Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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No. 49

Seismic and gravity surveys over the concealed granite ridge at Bosworgy, Cornwall

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Seismic and gravity surveys over the concealed granite ridge at Bosworgy, Cornwall

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London 1982

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48 Mineral investigations near Bodmin, Cornwall. Part 3 The Mulberry and Wheal Prosper area

49 Seismic and gravity surveys over the concealed granite ridge at Bosworgy, Cornwall

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Bibliographical reference
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CONTENTS

Summary 1

Introduction and objectives 1

Seismic survey 1
Survey considerations 1
Field techniques 4
Processing 4
Results 5

Gravity survey 5
Gravity observations and reductions 5
Interpretation 5
Results 13

Conclusions 13

References 13

FIGURES

1 Map of the Bouguer anomaly over the concealed granite ridge at Bosworgy, Cornwall 2
2 Simplified geological log and sonic velocity measurements for Bosworgy borehole 3
3 Playback of field records, line A 6
4 Filter trial on field records, line A 7
5 Filtered playback of field records, line A 8
6 Final processed seismic record, line A 9
7 Final processed seismic record, line B 10
8 Computed depth of granite below sea level in km 11
9 Computed depths to granite on lines X, Y, Z (Figure 8) 12

SUMMARY

Detailed gravity surveys around the margins of the Carnmenellis granite have identified several near-surface granite ridges, including that drilled at Bosworgy. In an attempt to define the form of the granite ridge, two short reflection seismic lines were shot in 1975. For various reasons the seismic results were disappointing and a further detailed gravity survey was carried out.

This report describes the seismic results and an interpretation of available gravity data in the Bosworgy area.

INTRODUCTION AND OBJECTIVES

The general form of the Cornubian granite batholith is indicated by consideration of the Bouguer gravity anomaly field across the peninsula (Bott and others, 1958; Dunham, 1975). Further detailed gravity surveying in selected areas where geological and geophysical evidence suggested the presence of near-surface granite identified various subsurface granite ridges and local gravity minima, two of which, at Bosworgy [Grid Reference SW 5806 3367] and Parbola [SW 6157 3633], became targets for exploratory drilling. The results of this detailed gravity survey and drilling are given in Beer and others (1975).

The aim of the survey reported here, was to provide a detailed geological section across the granite ridge at Bosworgy by the use of the reflection seismic technique. It was also hoped that, by producing a more detailed Bouguer gravity anomaly map, the shape of the granite cusp at Bosworgy could be determined by the application of gravity modelling techniques.

SEISMIC SURVEY

SURVEY CONSIDERATIONS

Figure 1 shows the Bouguer anomaly field in the area of the survey, together with the positions of the seismic lines and relevant boreholes. Seismic line locations were determined by the need for borehole control of the seismic data, the trend of the Bouguer gravity field and land access consideration.

The solid geology consists of folded Devonian slates (Mylor Series) overlying granite. The slates are variably altered and frequently cut by chloritised and haematitised quartz veins. The geological log for the Bosworgy borehole is given in Beer and others (1975); and a simplified geological section with sonic velocity measurements made on core samples (Gibb, 1973) is given in Figure 2.

In the Bosworgy borehole the slates extend to a depth of 171 m below ground level (-87 m OD) although stringers of granite occur above that depth. In the commercial borehole CLV 28, the slates have a downhole thickness of 637 m and the granite contact [at 5993 3501] is at a depth of -397 m OD.

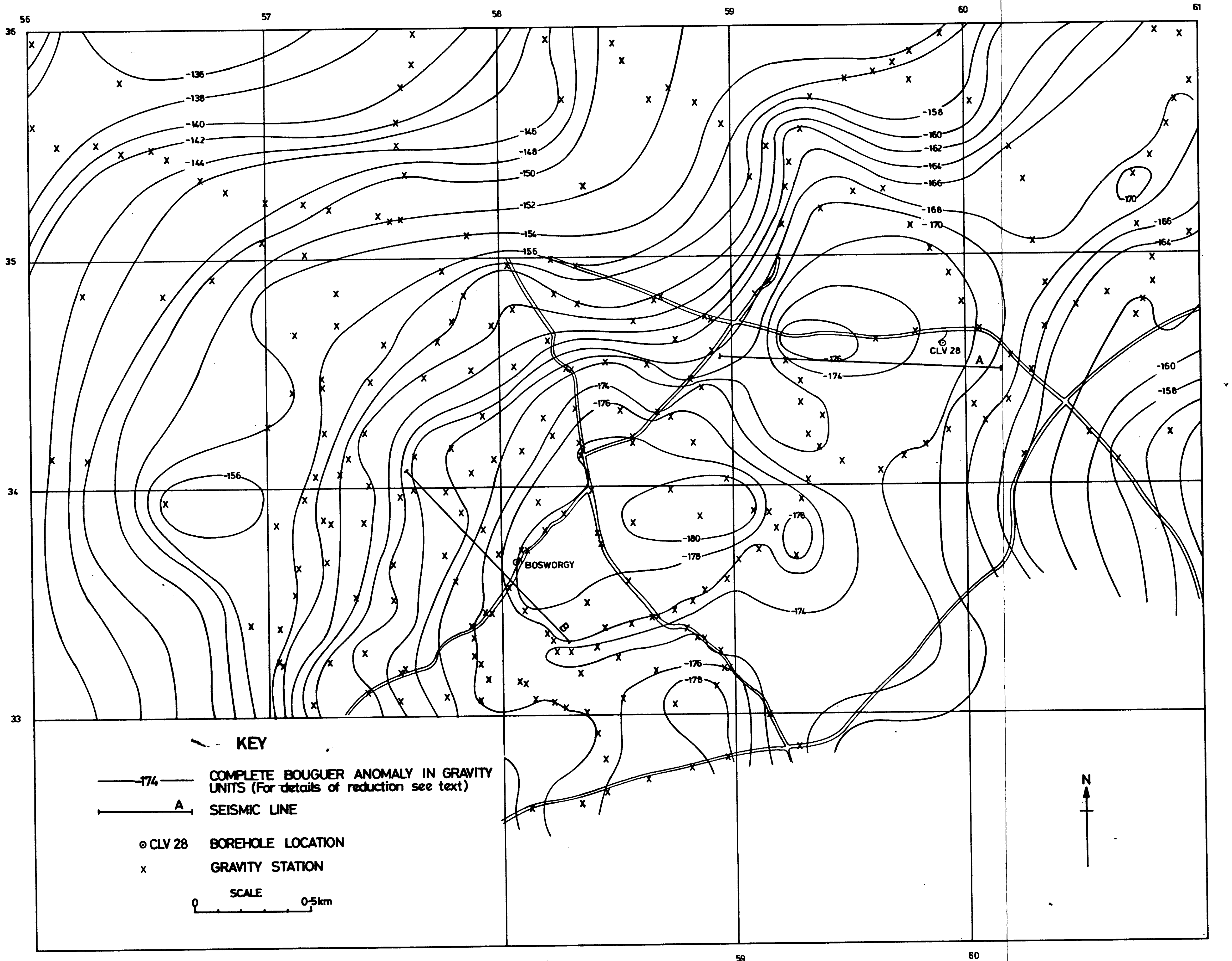
For the purpose of interpreting the geophysical observations the geological situation was approximated to a variable thickness of metasediments of sonic velocity V_1 and density ρ_1 overlying granite of sonic velocity V_2 and density ρ_2. Measurements on saturated samples from the Bosworgy borehole give mean values $V_1 = 3.19$ km s^{-1}, $V_2 = 5.14$ km s^{-1} and $\rho_1 = 2.56$ g cm^{-3}, $\rho_2 = 2.67$ g cm^{-3}. With granite known to occur within 200 m of the surface, two-way travel times of less than 125 milliseconds could be anticipated.

These densities are inconsistent with the evidence provided by the Bouguer gravity anomaly field, which indicates the granites to be less dense than the surrounding slates. The metasediment density of 2.56 g cm^{-3} was for samples taken from less than 300 m deep. The most likely explanation is that the slate samples have undergone physical alteration prior to measurement. Earlier density determinations on more varied lithologies (McCann, 1973) suggest an average density of 2.70 g cm^{-3} for the metasediments. Geophysical density logs from Bosworgy borehole (Beer and others, 1975, appendix B) have not been calibrated, but qualitatively they indicate the granite density to be lower than the overlying slates. Also, for samples taken from deeper than 300 m, Gibb (1973) gives an average saturated sample density of 2.72 g cm^{-3} for the metasediments.

Using a value of 2.70 for ρ_1 a reflection coefficient k may be calculated for the slate-granite interface.

$$k = \frac{v_2 \rho_2 - v_1 \rho_1}{v_2 \rho_2 + v_1 \rho_1} = \frac{5.14 \times 2.67 - 3.19 \times 2.70}{5.14 \times 2.67 + 3.19 \times 2.70} = 0.22$$

Conformably sedimentary contacts with a reflection coefficient of 0.22 could readily be detected by reflection seismic techniques, but in the study area the situation is complicated by



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-148
-150
-152
-154
-156
-158
-160
-162
-164
-166
-168
-170
-174
-176
-178
-180
CLV 28
A
B
BOSWORGY
KEY
-174
COMPLETE BOUGUER ANOMALY IN GRAVITY UNITS (For details of reduction see text)
A
SEISMIC LINE
⊙ CLV 28
BOREHOLE LOCATION
x
GRAVITY STATION
SCALE
0
0·5km
N

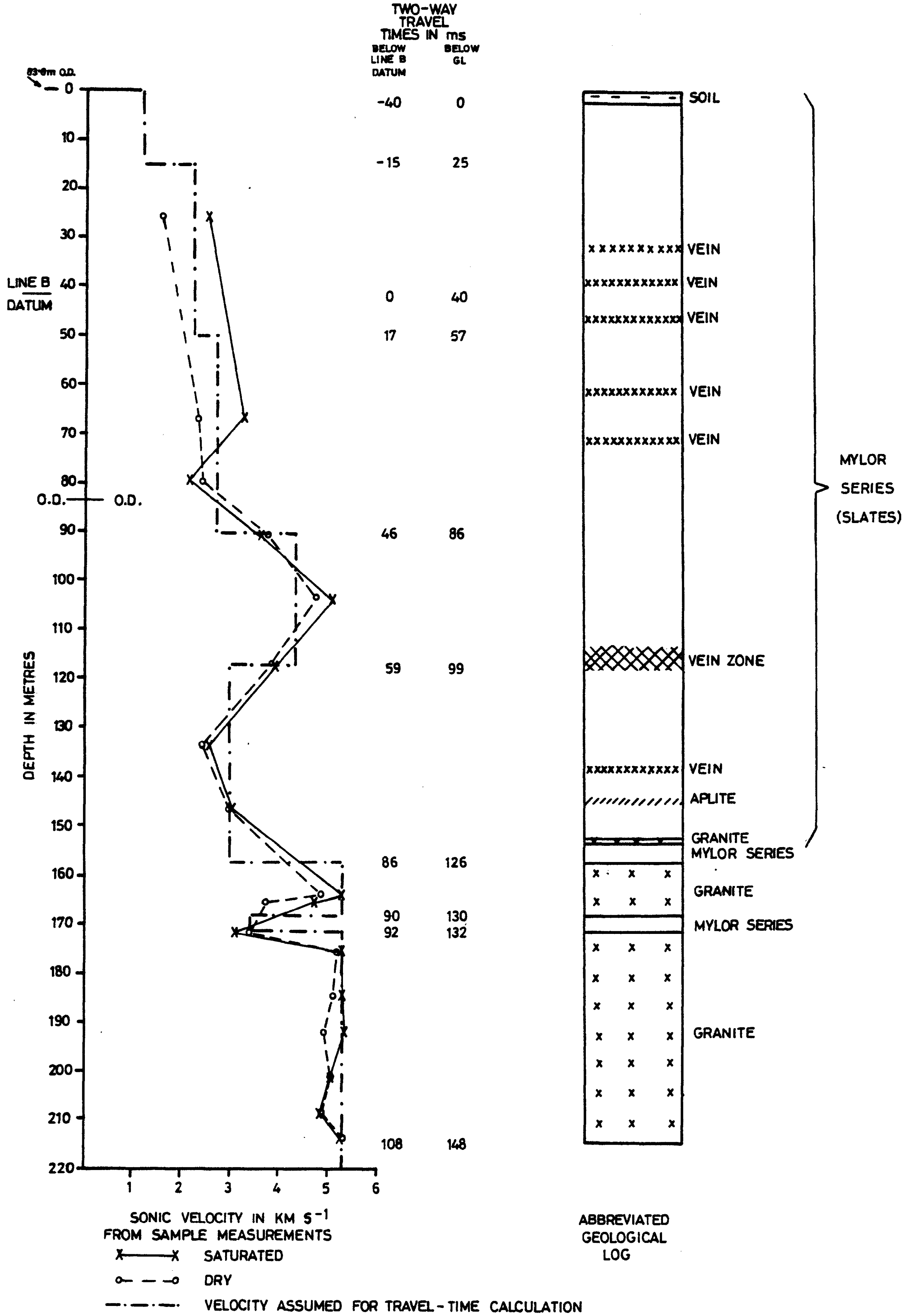


FIG. 2. SIMPLIFIED GEOLOGICAL LOG AND SONIC VELOCITY MEASUREMENTS FOR BOSWORGY BOREHOLE

various factors:
i Alteration effects due to metamorphism and weathering may result in a gradual rather than distinct change of velocity and density at the granite contact.
ii Velocity irregularities are present in the metasediments due to dyke and vein structures, so that layer velocities greater than 5 km s^{-1} are present above the granite contact.
iii The Bosworgy and CLV 28 boreholes both show that the granite–slate contact consists of alternating layers of granite and slate. In such circumstances the reflectivity of the contact may be severely reduced by destructive interference. The frequency of the seismic signals at the contact on line B (near SP 20) is about 80 Hz, and the wavelength corresponding to the granite velocity of 5.1 km s^{-1} is thus about 60 m. At Bosworgy the top granite vein, 1 m thick, is too thin to show on the seismic data. The second, 11 m thick, will give no reflections at the highest frequencies used (120 Hz) because of destructive interference (thickness = $\lambda/4$), and very little at lower frequencies; the thickness of $\lambda/6$ corresponding to 80 Hz is about the minimum thickness that would normally give an observable reflection in a good seismic area. The major granite body, beginning at 171 m, will not give clear reflections because of the confused signals arising above it, and because the average velocity in the sequence above it will be sufficiently high to reduce the reflectivity of the interface.
iv The seismic technique is best suited to regions of deep sedimentary basins. In areas where metamorphism has occurred and stratification is not uniform, correlation from seismic trace to trace may be difficult to see, or it may even be absent. The possible effects of adjacent underground workings have also to be considered. Dines (1956) reports that in the Wheal Lewis (Wheal Nut) levels, down to 220 m depth (120 fathoms), stoping is up to 60% in parts.
v The target depth, 185 ms, was close to the shallowest reasonable depth for exploitation of the reflection seismic method. Near the surface large static corrections are caused by inhomogeneities in the weathering layer which may not be eliminated even with careful attention to detail during the velocity analysis at the processing stage. This problem is particularly evident under the stream on line B.
vi The geometry of the field layout means that full stacking is not reached until six shots in from the first and last SPs. Thus, on Line B, although shots were fired at SPs 12 to 41, full stacking only occurs from 18 to 35 inclusive.
vii In order to remove noise components such as ground roll and air wave which were incompletely eliminated by the field practice, early arrivals on the outer traces were eliminated at the processing stage. This procedure, known as 'muting' or 'blanking', further reduces the available amount of data. In this area, full stacking was not reached until 140 ms.

On line A, the Bouguer anomaly indicates (Figure 9) a target depth of 50 ms or less, and at this level single fold stacking or less is available. On line B the stacking at the target level is six-fold at the SPs with maximum stacking, but this deteriorates on either end of the record.

FIELD TECHNIQUES

The seismic records were collected on Sercel 338 24T equipment. A velocity log was obtained from a 40 m deep test hole (SP1 Line A) shot at 5 m intervals to 15 m deep and then at 3 m intervals to the surface. The hole was open and not tamped. The geophone spread consisted of 24 Hall-Sears single geophones laid out at 5 m intervals with geophone 1 and an up-hole geophone at the well-head. The results were irregular and repeated from 30 m deep to the surface using Sensor geophone strings clustered at the same geophone locations.

A reversed refraction profile designed to test the properties of the near-surface 'low velocity layer' was shot with geophones 1–12 at 1 m intervals and geophones 13–24 at 2 m intervals. A noise spread consisting of three geophone set-ups covering 0 to 355 m on line A at 5 m intervals was also shot from the same test hole. From the results of these tests the following field parameters were selected as optimum:
i spread geometry-20 m take-out intervals with a string of six geophones spaced 4 m apart symmetrically about the take-out position and in line with the geophone cable; centre shot;
ii shot hole depth 15 m (50 ft);
iii weathering layer velocity 1.2 km s^{-1};
iv sub-weathering layer velocity 2.2 km s^{-1};
v recording filters not applied.

Because of the slow drilling rate (3–4 holes per day) and the presence of a possible reflection on the field-trace record of the noise spread, it was decided to shoot line A with six-fold stacking. Subsequent computer print-out of the noise spread showed no sign of reflections so line B was shot with twelve-fold stacking.

PROCESSING

Static corrections for the shotpoints were calculated by the up-hole method, by which observed travel times are reduced to travel times from a datum plane, assuming vertical ray paths and that the shot point is at the base of the weathered layer. The data were processed by Seismograph Services Ltd, applying the following operations:
i Editing
ii Filtering data, bandpass 27–100 Hz
iii Deconvolution
iv Automatic statics
v Stacking: (line A – 600%, line B – 1200%)
vi Time-varying filtering: parameters as in Figures 6 and 7

vii Equalisation over 100 m window
viii Separate migration playback.

Three features of this survey should be noted before inspecting the seismic records.

i The six-fold stacking used on line A was performed by shooting at every 2nd station, i.e. at 40 m intervals. Line B, shot 12-fold, contains twice as many data, the most noticeable effect of this being in the top 50 ms. Each separate trace displayed on the records is displaced horizontally by 20 m from the adjacent traces.

ii Line A is displayed with the western edge on the right of the record, and B with the north-western edge on the right. In each case these are non-standard conventions.

iii Good velocity evaluations cannot be made from seismic data without good reflections. The data here are poor and little reliability can be placed on the values obtained from the multi-velocity stacks. Computation of two-way travel times downhole has thus been made using the values measured from Bosworgy samples.

RESULTS

The playback of the separate records obtained on line A (Figure 3) shows that a lot of LF noise was recorded, most of which was eliminated using a 20 Hz low-cut filter. It can also be seen that the geophones nearest the shot suffered severely from 180 Hz noise. The number affected reached five at some locations, e.g. SP 8. The application of a 27–100 Hz passband filter at the start of processing eliminated both these effects, but they inevitably lead to degradation of the final quality. The 180 Hz noise present on the traces adjacent to the shot is particularly disturbing, since in the top 50 ms these are the only ones used on the final record. The effect of different degrees of filtering can be seen on Figures 4 and 5. Figures 6 and 7 are the final processed records.

Approximate two-way travel times for the Bosworgy borehole are marked on Figure 2. This borehole is situated close to SPs 20 and 21 on line B, about 65 m from the line. Two-way travel times, computed from the gravity data for a velocity of 2.5 km s^{-1}, are indicated beneath each seismic record. The Bosworgy borehole indicates that the top of the granite should occur on line B about 85 ms at SP 20, and two faint events, labelled A, B on the record occur at about this time. A similar event can be picked on line A at about 100 ms, and the expected granite top is here thought to lie between 0 and 100 ms. Thus the top of the granite may be visible on both line A and line B. However, neither event correlates well with the surface predicted from gravity. It is suggested that the reflections may originate from the water table, although the event on line B cannot be primary in this case, since water is present above the datum of the record, in the stream at SP 36.

The major feature of line B is the reflection labelled C at 300 ms between SPs 10 and 25. This may actually extend further towards SP 50, but the severe statics problem beneath the stream, causing interference over the whole 1 second of the record, has destroyed any continuity which may exist. The presence of a good flat reflector within the granite was unexpected and is difficult to explain. The RMS velocities quoted on line B, 2800 ms^{-1} at 110 ms and 4800 ms^{-1} at 300 ms, give an interval velocity over this section, using the Dix formula (Dix, 1955), of 5640 ms^{-1}, and this is in reasonable accordance with the value measured for granite, considering the poor data quality.

Other events are apparently present on both lines, but only in an extremely fragmented form, and no conclusions can be drawn from the results other than that both lines were run over non-sedimentary sequences except for the surface veneer of sediments or metasediments. The migrated sections provided no extra information.

GRAVITY SURVEY

GRAVITY OBSERVATIONS AND REDUCTIONS

Gravity observations prior to 1975 have been compiled and incorporated in the Bouguer gravity anomaly map for the Hayle–Leedstown area (Beer and others, 1975). In order to improve the detail of the Bouguer anomaly map in the vicinity of the Bosworgy borehole, further gravity observations were made in 1975 using a LaCoste and Romberg gravity meter. Station elevations were determined by tacheometric levelling between Ordnance Survey benchmarks. After correction for instrument drift and tides, observed gravity values were derived from NGRN 73 (Masson Smith and others, 1974) bases. Combined elevation and partial terrain corrections were made using a density of 2.67 g cm^{-3}. Normal gravity values were calculated using the 1967 International gravity formula.

A compilation of all the available observations, recalculated using a density of 2.70 g cm^{-3} and with complete terrain corrections, is given in Figure 1.

INTERPRETATION

The semi-automatic modelling procedure used to derive depths to granite from Bouguer anomaly data has been described in detail elsewhere (Tombs, 1977). Essentially it involves separating from the Bouguer anomaly the gravitational attraction of the metasedimentary cover alone, and then computing the variable thickness of cover necessary to account for this attraction.

For the Bosworgy area the calculations were made over a rectangular area of 4 km × 3 km bounded by grid lines SW 56 to 60E, 33 to 36N. Final output was over a square grid of mesh size 0.2 km.

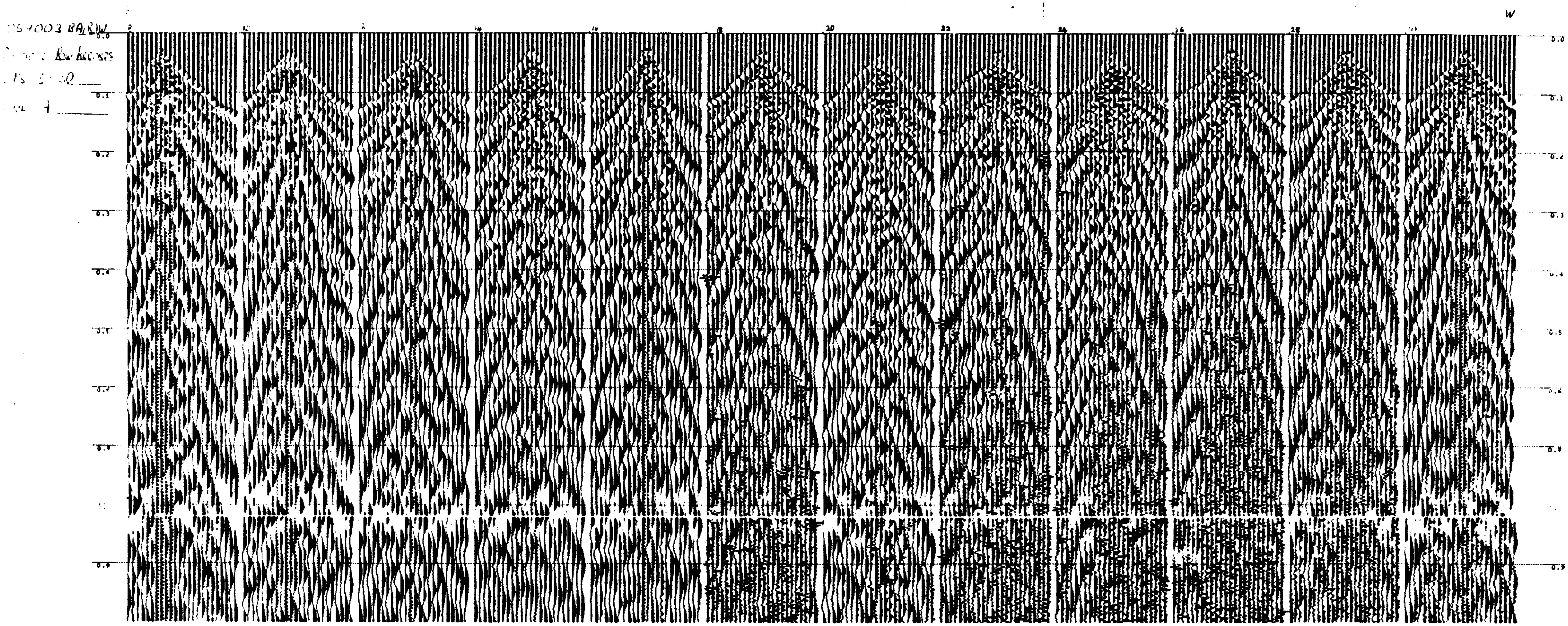


FIG. 3. . PLAYBACK OF FIELD RECORDS, LINE A.

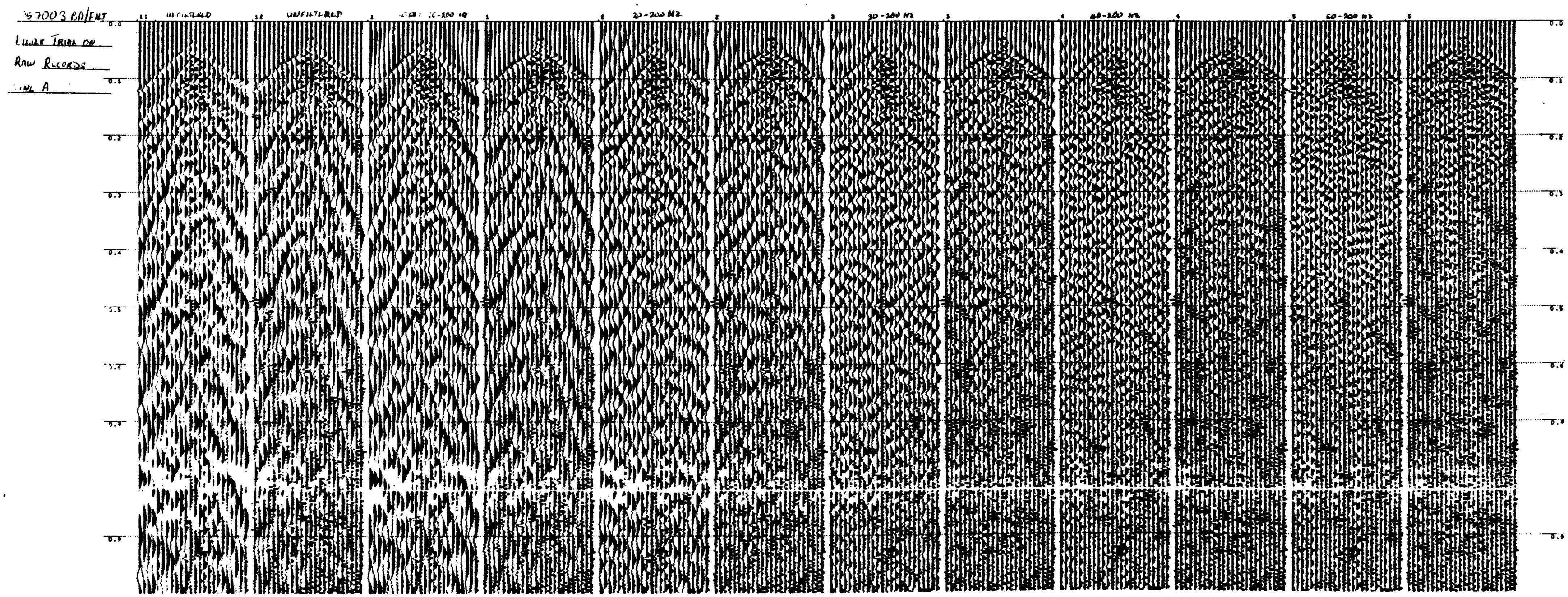


FIG. 4. FILTER TRIAL ON FIELD RECORDS, LINE A.

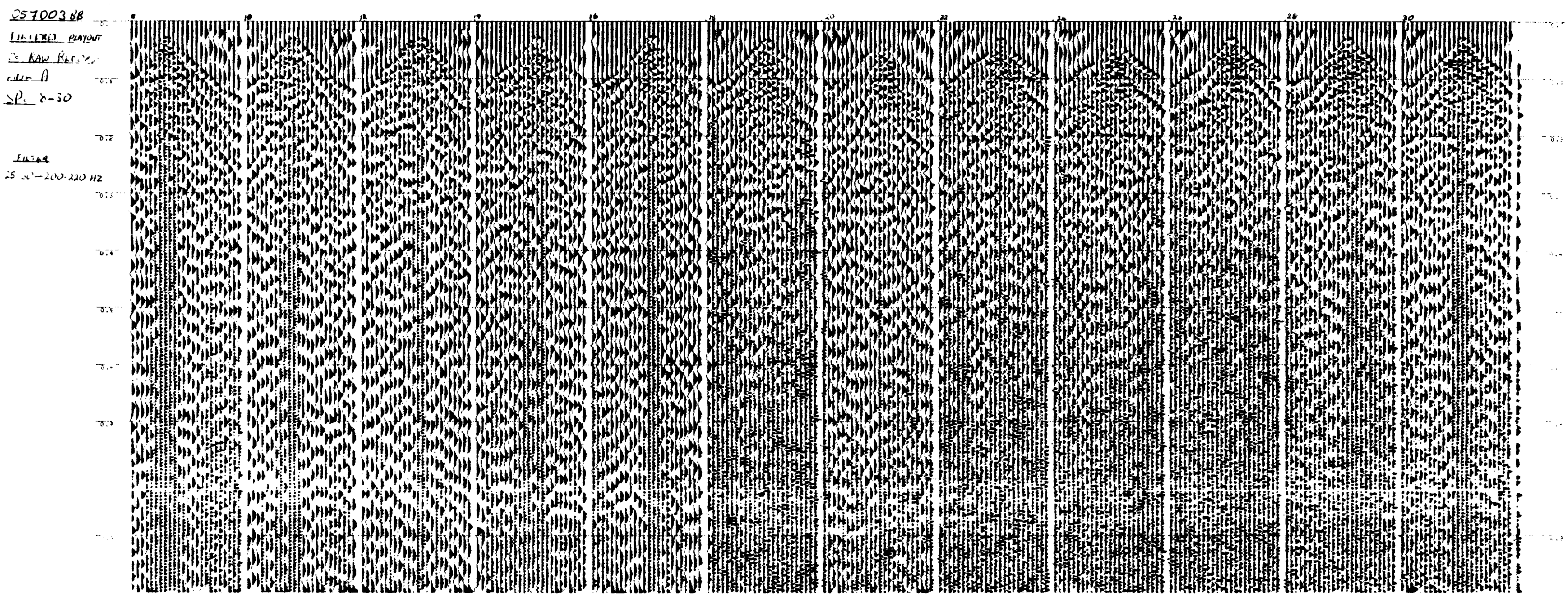


FIG. 5. FILTERED PLAYBACK OF FIELD RECORDS, LINE A

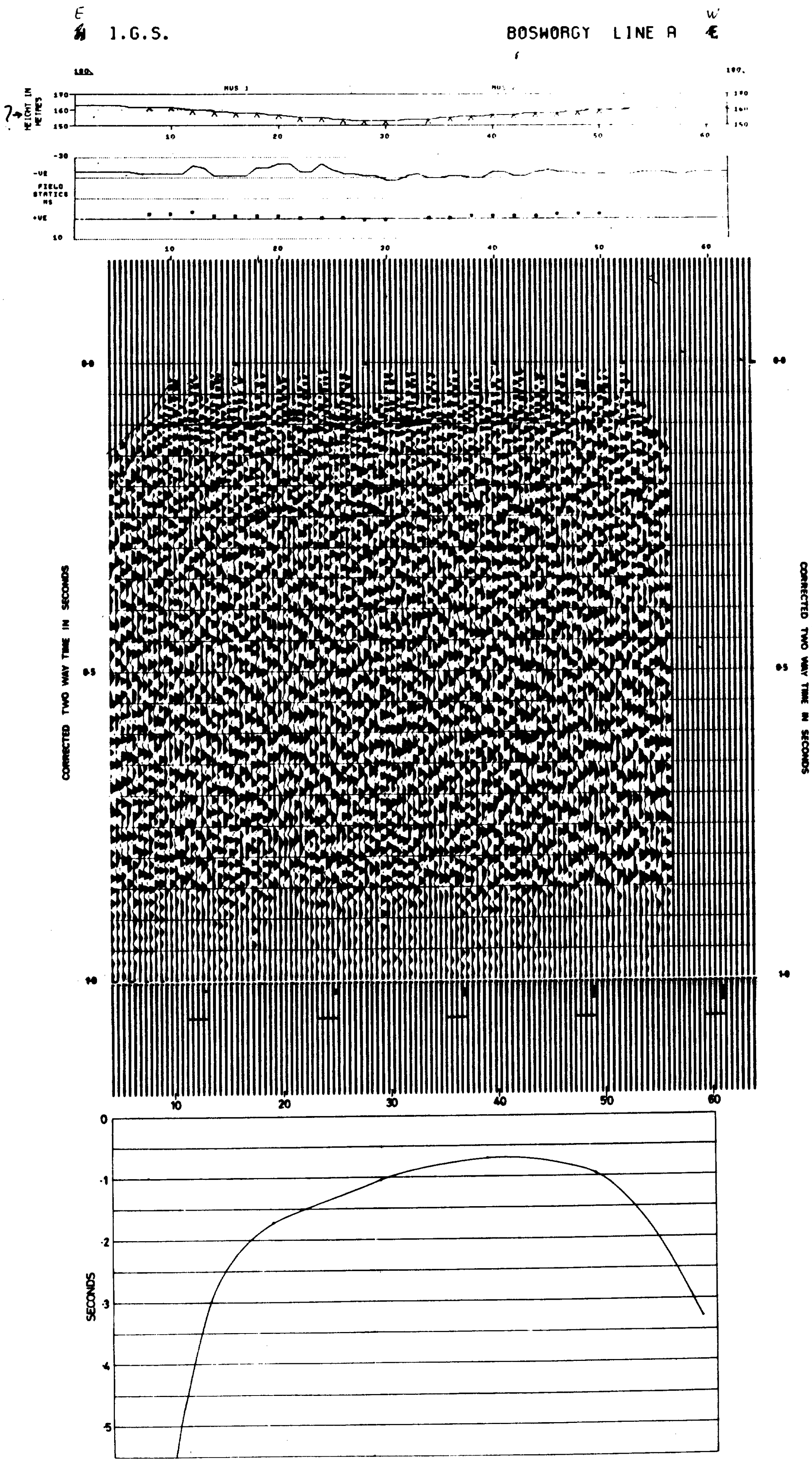


FIG.6. FINAL PROCESSED SEISMIC RECORD, LINE A

I.G.S.	LINE A SHOT POINTS 0-50

RECORDED BY I.G.S.
PROCESSED BY SEISMOGRAPH SERVICE (ENGLAND) LIMITED
PROSPECT BOSWORGY
SPECIAL REMARKS
CORRECTION DATUM 90 METRES ABOVE M.S.L.

PROCESSED THROUGH **PHOENIX**

RECORDING PARAMETERS	RECORDING GEOMETRY
CABLE 230-10-0-10-230 GEOPHONE INTERVAL 20M SHOT INTERVAL 40M FILTER OUT DATE SHOT 12-15JULY 1975 DATA SOURCE SERCEL 338 24 T SAMPLING INTERVAL 1 MS RECORD LENGTH 1 SECOND	SHOT POINT PATTERN SINGLE HOLE GEOPHONE PATTERN 6 GEOPHONES PER STATION 2M APART IN LINE NOMINAL COVER 6 FOLD

SEQUENCE	PROCESSING PARAMETERS		
1 PREPARATION	BINARY GAIN RECOVERY AND EDIT		
2 FILTER	23-27-100-120 HZ		
3 DECONVOLUTION	OPERATOR 50MS GAP 20MS WINDOW 100 500 MS		
4 CORRECTION	WITH AUTOMATIC STATICS WINDOW 50 550 MS		
5 STACK 6 FOLD			
6 BAND PASS FILTER	TIME VARIANT		
7 TV EQUALISATION	100MS WINDOW		
DISPLAY	HORIZ 1:? VERT 6INS TO 1 SEC	SECURITY NO. 0S?00J 3010 AUGUST 1975	PROCESSED LONDON A.W.ROGERS

VELOCITY CHARTS

THE VALUES LISTED BELOW ARE DERIVED FROM RMS VELOCITIES OBTAINED FROM THE MULTI-VELOCITY STACK (MVS) ANALYSES. VALUES ARE CALCULATED USING THE ASSUMPTIONS OF STRAIGHT PATH TRAVEL IN HORIZONTAL LAYERS WITH SNELL'S LAW APPLIED AT EACH INTERFACE. VELOCITIES ARE IN METRES PER SECOND AND INTERPOLATED BETWEEN DISPLAYED FUNCTIONS. TIMES ARE TWO WAY AND IN MILLISECONDS. DELTA-T VALUES ARE RELATED TO DISTANCES OF 414 METRES

LINE A SP 16

TIME (MS)	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH (M)
1	104	2200	2200	1
130	21	3006	3000	195
220	9	4466	3600	395
300	4	7725	4700	704
490	2	5473	5000	1225
1000	1	6960	6000	3000

LINE A SP 40

TIME (MS)	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH (M)
1	104	2200	2200	1
90	28	3008	3000	135
170	12	4275	3600	305
320	4	6160	4800	769
520	2	5040	5200	1351
1000	1	6066	6000	3000

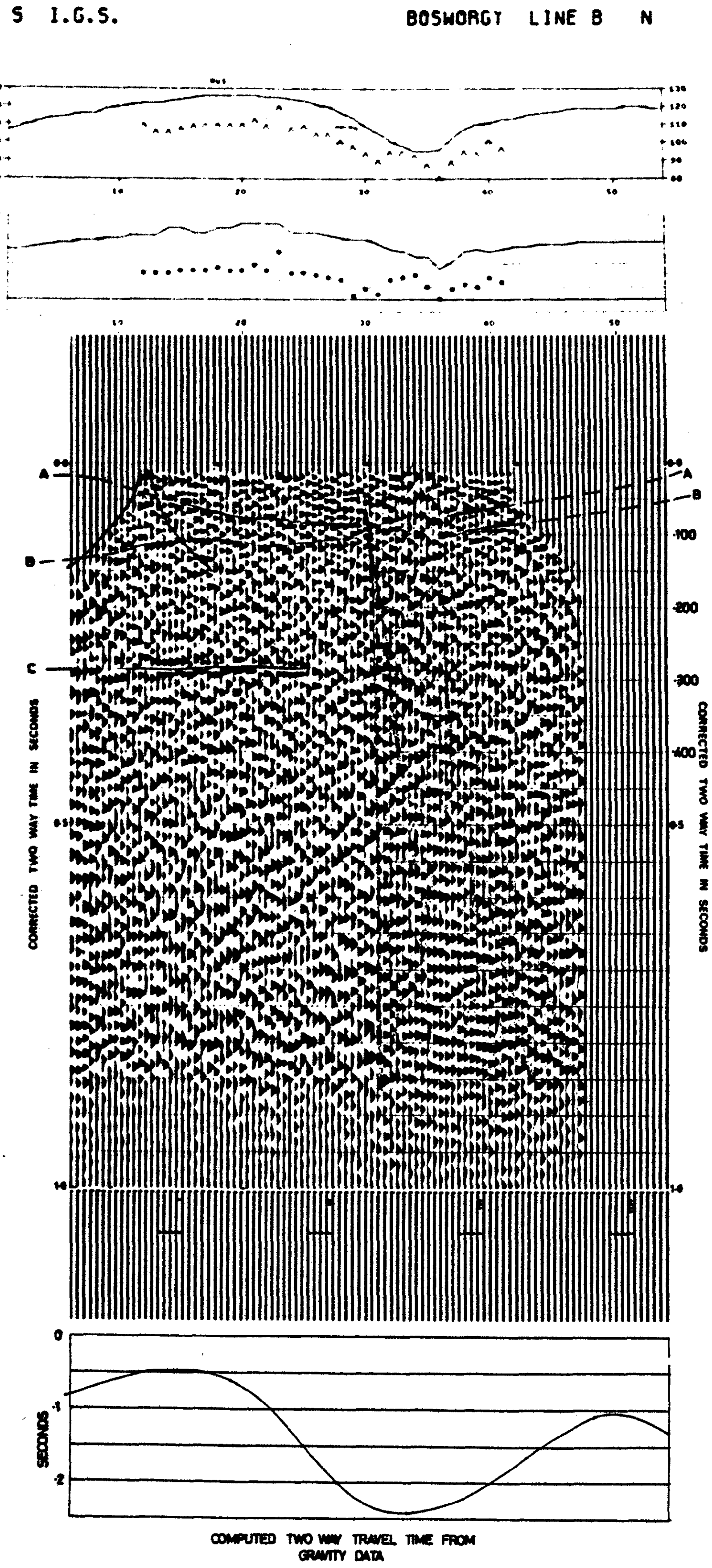
BAND-PASS FILTER

TIME(MS)	FREQUENCY(HZ)
4	18-20-100-102
120	18-20-100-102
300	23-25-80-82
500	18-20-60-62

BLANKING

LINE A SP 0-50

TRACE	TIME(MS)	DISTANCE(M)
11	50	30
9	90	110
1	140	230



I.G.S.	LINE B SHOT POINTS 12-41

RECORDED BY I.G.S.
PROCESSED BY SEISMOGRAPH SERVICE (ENGLAND) LIMITED
PROSPECT BOSWORGY
SPECIAL REMARKS
CORRECTION DATUM 42 METRES ABOVE M.S.L.

PROCESSED THROUGH PHOENIX

RECORDING PARAMETERS	RECORDING GEOMETRY
CABLE 230-10-0-10-230T GEOPHONE INTERVAL 20M SHOT INTERVAL 20M FILTER OUT DATE SHOT 17-24JULY 1975 DATA SOURCE SERCEL 338 24 T SAMPLING INTERVAL 1 MS RECORD LENGTH 1 SECOND	SHOT POINT PATTERN SINGLE HOLE GEOPHONE PATTERN 6 GEOPHONES PER STATION 4M APART IN LINE NOMINAL COVER 12 FOLD

SEQUENCE	PROCESSING PARAMETERS		
1 PREPARATION	BINARY GAIN RECOVERY AND EDIT		
2 FILTER	23-27-100-120 HZ		
3 DECONVOLUTION	OPERATOR 50MS GAP 20MS WINDOW 100-500 MS		
4 CORRECTION	WITH AUTOMATIC STATICS WINDOW 50-550 MS		
5 STACK 12 FOLD			
6 BAND PASS FILTER	TIME VARIANT		
7 TV EQUALISATION	100MS WINDOW		
DISPLAY	HORIZ 1:2M8 VERT 6IN8 TO 1 SEC	SECURITY NO. 057004/3030 AUGUST 1975	PROCESSED LONDON R.W.ROGERS

VELOCITY CHARTS

THE VALUES LISTED BELOW ARE DERIVED FROM THE VELOCITIES OBTAINED FROM THE MULTI-VELOCITY STACK (MVS) ANALYSES. VALUES ARE CALCULATED USING THE ASSUMPTIONS OF STRAIGHT PATH TRAVEL IN HORIZONTAL LAYERS WITH SNELL'S LAW APPLIED AT EACH INTERFACE. VELOCITIES ARE IN METRES PER SECOND AND INTERPOLATED BETWEEN DISPLAYED FUNCTIONS. TIMES ARE TWO WAY AND IN MILLISECONDS. DELTA-T VALUES ARE RELATED TO DISTANCES OF 414 METRES

LINE B SP 10

TIME (MS)	DELTA T	INTERVAL VELOCITY	R.M.S. VELOCITY	DEPTH (M)
1	104	2200	2200	1
110	27	2005	2000	153
200	9	4800	3700	369
300	4	7000	4800	719
410	2	6123	5200	1117
1000	1	4603	6000	3000

BAND-PASS FILTER

TIME(MS)	FREQUENCY(HZ)
4	18-20-100-102
120	18-20-100-102
300	23-25-88-92
500	10-20-60-64

BLANKING

LINE B SP 12-41

TRACE	TIME(MS)	DISTANCE(M)
11	50	30
7	90	110
1	140	230

FIG. 7. FINAL PROCESSED SEISMIC RECORD, LINE B.

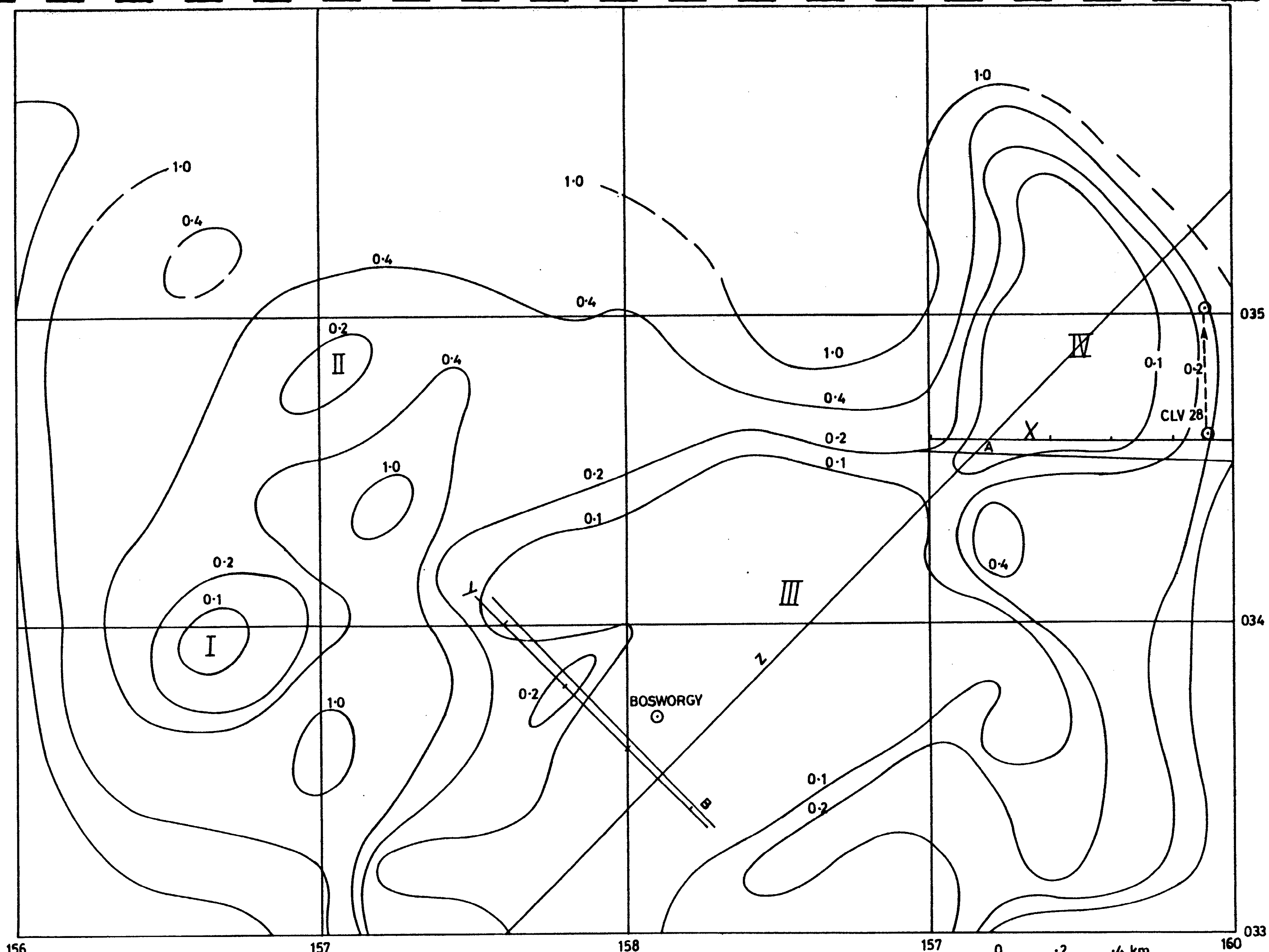


FIG. 8 COMPUTED DEPTH OF GRANITE BELOW SEA LEVEL IN km DENSITY CONTRAST 0·13 g cm -3

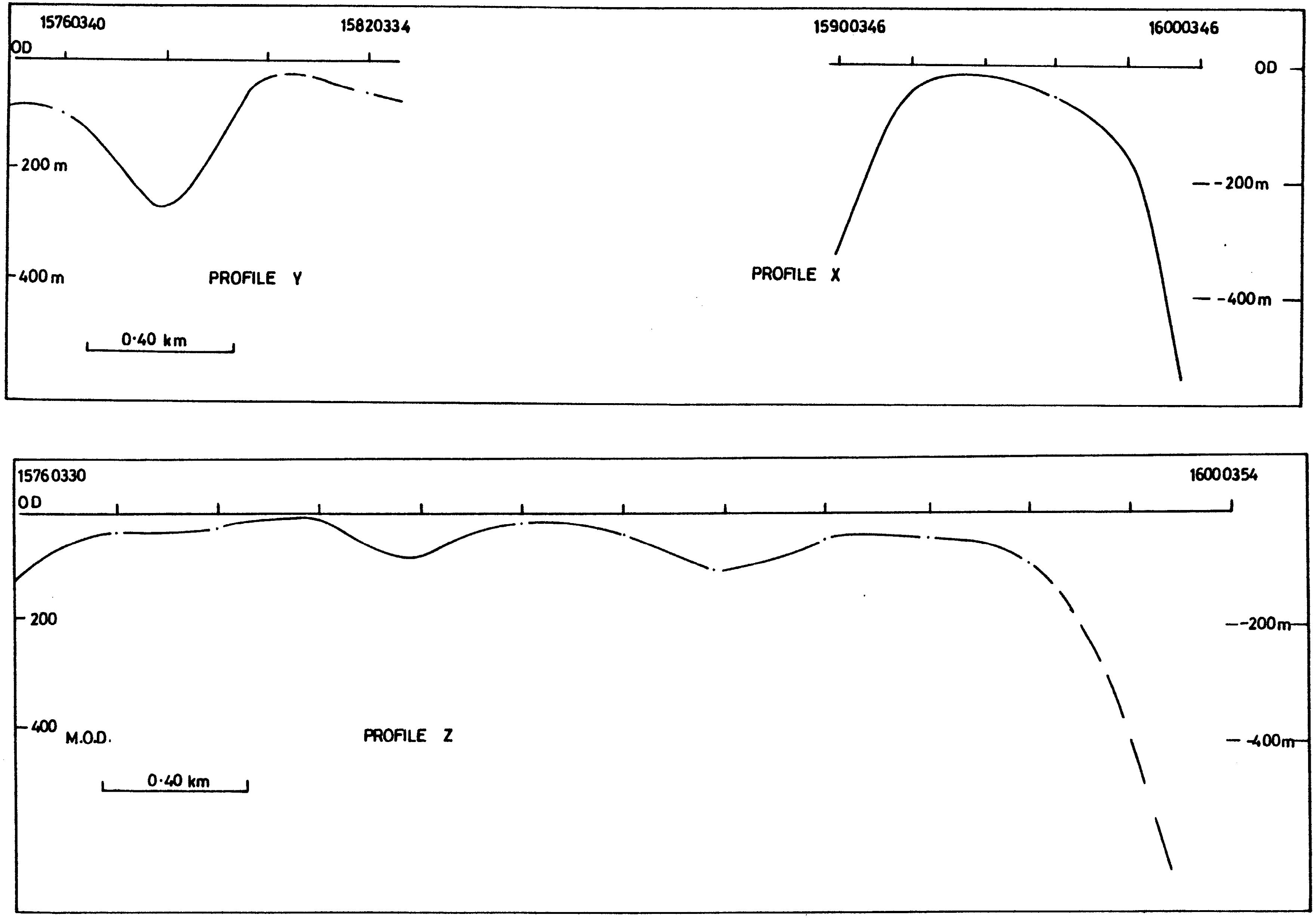


FIG. 9. COMPUTED DEPTHS TO GRANITE ON LINES X,Y,Z FIG. 8.

Geological control of the modelled depths to granite is provided by:

i Bosworgy borehole [SW 15806 03367] where continuous granite occurs below -87 m OD although granitic veins occur at depths as shallow as -68 m OD.

ii Borehole CLV 28 [SW 15991 03461] with a granite contact at [SW 15993 03501] at a depth of -397 m OD.

Preliminary calculations of depths indicated that a density contrast of 0.13 g cm^{-3} between slates and granite gave a reasonable approximation to borehole depths, although this was greater than the density contrast used above in the calculation of reflection coefficient.

RESULTS

Figure 8 shows contours of depths to granite below OD taken from the model assuming a density contrast of 0.13 g cm^{-3}. The final RMS error between the calculated gravity effect and the artificial 'slates only' field with which it was compared was 0.24 mgal. It should be noted that the accuracy is lowest around the margins of the area, due to external effects which have not been fully compensated. The computed depth at Bosworgy is about -30 m OD, and that for borehole CLV 28 is about -350 m OD. Discrepancy between single point observations and the depths computed by gravity interpretation is due mostly to incorrect definition of the regional field and therefore of residual values. The assumption of a uniform density contrast for a variable thickness of metasediments is also a source of error. However the interpretation given in Figure 8 is considered to show the broad form of the granite surface with reasonable accuracy.

The high area marked II on Figure 8 may represent a curved north-westward extension of the underground granite ridge, or may simply be due to less dense metasediments. The high labelled I is possibly spurious as the corresponding gravity 'low' is recorded on only one station.

Highs III and IV show the granite ridge, with granite rising to near sea level over a considerable area.

Data is relatively scanty in grid square 159 033 so that computed depths are less accurate. The granite ridge appears to have a steep slope to the east and to the north of high III where the computed slope is about 77°.

The sections X and Y shown in Figure 9 give approximate profiles for the seismic lines A and B respectively. Section Z gives the profile along the ridge axis.

CONCLUSIONS

The seismic results were ambiguous, producing reflections at the target depths which could be ascribed to sources other than the top of the granite. It is clear that given sufficient field time and expenditure the seismic reflection method could produce the desired information, but much more intensive coverage would be needed, possibly decreasing the station separation from 20 m to 2 m. This would be so expensive that further application of the method to this problem cannot be recommended.

At the time of the seismic survey, the Bouguer anomaly field was not as well defined as in Figure 1, the additional gravity surveying being, in fact, the result of disappointing seismic results. Consequently the seismic line locations in Figure 1 are not in optimum positions.

The gravity method is useful for providing an approximate shape of the granite ridge and an order of magnitude to the actual depths, but accurate definition of depth is limited by model approximations.

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