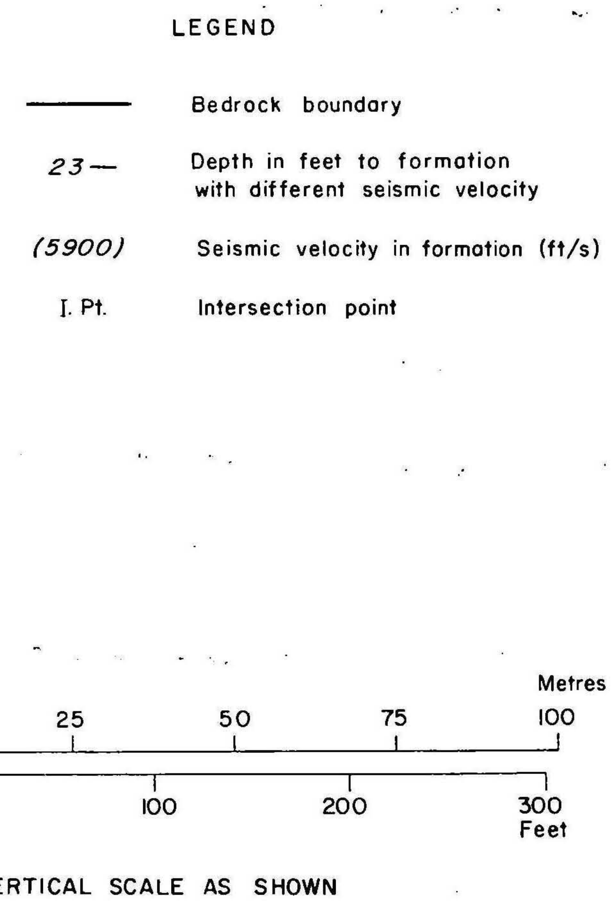
PLATE 7











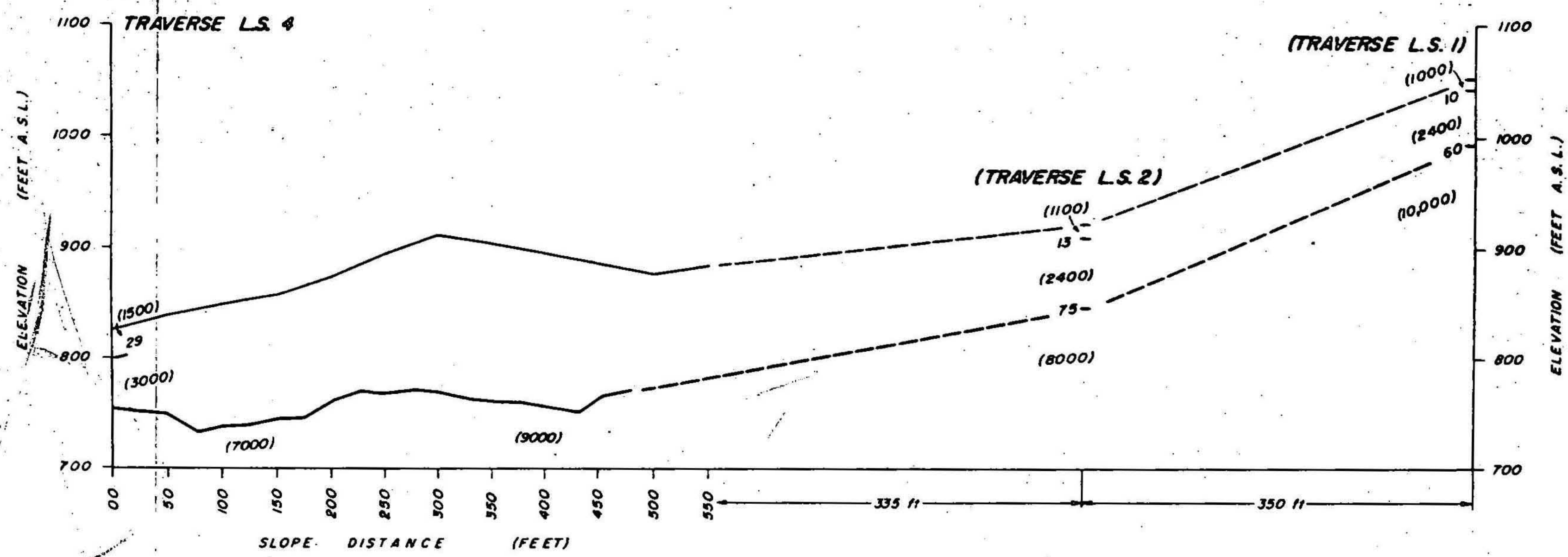
SEISMIC CROSS-SECTIONS

TRAVERSES B2, B3, B4 AND B5

To accompany Record No. 1971/121

C55/B5 - 7

PLATE 8



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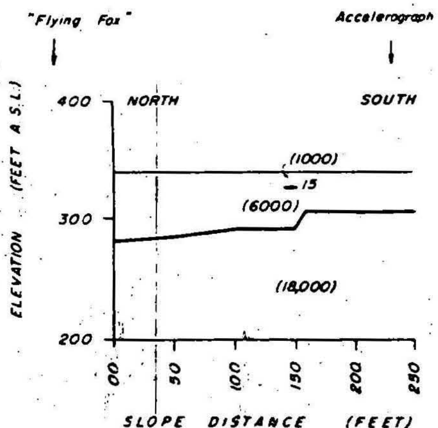
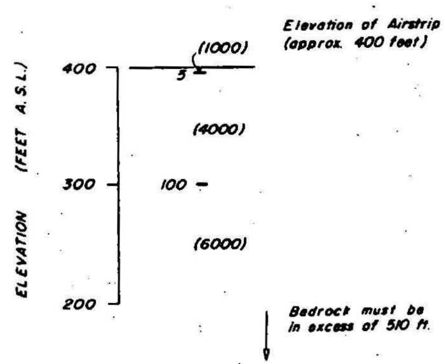


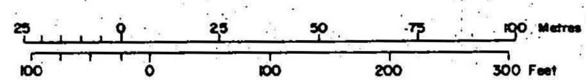
ACCELEROGRAPH SITE



SAFIA AIRSTRIP

LEGEND

———	Bedrock boundary
(5900)	Seismic velocity in formation (ft/s)
23 —	Depth in feet to formation with different seismic velocity



VERTICAL SCALE AS SHOWN

LANDSLIDE AREA, ACCELEROGRAPH SITE,

AND SAFIA AIRSTRIP

To accompany Record 1971/121

C 55/B5-8