

# MULTI-SHOT PROCESSING FOR BETTER VELOCITY DETERMINATION

by

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## ABSTRACT

We perform a technique called multi-shot processing on a section of 12-channel sonic logs in order to better resolve compressional and shear velocities. The data are from the ODP Leg 102 cruise, which occupied drill site 418A near the Bermuda Rise in 1985. Multi-shot processing has been done on a 9 meter section of this data, using different combinations of numbers of shots vs. numbers of receivers in an attempt to compare the vertical resolution and stability of this processing method. The method is stable only with certain shot-to-receiver subarray combinations. This paper demonstrates that the optimum combinations using this set of data are 4 shots with 6 receivers apiece, and 3 shots with 8 receivers each. While a combination using 5 shots with 4 receivers is possible, the method produces spurious results. This may be because of spatial aliasing over too few receivers, or it may be a result of poor outside control over the entire experiment (ship heave, etc.). It is hoped that an optimum subarray combination can be used to resolve velocities over shorter array lengths using the redundancy in the sonic data. This would result in a greater ability to characterize fracturing and alteration in the oceanic crust, since velocity variations have been shown to correlate with fracture zones.

## INTRODUCTION

The structure of the ocean crust has been an object of scientific study for many years. The results of this study have revealed the layered structure which characterizes most of

the earth's ocean basins. This structure is simply modelled as pelagic sediments (Layer 1) overlying basaltic pillows and flows (Layer 2A). These in turn overlie metamorphosed pillows (Layer 2B), which grade into metamorphosed intrusive dykes (Layer 2C) (Moos et al., 1986). Numerous sites drilled by the Ocean Drilling Program (ODP) and the Deep Sea Drilling Project (DSDP) have penetrated Layer 2, including Well 418A on the Bermuda Rise and Well 504B near the Costa Rican Rift zone. These two drill sites provide an ideal opportunity to study the chemical, lithological and structural characteristics of deep ocean crust. One aspect of the crust to be characterized is the amount and type of fracturing in Layer 2 as a function of depth, lithology and age. To accomplish this, good velocity estimates gleaned from multi-channel sonic (MCS) logging data can be correlated with fracture zones (Moos and Zoback, 1983; Paillet, 1980; Moos, 1988; Anderson et al., 1984). The presence of fracture zones will affect both  $V_p$  and  $V_s$ ; however, the interpretation of velocity data will depend heavily on the vertical resolution and signal to noise (S/N) ratio achieved through the processing technique. Multi-shot processing (Hsu and Chang, 1987; hereafter referred to as MSP) uses subarrays of the receiver section and the small moveup between source firings to combine velocity information over a depth interval. Thus both goals of vertical resolution and better S/N ratio may be achieved by using this technique.

A set of 30 depth points covering a 9 meter depth interval from the well site 418A in "old" oceanic crust has been processed using the MSP method. The data were processed using subarrays of 4 shots with 6 receivers, and 3 shots with 8 receivers for all depth points. Also, some runs were made using 1 shot with 12 receivers, and 5 shots with 4 receivers. Neither one of these combinations is satisfactory; 1 shot with 12 receivers does not take advantage of the method, and using 5 shots with only 4 receivers produces unstable results. By determining the optimum shot number-receiver number combination, the benefit of the method can be maximized. A larger subset of the MCS data can then be processed using this optimal combination in the hope that velocity variations in rapidly changing lithology will be better resolved.

## PROCEDURE

The multichannel sonic log is a full waveform array-type logging tool which utilizes 12 receivers at .15 m (.5 ft) spacing to record the entire waveform at each source firing. Since there are multiple receivers, a robust technique such as semblance can be used to give accurate estimates for the compressional, shear and Stoneley velocities. MSP makes use of the inherent redundancy in the MCS data. With an inter-receiver spacing of .15 m, and a source moveup of .3 m (1 ft), there is an overlap between up to 5 successive firings of certain receivers at common depth points. MSP takes advantage of this overlap by stacking the semblance estimates from a subarray of receivers covering the same depth interval. Figure 1 shows the shot moveup and

receiver-shot combinations possible in the MSP technique.

Semblance is a method used to estimate slowness from well logs (Kimball and Marzetta, 1984). The semblance is a quantity defined as the normalized coherent energy in a time window of length  $T_w$ , at arrival time  $T_0$  on trace 1, with linear moveout given by the slowness  $S$  (Kimball and Marzetta, 1984):

$$p(S, T_0) = \frac{\sum_{t=T_0}^{t=T_0+T_w} \left[ \sum_{j=1}^N A_j(t + (j-1)\Delta z S) \right]^2}{N \sum_{t=T_0}^{t=T_0+T_w} \left[ \sum_{j=1}^N A_j^2(t + (j-1)\Delta z S) \right]} \quad (1)$$

where:

$N$  = number of receivers,

$A_j$  = amplitude of trace  $j$ ,

$\Delta z$  = receiver offset.

Each subarray of the MCS data over a selected depth interval is processed using this technique. Characteristic plots of the semblance values as a function of arrival time ( $T_0$ ) and slowness ( $S$ ) for two different subarrays are shown in Figure 2. The major peaks are easily identified as the compressional, shear, and Stoneley arrivals. Since each subarray corresponds to a different offset range, the arrival time varies for each mode within different subarrays. However, since the slowness for each mode should be the same (averaged over the length of the subarray), the semblance data can be stacked by projecting the semblance onto the slowness axis. From Hsu and Chang (1987):

$$\tilde{p}_{i,n}(S) = \max_T(p_{i,n}(S, T)) \quad (2)$$

where:

$i$  = source position,

$n$  = subarray number,

$S$  = slowness (sec/m),

$T$  = arrival time at receiver 1 (sec),

$\tilde{p}$  = projected semblance statistic,

$p$  = semblance statistic.

Once the semblance from each subarray has been projected onto the slowness axis, the projected values from all the selected subarrays are combined via an algebraic mean. In this manner, velocity estimates as a function of depth can be found. The vertical resolution of these estimates depends on the length of the subarray chosen, and the S/N ratio depends on the number of shots used in the stacking procedure.

## PROCESSING RESULTS

A subset of the MCS data gathered by the ODP Leg 102 shipboard party has been processed using the MSP technique described in the previous section. The section chosen is located at a depth of 6300.7 meters below rig floor (mbs) which corresponds to a depth of 781.7 meters below the sea floor (mbsf). The depth interval spanned is 9 meters. It corresponds to an interval in the borehole characterized by pillow basalts grading into massive basalts (see Figure 3 for a reproduction of the MCS data results).

Using Figure 1 as a guide, it is clear that only certain shot number-receiver number combinations are available for use in the MSP procedure. In order to provide a basis for comparison, many different combinations were processed: 4 shots with 6 receivers each (a vertical resolution of .75 m), and 3 shots with 8 receivers each (a vertical resolution of 1.15 m). In addition to these combinations, 5 shots with 4 receivers each (a vertical resolution of .45 m), and semblance using the full array of 12 receivers were processed. The latter combination was uninteresting in that it did not utilize any of the power of the method of MSP, so we concentrated on the results the other combinations produced.

Semblance values are calculated for each subarray; the program scans for velocities between 1.3 km/s and 7.5 km/s, and arrival times between 0 and 1800  $\mu$ sec. In Figure 4, the output following the projection of the semblance values for three different shot-receiver number combinations is shown, along with the combined semblance statistic. A peak along these curves indicates that an event is present at a particular slowness. It is obvious from this figure that while the 4-6 and 3-8 combinations produced fairly consistent results from the semblance calculations, the 4-5 shot-receiver combination is highly uneven and unstable. The final combined semblance statistic for that combination reveals little information. Thus it seems that the optimal combinations for this particular data set (with a source moveup twice that of the inter-receiver spacing) are either 4 shots - 6 receivers, or 3 shots - 8 receivers. With another data set, other combinations might be possible, but below and above a certain threshold, the results using MSP apparently become degraded.

Figure 5 shows the results of processing all 30 depth points for compressional, shear, and Stoneley slownesses. This processing was done for both the 4-6 combination and the 3-8 combination. The results are fairly similar with greater variability visible on

the 4-6 results. This may be an indication of greater vertical resolution, but this cannot be verified until further data have been processed.

## CONCLUSIONS

The method known as multi-shot processing (MSP) has been applied to ODP data from well 418A, with the result that certain combinations of numbers of shots—numbers of receivers produce more consistent, stable values for velocity estimation. While each subarray independently produced good semblance values, the combination of subarrays across a depth interval tended to degrade above a certain number of shots. Thus an optimal combination is necessary to produce reliable results. In the work done so far, the combinations of 4 shots with 6 receivers or 3 shots with 8 receivers produce the best results. Above that number of shots, a smearing of the semblance peaks occurs, and the results are not reliable. It is possible that with better outside control of the logging experiment (knowledge of ship position, better instrument control, etc.), more shot number - receiver number combinations will be possible with MSP. In the future, this method may be useful in characterizing velocity variations in a rapidly changing lithological zone. Further, the type and amount of fracturing in various zones may be verifiable using multi-shot processing.

## ACKNOWLEDGEMENTS

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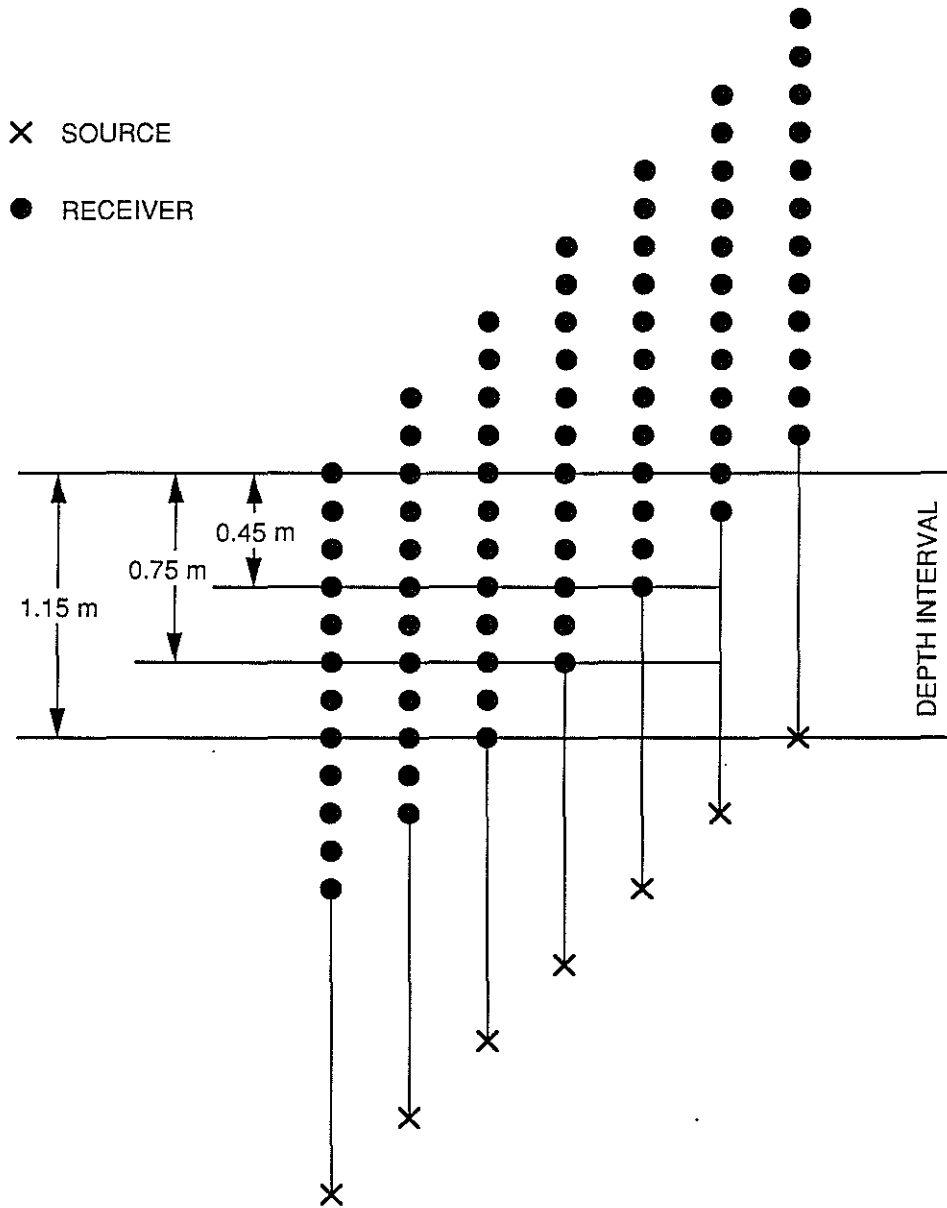


Figure 1: Successive source locations for a 12-receiver tool, assuming an inter-receiver spacing of .15 m and a source moveup of .3 m. Some various source number-receiver number combinations to be used in MSP are shown (after Hsu and Chang, 1987).

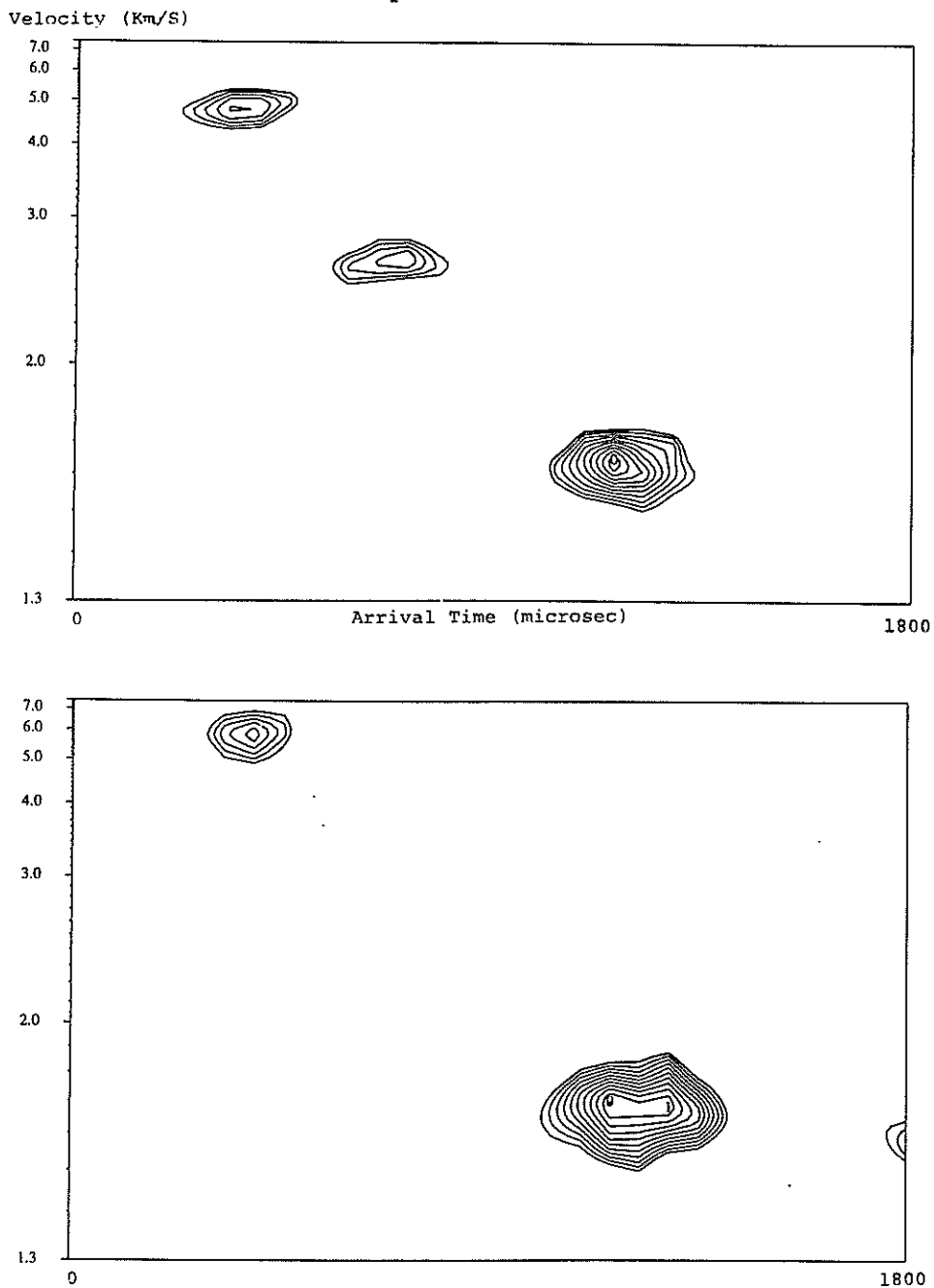


Figure 2: Example output from semblance calculations from the MCS data. The semblance values are contoured in the arrival time–slowness plane. At the top are the results from processing an array of 12 receivers; at the bottom are the results from a subarray using 6 receivers. The compressional and Stoneley arrivals are easily seen.



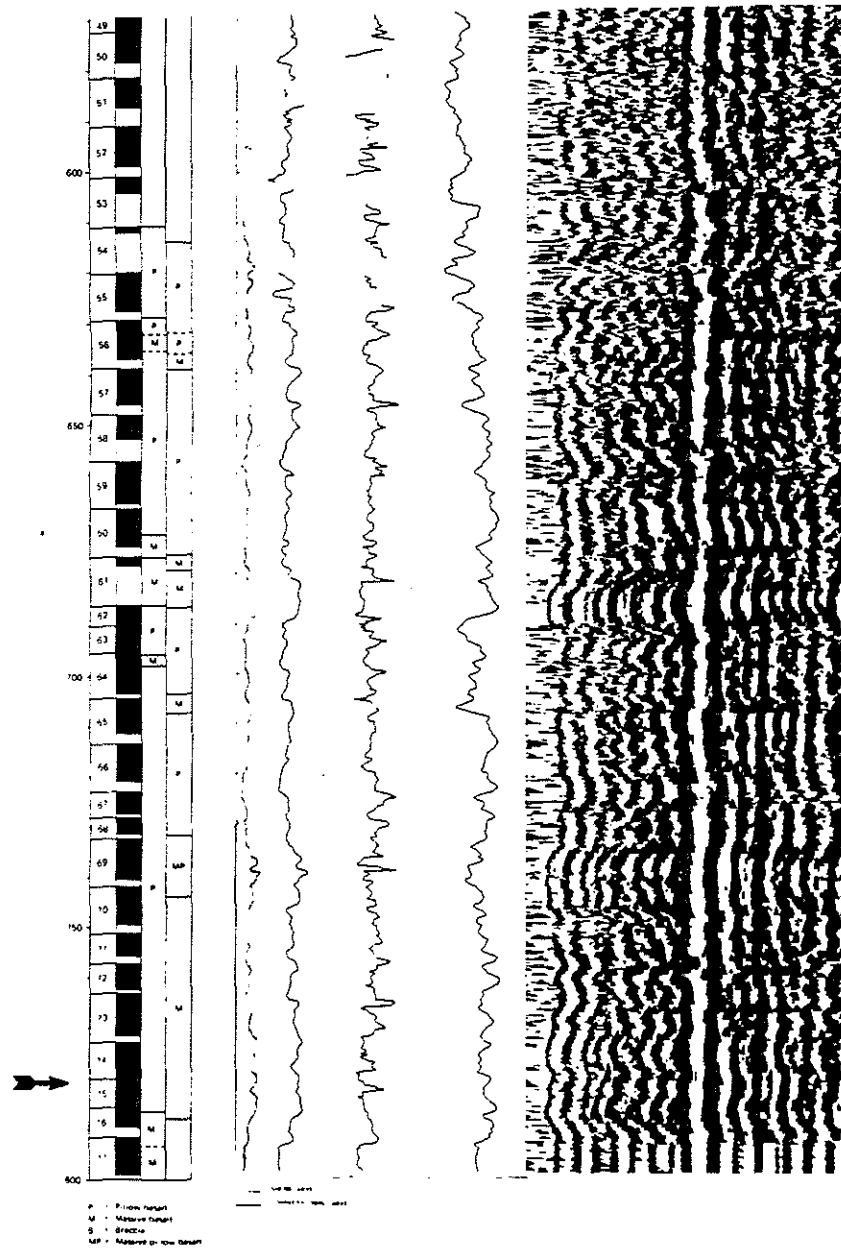


Figure 3: MCS data from drill site 418A. The section shown is from near the bottom of the well (from Leg 102 Shipboard Scientific Party, 1986). An arrow points to the approximate starting depth of the data processed in this paper.

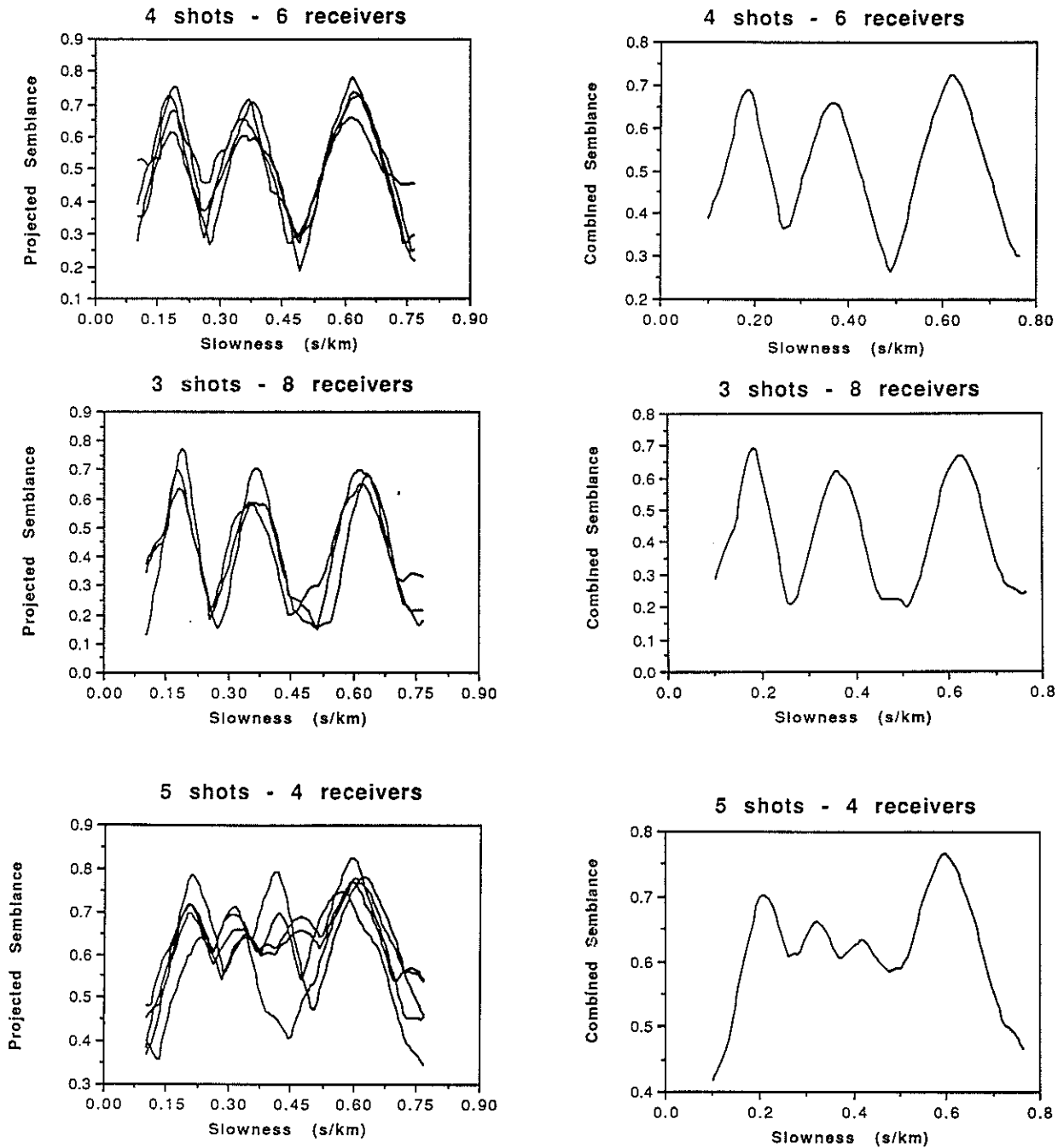


Figure 4: On the left are the projected semblance values as functions of slowness for various shot number - receiver number combinations. On the right are the results from combining the projected semblance curves through an arithmetic mean. The estimates are taken from depth point 6302.1 mbs.

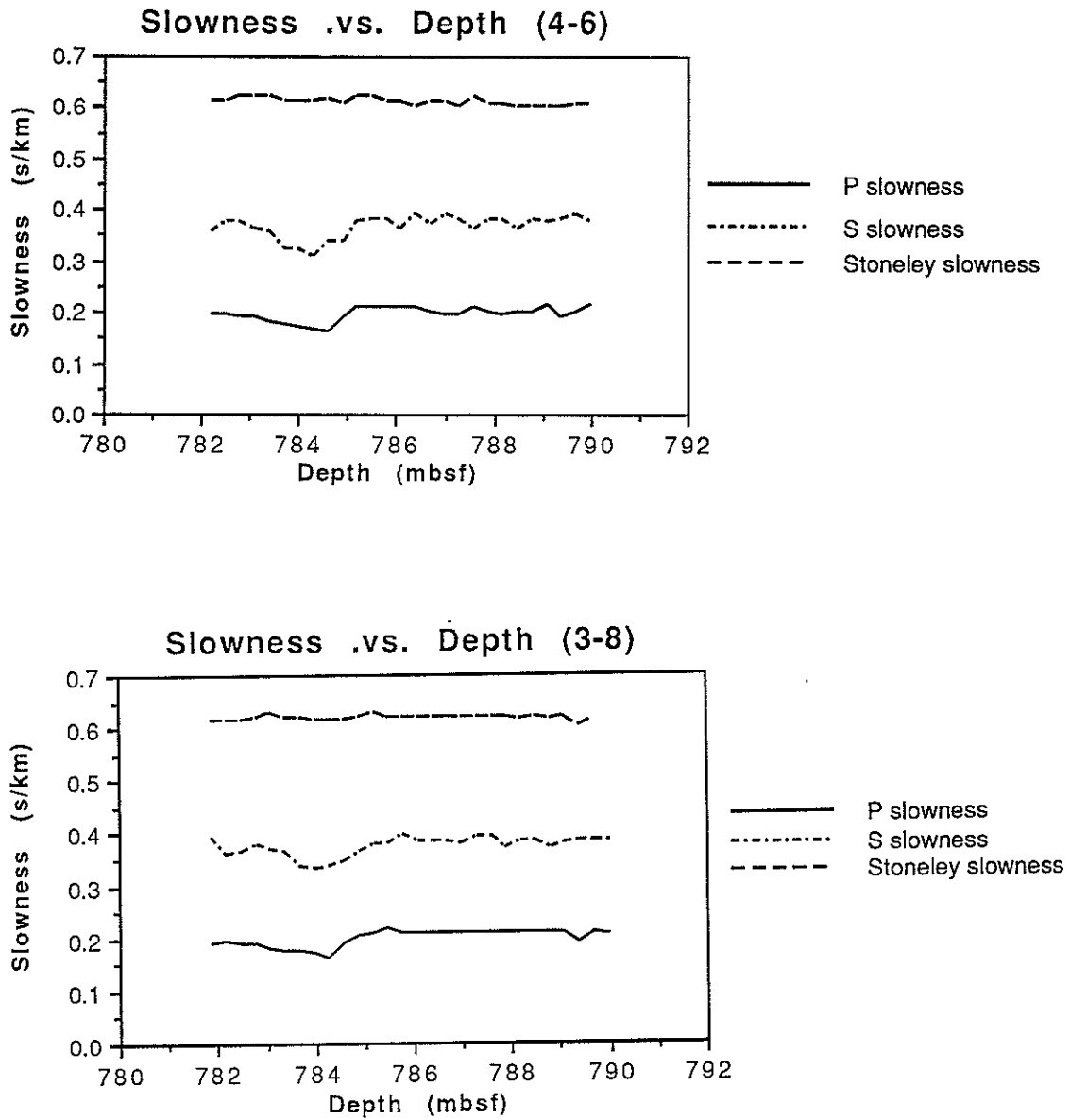


Figure 5: The estimates of compressional, shear, and Stoneley velocities as a function of depth below the sea floor for (top) 4 shots with 6 receivers each, and (bottom) 3 shots with 8 receivers. Note the many similarities in the results.

