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PHYSICAL MODELING: AN AID FOR PRODUCTION GEOPHYSICISTS

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ABSTRACT

The Seismic Acoustics Laboratory (SAL) has as its principal research facility a physical modeling system. Experiments conducted with this system in the area of 3D seismic profiling have led to practical applications of physical modeling for both exploration and production geophysicists.

The physical models, which are scanned in a large water tank, have been fabricated to represent various structural and stratigraphic traps. Across these models, the scanning source and receiver are independently controlled which allows for an infinite number of data acquisition schemes. To insure proper scaling of the model to the earth prototype, the large transducer source is focused to a point and the subsequent propagating wavelet is consistent enough to allow wavelet processing of the data. The resulting time sections from the physical models have a high enough signal-to-noise ratio to allow comparisions to both theoretical models and field seismic data.

Time sections which profile in the modeling tank a simple anticline and also a more complicated faulted delta compare favorably with theoretical time sections. Using these two geological models, we describe various applications and pitfalls of modeling which will be of interest to interpreters working in problem areas.

INTRODUCTION

Practical applications of physical modeling have been discussed in the past by several authors.[1,2,3,4,7] This paper is a non-mathematical update and overview of how geophysicists can use physical modeling, along with theoretical modeling, as an interpretational tool.

Because many seismic processing techniques are based on the scalar wave equation, it will be interesting to note the differences between theoretical and physical model data. These differences will provide us with insight as to when our processing and/or interpretation might be incorrect with reference to different geological structures and lithology.

References and illustrations at end of paper.

THE PHYSICAL MODELING SYSTEM

The physical modeling system at SAL was based on the system described by French[1] and exact details are given in SAL Annual Reports.[5,6]

Working with the scale factors which are given in Figure 1, an 8x6x5 ft water tank was designed and built in 1977. The tank's large size insured that reflections from the sides, top or bottom would be outside the time window of signals reflecting from the physical model in the middle of the water tank. Resting on top of the tank are the computer-controlled positioning mounts (Figure 2), one for the source and the other for the receiver. These mounts control the xyz-coordinates of the source and receiver within a .01 tolerance (equivalent prototype 10 ft). Figure 3 is a top view of the tank with the source and receiver positioned over a geological model resting on thin wires.

The models built to date have been approximately 16 in square and up to 4 in thick. Multi-layer models are fabricated by pouring RTV silicone rubber into a plaster cast and after the rubber hardens, the second layer with its different RTV properties is poured between a second plaster cast and the first RTV layer. Models with four-layers have been built in this manner.

The total system is block diagramed in Figure 4.

SOURCE AND RECEIVER

The source needs to transmit significant energy into a small volume and this was accomplished by focusing a Panametrics V3034 transducer as shown in Figure 5. The 250-kHz transducer produces a pulse which corresponds to a field seismic wavelet with a 50-Hz apparent frequency.

The styrofoam cup (common coffee cup) is probably the most important feature of the source setup. The cup has a one-wavelength aperature in the middle of the bottom which is positioned at the focal point of the lens. The aperature shapes the pulse and focuses the wavelength as it emerges from the cup. That is, the aperature acts as a point source. Meanwhile, the unwanted energy from the tips of the solid lens is attenuated by the guaze pads and the cup itself. The ironic part of this research is that it took us three months of fancy designs and aperatures before we tried one of the coffee cups sitting around the Lab.

Point probes, which act as receivers, are fairly easy to come by and an ITC 1089 spherical transducer has a satisfactory impulse response. It has an 1/8 in active element protected by a 5/8 in diameter rubber mold.

CHARACTERIZATION

The source-receiver configuration just described has excellent spatial and temporal characteristics. A direct transmission experiment, as outlined in Figure 6, was conducted to document the source-receiver angular response. Two perpendicular profile lines were obtailed by first scanning the source in the x-direction and then in the y-direction. Each profile line had 201 traces and a typical profile line is shown in Figure 7.

The enlargement inserts have been corrected for spherical spreading losses and they show remarkable similarity in waveshape from the near traces to the far traces. This desirable feature allows us to measure one seismic pulse for future wavelet processing of the physical model data. This also assures that the migration programs, which assume a consistant pulse shape in all directions, will operate correctly.

ACQUISITION GEOMETRIES

Figure 8 depicts some examples of the shooting geometries that can be accomplished with the present software. The allowable variations in offset distances, fold, areal coverage and type of gathers make for a wide variety of possible acquisition schemes. Of considerable interest are the differences in areal acquisition schemes (3D) versus conventional profile lines (2D) when taken over the same geological structure. Profiling comparisons such as these have been used to develop actual field programs for exploration of deep grabens and overthrust structures and for field delineation of stratigraphic traps. Typical model runs contain 25000 4 sec traces and take 10 to 12 hours to complete.

PHYSICAL MODEL EXAMPLES

In order to show the value of modeling as both a processing and interpretational aid, two models will be discussed. Both models were centered in the middle of the water tank which has an earth prototype velocity of 12000 ft/s.

The first structure to be examined was a simple 2D anticline. This structure was modeled twice. First, the anticline was built out of plexiglas (Figure 9) which simulates a high-velocity formation of 21,600 ft/s and then out of RTV which has a low-velocity of 8400 ft/s.

In Figure 10, a comparison of single-fold to six-fold was made over the high-velocity anticline; this acccounts for the velocity pullup (4) of the flat bottom reflector. When the correct stacking velocity is employed, the stacked section has a less ringy appearance (2) as if a deconvolution were performed. Because the velocity increased with depth, the reflections from the side of the anticline (1) were enhanced when they were stacked; this will not be the case for the low-velocity anticline. Diffraction events (3), we have noticed, are stronger for the high-velocity (elastic) material than for the low-velocity (RTV-acoustic) material. Compare the diffraction event (3) in Figure 10 to (1) in Figure 11, where Figure 11 represents the low-velocity model. This could be a diagnostic tool for evaluating the lithology of "bright spots".

Figure 11 shows a low-velocity pushdown event (2) which is similar on both sections. Also, the amplitude of the diffraction event (1) is the same on both sections. This suggests that conventional processing algorithms which incorporate wave theory would function better for low-velocity structures. However, this is not the case when the processing sequence is done incorrectly. For instance, in Figure 12, the low-velocity structure shows a very poor 6-fold stack of the reflections from the flank of the anticline(1)These are suppressed during the stack and this suppression causes apparent faults on the migrated section. Of course, this could have been resolved if the data were migrated first and then stacked. Expensive, but necessary for detailed evaluation.

The final model in Figure 13 illustrates the problem of trying to interpret a complicated 3D geological structure from conventional 2D seismic data. The heavy line across the physical model locates the profile line used in this example. The profile line was then modeled theoretically twice, first as a 2D structure and then as a 3D structure. Obviously, the 2D time section when migrated showed excellent results; while the 3D time section, when migrated, illustrated many misleading events. Unfortunately, it is difficult to examine the 2D and 3D theoretical sections and discern side-swipe events. The bottom two sections are physical data which compare favorably to the theoretical data in the middle two sections.

One of the most impressive features of this model is that fault cuts picked on the seismic sections can be off by over 1/2 mile because the fault edge is oblique to the profile line and dipping. Migrated sections (2D) do not help to resolve this problem either. We have done a limited amount of areal coverage and 3D migration on this model; and, the fault cuts are very distinct and in their proper spatial position after 3D migration.

CONCLUSIONS

Physical modeling can be a worthwhile tool for understanding complex structural and stratigraphic events on seismic record sections. Because the physical model can be measured and data collection repeated, there is an opportunity to tie a model to a specific prospect and modify the model until a thorough understanding, like a case history, is achieved. In many cases, diffractions, multiples and thin bed "noise" generated by physical models are a closer representation of the real world than that generated by theoretical seismic modeling which has questionable assumptions built into it.

REFERENCES

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5. Nelson, H.R., F.J. Hilterman and G.H.F. Gardner: "Improvements to the Physical Modeling Hardware and Software," SAL Annual Report {1980} B1-B13.

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SCALE FACTORS

	Model	Oil Exploration	Coal Exploration
Length	1"	1000'	300'
Sample Rate	0.2 μs	1 ms	0.5 ms
Velocity			
RTV	3500 '/s	8400 '/s	5040 '/s
Plexiglass	9000 '/s	21600 '/s	12960 '/s
Water	5000 '/s	12000 '/s	7200 '/s
Frequency	250 kHz	50 Hz	100 Hz

Fig. 1 - Model scale factors for conventional and high resolution seismic exploration.

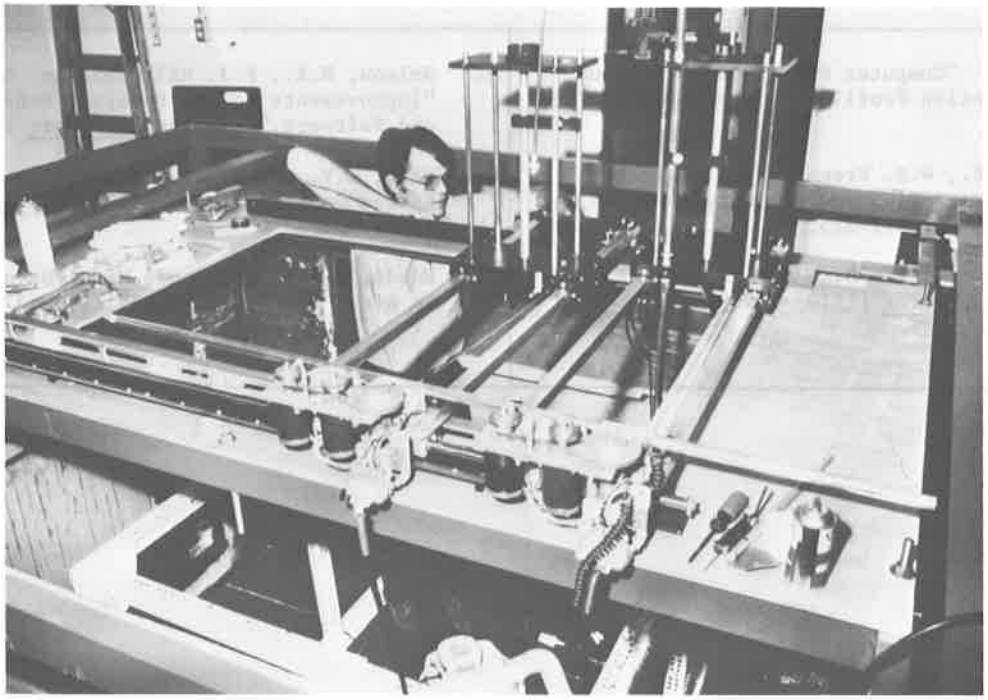

Fig. 2 - Physical modeling tank.

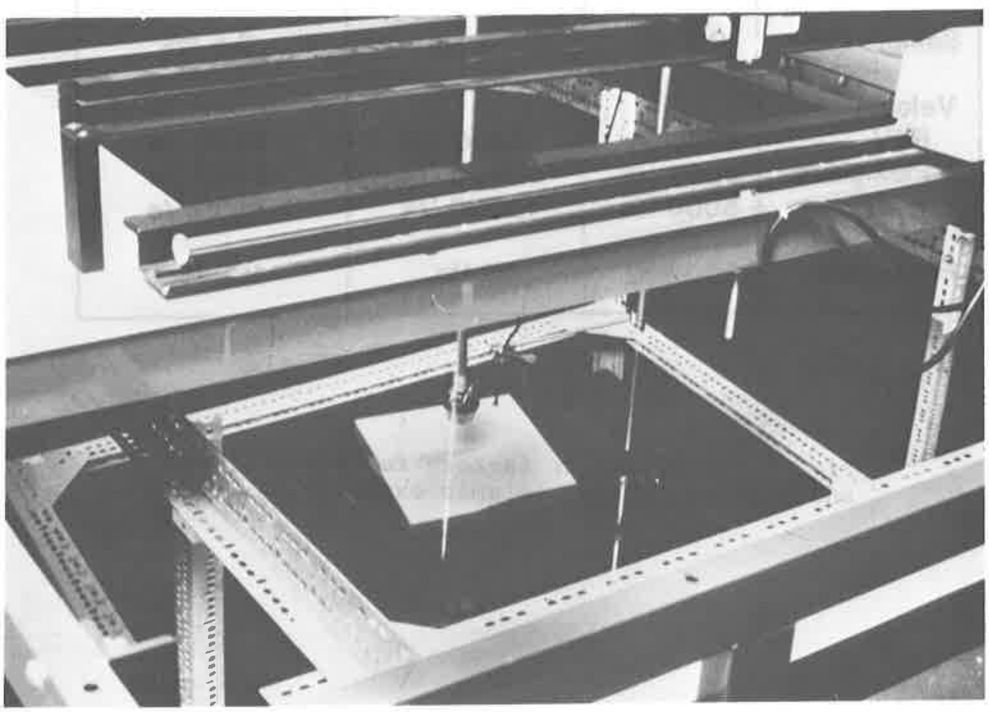

Fig. 3 - Top view of modeling tank.

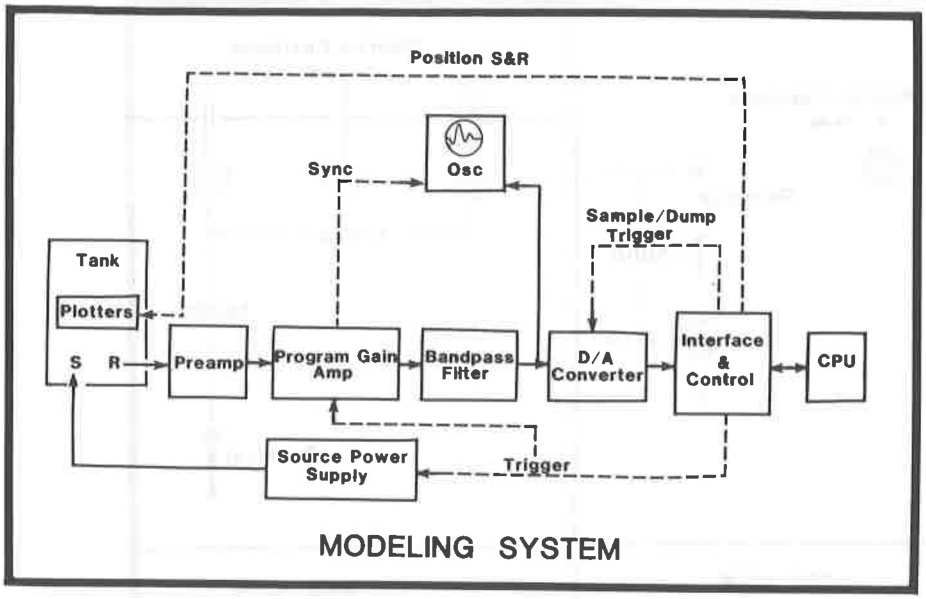

Fig. 4 - Block diagram of modeling system.

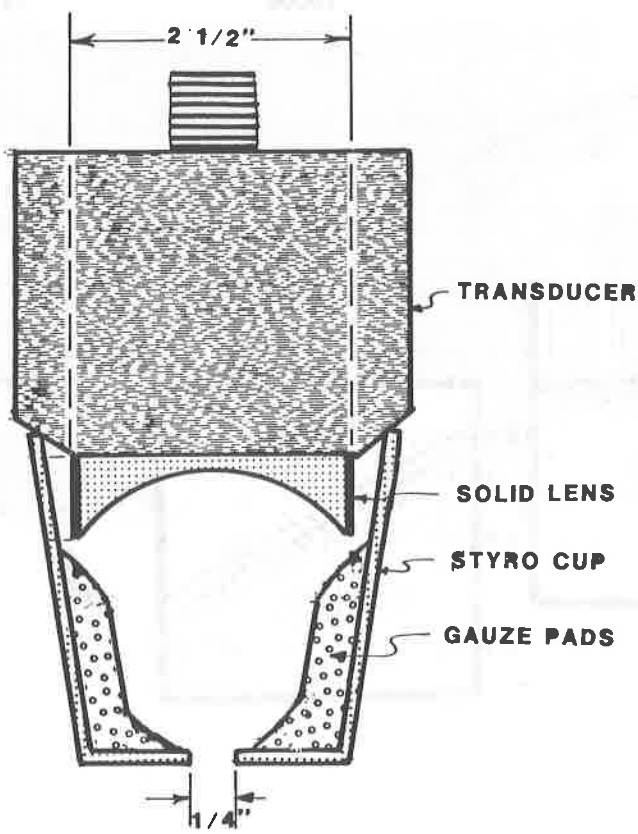

Fig. 5 - Focused source transducer with noise attenuating coffee cup.

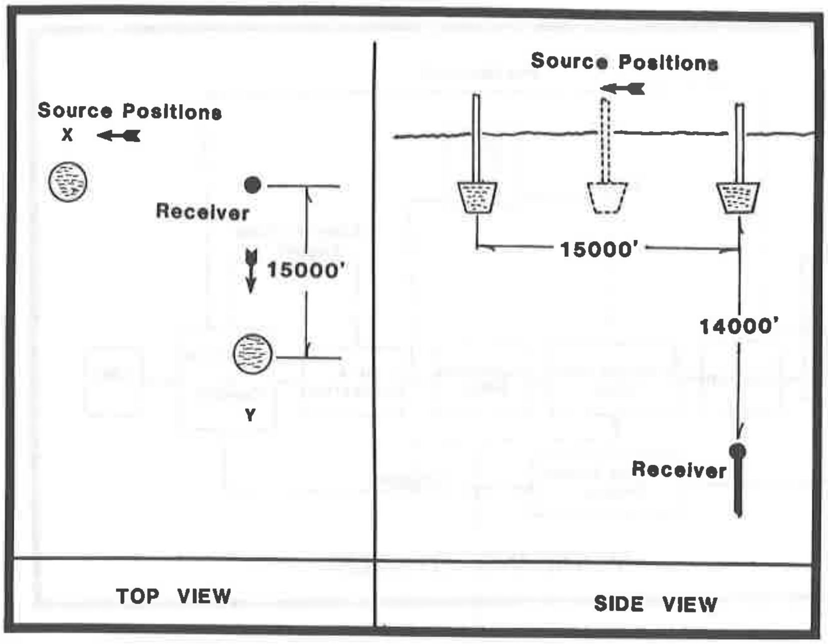

Fig. 6 - Source-receiver characterization setup.

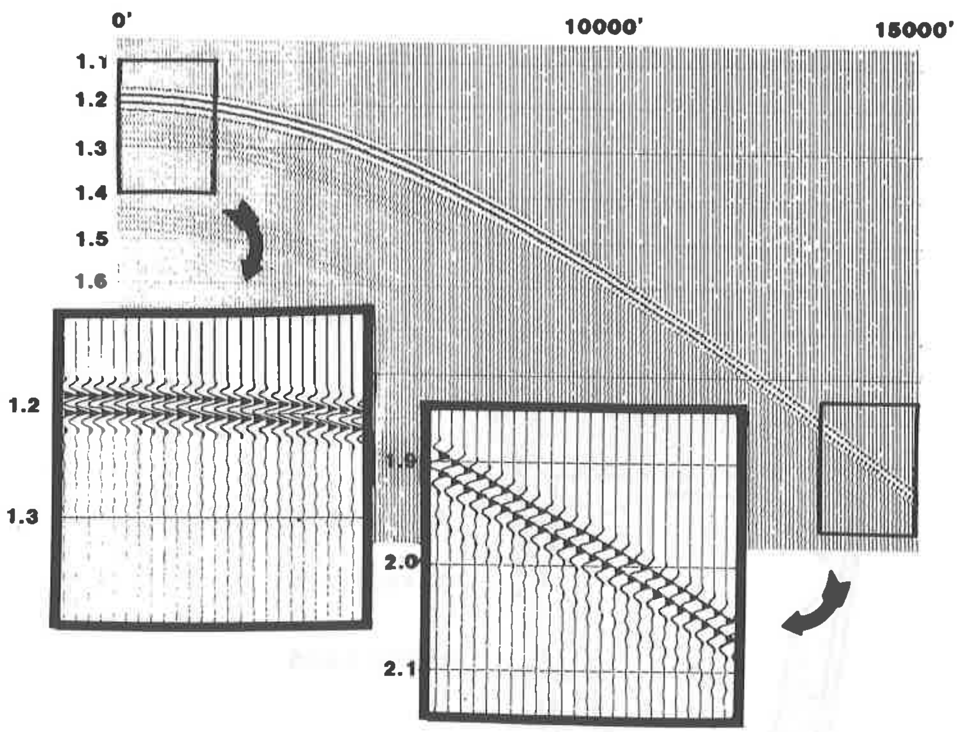

Fig. 7 - Time section from characterization test of Figure 6.

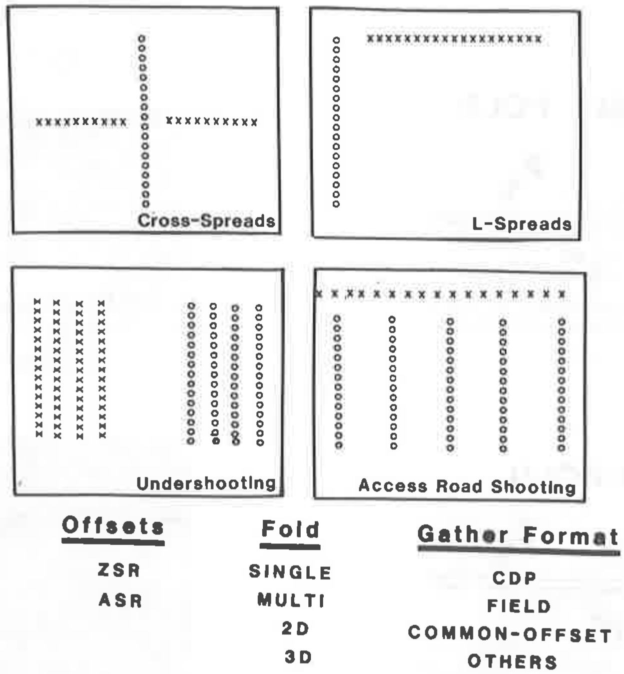

Fig. 8 - Typical seismic acquisition programs available.

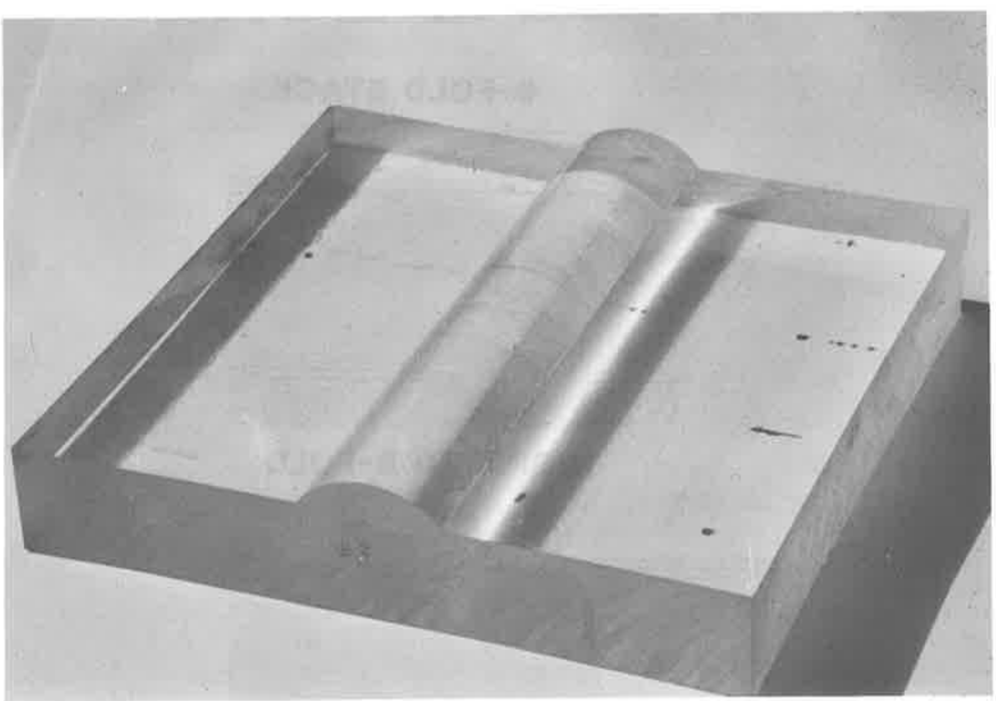

Fig. 9 - 2D anticline made from plexiglas.

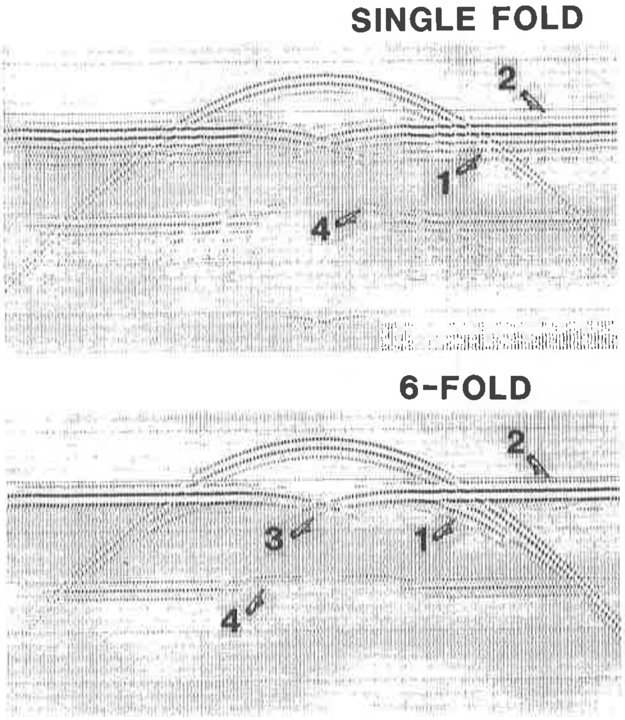

Fig. 10 - Stacking example across high-velocity anticline.

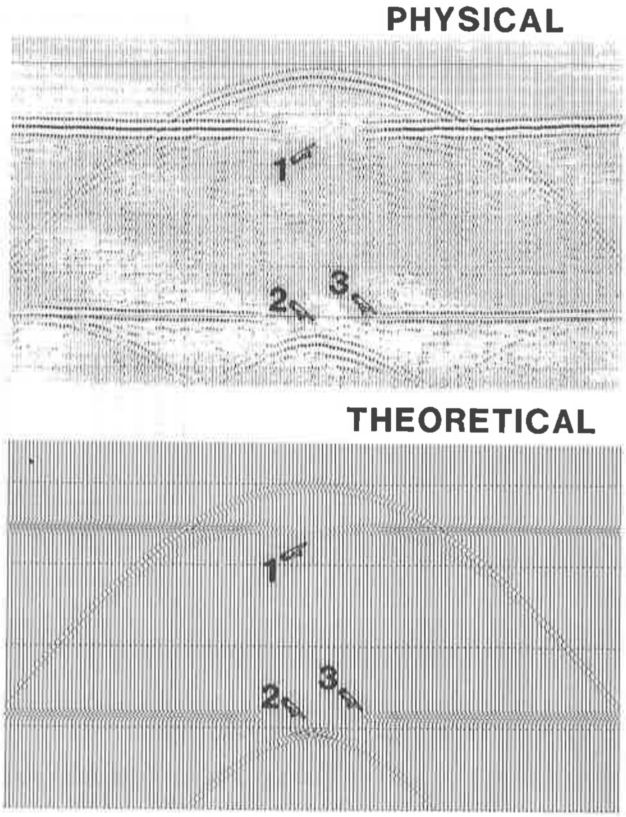

Fig. 11 - Physical vs. theoretical example across low-velocity anticline.

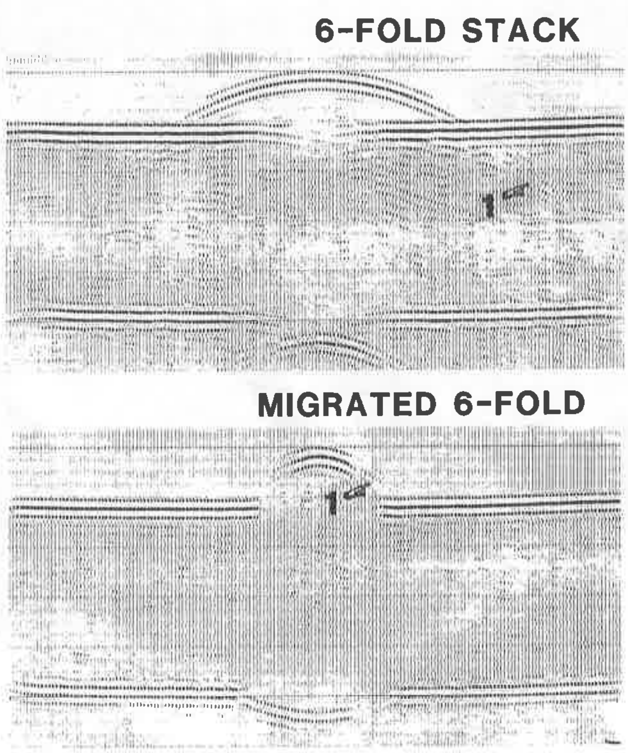

Fig. 12 - Migration example across low-velocity anticline.

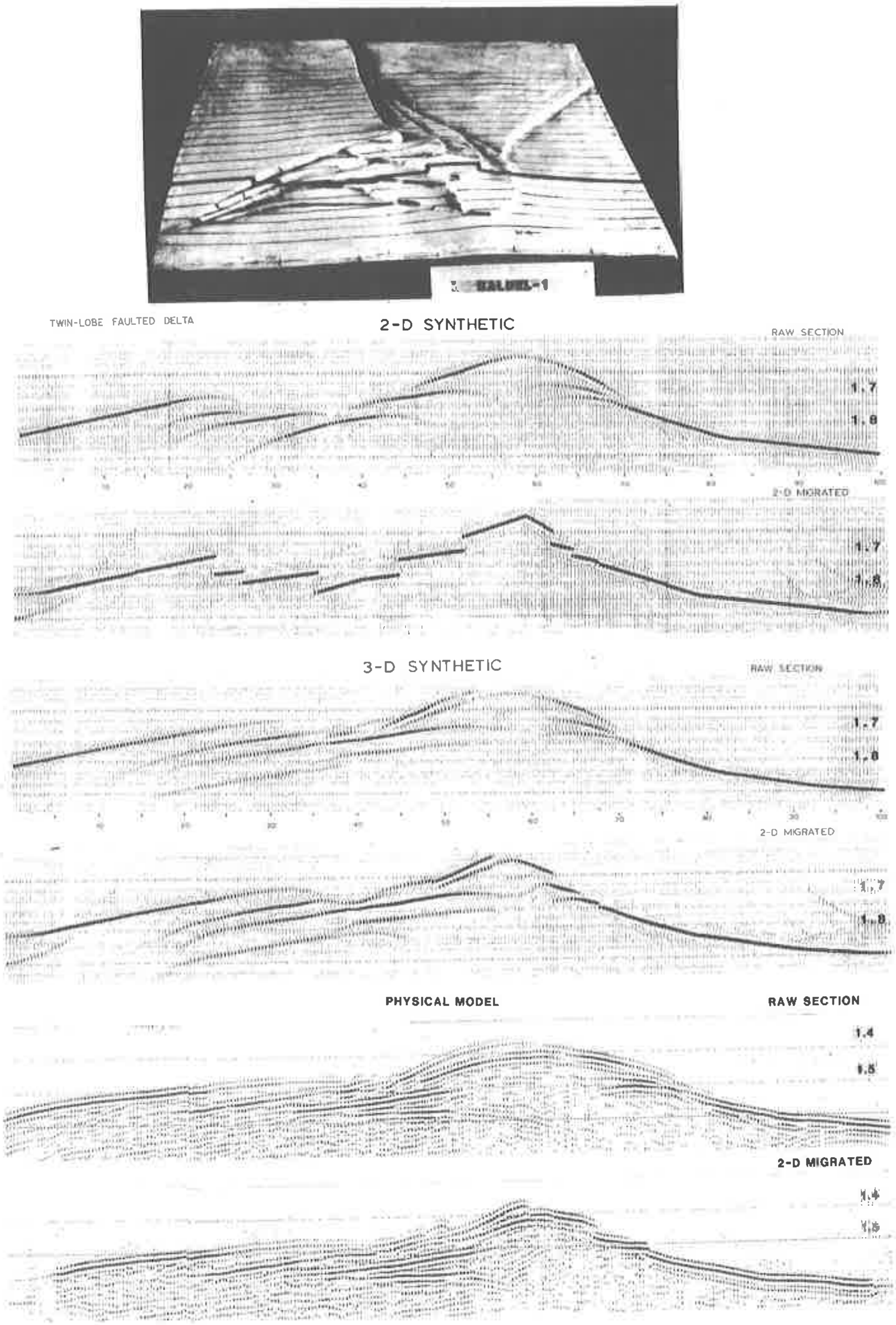

Fig. 13 - Physical and theoretical time sections across a highly-faulted deltaic model.