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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1962/162

WILKES ICE THICKNESS MEASUREMENTS, ANTARCTICA 1961

by

F. Jewell

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SUMMARY

Ice thickness measurements were made in 1961 by seismic methods on a line southward from S-2, a glaciological station 50 miles east-south-east of Wilkes Base, Antarctica. The traverse constituted the first year's work of a three-year programme.

The results showed that the rock underlying the ice dips below sea level at a point between 20 and 40 miles south of S-2. It remains below sea level at all the locations occupied to the south, as far as 280 miles south of S-2, where the rock surface is again above sea level.

The main feature is a valley disclosed in the rock formation between 40 and 80 miles south of S-2. Midway between these two points the rock lies at approximately 7500 ft below sea level. The positions of the Totten Glacier and the John Quincy Adams Glacier suggest that the valley may have been responsible for their formation.

1. INTRODUCTION

The ice thickness measurements described here were made in 1961, the first year of a three-year programme by members of the Australian National Antarctic Research Expedition wintering at Wilkes Base. The seismic equipment was supplied by the Bureau of Mineral Resources, Geology and Geophysics, and the writer, a geophysicist of the Bureau, acted as seismic observer.

The party of six, led by Captain N.R. Smethurst, also made glaciological and meteorological observations. Where other duties permitted, all members of the party helped with the seismic work; in particular J. McGhee, mechanic, and S. Stadler, weather observer, did most of the shot-hole drilling.

The equipment and techniques used, and the relevance of ice thickness measurements to other studies, have been largely covered by Goodspeed (1958), who describes similar work done in 1957-58 near Mawson, Antarctica.

2. WORK PROGRAMME

A seismic reflection shot was made at a glaciological station S-2, approximately 50 miles east-south-east of Wilkes Base, before the party set out in February on a preliminary traverse to a point 120 miles south of S-2. Fuel was dumped here in preparation for the major traverse, and the party returned to S-2, making experimental shots at points 110, 80, and 60 miles south of S-2 before returning at the end of March.

The train consisted of two Caterpillar D-4 tractor, one hauling fuel sleds and a caravan, the other a caravan and a drill sled, and two weasels each hauling fuel sleds. Progress was slow in the early stages, owing to bad weather and a soft snow surface on which the tractors tended to bog down. One weasel broke a track at the farthest point and had to be towed back on a sled.

The major traverse, beginning in October, covered the same ground and extended the work to a point 300 miles south of S-2. Seismic shots were made at intervals of 20 miles. Glaciological stakes had been placed at one-mile intervals as far as 180 miles south of S-2 by the previous wintering party led by Black. The same line was followed by the 1961 party, though some of the stakes which had been snowed in were difficult to find. The party travelled the remaining 120 miles on a south bearing by means of an astro-compass mounted on one of the weasels.

Only very slight crevassing was encountered, and mechanical breakdowns were not excessive although one of the weasels repeatedly broke a track and had to be towed back on a sled. About one third of the total time was wasted by breakdowns, poor visibility, and blizzards. The homeward journey to Wilkes was completed in 12 days.

In addition to the traverse work some refraction shots were made, during May, at weather station S-1, about five miles east-south-east of Wilkes. This station is located on blue ice, with a negligible snow cover.

3. EQUIPMENT

Changes in equipment

The seismic cab and accessories had previously been used at Mawson by M.J. Goodspeed, in 1957-58, and by E.E. Jesson in 1958-59. Alterations made, for the Wilkes survey, to the equipment used by Jesson (1959) were as follows:

(a) replacement of the Askania microbarometers by two sets of ordinary aircraft altimeters, three in each set, manufactured by National Instrument Co., Melbourne. These had a much lower reading accuracy but were calibrated directly in intervals of 20 ft.

(b) replacement of the Goldfields Diamond Drilling Company auger drill by a Proline HDBA auger drill, with a capacity of about 200 ft, manufactured by Proline Sales, Adelaide. The drill, a photograph of which is shown on Plate 4, was sled-mounted at Wilkes and coupled to the hydraulic system of a D-4 tractor by rubber hoses. These supplied fluid under pressure to a hydraulic motor which rotated the drill head through a gearbox and also turned a hydraulic pump which motivated a separate hydrualic system to power the rams.

The augers were in three-foot lengths with an outside diameter of 3½ inches. The cutting heads were four-wing drag bits with an outside diameter of 3¾ inches.

(c) replacement of the 32-volt D.C. generating set by a 115-volt A.C. motor-driven Wisconsin generator with a capacity of 5kW. This was used for heating the seismic cab by means of a 1-kW strip heater and three 200-W lamps. A 115-volt A.C. Onan generator with a capacity of 2.5 kW was carried as a standby.

(d) a 30-volt D.C. generator, installed in one of the D-4 tractors, was used to charge the tractor battery as well as the four 6-volt batteries in the seismic cab.

(e) the stainless steel developing tanks were not taken, owing to an oversight; they were replaced by plastic jars. The immersion heater system for warming the photographic solutions could not therefore be used.

Functioning of equipment

Ice drill. The main defect was the inability of the rubber seals in the boring ram to withstand the hydraulic pressure. Three sets of seals were used during the year, the third set lasting only a week before beginning to leak badly. In order to conserve hydraulic fluid the majority of the shot holes were drilled to only 24 ft. With fresh seals which had not yet begun to leak, holes could be put down to 100 ft in two or three hours; nevertheless the drill could not be adjudged satisfactory without seals efficient in cold climates.

The hydraulic lines to the tractor were not supplied by the Proline manufacturers and were not designed to withstand the required pressure. Consequently they burst frequently. Stronger hoses are to be used in 1962.

The drill proved to be simple to operate even though the party included no experienced driller. No trouble was experienced while drilling, apart from a tendency of the augers to slip through the slotted fork used for holding them at the surface, and two instances of the bit sticking in the hole, possibly owing to drilling too quickly.

Seismic equipment. The equipment gave very little trouble electronically but there was considerable cross-feed from the time break on many of the records. Pratt (1960) had the same experience on the Trans-Antarctic Expedition and attributed it to the lack of an electrical earth for the seismic cab.

The timing motor in the camera was difficult to start, particularly when the cab could not be effectively heated owing to failure of the 115-volt generators.

In order to conserve petrol, the cab was heated for only two or three hours prior to shooting. The equipment might have benefited from being kept at a constant temperature during the whole traverse.

The photographic development of the records left much to be desired as the solutions, made from water heated in the caravan, cooled down very quickly in the absence of the immersion heating arrangement. It was also difficult to keep the plastic jars clean and some of the records acquired a patchy dark-coloured deposit in consequence.

The 6-volt camera battery, also used for energising the dynamotor, tended to discharge quickly, causing dimming of the camera light bulbs. From November onwards therefore a separate 6-volt battery was used for the camera.

The heating arrangement, in which the seismic cab utilised the Wisconsin generator, was satisfactory. The temperature could be raised from say - 10°F to +40°F in a couple of hours. The Wisconsin occasionally gave trouble owing to ice in the petrol feed line and also to drift snow in the A.C. generator itself, but this was eliminated by wrapping it in a piece of silk material. The Onan generator failed after the first few weeks and was not used.

The 30-volt battery-charging generator in the D-4 engine gave no trouble and allowed the batteries to be charged while travelling.

4. TECHNIQUES EMPLOYED

Seismic shooting

At most of the stations the 12 geophones were laid out in an L spread, with a spacing of 50 ft between geophones. As a variation, in order to obtain more information about near-surface velocities, an R spread was used with a spacing of 110 ft. The terrain was so flat that no levelling was required apart from a comparison by aircraft altimeter of the levels of the shot hole and the farthest geophones.

As a result of the restriction imposed by the drill, most of the holes were shot at a depth of about 20 ft. Charges of between one and three pounds of RDX/TNT explosive were used. The seismic amplifier filters were set to K70/KK120 so as to bracket a frequency of 100 c/s, following the experience of Goodspeed (1958).

For refraction work an R spread of 12 geophones with a spacing of 220 ft sufficed to record what was considered to be the maximum velocity of the seismic waves, viz. 13,000 ft/sec. An R spread of one mile, offset two miles from the shot-point, was attempted at S-2 in order to obtain refraction through the underlying rock. Radio transmission of the time break had been previously tested over short distances, and although the radio receiver in the seismic cab, an AN/GRC-9, picked up a great deal of noise from the dynamotor in the seismic equipment, the transmitted signal was powerful enough to break through, enabling a low receiver gain setting to be used. Over the greater distance, however, a higher gain setting had to be used to compensate for the weaker radio signal. The noise on all amplifier channels picked up from the radio receiver effectively blotted out the breaks produced by the shot, rendering the attempt abortive.

Levelling

An altitude of 860 ft at station S-1, five miles east-south-east of Wilkes, was assumed following previous surveying by conventional methods by members of the former United States party at Wilkes. Altitudes were read at intervals of one mile beyond this point by means of two sets of aircraft altimeters observed simultaneously at stations one mile apart. The readings were corrected for air temperature. The altitudes found in this manner at S-2 agreed quite well with the figure of 3820 ft which was taken as an average by the United States party after three separate barometric measurements.

It is a defect of the altimeter method that any lateral pressure changes along the traverse are measured as spurious height differences. As the winds in the traverse area blow for the most part from one direction, viz. from the south-east, such lateral changes may have produced substantial errors in the observed altitudes, the errors accumulating towards the end of the traverse. Owing to the breakdown of one of the weasels, it was not practicable to repeat the observations on the homeward run.

5. RESULTS

Seismic velocities

The refraction time-distance curve, taken at station 200, i.e. 200 miles south of S-2, shows velocities increasing from 9000 ft/sec (with shot-to-geophone distance 440 ft) to a maximum of 13,000 ft/sec (with shot-to-geophone distance 1980 ft). Such a variation can be fitted by assuming the following linear variation of velocity with depth, as shown in Plate 1:

$$v = 9000 + 10d$$

Where d is the depth below the level whose velocity is 9000 ft/sec. The relation is assumed to hold for values of d between zero and 400 ft, the velocity v thereafter remaining at the value 13,000 ft/sec, corresponding to 'true' ice.

The early part of the time-distance curve shows lower velocities which decrease from 9000 ft/sec to a low value at the surface. The curve can be divided approximately into straight-line segments which correspond to a layer of thickness 30 ft, with a velocity of 5000 ft/sec, underlain by a layer of thickness 35 ft with a velocity of 7500 ft/sec.

Most of the reflection shots gave first-break times that showed velocities, increasing with shot-to-geophone distance, up to 9000 ft/sec or more. In the absence of more detailed information, therefore, the layers of velocity less than 9000 ft/sec shown by the first breaks have been considered as overlying ice whose velocity increases with depth in the manner shown above, viz. to 13000 ft/sec at a depth of 400 ft below the low-velocity layers. Quite evidently the true velocity distribution at each shot-point varies with the thickness of wind-blown drift and with the change of temperature with depth.

Deeper shot-holes would have allowed the up-hole times to be used directly in the reflection time corrections, a knowledge of the near-surface velocities then becoming unnecessary.

The refraction shots at S-1 indicated a thin layer of velocity 5000 ft/sec overlying ice with a velocity ranging from 12,000 to 13,000 ft/sec.

Reflection records

Some of the records, for example the one displayed on Plate 2, show negligible incoming energy apart from the first breaks and the reflection from the underlying rock, which is consequently easily recognised. Others, particularly for stations south of station 200, show a great number of small events appearing successively after the first breaks, the reflection from the rock being poor or non-existent. Deeper shot-holes might have eliminated some of this interfering energy, which may be from near-surface layers.

The altitudes of the stations and the computed depth to the underlying rock, assuming the velocity distribution discussed above, are set out in Table 1. The profile of surface altitudes and rock level is shown on Plate 3. The outstanding feature is the deep valley between stations 40 and 80, the rock level descending to more than 7000 ft below sea level at station 60. There is a corresponding drop of 1150 ft in ice surface. As the rock level at station 20 is above sea level it appears that the barrier so formed may have partially diverted the ice in its flow northward from the interior of the continent. The positions of the Totten Glacier and the John Quincy Adams Glacier (Plate 3) suggest that they may be due to a gap in the rock formation, extending roughly westwards through the outlet of the Totten Glacier, through station 60 and thence to the outlet of the John Quincy Adams Glacier. Station 20 and S-2 appear to lie on an island therefore, though future traverses may change this preliminary picture.

South of station 80 the rock level appears to lie consistently below sea level as far as station 280, where a weak reflection indicates that the rock lies about 1200 ft above sea level. Where the reflections were good enough to provide reliable step-out times, i.e. reflection time differences between geophones at different distances from the shot-hole, these indicated only small inclinations of the rock surface. The apparent rock surface dips in the north-south direction have been shown on the profile (Plate 3) as short lines drawn through the plotted rock depths. They are tabulated below for the two directions of the L spread where used.

Stn	S-2	20	40	60	80	100	120	140	160	180	200	220	240	260	280
Dip	6°N		3°S	Nil	Nil	Nil		Nil	Nil	3°S	11°N				
	6°W		6°E	Nil	4°W	11°E		5°W	Nil	6°W	=				

Such small dips are not considered to be very reliable especially as the geophone altitudes were not measured by conventional survey methods.

The accuracy of the depth determinations depends mainly on (1) the error caused by timing the reflections at the first definite trough instead of at the onset of reflected energy, and (2) the error in the assumed velocity distribution.

If the first trough were missed and the second trough picked, then the reflection time would be over-estimated by about 10 milliseconds, this being the approximate time difference between troughs. The seismic instruments also contribute a time delay to the reflected pulse; consequently the reflection may be timed up to roughly 15 milliseconds too late. The resulting over-estimate in depth would be about 100 ft.

The velocity 13,000 ft/sec adopted for 'true' ice, compares with the value 12,910 ± 30 ft/sec, found by Pratt (1960), and the range 12,550 to 12,660 found by Goodspeed and Jesson (1959). A programme of refraction shooting carried out in Greenland by Joset and Holtzscherer (1953) yielded velocities ranging from 12,500 to 13,000 ft/sec at station altitudes ranging from 3600 to 9800 ft above sea level, the velocities appearing to correlate with altitude.

It is not known whether the ice in any part of the Wilkes area is isotropic or whether the basal plane of the ice crystals is orientated parallel to the rock floor, a phenomenon which would result in vertical seismic velocities slightly greater than those measured in refraction shooting (Thiel and Ostenso, 1961).

It would seem that the adopted figure of 13,000 ft/sec may be not too far from the correct value for the southern end of the traverse where the altitude approaches 10,000 ft. Assuming that the velocity may be over-estimated by up to 400 ft/sec at some locations, an over-estimate in depth of up to 160 ft in 5000 ft or 320 ft in 10,000 can be anticipated.

The error caused by a wrongly assumed velocity distribution in the layers above the 'true' ice is unlikely to be more than 20 milliseconds; for instance, were the 500 or so feet of upper layers to be traversed at the 'true'-ice velocity, the decrease in two-way time would be approximately that figure. The error in depth corresponding to a 20-millisecond error in time would be 130 ft.

To sum up, a depth of 5000 ft derived from a reliable reflection could be over-estimated by 390 ft or under-estimated by 130 ft. For a depth of 10,000 ft, the corresponding errors could be 550 ft and 130 ft. On most of the records there is only one event that appears on all traces; it is also much stronger than any other event, consequently there is little doubt that it corresponds to a reflection from the underlying rock. South of station 200, however, it is not certain that the reflections picked are the true ones, although they appear on all traces and exhibit very small step-out times. At stations 120, 220, and 260 no reflection could be picked with any confidence.

6. REFERENCES

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PRATT, J.G.D. 1960 Seismic soundings across Antarctica. Trans-Antarctic Expedition Committee Sci. Rep. No. 3.

THIEL, E. and OSTENSO, N.A. 1961 Seismic studies on Antarctic ice shelves. Geophysics 26 (6), 706-715.

TABLE 1

Stn.	Height Above sea level (ft)	Shot Depth (ft)	Thickness of Low-Velocity Layer (ft)	Correction For Low-Velocity Layer (msec)	Refl. Time (msec)	Relia-bility	Corrected Time (msec)	Depth Below Low-Velocity Layer (ft)	Depth Below Surface (ft)	Height of Reflector above Sea Level (ft)
S-2	3820	2	20	10	539	R	529	3370	3390	430
20	4000	15	22	7	417	R	410	2670	2690	1310
40	3470	2	28	11	802	R	791	5005	5030	-1560
60	2900	18	63	17	1636	R	1619	10,420	10,480	-7580
80	3490	18	46	16	732	R	716	4550	4600	-1110
100	4390	16	65	20	974	R	954	6110	6170	-1820
120	5470	18	40	13	N.R.					
140	6410	20	52	21	1283	R	1262	8100	8150	-1740
160	7170	20	52	21	1563	R	1541	9920	9970	-2800
180	7660	20	60	17	1280	R	1263	8120	8180	-520
200	7900	20	65	18	1377	R	1359	8725	8790	-890
220	8360	20	100	27	N.R.					
240	8780	20	(assumed) 100	(assumed) 27	2052	U	2025	13070	13170	-4400
260	9250	18	113	35	N.R.					
280	9630	18	64	23	1322	U	1299	8350	8410	+1220

TABLE 1

Rock level at Wilkes Base is approximately 30 ft above sea level. Ice cover is negligible.

Wilkes Base is situated at Lat. 66° 15.4'S, Long. 110° 31.5'E

S-2 is situated at Lat. 66° 30.7'S, Long. 112° 12.8'E

Station 300 is situated at Lat. 70° 52.2'S, Long. 111° 50'E

Reliability

R and U refer to the probability that the reflection picked corresponds to the ice/rock interface.

R = reliable; U = uncertain

APPENDIX 1

STAFF AND EQUIPMENT

STAFF

Traverse Party Leader	N.R. Smethurst
Geophysicist	F. Jewell
Glaciologist	W. Budd
Weather Observer	S. Stadler
" " (prelim. traverse)	E. Harrigan
Diesel Mechanic	J. McGhee
" " (prelim. traverse)	M. Berrigan
Radio Officer	S. Church
" " (prelim. traverse)	T. Cordwell

EQUIPMENT

Seismic Amplifiers	HTL 7000B
Seismic Oscillograph	TIC 25-trace, 6 in.
Geophones	TIC 20-c/s
Drill	Proline HDBA Auger Drill
Levelling Instruments	Altimeters, aircraft type (Nat. Inst. Co.)

APPENDIX 2

TABLE OF OPERATIONS

Area	Wilkes Land, Antarctica
Base	Glaciology Station S-2, 50 miles E.S.E. of Wilkes
Period of Traverse	26.2.61 to 31.3.61 and 7.10.61 to 6.1.62
Miles Surveyed	300
Altitude Control	Aircraft type altimeter
Explosives Used	250 lb RDX/TNT
Datum Level for Corrections	Surface
'Weathering' Velocities	3500 to 9000 ft/sec
'Sub-weathering' Velocities	9000 to 13,000 ft/sec
Source of Velocity Distribution	Linear variation based on refraction

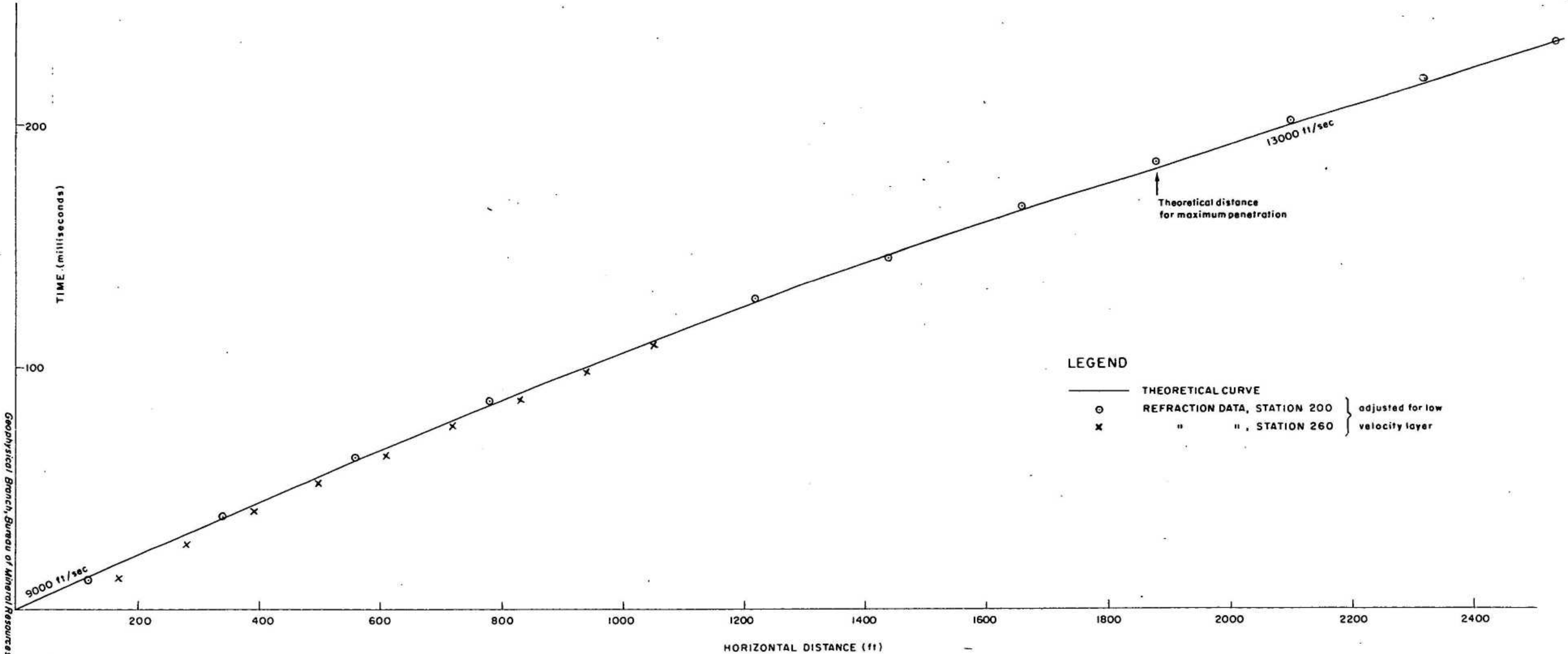
REFLECTION SHOOTING DATA

Shot-point Interval	20 miles
Geophone Group	Single geophone
Geophone Group Interval	50 ft or 110 ft
Holes Shot	20
Common Shooting Depths	18 to 20 ft
Usual Recording Filter	K70/KK120
Common Charge Sizes	1 to 3 lb
'Weathering' Corrections	From first-break times

REFRACTION SHOOTING DATA

Geophone Group	Single geophone
Geophone Group Interval	220 ft
Holes Shot	5
Usual Recording Filter	Nil/KK120
Number of Refraction Traverses	5
Charge Sizes	5 to 10 lb
Maximum Shot-to-Geophone Distance	$\frac{3}{4}$ mile
Weathering Control	From reflection shooting
Weathering and Elevation Correction	From first-break times; elevation differences negligible.

WILKES, 1961



THEORETICAL REFRACTION TIME: DISTANCE CURVE

CORRESPONDING TO LINEAR VARIATION OF VELOCITY v WITH DEPTH d

$v = 9000 + 10\,d$ ft/sec

(v CONSTANT FOR DEPTHS GREATER THAN 400 ft)

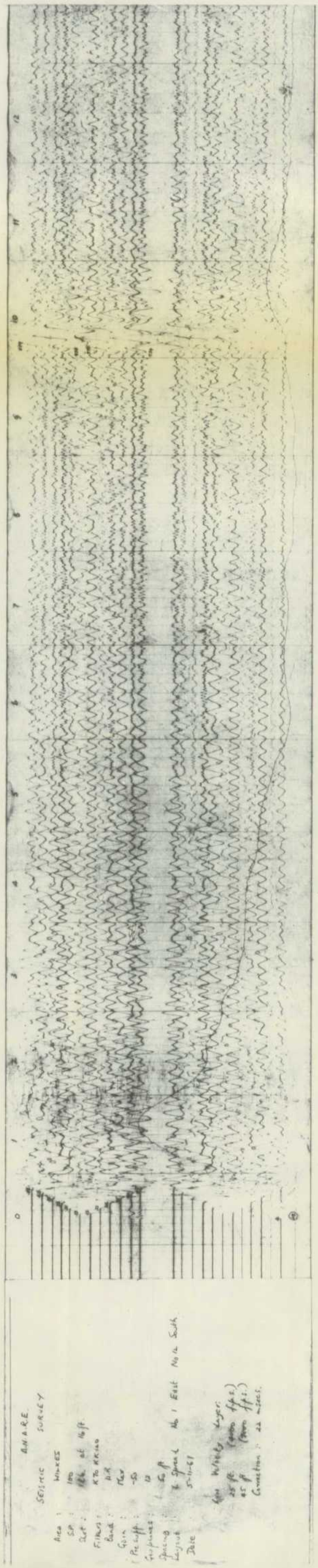
PLATE 1

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 364-17

To Accompany Record No 1962/162

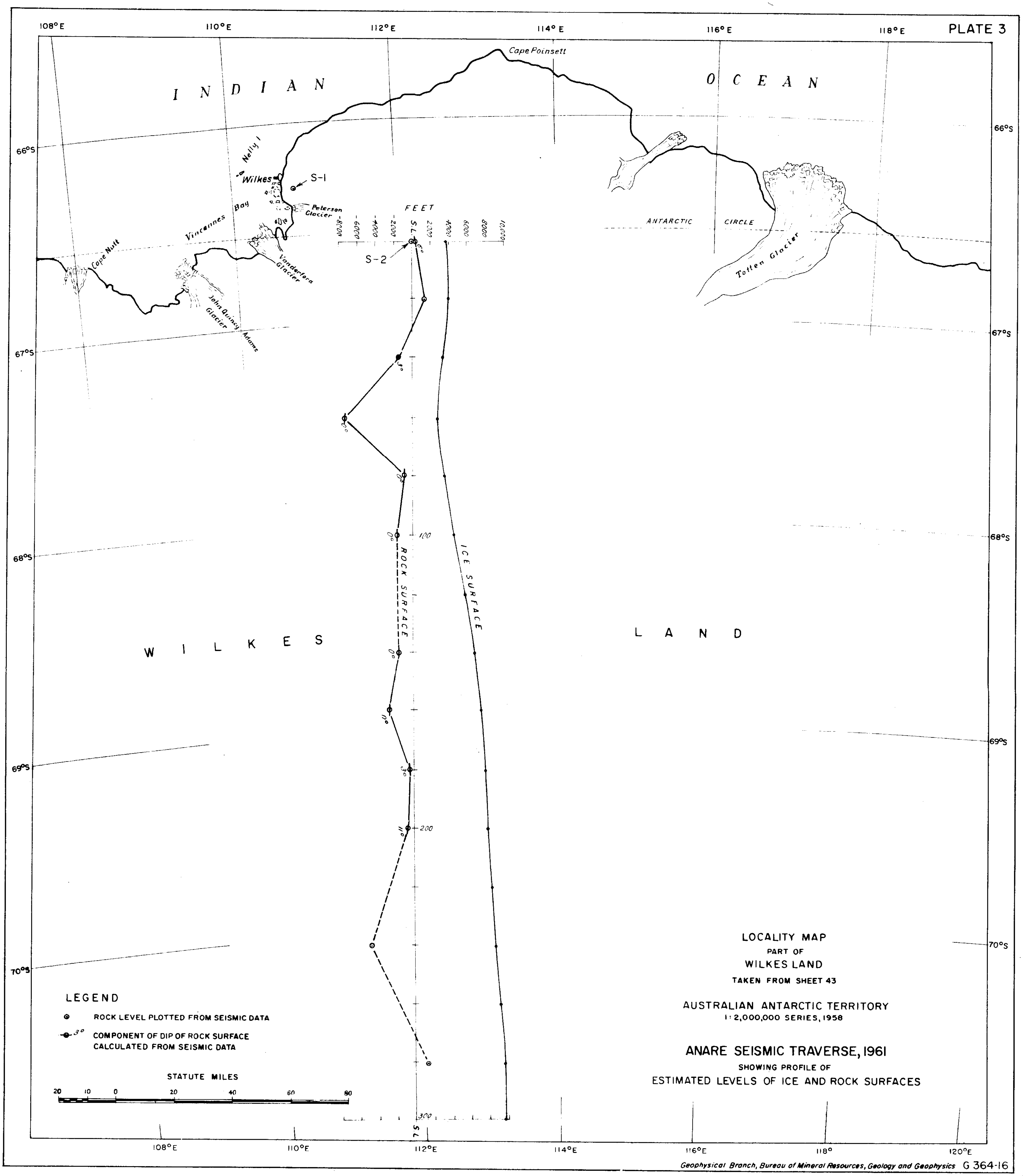
PLATE 2

WILKES, 1961



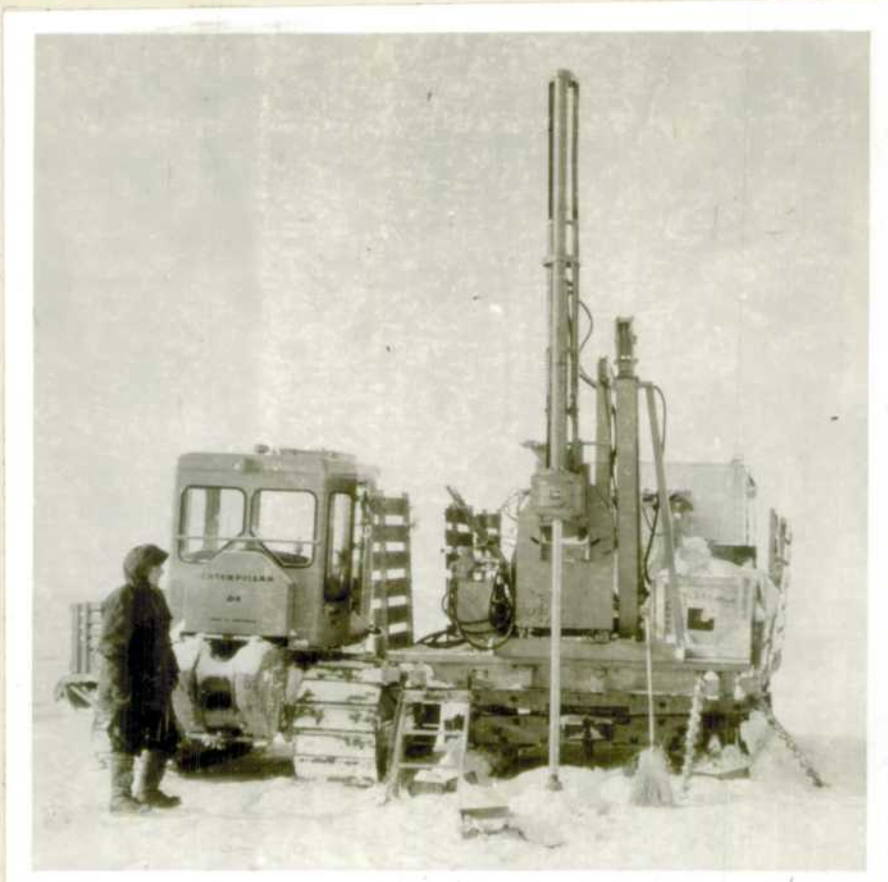
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 364-27

TO ACCOMPANY RECORD No 1962/162



To Accompany Record No 1962/162

PLATE 4



PROLINE H D B A AUGER DRILL

SHOWN COUPLED TO CATERPILLAR D-4 TRACTOR