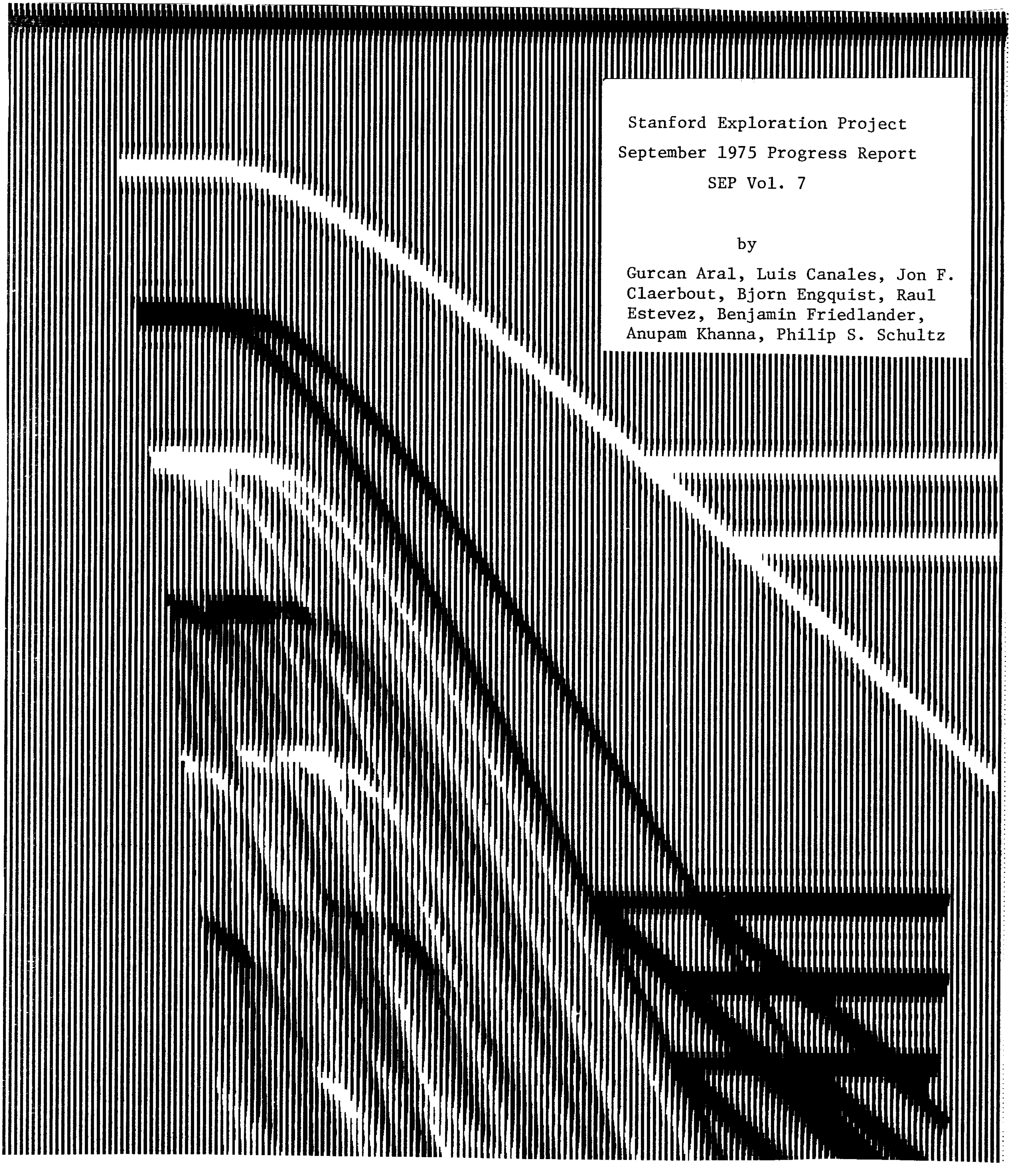

Stanford Exploration Project

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by

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Purpose, Progress and Goals

The Stanford Exploration Project springs from the belief that valuable petroleum prospecting information is not being extracted from reflection seismic data by current industry data processing techniques. A fundamental operation in the extraction of such information is the downward and upward extrapolation of seismic waves. In simplest form this is just migration. We have made and will continue to make technical improvements in accuracy, speed and memory organization to these basic migration-like operations. Beyond this continuing task are three major achievements; the completed works of Don Riley (SEP-3), Steve Doherty (SEP-4) and John Burg (SEP-6).

Riley's work began with the contention that the industry has failed to solve the deep water multiple problem, particularly on the Canadian Atlantic Shelf. He found that conventional deconvolution does not even solve the problem correctly in the noise-free case; it doesn't predict the correct peglegs. He developed a modified one-dimensional theory which worked satisfactorily in flat regions. A study of field examples showed the importance of small variations from horizontal stratification. This motivated an entirely novel approach to synthesis and removal of deep water multiples which was based on wave equation migration techniques.

Doherty investigated the problem of migration of offset information before stacking. This is important for velocity estimation in regions of complex earth structure as may be expected for the remaining U. S. continental undiscovered reserves. One surprising result of Doherty's is that it should be possible to estimate velocity on data which has no lateral (midpoint) continuity. Such data would arise hypothetically in an earth of random point scatterers and could arise practically in a region of poor geologic continuity. Even more surprising is that velocity estimation in such a situation should work with two-dimensional data coverage over a three-dimensional distribution of scatterers! Although Doherty's technique has yet to be proven in the field it is tantalizing because of the many large sedimentary basins in the world which have been unexplored; not because there is no oil, but because the seismic data recorded there shows such poor lateral continuity. For example, the state of Oregon has large regions in which volcanic rocks among the sediments destroy lateral continuity in the data.

John Burg completed what must be nearly a decade of work on maximum entropy spectral estimation. Spectral estimation is important in exploration mainly in shallow water Gulf Coast type environments, but work has now begun in the present report on maximum entropy source waveform estimation in deep water.

The work of Riley, Doherty and a number of contractors has led us to the certain knowledge that seismic data often contains a considerable amount of information which we cannot extract by routine processing. The Bass Straits strike which by itself left Australia nearly self sufficient in petroleum was almost missed due to small scale lateral velocity variation. A number of contractors have pointed out the difficulty of resolving velocity variation within the geophone spread. Also, although Riley's diffracted multiple theory worked well on synthetic data, we were unable to get it to work on field data. The problem was traced to the point where we recognized strong differences between common reflection point (crp) stacks and vertical stacks. We were able to establish that Riley's method should work exactly on individual common shot profiles or on vertical stacks, but we were unable to show that it would have practical utility on crp stacks.

Our main goal as put forth in the last progress report (SEP-5) was to find out whether the difficulties of the preceding paragraph could be resolved by the slant stack. Suppose shots were fired in rapid succession so as to provide a slanted downgoing plane wave for earth illumination. Such a situation may be synthesized from conventional data by means of the <u>common geophone slant stack</u>. This stack differs from the industry common reflection point stack in two important respects.

(1) First, in the slant stack the moveout function is linear with offset and independent of time. Thus, the usual industry hyperboloidal moveout before stack has a "focusing" advantage.

(2) Second, the industry stack is done at a common midpoint, not at a common geophone. Thus, the industry stack has the advantage that for layered media it does not "smear" subsurface information.

The above advantages of the industry stack are degraded where the earth is not horizontally stratified. This degradation appears as processing artifacts which seem to be impossible to remedy by subsequent processing. For the common geophone slant stack, however, the seismic section is also a seismic wave from a possible experiment. Any "artifact" in this stack must be manageable with the wave equation. Our most immediate goals are to show that we can predict diffracted multiples and estimate rapid but smooth horizontal velocity variations on slant stacked data. Achieving these goals we may then seek the remaining advantages of the industry stack by stacking the cleaned up slant stacks.

The present report is mainly concerned with our recent progress. I am pleased to report that the first slant stack on field data which Phil Schultz just completed is comparable in quality to the industry common reflection point stack. See pages 102-131 . We had expected this theoretically, but it is a big relief to be assured that we will not be immediately thwarted by unexpected practical realities. The bulk of the present report is theoretical developments which will be required before we can go to the next steps, namely, synthetic data, analysis of synthetic data and finally, velocity analysis and multiple suppression on field data.

Theoretically and experimentally one finds different waveforms on plane wave stacks of different angles. These arise from antenna pattern effects of source and receiver arrays and from angle dependence of reflections. Before velocity analysis it is worthwhile to balance the spectra of the various traces. The conventional approach balances spectra by following a whitening deconvolution filter by a bandpass filter. An alternative approach advocated in a section of this report is to replace the spectrum of each trace by the geometric mean spectrum.

Finally I would like to provide some introductory remarks to the work of Bjorn Engquist, a mathematician from Uppsala, Sweden, who recently joined us. In SEP-2, page 296, we got a glimpse of the magnitude of the advantage of fourth order accuracy compared to second order accuracy in migration. In terms of spatial x differences, a 1.5 percent accuracy occurs at 10 points per wavelength for second order and 4 points per wavelength for fourth order. There is obviously a considerable saving in computer memory in going to fourth order. There is also a speed advantage. The problem of accuracy is even more acute with time differencing and time derivatives. Again in SEP-2, page 296, we see that 16 points per wavelength are required to achieve one percent accuracy on the time axis. To be honest, we have usually been doing our migrations on 4 millisec data which often corresponds to about 10 points per wavelength or about 3% accuracy. Engquist's work shows how we can use fourth order accuracy on the time derivative and also achieve fourth order accuracy on the lateral x axis without restricting our choice of Δz .

While we have not yet had time to fully analyze the implications and best use of Bjorn's results, it seems that we may reasonably hope to be able to migrate 8 millisec data with equal or slightly better accuracy than we now get on 4 millisec data. Also, the calculation should require about half the memory and roughly half the computation time. These will be important savings as migration is later applied to multiple elimination and velocity analysis.

Jon F. Claerbout
10 September 1975

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