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RECORD

BMR Record 1990/18

A Field and Laboratory Study of Acoustic Impedances of Rocks from Tumut, NSW

P.N. Chopra and A.G. Spence

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Abstract

In-situ measurements of density and compressional-wave velocities and laboratory measurements of density, compressional and shear-wave velocities were made on rocks from the seismic corridor of the 1987 Tumut seismic reflection survey. The P and S-wave impedances of these rocks were calculated from these data.

Results applied to the upper crust, where ultrabasic rocks are far from their P/T stability fields and are thus particularly prone to weathering and alteration, suggest that the seismic impedances of these rocks may be lower than or indistinguishable from those of the flysch and granitoids which also occur associated with the Trough. At deeper crustal levels however, serpentinites should exhibit slightly higher seismic impedances than the granitoids and meta-sediments, while harzburgites should have significantly higher values.

Thus in the deeper crust, the juxtaposition of harzburgitic rocks with flysch and granitoids across faults should be seismically resolvable if the geometry of the interface is suitable for seismic imaging. The presence of serpentinite along faults cutting across the meta-sedimentary sequences and granitoids should improve the resolution of these features by seismic reflection.

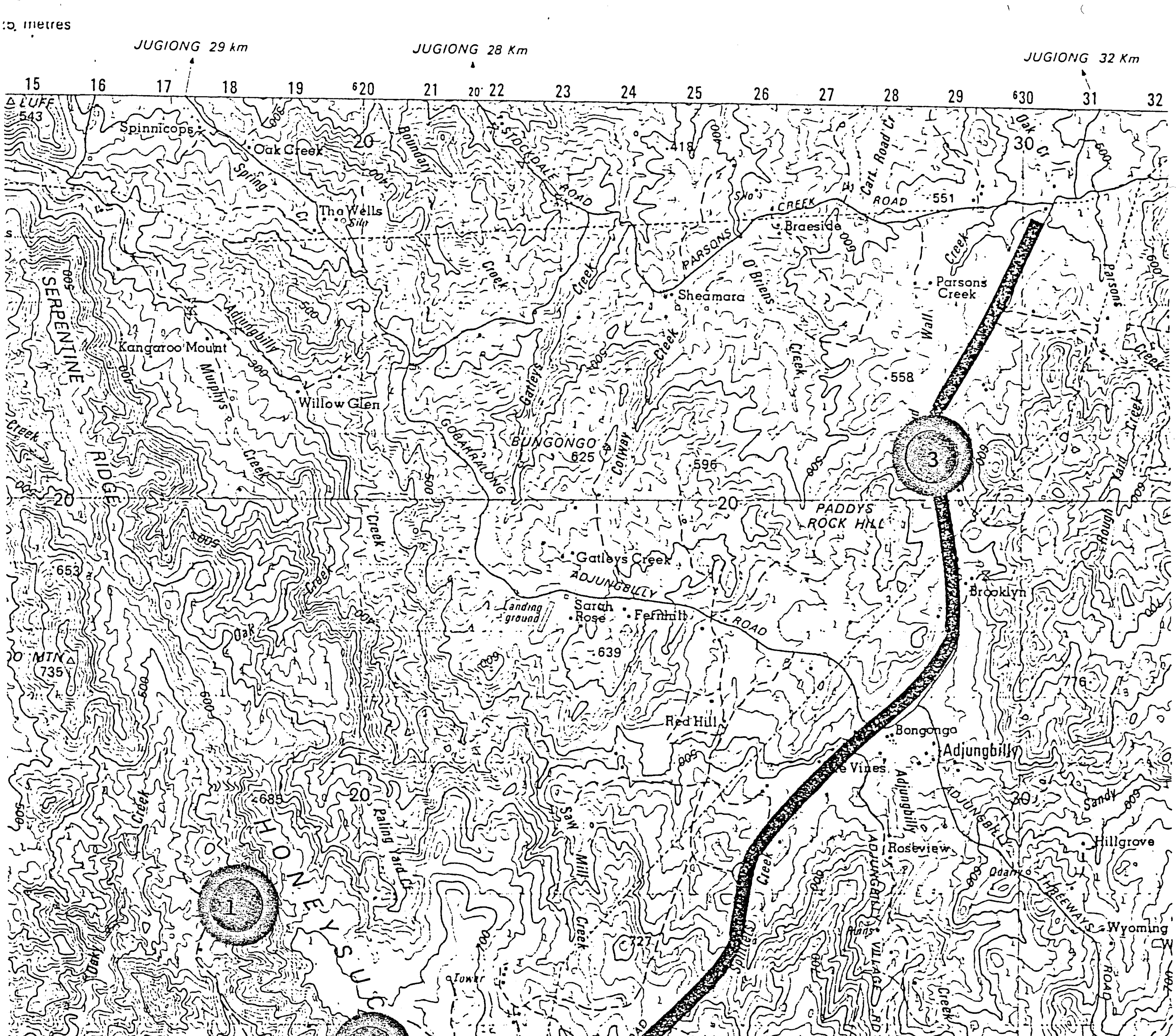


Fig 1.

1. Location of serpentinite samples
2. Location of harzburgite samples and shotholes # 1658 # 1659 # 1668 # 1669
3. Location of shothole # 1926

Introduction

In April- May of 1987, BMR and the Geology Department at the Australian National University jointly conducted a seismic reflection survey in the Tumut Trough region of SE New South Wales (see Figure 1). This survey was intended to investigate the deep structure of the Tumut Trough and to image the bounding faults which were thought, on the basis of geological evidence, to be listric in character and probably dipping to the east. The known occurrence of serpentinite along these faults in the near surface, and the anticipated continuation of this association with depth, was expected to provide a marked impedance contrast with the surrounding rocks. The operational aspects of this work have been described by Leven and Rickard (1987).

As an adjunct to the seismic work, a study was undertaken of the acoustic impedances of several of the rock types representative of those traversed by the seismic experiment. Of particular interest were the serpentinites and harzburgites outcropping on the Honeysuckle Ranges and the granodiorite of the Young batholith. Measurements of rock densities and compressional wave velocities were made *in-situ* using geophysical well-logging techniques in selected shot-holes (some of which had been deepened for the purpose). Laboratory measurements of density and compressional and shear wave velocities were also made on a suite of samples collected from sub-outcrops along the seismic corridor.

The results of these physical property measurements are presented in this Record together with comparable data from the literature and results from some granites elsewhere in Eastern NSW.

Methods

Geophysical Well-logging

Field operations were carried out on 28-29 April 1987 using the BMR's vehicle-borne well-logging system. This system and its mode of operation, has been described previously by Chopra and de Bruyn (1987) and Chopra (1987).

Each shot-hole was logged with a 54mm diameter Comprobe Formation Density Logging (FDL) tool and in addition some of the holes were logged with a Mt. Sopris sonic tool. The density probe contains a short-spaced and a long-spaced detector. The former is situated 15 cm from the ^{137}Cs gamma radiation source, while the latter is located 48 cm above this source. All logging runs were carried out at a speed of 3 metre per minute which resulted in data being collected at centimetre intervals.

Each of the sets of data from the FDL detectors were filtered to reduce noise arising from statistical fluctuations in the output of the ^{137}Cs source by calculating a moving average over 15 points. Similar filtering was applied to the other data again to reduce the degree of noise.

An added feature, peculiar to this particular logging project was the necessity to maintain high water levels in the holes so as to allow the density and sonic tools to operate below water at the shallow depths characteristic of the seismic shot-holes.

Laboratory Measurements

Samples of harzburgite, serpentinite and granite were collected from sub-outcrops within the seismic corridor. These samples were subsequently drilled using a diamond coring bit and cut with a diamond saw to produce cylindrical specimens of 3.5 cm diameter and lengths between 5 and 10 cm. This procedure resulted in 3 usable cores of harzburgite, 2 of serpentinite and 1 of granite.

The density of each core was calculated from its mass and volume. The former was measured using a sensitive electronic balance and the latter was calculated from

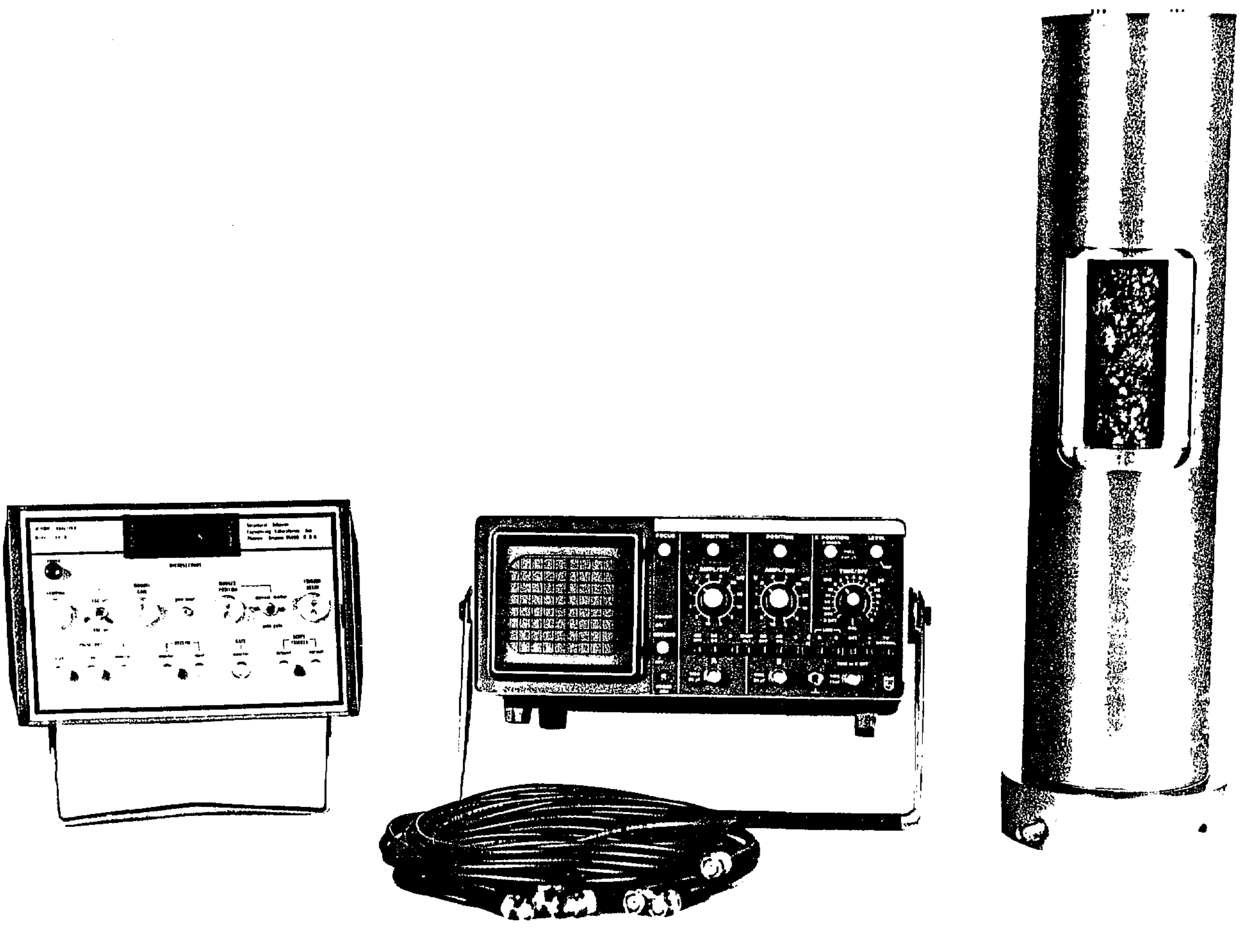


Figure 2

Apparatus for measurement of P and S wave velocities in rock core samples subjected to a uniaxial load.

measurements of core diameter and length made using vernier calipers.

Acoustic velocities, both compressional and shear, were measured using a model 2007-H Seismic Analyser manufactured by Structural Behaviour Engineering Inc. of Phoenix, Arizona, USA (see Figure 2). This apparatus employs piezo-electric transducers operating at 200 kHz.

Samples, with their ends thinly coated with a viscous silicone oil, were loaded into the testing frame and subjected to a uniaxial load through the application of compressed air to a loading jack in the base of the frame. A Phillips model PM3111 (0-60 MHz) oscilloscope was used in conjunction with a Tektronix CRO camera to record the wave-train propagating through the specimens. The time of flight of the pulses was read off the digital display of the model 2007-H after aligning the marker pulse with the onset of the wave-train (see Figure 8 below).

The recorded times of flight for the propagating waves were corrected in each case for delays in the cables and platens by subtracting the time of flight measured in a calibration in which the platens were pressed together. Velocities for each sample were then calculated from the times of flight by dividing by the sample length.

Results

Geophysical Well-logging

Five of the shot-holes drilled along the seismic line were geophysically logged prior to the loading of explosive charges for the seismic experiment. The locations of these shot-holes are given in Figure 1 and Table 1.

The results of the logging are given in Figures 3 to 7. In each case, the density data are plotted in terms of g/cm^{-3} using the FDL calibration of Chopra et al (1989). This calibration generally results in accuracies in determined densities of within +/- 0.05 g/cm^{-3} for smooth-walled water-filled boreholes. In the present cases however, since the shot-holes were rotary-drilled rather than cored, the walls are far from smooth. This is borne out by the results of the caliper logs. Thus the measured densities are likely to have greater errors than +/- 0.05 g/cm^{-3}. Indeed, these measurements are likely to systematically under-estimate the true densities since the roughness of the walls interposes some water in the path of the gamma rays between the source and the detectors.

Table 1 Locations of geophysically logged shot-holes

Shot-hole Number	Easting	Northing
1658	619 943	6111 500
1659	620 003	6111 512
1668	620 533	6111 613
1669	620 592	6111 625
1926	628 672	6120 734

Note: Grid references are for the Tumut 1:100000 sheet Sheet 8527 (Edition 1) 1976

Figure 3 Well-log results from Shot-hole #1658 of the Tumut Survey

Lithology:	Harzburgite		
Depth:	24.52 metre		
Water-level:	9.20 metre		
Nom. diameter:	11.5 cm		
Log quality:	Short-spaced density	- OK	
	Long-spaced density	- OK	
	Caliper	- OK	
	Sonic	- OK below water table	

Both the density and sonic data suggest that the harzburgite intersected by this hole varies widely in competence. Regions of low density and sonic velocity often correspond with parts of the hole which have relatively large diameter. Such regions are suggestive of more intense weathering. Other parts of the intersected rockmass appear to be much less weathered and display relatively high P-wave velocities and densities.

BMR ROCK PROPERTIES RESEARCH

COMPUTERISED BOREHOLE LOGGING

TUMUT SURVEY
The Honeysuckle

LOGGING SPEEDS·
SONIC PROBE 3 M/MIN
DATUM ABOVE GROUND LEVEL .01 M.
OPERATOR· : Prame and Alex
DATA LOG VER· 78506.01
DATA PLOT VER·78607.31
WATER LEVEL· 9.20 M.

PLOTTING SCALE· 1:50

BOREHOLE NO. #1658

DEPTH LOGGED 24.52 M.
DATE LOGGED 29 04 87
DATE PROCESSED 04 05 87

CALIPER cm.
CAL CM 10 20 30

SONIC VELOCITY m/sec
2000 4000 6000

SHORT SPACED DENSITY g/cc
CAL GM/CC 1.19 1.74

LONG SPACED DENSITY g/cc
CAL GM/CC 1.19 1.74

DEPTH (M.)

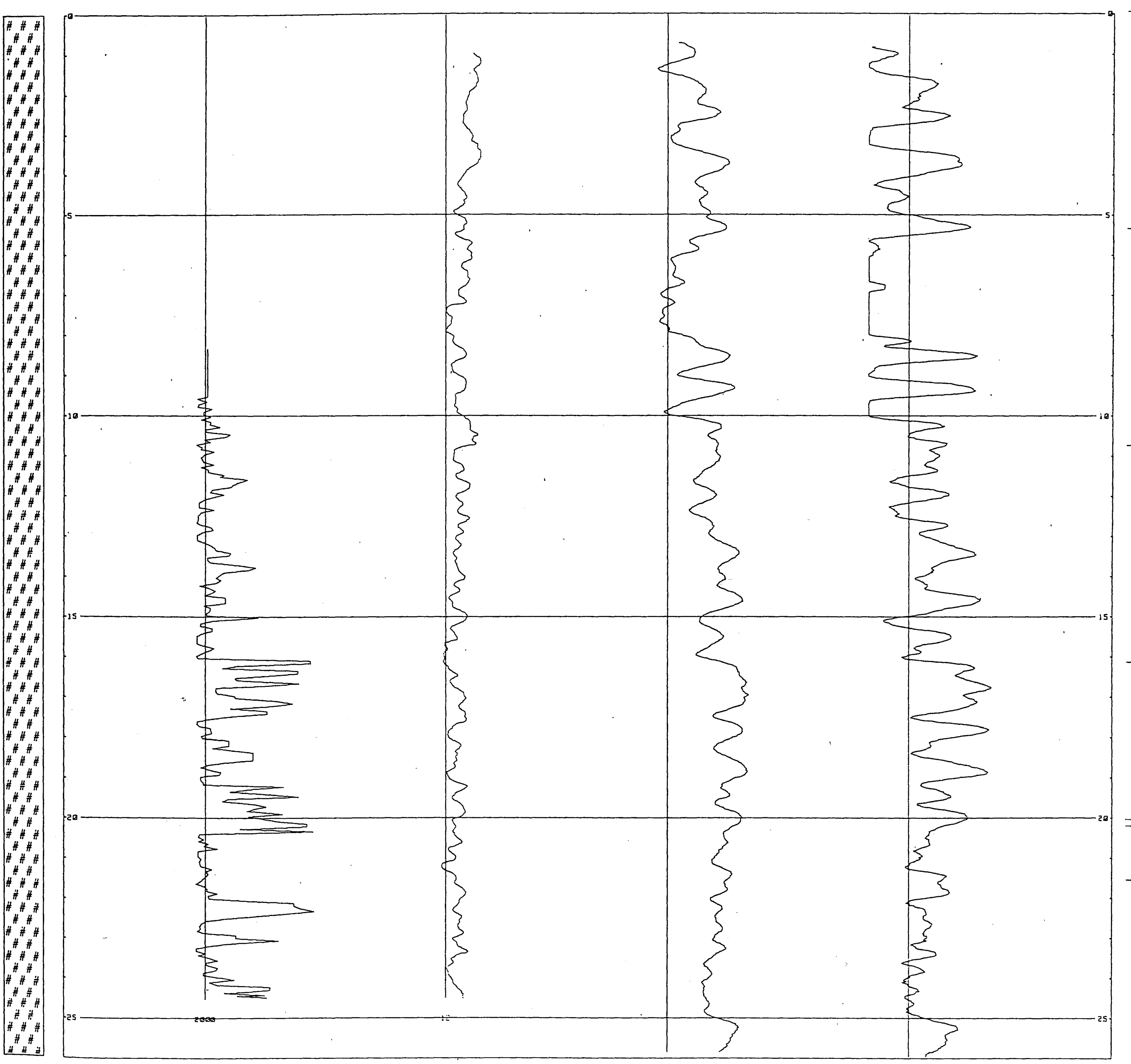


Figure 4 Well-log results from Shot-hole #1659 of the Tumut Survey

Lithology:	Harzburgite	
Depth:	17.74 metre	
Water-level:	1.00 metre	
Nom. diameter:	11.5 cm	
Log quality:	Short-spaced density	- OK
	Long-spaced density	- OK
	Caliper	- zero error, absolute values are too low
	Sonic	- not run

BMR ROCK PROPERTIES RESEARCH

COMPUTERISED BOREHOLE LOGGING

TUMUT SURVEY

The Honeysuckle

LOGGING SPEEDS·
DENSITY PROBE 3 M/MIN
DATUM ABOVE GROUND LEVEL .01 M.
OPERATOR· : Pramc and Alex
DATA LOG VER· 78506.01
DATA PLOT VER·78607.31
WATER LEVEL· 1.00 M.

PLOTTING SCALE· 1:50

BOREHOLE NO. #1659

DEPTH LOGGED 17.74 M.
DATE LOGGED 29 04 87
DATE PROCESSED 17 06 87

LINEAR DENSITY EQUATION IS Counts= A*Dens*EXP(B*Dens)

CALIPER cm.
Fil = 3 Skle = 8
8 12 16 20 24
CAL CM 10 20 30

SHORT SPACED DENSITY g/cc
Fil =15 Skle = 1 A = 472.8700 B= -.5518
1 1.5 2 2.5
CAL GM/CC 1.19 1.74

LONG SPACED DENSITY g/cc
Fil =15 Skle = 1 A = 3065.1000 B= -2.4350
1 1.5 2 2.5
CAL GM/CC 1.19 1.74

DEPTH (M.)

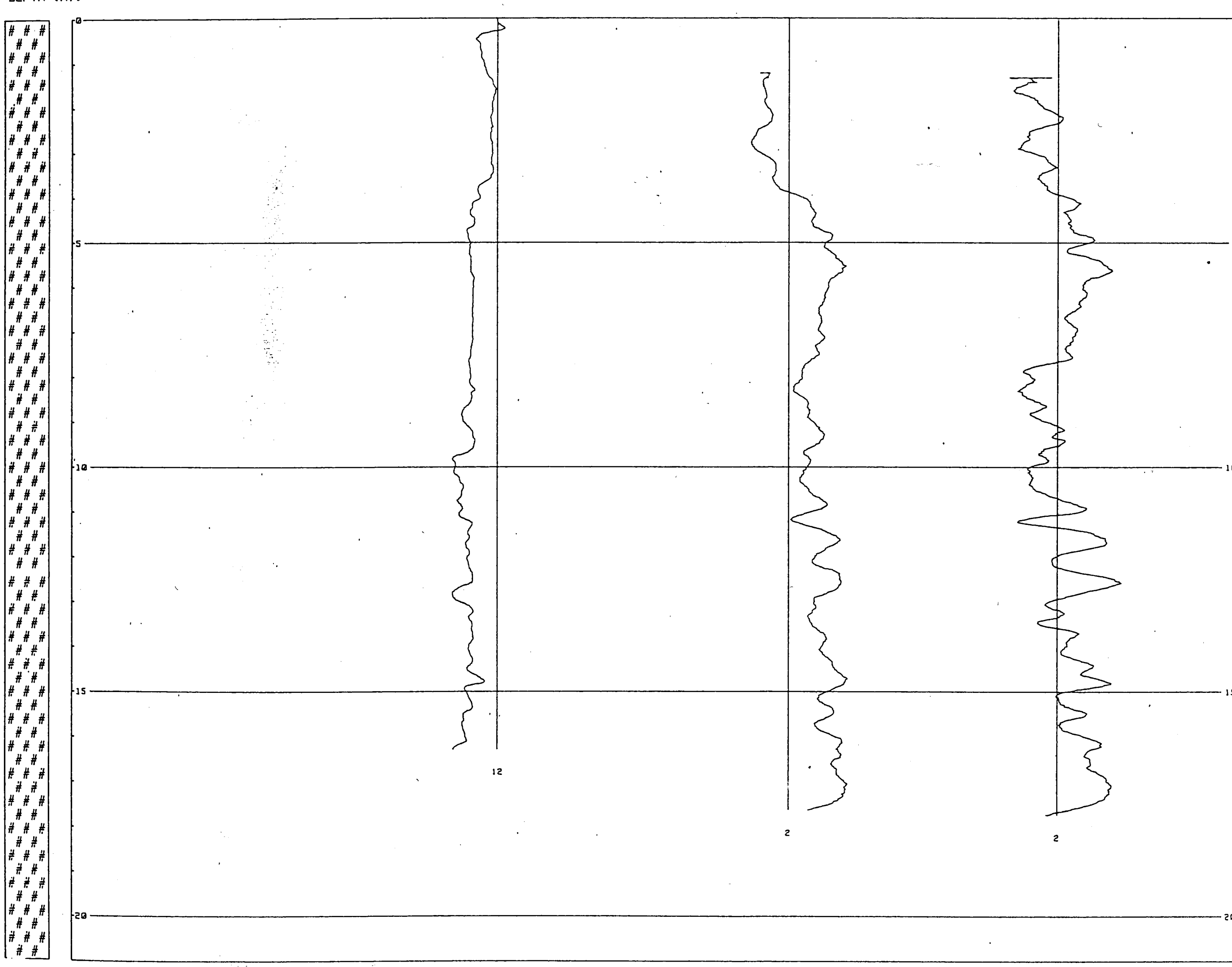


Figure 5 Well-log results from Shot-hole #1668 of the Tumut Survey

Lithology:	Serpentinite	
Depth:	16.24 metre	
Water-level:	1.00 metre	
Nom. diameter:	11.5 cm	
Log quality:	Short-spaced density	- OK
	Long-spaced density	- OK
	Caliper	- zero error, absolute values are too low
	Sonic	- not run

BMR ROCK PROPERTIES RESEARCH

COMPUTERISED BOREHOLE LOGGING

TUMUT SURVEY
The Honeysuckle

LINEAR DENSITY EQUATION IS Counts= A*Dens*EXP(B*Dens)

LOGGING SPEEDS:
DENSITY PROBE 3 M/MIN
DATUM ABOVE GROUND LEVEL .01 M.
OPERATOR: Praze and Alex
DATA LOG VER: 78506.01
DATA PLOT VER: 78607.31
WATER LEVEL: 1.00 M.

PLOTTING SCALE: 1:50

BOREHOLE NO. #1668

DEPTH LOGGED 16.24 M.
DATE LOGGED 29 04 87
DATE PROCESSED 17 06 87

CALIPER cm.
CAL CM 10 20 30

SHORT SPACED DENSITY g/cc
CAL GM/CC 1.19 1.74

LONG SPACED DENSITY g/cc
CAL GM/CC 1.19 1.74

DEPTH (M.)

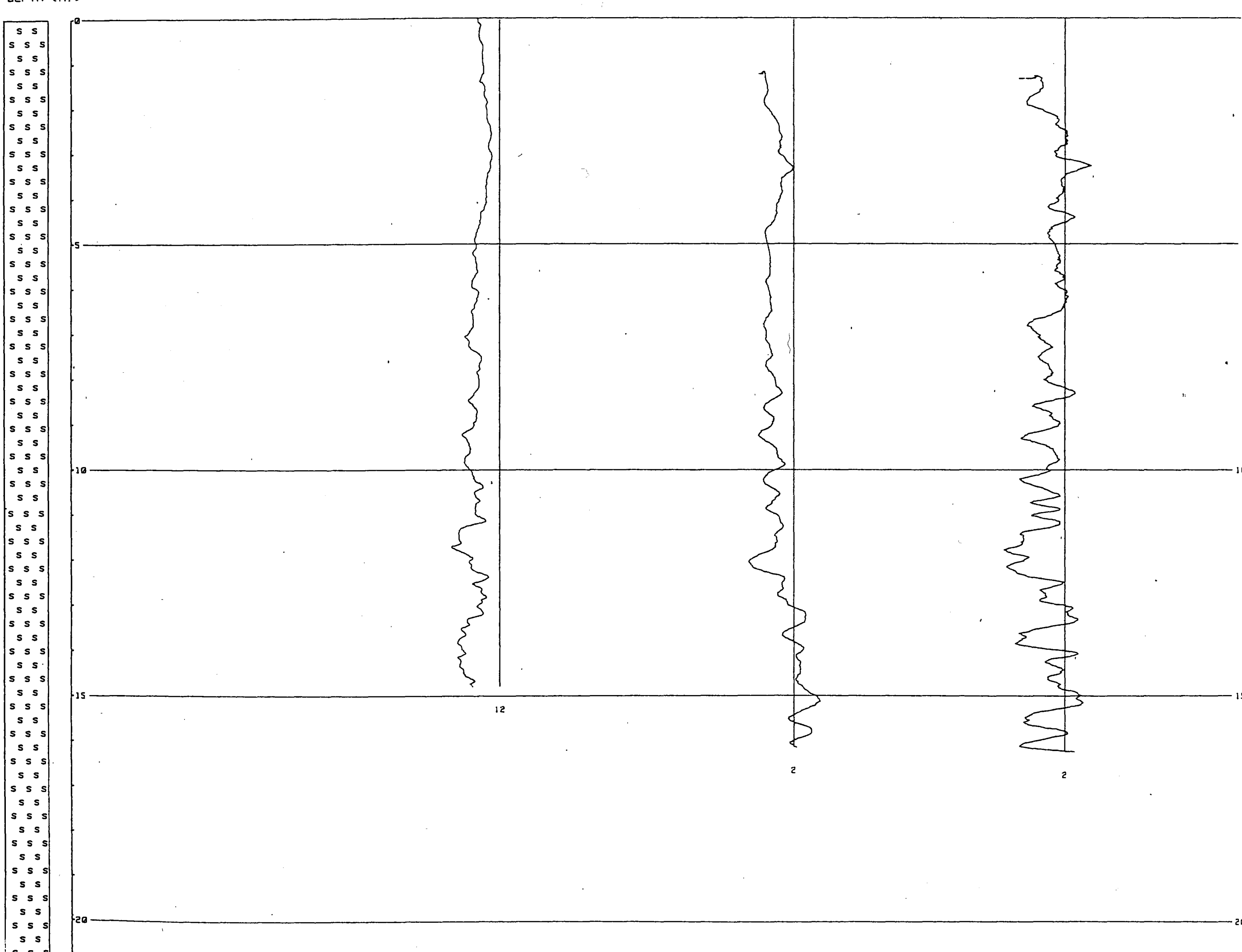


Figure 6 Well-log results from Shot-hole #1669 of the Tumut Survey

Lithology:	Serpentinite	
Depth:	22.17 metre	
Water-level:	1.00 metre	
Nom. diameter:	11.5 cm	
Log quality:	Short-spaced density	- OK
	Long-spaced density	- OK
	Caliper	- OK
	Sonic	- not run

BMR ROCK PROPERTIES RESEARCH

COMPUTERISED BOREHOLE LOGGING

LOGGING SPEEDS·
DENSITY PROBE 3 M/MIN
DATUM ABOVE GROUND LEVEL .01 M.
OPERATOR· : Prame and Alex
DATA LOG VER· 78526.01
DATA PLOT VER· 78607.31
WATER LEVEL· 1.00 M.

PLOTTING SCALE· 1 50

BOREHOLE NO. #1669

DEPTH LOGGED 22.17 M.
DATE LOGGED 29 04 87
DATE PROCESSED 17 06 87

TUMUT SURVEY
The Honeysuckle

LINEAR DENSITY EQUATION IS Counts= A*Dens*EXP(B*Dens)

CALIPER cm.
Fi -3 Scle - 8
8 12 16 20 24
CAL CM 10 20 30

SHORT SPACED DENSITY g/cc
Fi -15 Scle - 1 A - 472.0700 B- -.9510
1 1.5 2 2.5
CAL GM/CC 1.19 1.74

LONG SPACED DENSITY g/cc
Fi -15 Scle - 1 A - 3965.000 B- -2.4350
1 1.5 2 2.5
CAL GM/CC 1.19 1.74

DEPTH (M.)

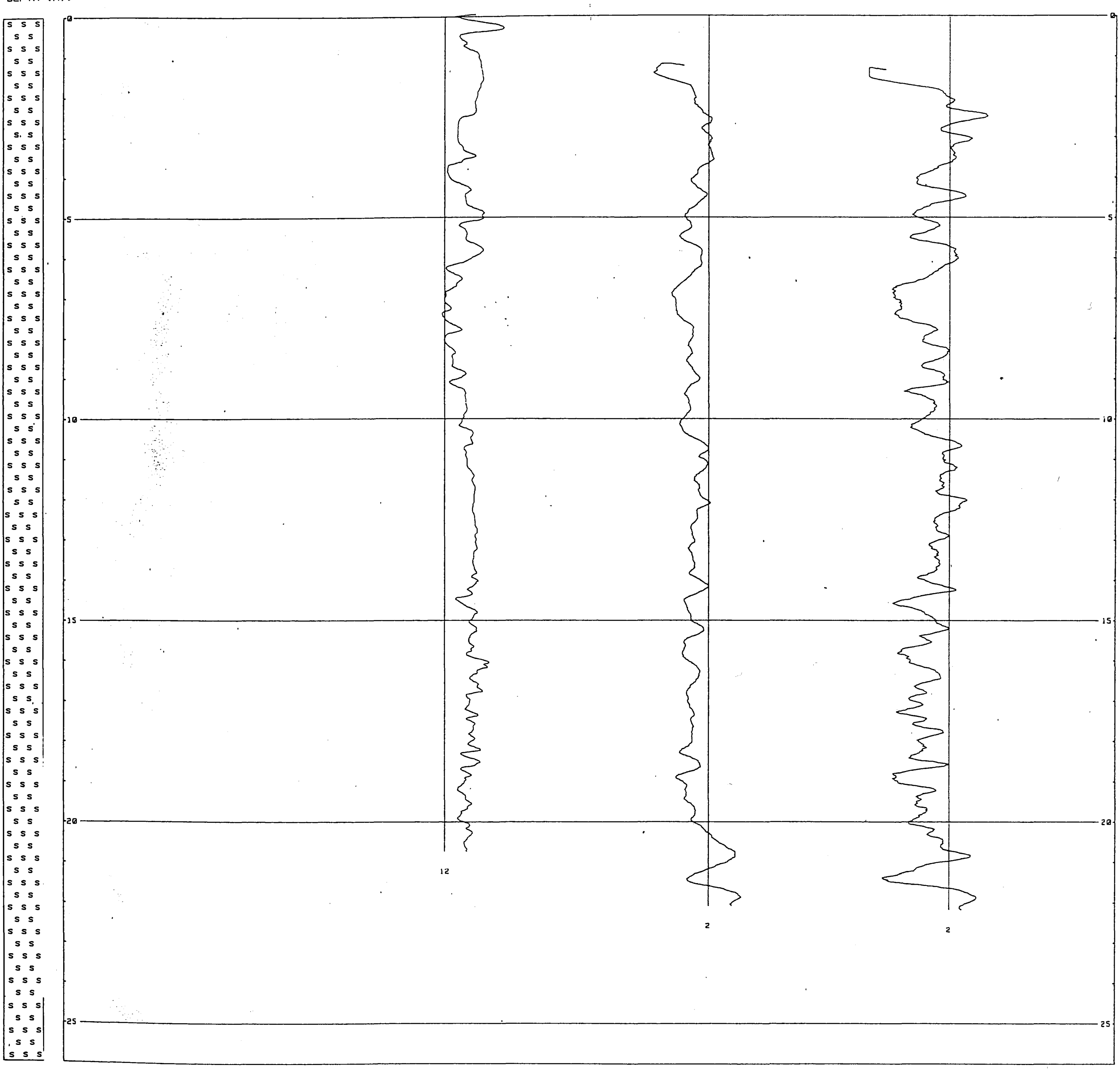


Figure 7 Well-log results from Shot-hole #1926 of the Tumut Survey

Lithology:	Weathered granite	
Depth:	26.23 metre	
Water-level:	0.00 metre	
Nom. diameter:	11.5 cm	
Log quality:	Short-spaced density	- OK
	Long-spaced density	- OK
	Caliper	- OK
	Sonic	- OK between 9.25 and 19.25 metre

BMR ROCK PROPERTIES RESEARCH

COMPUTERISED BOREHOLE LOGGING

LOGGING SPEEDS
DENSITY PROBE 3 M/MIN
DATUM ABOVE GROUND LEVEL 0. M.
OPERATOR: : Frame and Alex
DATA LOG VER· 78506.3
DATA PLOT VER·78607.3
DRY HOLE

PLOTTING SCALE .50

BOREHOLE NO. #1926

DEPTH LOGGED 26 23 M.
DATE LOGGED 29 04 87
DATE PROCESSED 16 06 87

TUMUT SURVEY
Adjungbilly

LINEAR DENSITY EQUATION IS Counts= A*Dens*EXP(B*Dens)

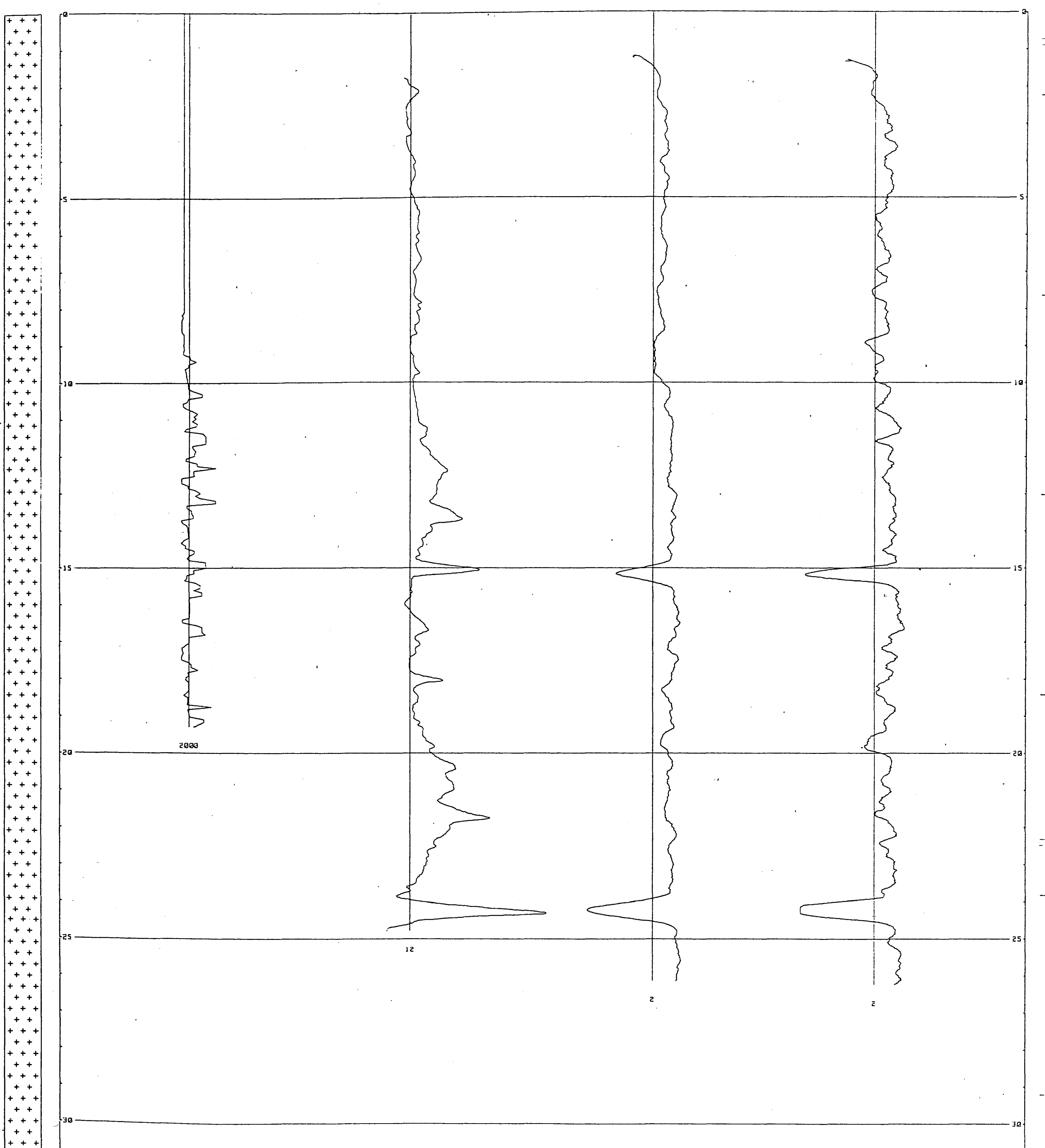
CALIPER cm.
CAL CM 10 20 30

SONIC VELOCITY m/sec
2000 4000 6000

SHORT SPACED DENSITY g/cc
1.5 2 2.5
CAL GM/CC 1.19 1.74

LONG SPACED DENSITY g/cc
1.5 2 2.5
CAL GM/CC 1.19 1.74

DEPTH (M.)



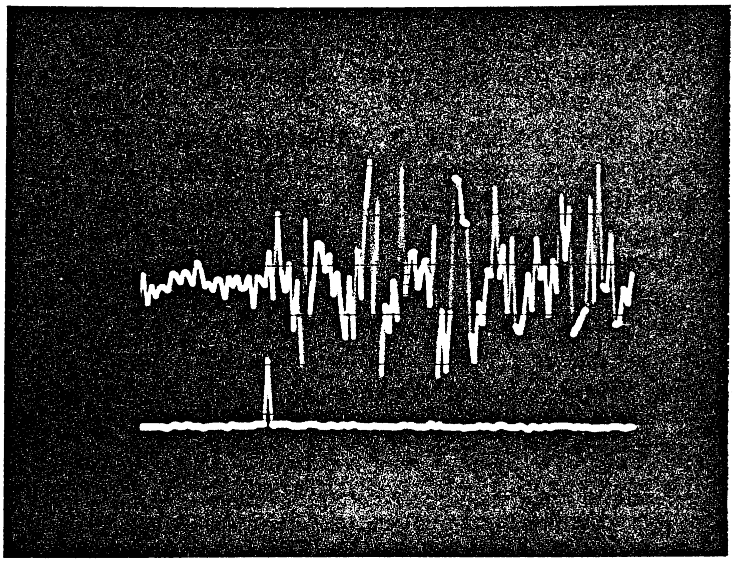
Laboratory Results

The results of the laboratory measurements on the core samples are summarised in Table 2. Typical ultrasonic velocity measurement results are illustrated in Figure 8 for both P and S waves. With reference to this figure, it is clear that the onset of the S-wave signal is inherently more difficult to identify than is that for P. As a consequence, there is likely to be more error in the S-wave velocity estimates than for P.

Table 2 Laboratory Data on the Collected Samples and Comparisons with Well-log Results

Rock Type	density (kgm^{-3})	V_p (ms^{-1})	V_s (ms^{-1})	Acoustic Impedance P ($kgm^{-2}s^{-1}$ $*10^6$)	Acoustic Impedance S ($kgm^{-2}s^{-1}$ $*10^6$)
weathered harzburgite	2615	4279	2665	11.19	6.97
" "	2667	4117	3181	10.98	8.48
" "	2614	4202	3083	10.98	8.06
weathered serpentinite	2576	4676	3219	12.05	8.29
" "	2520	4861	3829	12.25	9.64
fresh granite	2650	5600	3800	15.4	10.1
Well-log Results					
weathered granite	~2500	2000	ND	~5.0	-
less-weathered harzburgite	>2500	>6950	ND	>17.4	-

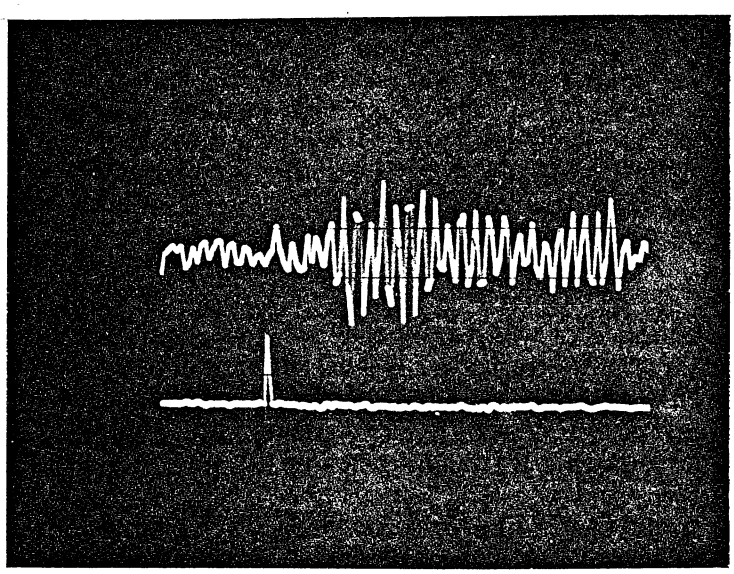
P-wave signal



-- transmitted signal

-- marker

S-wave signal



-- transmitted signal

-- marker

Figure 8

Ultrasonic velocity results for a sample of weathered Serpentinite from the Honeysuckle Range (see text).

Discussion and Conclusions

The geophysical well-logging results and the data collected in the laboratory serve to delineate the P and S-wave impedances of the principal rock types encountered along the seismic corridor, with the exception of the sediments. Data for the latter can however be obtained from the literature for rocks in other parts of the world. Some of these data are listed in Table 3 together with additional data on other serpentinites, harzburgites and granites.

The data of Table 3 have, in the main, been collected from rock samples subjected to high confining pressures in order to close cracks and voids which might be present. As such, these data reflect on the velocities and impedances of similar rocks emplaced at deeper levels in the crust where dilatant features such as cracks are on the whole, unlikely to be widespread. These tabulated data are therefore an excellent complement to the data that we have collected from rocks either at the Earth's surface or in the near-surface. Our measurements all pertain to rocks containing populations of cracks.

The results of our study and the literature values of Table 3 are illustrated in Figure 9. As can be seen in this figure, the P-wave impedances of the ultrabasic harzburgites are relatively high when these rocks are crack-free as would be expected from their high densities. The effect of weathering is dramatic however. The introduction of cracks and the formation of layer silicate minerals in the weathering environment results in very substantial decreases in P-wave impedance values. Similar observations can be made with regard to the serpentinites and the granite, though in these cases the pristine rocks have much lower P-wave impedances.

The P-wave impedances of common sediments are found to lie within a fairly narrow band when these rocks are crack-free. Presumably, weathering would again act to lower their impedances, though particularly in the case of clean quartzose rocks such as sandstone and of its metamorphic relation, quartzite, the impact of weathering might be expected to be much lower since these rocks are very stable in the weathering environment.

The smearing out of the P-wave impedances due to weathering makes it necessary to draw separate conclusions *vis a vis* the magnitudes of any seismic impedance contrasts. Thus we will consider on the one hand, the likely situations in the shallow crust and on the other, that likely at deeper crustal levels.

Shallow Depths

Harzburgite and serpentinite will probably not be seismically separable as a result of any consistent seismic impedance contrast. There is however a strong likelihood that these rocks will have a significantly higher impedance than that of weathered granite. Given the expected but unquantified reductions in impedance expected in the sedimentary rocks as a result of weathering, there is a possibility that in some cases, these rocks will have significantly lower seismic impedances than those of the plutonic rocks. Quartz-rich sediments on the other hand might conceivably show the opposite relationship with higher impedances than the plutonic rocks.

Greater Depths

At depths below the influence of weathering and where metamorphic retrogression has not played a significant role, the harzburgites would be expected to display much higher seismic impedances than either the serpentinites or the meta-sediments and granite. Thus in the deeper crust, the juxtaposition of ultrabasic rocks with flysch and granitoids along faults should be seismically resolvable if the geometry of the interface is suitable for seismic imaging.

Granite on the other hand, is not likely on the basis of the impedance measurements, to be seismically resolvable from the sediments. Such resolution may however be possible if there are seismically resolvable differences in the internal structures of juxtaposed granitic and sedimentary bodies.

Finally, serpentinites in the deeper crust may exhibit slightly higher seismic impedances than the granitoids and metasediments and thus should, when associated with major faulting, aid in the delineation of these structures.

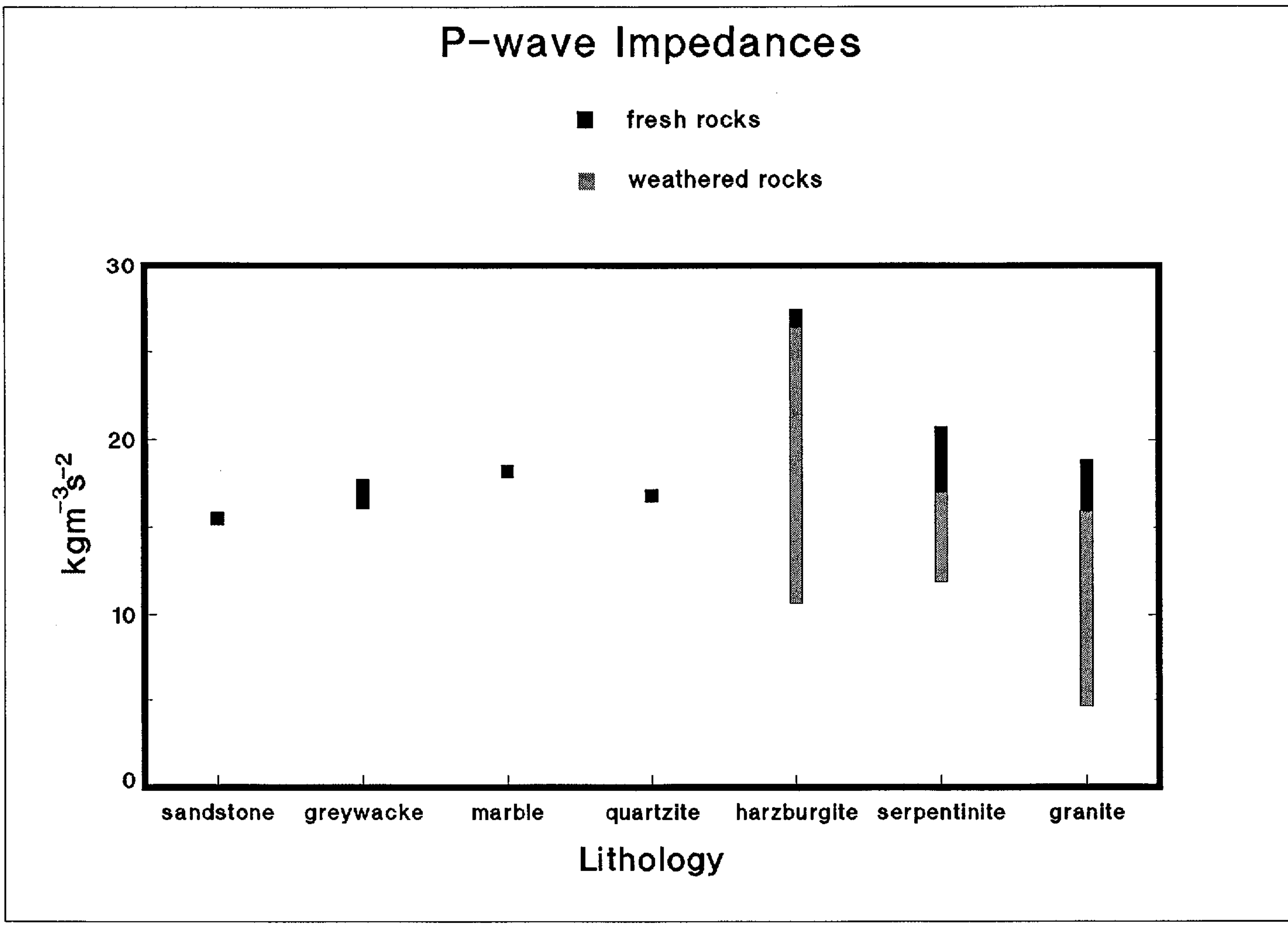


Figure 9

Graph of the data of Tables 2 and 3 (see text).

Table 3 Acoustic Impedance Calculations from Other Data

Rock Type	density (kgm^{-3})	V_p (ms^{-1})	V_s (ms^{-1})	Acoustic Impedance P ($kgm^{-2}s^{-1}$ $*10^6$)	Acoustic Impedance S ($kgm^{-2}s^{-1}$ $*10^6$)	Ref.
		Data at 1GPa unless otherwise indicated				
sandstone	2659	5850	4080+	15.5	10.8+	1
greywacke, (NZ).	2679	6130	-	16.4	-	1
greywacke, (Quebec)	2705	6280	-	17.0	-	1
greywacke, (Czech.)	2688	6280+	3710+	16.9+	10.0+	1
	2749	6330+	4080+	17.4+	11.2+	1
quartzite	2647	6350	4000+	16.8	10.6+	2
marble	2704	6720+	3490+	18.2+	9.4+	2
granite, (Westerly, USA)	2619	6230	3580	16.3	9.4	1
granite, (Rockport, USA)	2638	6510	3770	17.2	9.9	1
granite, (Gunning)	2747	6720	-	18.5	-	3
granite, (Berrigan)	2615	7060	-	18.5	-	3
granite, (Eugowra)	2653	6590	-	17.5	-	3
harzburgite, (Bushveld)						
X	3380	7820	-	26.4	-	1
Y	3371	8050	-	27.1	-	1
Z	3356	7970	-	26.7	-	1
harzburgite, (Bushveld)	3369	7950	-	26.8	-	2
serpentinite, (Vermont)	2806	6840	3830	19.2	10.7	1,2
serpentinite, (Massachusetts)						
X	2768	6680	-	18.5	-	1
Y	2807	7270	-	20.4	-	1
Z	2792	6970	-	19.5	-	1
	2789	6970	-	19.4	-	2
serpentinite, (California)	2718	6310	3280	17.2	8.9	1,2

References 1 = Anderson and Liebermann (1966),
2 = Press (1966)
3 = unpublished results of Chopra (1985)

+ signifies data collected at < 1GPa confining pressure

Acknowledgements

We wish to thank Jim Leven for his assistance with the collection of the well-logging data both for his own time and for the drilling support that he was able to provide us during his management of the field operations.

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