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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1961-136

BUFFALO RIVER No. 1 DAM SITE GEOPHYSICAL SURVEY, VICTORIA 1961

by

E.C.E. Sedmik

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ABSTRACT

The purpose of this geophysical survey was to investigate foundation conditions at a proposed dam site.

The seismic refraction method was used to determine the depth to bedrock along seven traverses. The results of this survey revealed that the depth to bedrock exceeds 150 ft over a large area where there is a thick layer of decomposed and highly weathered bedrock. Depths determined by the seismic method are compared with drilling results. Elastic constants for the rocks were determined. Maximum depth to bedrock along the proposed diversion tunnel line (Traverse H) was calculated as 77 ft.

The gravity method was tested on Traverses A and B. The residual gravity profiles obtained show a remarkable similarity to the bedrock profiles obtained by the seismic refraction method.

The magnetic method was employed on Traverses A and B, and the results suggest the possible existence of a dyke along Traverse F.

unweathered

1. INTRODUCTION

The State Rivers and Water Supply Commission of Victoria proposes to build a dam on the Buffalo River as part of the Murray Valley Irrigation Project. The purpose of the dam is to store water during the rainy season and release it at a controlled rate during the dry season to support irrigation in the Ovens and Murray valleys.

The proposed Buffalo River No. 1 dam site is located immediately down stream from McGuffies Bridge (Plate 2), about 8 miles south of the township of Myrtleford (Plate 1). The approximate co-ordinates of the site are: lat. 36°39'S, long. 146°41'E referring to the Wangaratta 4-mile map.

In response to an application from the Commission, the Bureau of Mineral Resources, Geology and Geophysics made a geophysical investigation of the site. The Commission's geologist, N. Harding, provided some geological notes. As the Commission contemplates establishing a geophysical organisation of its own, the geophysical survey served at the same time to demonstrate to the Commission various geophysical methods and techniques which may be applied.

The Bureau's geophysical party consisted of E.C.E. Sedmik, (party leader), M. Kirton (geophysicist), and J. Pigott, (geophysical assistant). The Commission provided four field assistants and did the topographical surveying.

W.A. Wiebenga, senior geophysicist of the Bureau, stayed with the party during the greater part of the survey. The field work was done between 28th June and 17th July 1961.

2. GEOLOGY

The Commission made a brief geological examination of the area and provided a preliminary geological report (Harding, 1960) from which the following notes are obtained.

The Buffalo River flows in a wide valley flanked by steep mountainous country. This valley narrows down considerably at the No. 1 site where a spur from the Mount Buffalo grandiorite block on the right* bank approaches a spur from Buttress Hill on the left bank.

In this Record the terms "overburden" and "bedrock" are used. By "overburden" is meant soil and unconsolidated material on the lower flanks of the valley, old terrace formations, recent river deposits (sandy soil, sand, gravel) and weathered rock; by "bedrock" is meant fresh, unweathered rock which may include jointed rock.

The bedrock consists of Ordovician sandstone and shale, in contact with Devonian granodiorite. The sediments along the granodiorite contact are markedly metamorphosed, forming hornfels, quartzite, spotted slate, and schist.

* looking down stream

Fig. 1

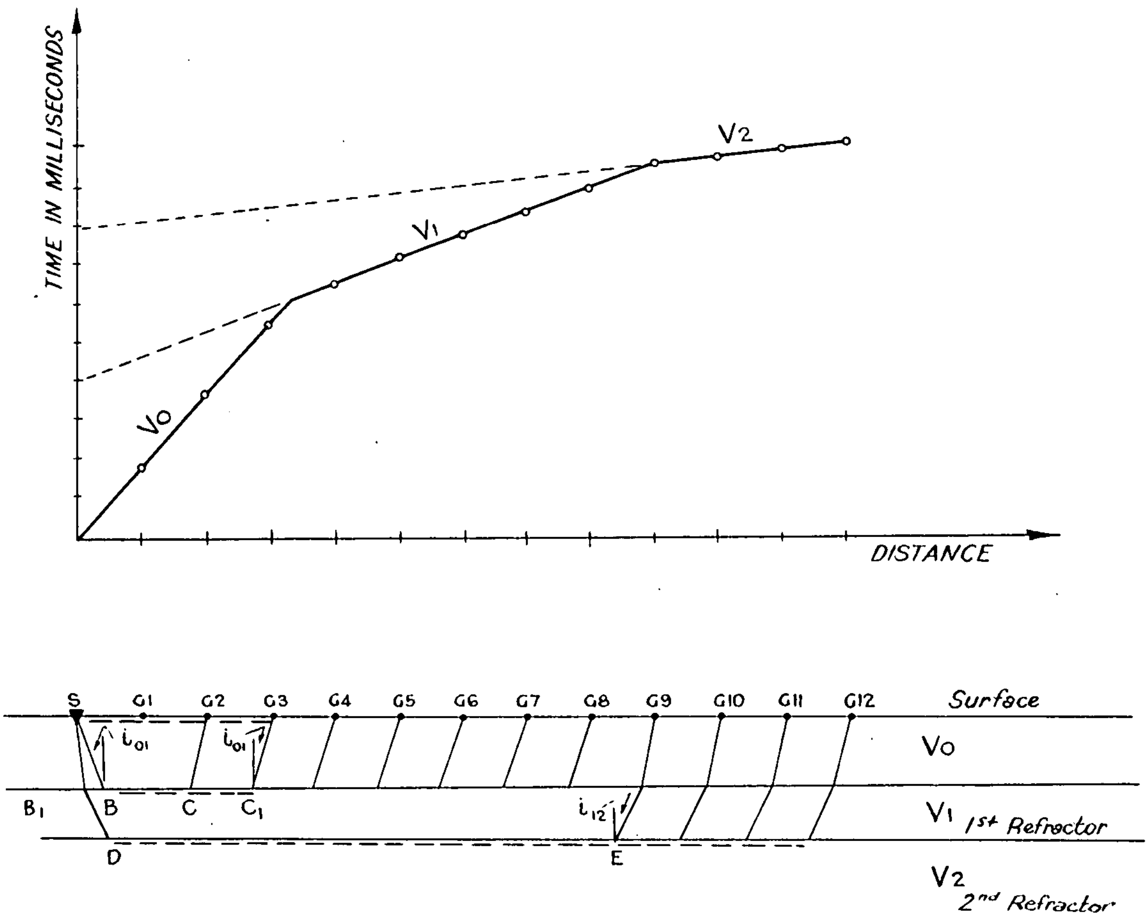

Fig. 1(a) *RAY PATHS AND TIME-DISTANCE CURVE FOR A THREE-LAYER CASE.*

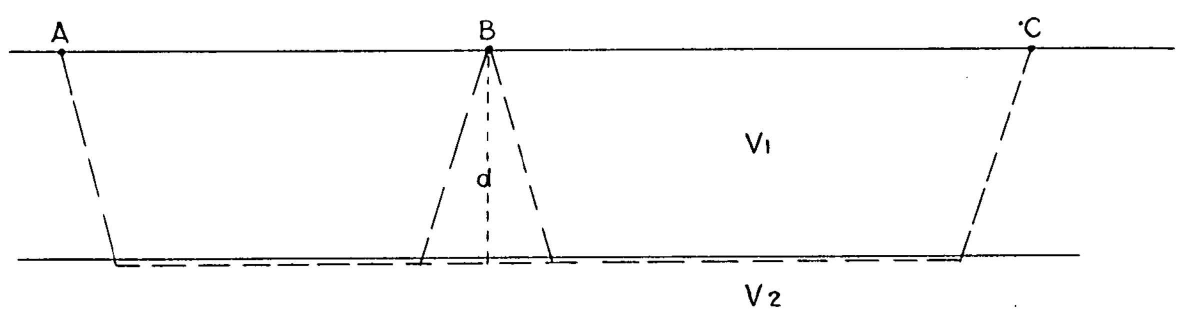

Fig. 1(b) *METHOD OF DIFFERENCES.*

To Accompany Report on Buffalo Riv. Dam Site.

To accompany Record No 1961 - 136

3. METHODS AND EQUIPMENT

Seismic refraction method

The seismic method of exploration depends on the contrast between the velocities at which elastic waves travel through different rock formations. Seismic phenomena are similar to optical phenomena in that both deal with a type of energy propagated in waves which undergo reflection and refraction at interfaces.

The seismic equipment used during this survey was an S.I.E. 12-channel refraction seismograph. T.I.C. geophones having a natural frequency of 20 cycles per second were used to detect longitudinal waves, and "Hall-Sears" 3-component vibration detectors to record both longitudinal and transverse waves.

In the seismic refraction method an explosive charge is fired in a shallow hole, and measurements are taken of the time of arrival of different seismic waves at a series of geophones placed on the ground. Generally, the charge and geophones are set up in a straight line with geophones equally spaced, but this arrangement may be varied to suit a particular survey. From data obtained by timing the first arrival of seismic waves, a time-distance curve is obtained. This indicates the velocity of propagation of the seismic waves through the different media encountered. Fig. 1a (opposite) shows the ray paths and time-distance curve for a "three-layer case".

Different types of seismic wave generally have different propagation velocities (Leet, 1950). The first wave arriving at the geophone is the longitudinal wave. This is the one most commonly used in calculations, but later events also can be useful if recorded.

The field arrangement and corresponding calculation method known as the "Method of Differences" was used (Heiland, 1946; p. 548). The technique is illustrated in Fig. 1b. A shot is fired at A and the travel times are recorded at B and C. A shot is then fired at C and the travel times recorded at A and B. The depth d measured to the refracting interface normally below point B is calculated from the formula

$$d = \frac{1}{2}\left[T_{AB} + T_{CB} - T_{AC}\right] V_a$$

where

V_a = the apparent velocity of the seismic wave within the overlying rocks.

In engineering seismic investigations the velocities of longitudinal and transverse waves can frequently be correlated with and used to identify different rock-types, and degree of weathering, jointing, or shearing near the surface. They provide data from which the elastic constants of the rocks may be determined (Leet, 1950; pp. 45-46).

The following types of spread were shot:

(a) Weathering spreads : These were used to obtain the thickness and seismic velocity of soil and surface layers. Geophones were spaced 10 ft apart and shots were fired at 10, 50, and 100 ft beyond each end of the spread, and in line with it.

(b) Normal spreads : Geophones were spaced 50 ft apart. Shots were fired at 50 ft and 200 ft or more beyond each end of the spread, and in line with it.

Gravity method

The gravity method depends on the detection of variations, in the Earth's gravitational field, due to uneven distribution of rocks of different densities in the subsurface.

Before being useful as a possible indication of sub-surface conditions, the observed gravity values must be corrected for latitude, elevation (Bouguer correction), and sometimes for terrain effects.

The gravity method can be used to estimate the thickness of overburden over deep valleys if certain favourable conditions such as flat topography, homogeneous bedrock, and marked density contrast between bedrock and overburden exist. Under these conditions, gravity profiles show a negative anomaly whose general shape is very similar to the seismic bedrock profile. However, gravity work does not give the same quantitative information as seismic work, such as accurate depth to bedrock and elastic properties of bedrock, and therefore it should be used in reconnaissance work only.

Gravity observations were made with Worden No. 61 gravity meter which is a quartz-suspension meter capable of measuring differences of gravity of about 0.01 milligal. The scale factor of the meter was 0.09015 milligals per dial division.

Magnetic method

The magnetic method depends on the detection of variations, in the Earth's magnetic field, due to uneven distribution of rocks of different magnetic susceptibility. Usually the vertical or horizontal variations in magnetic intensity are measured, and not the total field. Magnetic anomalies, in certain areas, can indicate features such as faults, dykes, and boundaries between near-surface formations. In areas covered with sediments, magnetic measurements can sometimes be used to obtain rough depth estimates to the basement.

The variations of the vertical component of the magnetic field were measured using an Askania variometer (No. 521633).

Table 1 shows the total length of traverse surveyed with each geophysical method.

TABLE 1

Method	Total length of traverses
Seismic refraction	9350 ft
Gravity	5350 ft
Magnetic	2700 ft

4. RESULTS

Seismic velocities

Seismic velocities as measured by the seismic refraction method are characteristic of certain rock types. Hence, if a limited amount of geological control is available, these velocities may be used to identify rocks in geological terms. Table 2 shows an interpretation of measured velocities in geological terms.

TABLE 2

Longitudinal wave velocity (ft/sec)	Rock type
800 to 1200	Soil
2000 to 3000	Scree material, valley flank deposits, not water-saturated.
3000 to 4500	Alluvium, predominantly clay, water-saturated.
4500 to 6000	Alluvium, predominantly sand and gravel, water-saturated.
6000 to 11,000	Weathered bedrock
11,000 to 15,500	Slightly weathered bedrock, more or less fractured or sheared.
15,500 to 20,000	Unweathered bedrock.

The identification of rock types, however, can be ambiguous; e.g. a measured seismic velocity of 6000 ft/sec could represent either weathered bedrock or compact, water-saturated alluvial sediments.

Plate 2 shows the seismic velocities of the bedrock. It may be observed that these velocities vary considerably, which may be explained by variations in fracturing, weathering, or rock type. For instance, the velocities measured near the intersections of Traverse F with Traverses A and B are high compared with the neighbouring velocities between A40 and A46, and B162 and B173. It is likely that the lower velocities belong to the sediments, whereas the higher velocities may belong to granodiorite (See Table 3).

Difference in velocities measured on two traverses at their intersection is named "velocity anisotropy", which may be explained by assuming that the velocity along the joint or fracture planes is larger than the velocity across these planes.

Seismic results

Plate 2 shows the traverse layout. Plates 3 to 5 show the results of the seismic refraction work.

The depth to unweathered bedrock exceeds 150 ft between A20 and A32, between B155 and B169, and along almost the whole length of Traverses D and E. Maximum depth of 252 ft is at E247. The maximum thickness of overburden along the proposed diversion tunnel (Traverse H) is calculated as 77 ft at H339.

Table 3 shows a comparison between drilling data and seismic data in three drill-holes close to Traverse A. The locations of the drill-holes are shown on Plate 2.

TABLE 3

Drill-hole No.	Depth to discontinuity in ft		Character of rock below discontinuity (after N. Harding)
	Seismic	Drilling	
B 1	46	41	Firm to moderately hard weathered sandstone.
B 4	178 to 188	187	Fresh hard granodiorite
B 6	119	Discontinued at 70	Decomposed granodiorite from 57 ft. No solid bedrock reached.

The error in depth determination with the seismic work is considered to be less than ± 15 percent of the true depth. This estimate is based on experience from other surveys carried out in areas with similar geological conditions.

Elastic properties of rocks

Table 4 shows the dynamic values of the elastic properties of rocks, and the data from which they were calculated. Two "Hall-Sears" 3-component vibration detectors were used to determine the longitudinal and transverse velocities.

TABLE 4

Traverse	Nature of refractor	Approx. depth to refractor	Refractor velocity in ft/sec		Poisson's ratio	Young's Modulus lb/sq.in.
			Longitudinal	Transverse		
C	Un-weathered grano-diorite bedrock	8 ft	16,200	8900	0.29	7.40×10^6
D	Grey gravel & sand over-burden	41 ft	7800	3550	0.37	1.03×10^6
E	Grey gravel & sand over-burden	35 ft	6700	4200	0.18	1.25×10^6

It will be seen that Young's modulus for the unweathered granodiorite is very much higher than for the overburden of gravel and sand. For comparison, Table 5 gives a few laboratory determinations of Young's modulus on cores from Drill-hole No. 1. Experience shows that lower seismic velocities correspond to lower rock strengths in terms of a compression test.

TABLE 5

Sample No.	Depth where sample taken	Density lb/cu.ft.	Velocities (ft/sec) Along sample	Across sample	Young's Modulus lb/sq.in.	Poisson's ratio
BRV_1	96' - 97'6"	167.7	18,600	16,300 15,740	9.6×10^6	0.19
BRV_2	39'6" - 40'	120		2930 4350	2.6×10^6	
BRV_3	25'3" - 25'9"	122		5850 6160	7.2×10^6	
BRV_4	41' - 41'6"	144		4700 5420	6.1×10^6	

Sample BRV_1 is very hard, fresh sandstone. The other samples are weathered sandstone.

When the elastic properties are determined dynamically (e.g. by seismic survey), higher values are found than when they are determined in static tests such as those on which Table 5 was based (U.S. Department of Interior, 1953).

Gravity results

Only Traverses A and B were surveyed by this method. All gravity readings were referred to a base station near B52, and the surveying procedure adopted was such as to give a check on instrument drift and on the accuracy of the measurements.

A latitude correction of 1.252 milligals per mile was used. Elevation corrections (combining the Bouguer and free-air corrections) were applied to a reference level R.L. 730.0 ft. A density of 2.6 g/c.c. was used for Bouguer corrections.

The results of the gravity survey, after correction for instrument drift, latitude, and elevation, are presented on Plates 3 and 4. The Bouguer gravity profiles show a strong regional effect, the gravity values decreasing sharply from west to east. This regional effect, caused by deep-seated changes in subsurface conditions, dominates the general picture and obscures the presence of a much smaller effect caused by changes of overburden thickness. Hence, the removal of the regional effect from the Bouguer gravity profiles facilitates the recognition and interpretation of the small negative gravity effect caused by local thickening of overburden. This removal has been done by assuming a linear regional gradient, as shown on the Plates; the plotted residual gravity profile was obtained by subtracting the regional gravity values from the corresponding Bouguer gravity values.

The residual gravity profiles show a remarkable similarity to the corresponding seismic profiles, although they do not give the same quantitative information such as accurate depth to bedrock and elastic properties of bedrock.

The residual gravity profile of Traverse B (Plate 4) shows a minimum of minus 0.60 milligals, indicating the maximum depth of overburden at B164, the same peg at which the seismic results show a maximum depth. The residual gravity profile of Traverse A (Plate 3) shows a minimum of minus 0.75 milligals at A26, suggesting that the maximum thickness of overburden is at this point. This is slightly different from the information obtained from seismic results, which show A28 as the point having the maximum depth to bedrock.

No accurate terrain corrections could be applied to the gravity data because no suitable topographic map of the surrounding country (with accurate levels) was available. However, the influence of the steep country in the immediate vicinity of the surveyed area and the distant influence of Mt. Buffalo and Buttress Hill must be quite considerable. Hence, the gravity profiles produced without application of terrain corrections may be subject to serious errors.

A rough calculation of terrain correction can be made by using a simplified method of terrain corrections described by Hubbert (1948).

The surface topography of Traverses A and B shows a relatively flat middle section flanked by sections showing nearly constant slopes of 20 degrees at both ends. The sloped section becomes flat at an elevation about 300 ft above the river level. Using these values, a simplified terrain correction was made according to a nomogram by Hubbert (1948, Fig. 7).

The terrain-corrected gravity profiles are shown on Plates 3 and 4. They show a more pronounced relief than the profiles without terrain corrections.

An approximate depth estimate may be obtained from the formula :

$$\Delta g = 2\pi G h \Delta d$$

in which

Δg = gravity anomaly in milligals, caused by an infinite slab h ft thick

G = gravitational constant

Δd = density contrast between bedrock and overburden

h = thickness of overburden

For d = 0.4 and Δg = 1.3 milligals, as obtained at B164 after application of simplified terrain corrections, the calculated thickness of overburden is 236ft; this figure is 13 percent more than the depth obtained from seismic work.

Magnetic results

The magnetic method was tested on Traverses A and B and the results of the magnetic survey are presented on Plates 3 and 4 for easy comparison with results obtained by other methods. Only variations of the vertical component of the magnetic force were measured. All magnetic observations were referred to a base at A10.

The results show slightly higher vertical magnetic intensity over the portions of traverse where the overburden is thicker. This may be due to concentration of minerals of higher magnetic susceptibility, for instance magnetite, in the alluvium of the valley.

The well-defined positive anomalies of 188 gammas half way between A46 and A47, and 161 gammas at B179, suggest the existence of a nearly vertical dyke whose strike roughly follows Traverse F. The small negative anomalies on either side of the main positive anomalies indicate that the dyke must be very close to the surface. More evidence of the presence of a dyke is given by the seismic results, which show that along Traverse F the bedrock is shallow and that seismic velocities are greater than are usually found in sediments.

5. CONCLUSIONS

The geophysical survey provided information on the thickness and character of alluvial deposits, and the depth to and nature of the bedrock.

The depth to unweathered bedrock is greater than 150 ft over a wide zone close to the contact between granodiorite and consolidated or metamorphosed sedimentary rocks. However, the depth to weathered bedrock or semi-consolidated material of seismic velocity 6500 to 7500 ft/sec is about 57 ft on Traverse A and about 28 ft on Traverse B. The elastic properties of this layer, calculated from longitudinal and transverse wave velocities, suggest that this layer is not a suitable foundation rock for a dam (see Table 4).

Maximum thickness of overburden above the proposed diversion tunnel (Traverse H) is 77 ft at H339. The overburden there is scree material and weathered bedrock.

The results on Traverses A and B show a remarkable resemblance between the general shape of the residual gravity and seismic profiles. However, the seismic results give more detailed and accurate information about the bedrock than the gravity results.

The magnetic results suggest the existence of a nearly vertical dyke roughly following Traverse F.

Testing of the geophysical results by drilling is recommended. Test drilling is suggested at A28.

6. REFERENCES

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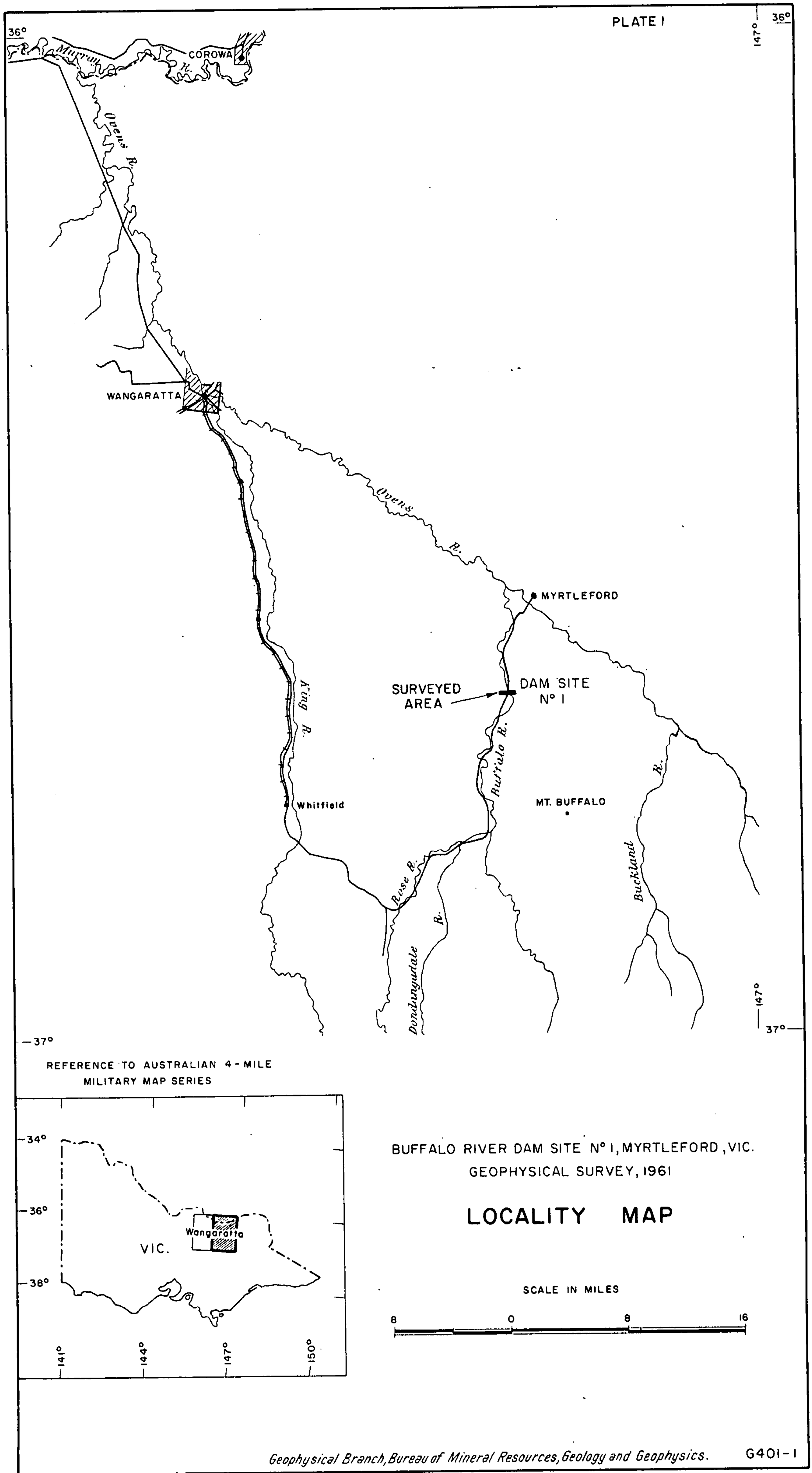


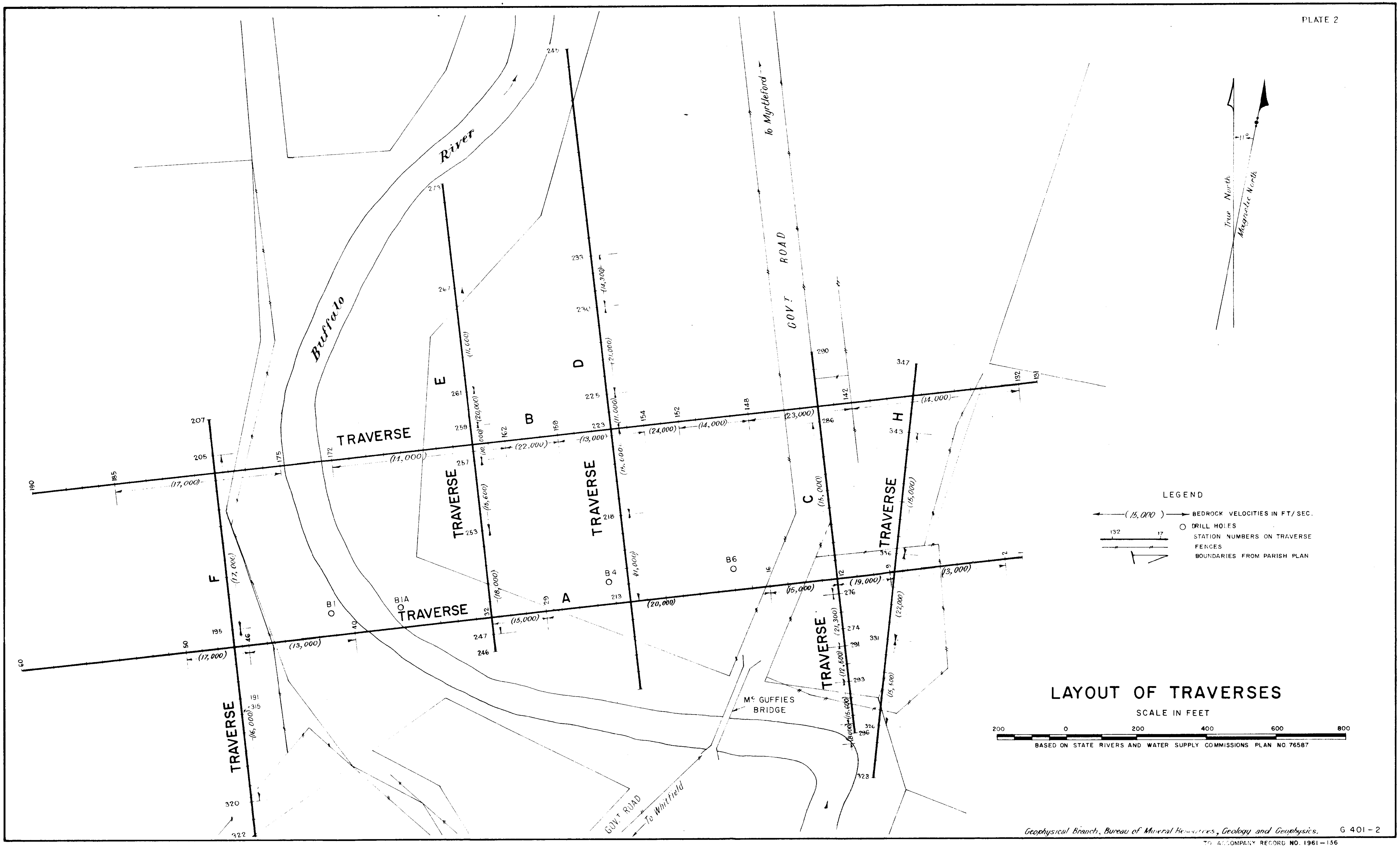
BUFFALO RIVER DAM SITE N° 1, MYRTLEFORD, VIC.
GEOPHYSICAL SURVEY, 1961

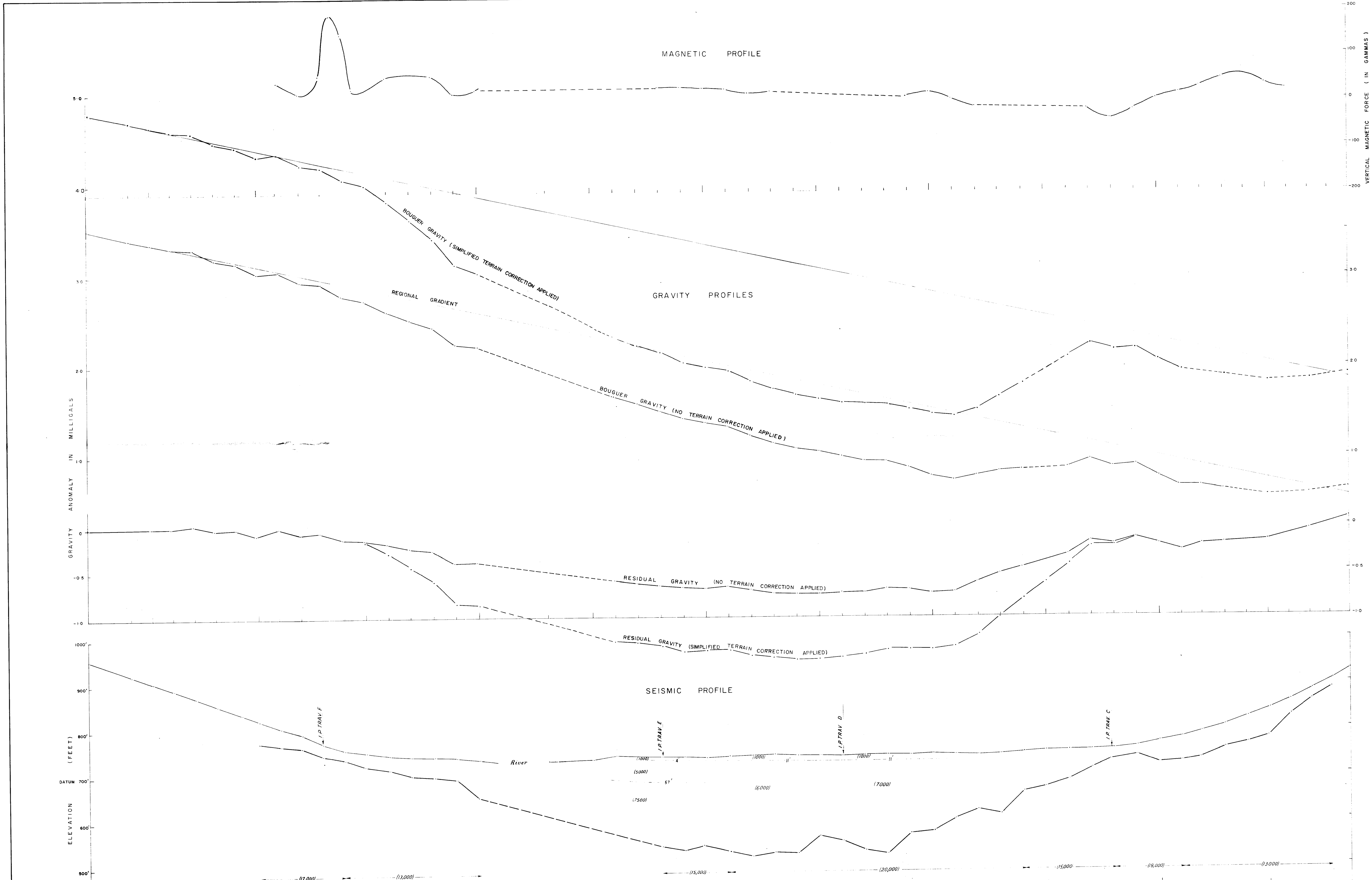
LOCALITY MAP

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G401-1

To Accompany Record No. 1961-136

Buffalo River, Dam Site 1961





STATION NUMBER	58	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40
STATION ELEVATION	955	922	905	889	873	857	841	824	808	792	774	757	752	745	741	741	737	732
DEPTH TO BEDROCK								48	38	29	27	21	29	33	40	45	46	82

STATION NUMBER	37	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19
STATION ELEVATION	729	735	742	737	739	739	738	740	741	741	741	740	740	742	742	741	743	743
DEPTH TO BEDROCK					198	208	195	210	223	215	215	178	188	210	220	172	170	142

STATION NUMBER	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
STATION ELEVATION	741	745	749	749	751	750	751	759	769	777	790	803	820	837	856	877	898	922
DEPTH TO BEDROCK	119	132	88	80	68	41	29	23	45	54	54	50	57	60	32		17	

LEGEND

(5000) FORMATION WITH SEISMIC VELOCITY 5000 FT/SEC
4' DEPTH TO FORMATION WITH DIFFERENT SEISMIC VELOCITY
I.P. TRAV E INTERSECTION POINT
INFERRED SEISMIC BOUNDARY
UNWEATHERED BEDROCK BOUNDARY
(15,000) BEDROCK VELOCITY OF 15,000 FT/SEC

HORIZONTAL SCALE IN FEET
100 0 100 200 300
VERTICAL SCALE AS SHOWN

BOUGUER ANOMALY VALUES BASED ON DENSITY = 2·6 g/cc

BUFFALO RIVER DAMSITE No. I

TRAVERSE A
PROFILES

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G401-4

TO ACCOMPANY RECORD No 1961-136

MYRTLEFORD, VIC. 1961

STATION NUMBER	190	188	187	186	185	184	183	182	181	180	179	178	177	176	175	173	172	171	170	169
STATION ELEVATION	970	933	914	894	875	856	838	821	804	790	778	761	748	743	739	731	738	737	738	738
DEPTH TO BEDROCK					48		47	46	45	41	40	34	28	29	31		106	110	133	

STATION NUMBER	168	167	166	165	164	163	162	161	160	159	158	157	156	155	154	153	152	151	150	149
STATION ELEVATION	739	737	736	730	737	737	738	737	739	741	740	740	740	740	739	749	750	750	750	750
DEPTH TO BEDROCK	180	184	195				188	182	184	181	179	185	174	166	148	134	113	103	100	96

STATION NUMBER	148	147	146	145	144	143	142	141	140	139	138	137	136	135	134	133	132	131
STATION ELEVATION	749	749	748	750	748	750	751	753	759	769	781	795	810	825	842	860	883	894
DEPTH TO BEDROCK	90	85	75	60	48	35	34	11	22	36	49	51	49	54	63	66	59	

LEGEND

(17,000) FORMATION WITH VELOCITY 17,000 FT/SEC
32' DEPTH TO FORMATION WITH DIFFERENT SEISMIC VELOCITY
I.P. TRAV. E INTERSECTION POINT
INFERRED SEISMIC BOUNDARY
UNWEATHERED BEDROCK BOUNDARY
14,000 BEDROCK VELOCITY OF 14,000 FT/SEC

HORIZONTAL SCALE IN FEET
100 0 100 200 300
VERTICAL SCALE AS SHOWN

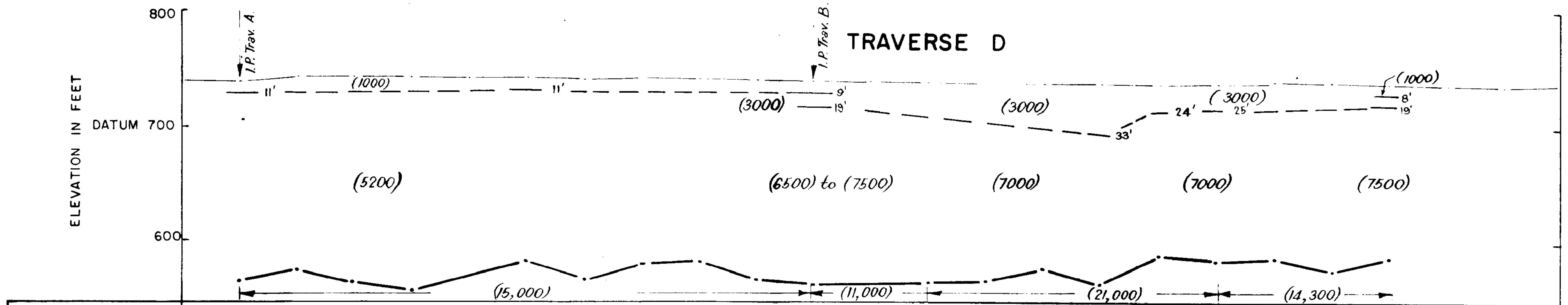
BOUGUER ANOMALY VALUES BASED ON DENSITY 2.6 g/cc

BUFFALO RIVER DAMSITE No. I
TRAVERSE B
PROFILES

G401-5

TO ACCOMPANY RECORD No. 1961-136

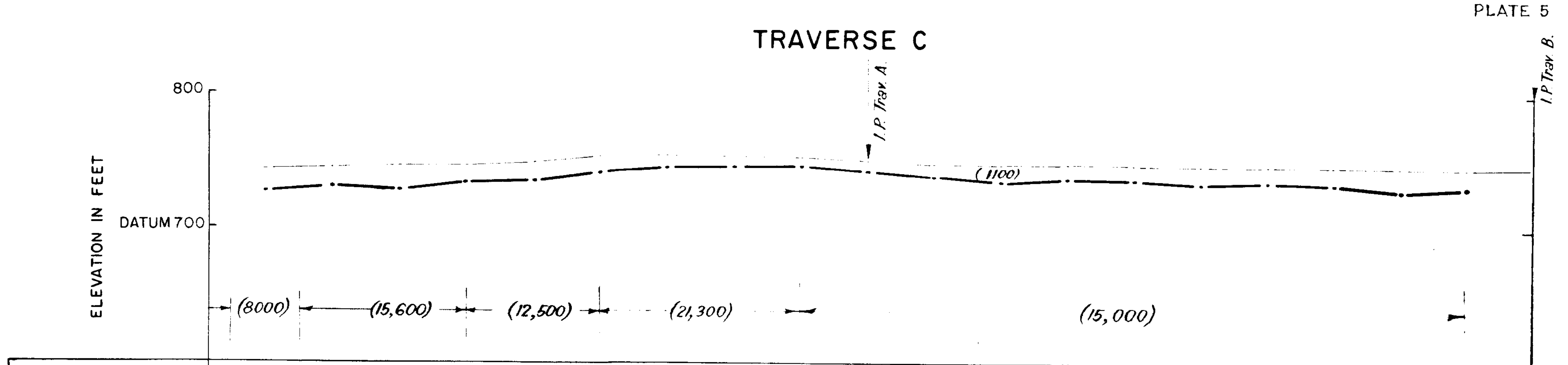
TRAVERSE D



STATION NUMBER	212	213	211	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236
STATION ELEVATION	740	739	741	742	742	741	741	741	741	740	740	740	740	739	739	739	738	738	739	739	738	737	737	737	738
DEPTH TO BEDROCK		172	166	171	185		158	174	161	158	172	174		172	172	159	174	148	154	151	162	151			

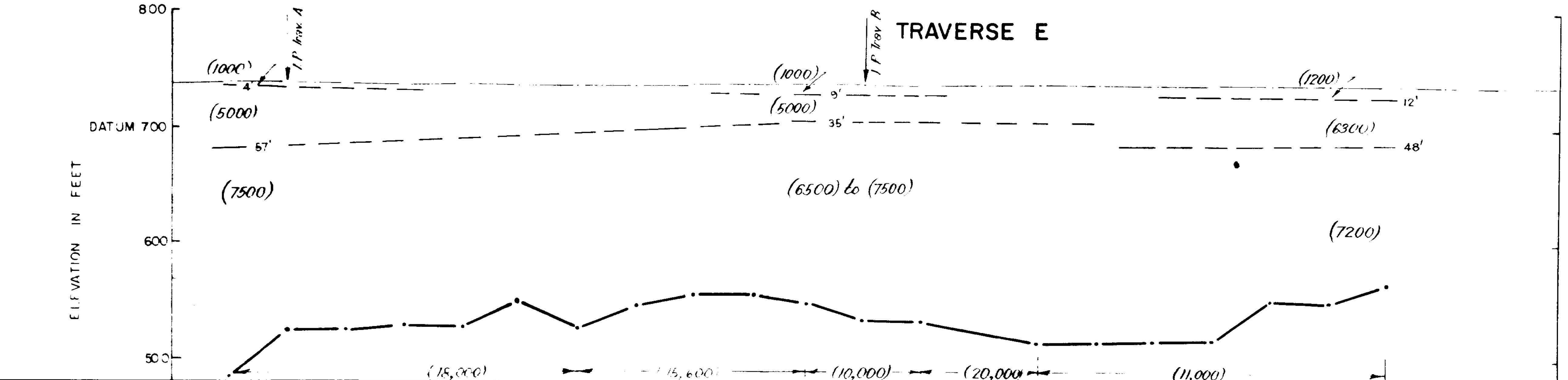
EXTRAPOLATED

TRAVERSE C



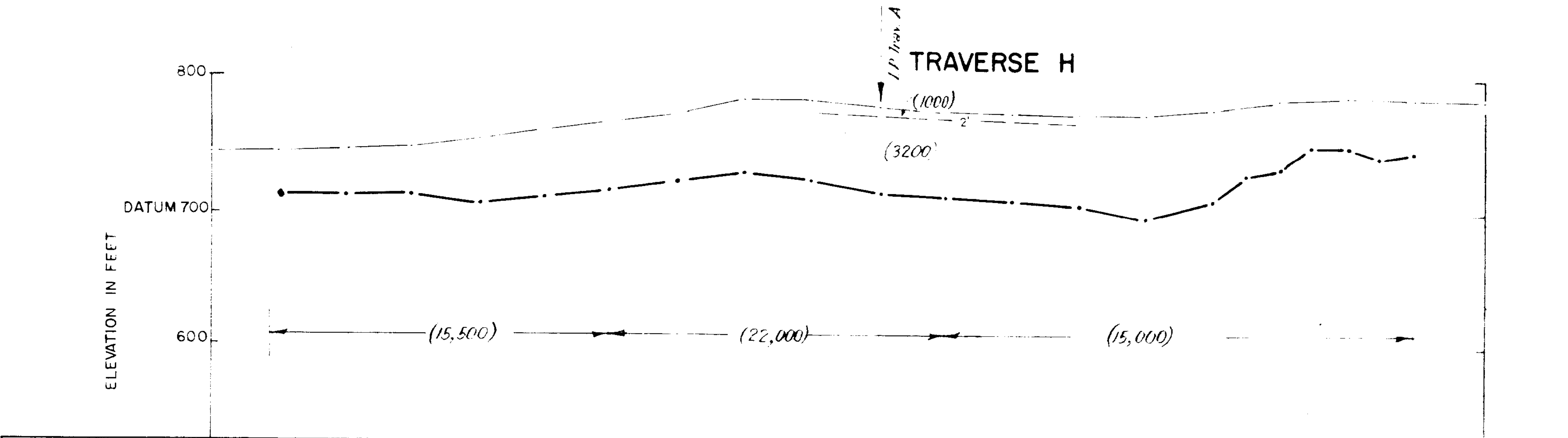
STATION NUMBER	296	295	294	293	292	291	274	275	276	277	278	279	280	281	282	283	284	285	286	287
STATION ELEVATION	744	746	747	747	750	754	755	755	753	751	750	750	750	750	749	749	749	748	748	748
DEPTH TO BEDROCK	17	15	16	12	14	12	9	8	8	7	9	14	12	12	13	12	13	15	13	

TRAVERSE E



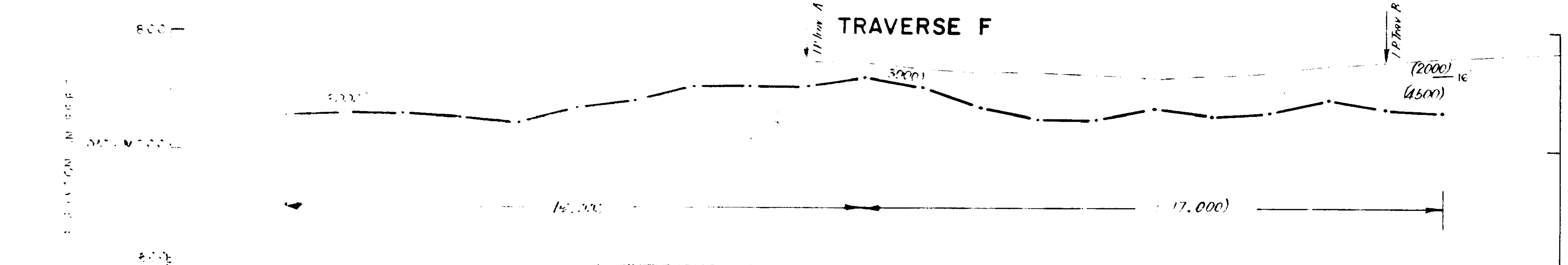
STATION NUMBER	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270
STATION ELEVATION	738	739	739	738	738	738	737	737	737	737	738	738	737	736	737	738	738	738	737	737	737	737	736	737	737
DEPTH TO BEDROCK		252	214	215	210	209	190	210	186	179	182	190	203	203		222	222	220	221	187	188	171			

TRAVERSE H



STATION NUMBER	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344
STATION ELEVATION	739	746	747	749	754	761	768	773	784	783	778	775	774	773	773	778	784	787	785	783
DEPTH TO BEDROCK		32	33	35	47	48	48	48	53	58	62	62	65	69	77	68 56	51 39	41 48	41	

TRAVERSE F



STATION NUMBER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207
STATION ELEVATION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	771	773	774	773	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	163	166	171	176	779	781	784
DEPTH TO BEDROCK			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	20	21	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	33	21	40	[illegible]		

LEGEND

(18,000)	FORMATION WITH SEISMIC VELOCITY 18,000 FT/SEC
49'	DEPTH TO FORMATION WITH DIFFERENT SEISMIC VELOCITY.
I.P. Trav. A	INTERSECTION POINT.
	UNWEATHERED BEDROCK BOUNDARY.
	INFERRED SEISMIC BOUNDARY.
(18,000)	BEDROCK VELOCITY OF 18,000 FT/SEC

TRAVERSES F, E, D, C, and H SECTIONS

HORIZONTAL AND VERTICAL SCALES IN FEET

100 0 100 200 300 400

BASED ON STATE RIVERS AND WATER SUPPLY COMMISSIONS PLANS NOS 76588 SHEETS 2&3

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G 401-3

TO ACCOMPANY RECORD No 1961-136

Buffalo River Dam Site No 1 1961