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Pitfalls IN SEISMIC INTERPRETATION

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We believe that this outstanding contribution to today's seismic interpreter should receive as wide distribution as possible. We gratefully acknowledge the cooperation that has made this reprint possible.

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PITFALLS IN SEISMIC INTERPRETATION

by

Paul M. Tucker
Howard J. Yorston

ABSTRACT

"He that diggeth a pit shall fall into it" - Ecclesiastes 10:8

Many pitfalls in seismic interpretation are concealed within seemingly straightforward reflections. Some of these pitfalls are dug for us by nature and some are of our own doing. But these can be avoided. They can be classified into three groups: those caused by velocity, those due to the geometry of the reflector, and those resulting from recording and playback.

Regional velocity changes seldom give trouble, but within small, deep, intermontane basins, or along continental margins, a false indication of basinward thinning is sometimes observed. Of greater concern is the abrupt change in velocity due to an equally abrupt structural change: the fault which creates false reversals, the reef with its underlying "high", the surface or seafloor irregularity with its coincidental subsurface reversal. The depth section can be used to avoid these pitfalls, providing it is not in itself a pitfall.

The geometry or shape of the reflecting surface is equally tricky. It can turn synclines into anticlines, reverse the throw of faults, superimpose one structure on another by sideswipe, and create a diffraction-anticline.

Our latest and perhaps most serious pitfall is computer-derived. The recording and playback can mess up both the structure and stratigraphy. Here real structures can be suppressed, false bedding created, faults smeared, and all of the geology lost. Only through constant rapport between the geologist, the interpreter, and the processing engineer will these recording and playback errors be avoided.

We will first demonstrate the geologic phenomena that led to these errors, then use geologic models and their seismic expressions to explain their origin, and finally provide simple validity tests for spotting the pitfalls.

INTRODUCTION

Since current data processing and presentation yield seismic sections that resemble geologic cross sections, geologists and geophysicists not experienced in seismic interpretation are often greatly tempted to read geology more or less directly from the seismic section. Where the geology is simple, this will not present a problem. However, in areas of complex structure, rapid changes in lithology or velocity, or irregular surface or near-surface conditions, serious errors may result from the literal interpretation of seismic sections.

Interpretation pitfalls fit into one of the following three categories:

1. Pitfalls associated with velocity occur because seismic data are presented in travel time rather than depth,

2. Pitfalls associated with geometry occur because reflections from a three-dimensional space are plotted in a two-dimensional section, and

3. Pitfalls associated with recording and processing occur because all recorded events are not geological and improper processing can mask geology.

In this report we will discuss pitfalls associated with 18 features frequently seen on seismic sections. *It is important that the reader note the order of presentation.* First we will show a seismic profile and give a *seemingly* good geological explanation of the features shown on the section. Then we will use a geologic model and its seismic expression to show that what seems to be straightforward geology is, in fact, a pitfall. Finally, we will present validity checks for spotting the pitfall so that correct interpretations can be made, along with correction methods where applicable.

The following table summarizes this entire presentation.

PITFALLS IN SEISMIC INTERPRETATION

PAUL TUCKER
HOWARD YORSTON

ESSO PRODUCTION RESEARCH COMPANY
NOVEMBER 1971

SUMMARY

Pitfall: "Any concealed danger or trap for an unsuspecting person" (Webster).

CATEGORY	EXAMPLE-MODEL	OBSERVED PHENOMENON	EXPLANATION	VALIDITY CHECK
I. VELOCITY A. Interval Changes 1. Gradational	1	Downdip thinning of reflection intervals.	Geologic: Compaction, starved basin, basin inversion. Non-geol: Increased velocity with an increase in overburden.	1. Thinning decreases with unit mean burial depth. 2. Assumed constant thickness produces reasonable velocity function. *3. Depth section eliminates thinning.
2. Abrupt a. Faults	2 3	1. Inclined fault trace: beneath fault trace, lows for normal faults, highs for reverse faults.	Geologic: Drag folds. Non-geol: Juxtaposition of differing velocity rock.	The anomaly coincides with the fault shadow.
	4	2. Vertical fault trace: reflection intervals thinner on downside (also true for normal faults).	Geologic: Strike-slip fault. Non-geol: Increased velocity with depth, faster velocity on down side.	*1. Same as No. 2 and No. 3 above. 2. Interval difference and throw decreases with depth.
b. Superimposed Structure 1) Flowage	5	1. Low beneath high.	Geologic: Two deformations, gravity gliding, fault butress. Non-geol: High-pressure shale, slower velocity.	1. A ratio exists between thickness increase, and low coincidence of high to low. 2. "Flowage is slowage".
	6	2. High beneath high. (Note high beneath low on Example 11)	Geologic: Initial deformation triggered subsequent flowage. Non-geol: Fast and slow velocity juxtaposition.	*1. Depth conversion or depth section. 2. Ratio of bulge to high.
2) Character Change	7	Supratenuous folding with loss of continuity in lower section over high.	Geologic: Compaction on pre-existing high. Non-geol: Velocity contrast juxtaposition.	The anomaly coincides with the reefal outline.
B. Surface-Subsurface Coincidence		Structure is usually local and abrupt but may be spread out over many profiles.	A surface or near-surface effect has contaminated the entire section.	1. Equal displacement of all horizons. *2. Depth section may correct effect of velocity from anomalous zone.
	8	1. A syncline beneath a sea channel.	Geologic: Recent syncline localized floor currents. Non-geol: Insufficient velocity correction. Synclinal character depends on velocity function.	1. Coincidence of low to channel. 2. No "bow tie" (see Example 11). *3. Relief of low varies and expands with depth, check velocities.
	9	2. Equal reversal for all horizons.	Geologic: Young anticline. Non-geol: Varying thickness of permafrost creates a velocity anomaly.	*Plot refraction first kicks to outline anomaly, and[(1)] check coincidence with reversal.

*Many pitfalls are velocity induced and can be recognized by velocity analysis and eliminated by the depth section. The depth section requires a very precise and detailed knowledge of velocity, otherwise it doesn't automatically correct all velocity anomalies; it may well overcorrect or undercorrect.

[(1)] Refraction first kicks are useful in testing a variety of seismic anomalies and should be considered for all seismic sections.

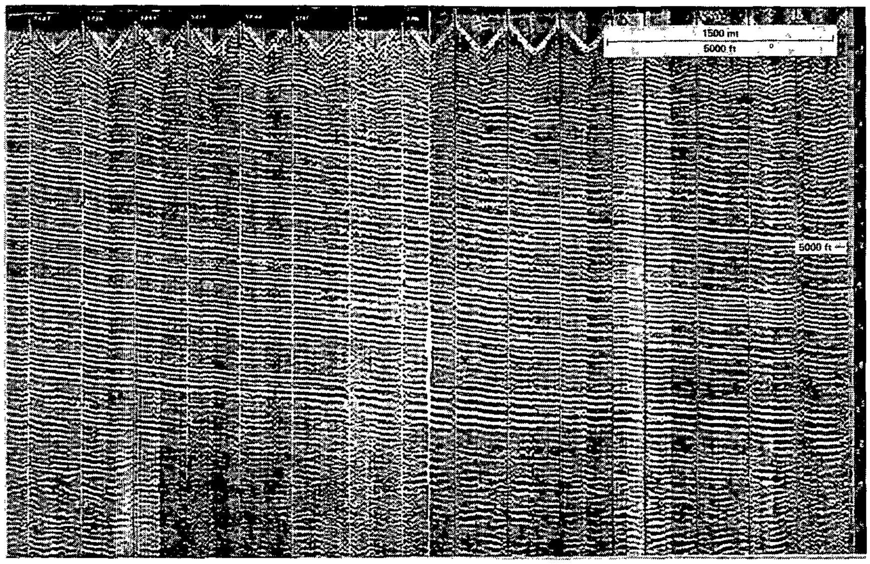
CATEGORY	EXAMPLE-MODEL	OBSERVED PHENOMENON		EXPLANATION	VALIDITY CHECK
II. GEOMETRY A. Steep Dip (over 10°) 1. Anticlines	10	Simple shallow reversal, but becoming more complex at depth.	Geologic: Non-geol:	Seemingly a simple anticline. The seismic expression is always less arcuate than the actual. Crustal faults may appear as horsts and grabens; normal flank faults may appear vertical or reversed. Folds may appear as diffractions.	Hand migration is a first step (and if it's really a tough one, a hope for a transfer).
2. Synclines	11	High beneath low. Synclinal reversals at shallow depth become accentuated with depth, then changing into "bow-tie" anticlinal dips (multiple branched reflections).	Geologic: Non-geol:	Complex history of anticline-unconformity-syncline. If the center of curvature is above ground, the syncline is recorded normally. As the depth and/or steepness increases, the center of curvature is below the ground and "bow-tie" cross-over occurs.	Migration of the flanks will reshape the syncline into a more logical appearance. (Note difference with velocity-derived "syncline", Example 8.)
3. Intrusions	12	Reflection termination is abrupt. Diffractions may appear in the blank area, and anticlinal dips border intrusion at depth.	Geologic: Non-geol:	Intrusion outlined by reflection terminations. The sharp, upturned beds are recorded away from the intrusive as multi-branched reflections; they may appear diffraction-like. The inner diffractions may be the true terminations.	1. The true edge of intrusive is inside the reflection termination. The rim syncline becomes an anticline at depth. A few hand migrations may give you a rough outline and suggest a more complete approach. 2. The inner diffractions may be the real edge, and the inside legs may have the intrusive velocity.
B. Disconformable Superimposed Dip Sets	13	Straight-forward interpretation on the left abruptly becomes unclear and unorthodox on the right.	Geologic: Non-geol:	Complex growth history. Sideswipe: two or more adjacent structures recorded simultaneously.	1. Sufficient background on geology. 2. Interpret dip lines first before tackling the more confusing strike lines. 3. Anticipate complexities, "sideswipe" can be recorded from any direction.
C. Faults and D. Diffraction-like Events	14	Monoclinal dips or terraces blend at depth into anticlinal reversals.	Geologic: Non-geol:	Supratenuous folding over deep-seated uplifts. A horst or steep anticline whose width is about ¼ the depth will display a continuous reflection-diffraction, much as a point source.	1. A true anticline is sigmoidal, not hyperbolic. 2. Test with a velocity determination using a diffraction formula. 3. Test with a diffraction overlay. 4. Migration is suggested.
III. RECORDING AND PROCESSING A. Input Pulse	15	Recent deposition over multi-cycle paleo-unconformities.	Geologic: Non-geol:	Even-bedded marine sequence. Multi-cycle bubble-pulse energy train; precludes any hope of mapping any lesser interval without distortion.	1. Look for water bottom reflection or direct pulse. It will tell you what kind of signal you are putting in the ground. 2. Beware if majority of events are three or more cycles.

CATEGORY	EXAMPLE-MODEL	OBSERVED PHENOMENON	EXPLANATION	VALIDITY CHECK
B. Multiples 1. Conformable dip sets	16	A simple shallow anticline or reef, with a no-reflection shadow zone, sedimentary wedges, and an unconformity.	Geologic: Complex growth history. Non-geol: The surface-air interface generates multiples. Energy trapped in near surface or water layer causes reverberation. Both may be subdued by processing.	1. A simple finger span or dividers will show the double path multiple quite readily. 2. The wedges may be inter-bed multiples.
2. Non-conformable dip sets	17	Simple anticline.	Geologic: Young anticline. Non-geol: Multiple from base of low velocity layer.	Coincidence of structure with refraction first kick anomaly. Structure is mirror-image of surface anomaly.
C. Playback	18	Smeared cycles, sharpness and amplitude changes across highs and into the lows, multiples, ringing, dead zones below strong reflections conflicting dip sets.	Geologic: See selected geologic explanations above. Non-geol: Improper selection of processing control parameters and/or inadequate *processing*	1. Check stacking velocities, automatic volume controls, and other processing control parameters 2. Constant communication must be maintained between Geologist, Interpreter and Process Engineer so as to produce the desired geologic section.

VELOCITY PITFALLS

Example 1 - Basinward Thinning

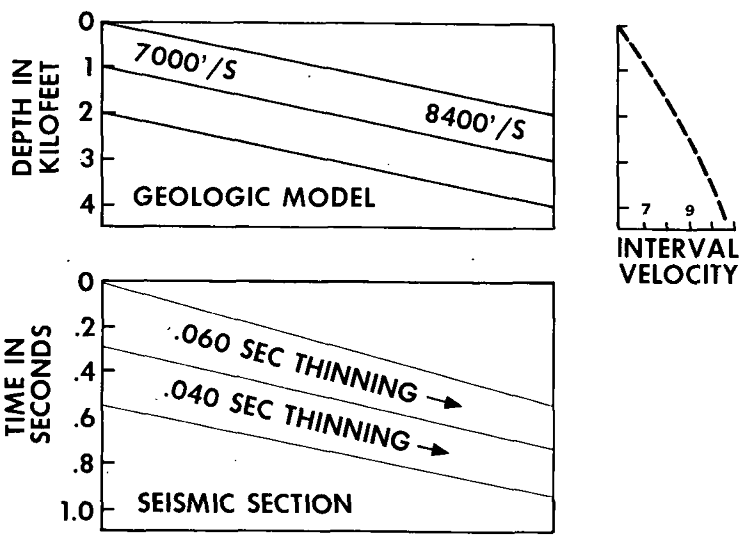
Observed Phenomenon



Example 1-A

Example 1-A is a regional line into an intermontane basin but could also be a marine line along a continental margin. Thinning into the basin from left to right is readily seen. Three seemingly good geological interpretations can be read directly from this section. The thinning could be a result of greater compaction in the deeper part of the basin. It could be a starved basin, in which the deposition into the basin has been restricted. Or, it could be an inverted basin—the thick section on the left being originally the center of the basin, with later inversion, or upward push, the center of deposition could have shifted to the upper right over what had been the flank of the basin. Which of these three explanations seems the most logical?

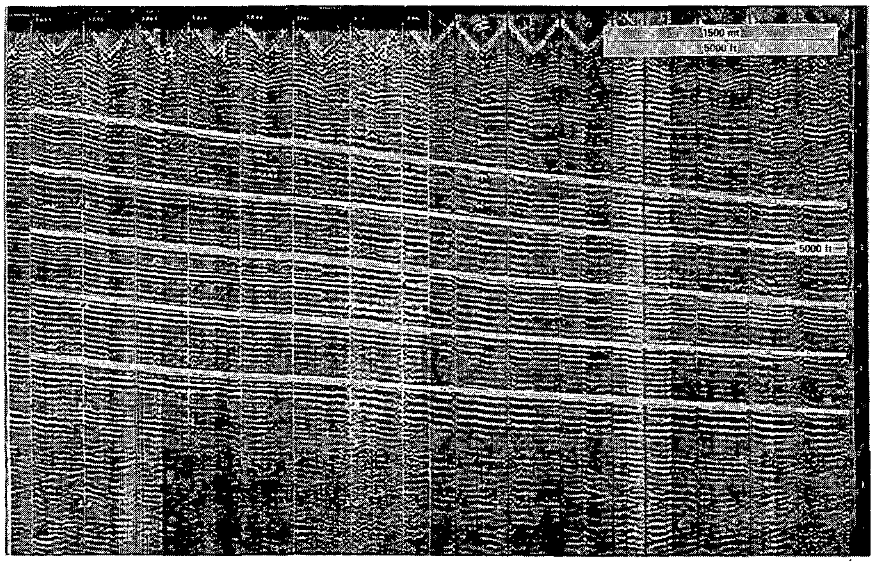
Model Study



Model 1. Basinward thinning.

All three are logical. However, *it is a pitfall to assume that all thinning on the seismic section represents thinning in the subsurface.* The first explanation, compaction, is involved but is not the full answer. The interval velocity of a given rock body increases with increasing depth according to a function similar to that shown in Model 1. This normal increase in interval velocity with depth is associated with the progressive deepening of stratigraphic units into a basin. With the higher velocities, seismic travel times decrease and intervals on the seismic time section also decrease. The velocities and intervals shown on Geologic Model 1 will be seismically expressed as shown on the accompanying Seismic Section. The time intervals on this section decrease by 60 milliseconds for the upper unit and 40 milliseconds for the lower unit. However, there is no change in the actual thickness.

Validity Check



BASIN "THIN"
Example 1-B

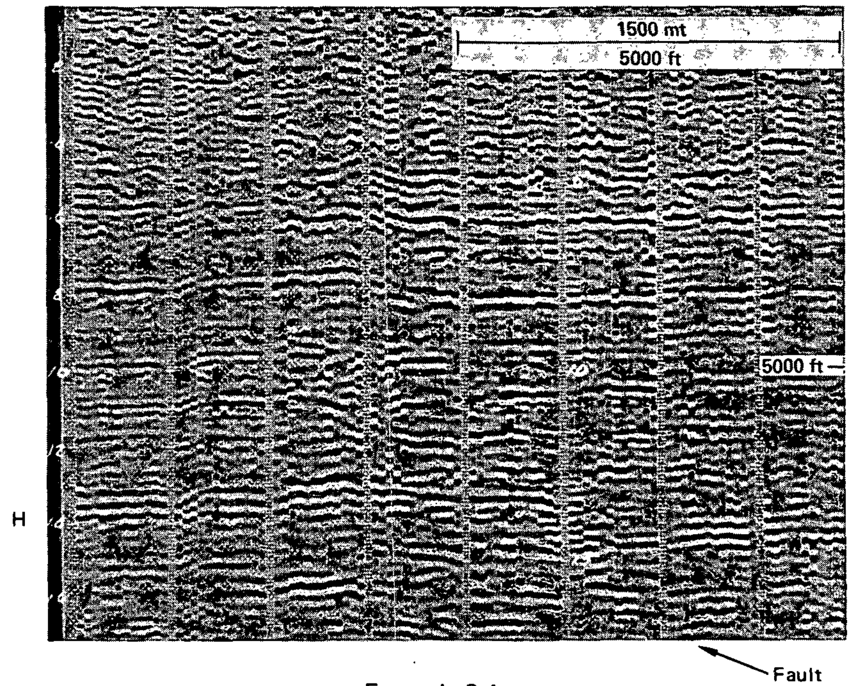
There are three ways of obtaining a correct interpretation of Example 1-A. One is to use systematic interval changes as a means of identifying apparent thinning that is in fact a velocity effect. The interpreted section, Example 1-B, shows four equally spaced updip intervals, each of about 300 ms. These intervals thin progressively downdip: 60 ms for the upper interval, 50 ms for the second, 30 ms for the third, and 20 ms for the fourth. The progressive downdip decrease in these intervals indicates that velocities are becoming progressively faster with depth, thus explaining the basin "thins".

A second means of identifying these interval changes as velocity effects is to assign a reasonable velocity for the first interval updip and determine its thickness. Assume the same thickness for the interval downdip and determine its interval velocity. The interval velocity should show a reasonable increase, which in this example is about 2000 ft/sec. Each successive interval should show an increase in velocity basinward, but the differential will lessen with depth.

A third recourse is to convert the section to depth. However, a depth section requires a very precise and detailed knowledge of velocity; otherwise it does not correct all velocity anomalies. It may well become a pitfall itself.

Example 2 - Fault Shadow (Normal)

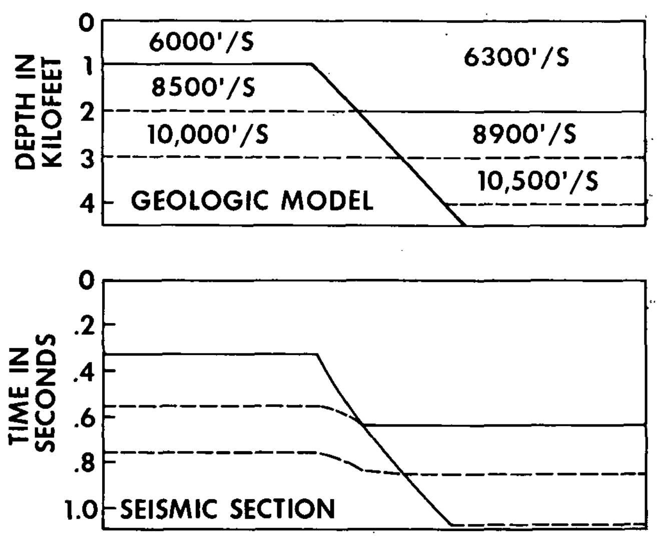
Observed Phenomenon



Example 2-A

Example 2-A shows various interrupted reflections that suggest the trace of an inclined fault. A very definite rollover into the fault of about 20 ms, or 100 ft, is apparent in a lower horizon, H. This reversal could be, and quite commonly is, a drag fold into a normal fault. Normally, it would be considered a good oil trap.

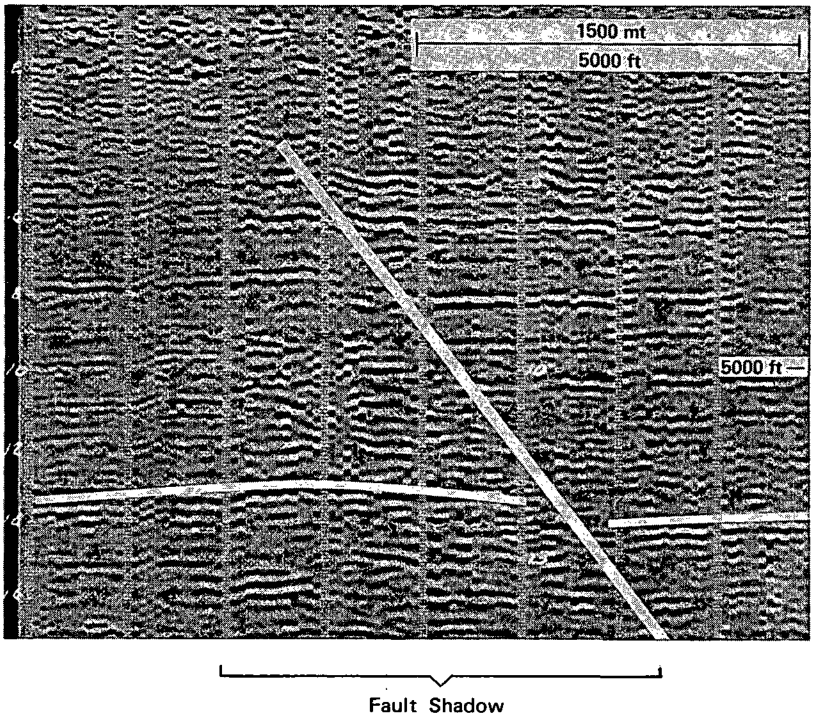
Model Study



Model 2. Fault shadow structure.

Unfortunately, traps of this type are more likely to catch interpreters than hydrocarbons, for the rollover could be due to velocity rather than structure. Model 2 shows the velocity character of this type of anomaly. Rocks on the downthrown side are subjected to greater overburden pressure than their high-side counterparts, and their interval velocity therefore increases. Within any horizontal layer containing the fault, the seismic waves will encounter progressively changing interval velocities along the profile. As a result, reflections within the fault shadow bend downward into the fault.

Validity Check

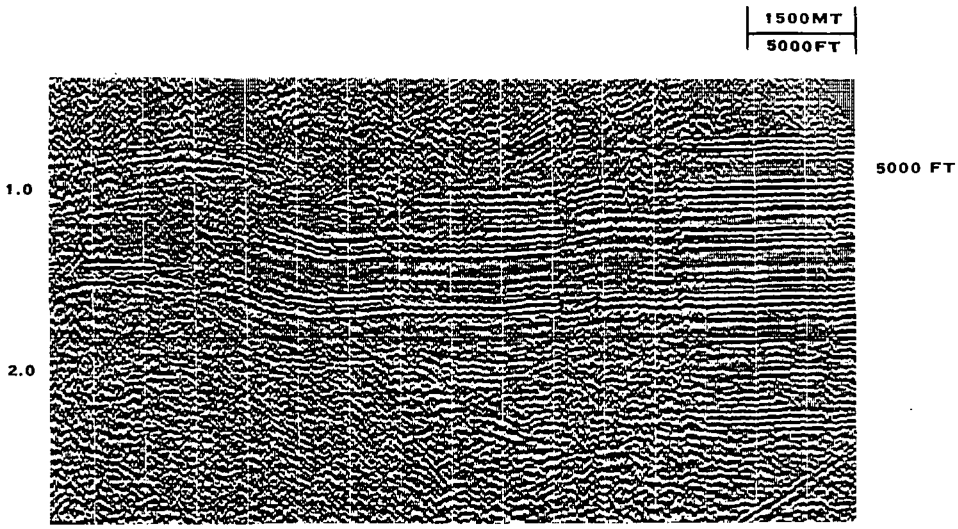


Example 2-B

This coincidence of a fault trace and its shadow with a reversal is the validity check for spotting such velocity anomalies as those seen in Example 2-B. Coincidence alone does not necessarily condemn a structure, but when the coincidence does occur, it should be checked out to be sure it is not velocity-derived.

Example 3A - Fault Shadow (Reversed)

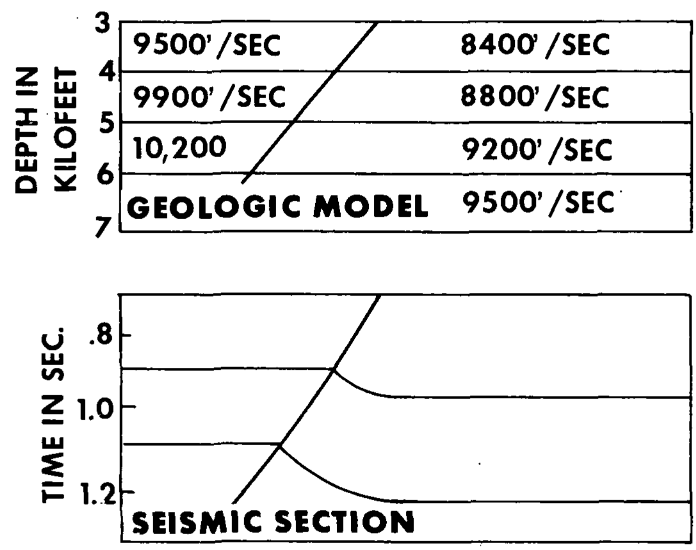
Observed Phenomenon



Example 3-A

Example 3A has a very nice reversal in the lower horizon. Above this rollover the younger beds indicate a somewhat similar structure but with minor differences. The reversal is slightly larger and is offset from the lower structural crest. This would indicate an unconformity and differing periods of movement, or differential folding.

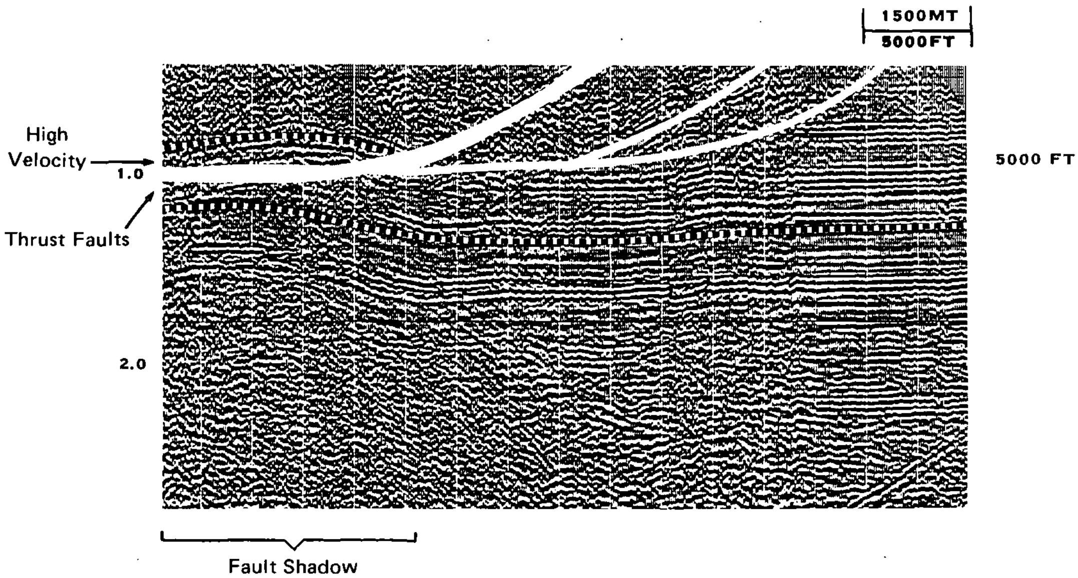
Model Study



Model 3. Reverse fault shadow

The fault shadow effect is more common in reverse faults than normal faults because thrust faults tend to have a larger displacement. The velocity pattern is shown in Model 3. Reflections beneath the fault in the downthrown block are upswept into the fault plane. This apparent flexure plus the apparent offset in the crest of the structure with depth gives the appearance on the seismic section of an asymmetric fold rather than a reverse fault.

Validity Check

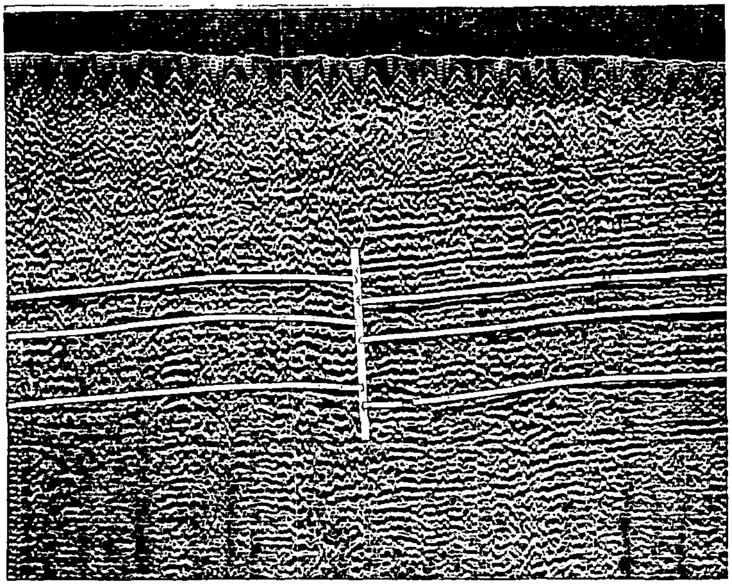


Example 3-B

The apparent upbending of the beds underneath the trace of the thrust fault, Example 3-B, coincides with slivers of high velocity material on the overthrust. The flexure beneath the fault is the red flag of caution.

Example 4 - Vertical Fault

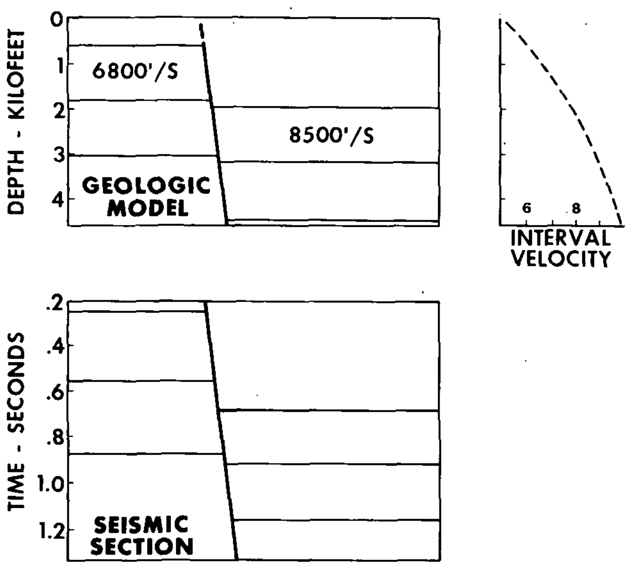
Observed Phenomenon



VERTICAL FAULT
Example 4-A

The continuity of the reflections again is interrupted, as on Example 4-A, but this time the plane is nearly vertical. This suggests a strike-slip or wrench fault. Such a lateral movement would normally bring beds of differing depositional environment, and possibly of differing thicknesses, in juxtaposition. A close examination of Example 4-A does show a thinning on the deeper (right) side of the fault. Since this is a vertical fault, there would be no fault shadow velocity effect such as in the previous two examples.

Model Study

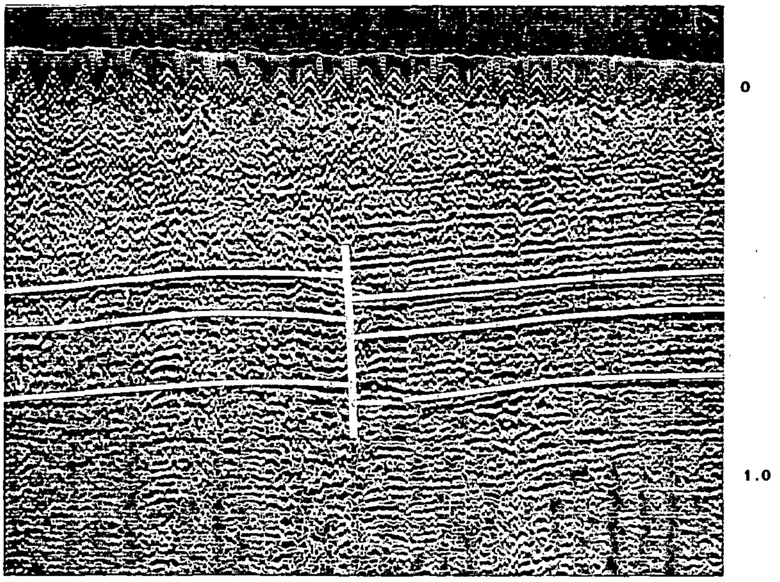


Model 4. Thinning across fault.

Should the fault plane be nearly vertical rather than inclined, as in Model 4, a change in interval may occur across the fault. If the downside intervals are thicker than upside and the displacement increases with depth, fault growth and sedimentation are indicated. If the downside intervals are thinner and the displacement decreases with depth, we might interpret either a 'yo-yo' fault, where the throw has reversed, or a strike-slip fault, as indicated in Example 4.

It is true there is no fault shadow effect but we should still consider the influence of velocity, which might alter natural interval thicknesses. In Model 4, the beds have been displaced 1500 feet and the interval velocity has been significantly increased because of the additional overburden. The seismic time section expresses this velocity change as thinner intervals on the down side and a decrease in throw with depth. This type of anomaly is generally confined to the shallow beds and to sediments undergoing active compaction.

Validity Check

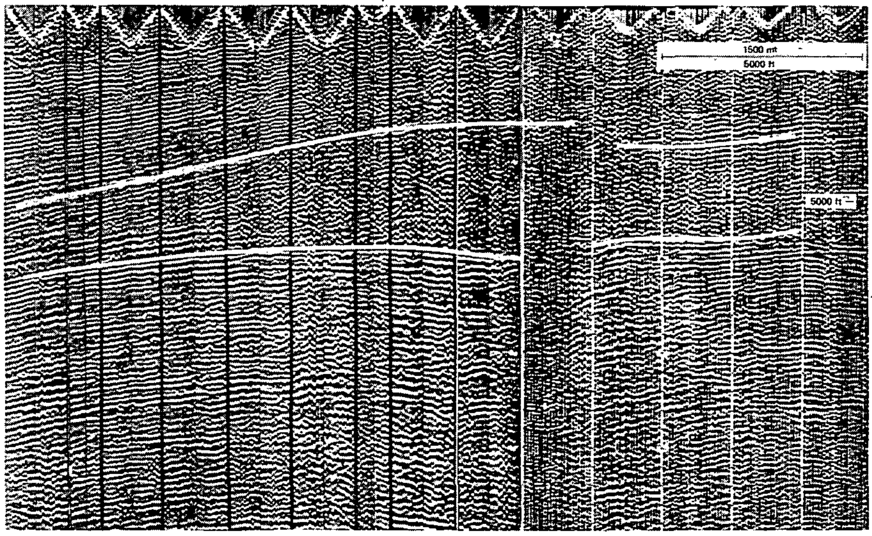


VERTICAL FAULT
Example 4-B

A validity check on Example 4-B for the authenticity of thickness changes across the vertical trace fault is tough to find. These faults frequently indicate a strike-slip movement, such that correlative beds across the fault are of different thicknesses and velocities. Geologic correlation across strike-slip faults is problem enough, but the velocity effect makes the problem even worse. Validity checks? There are none; one can only recognize that a problem exists and try to live with it.

Example 5 - Shale Flowage

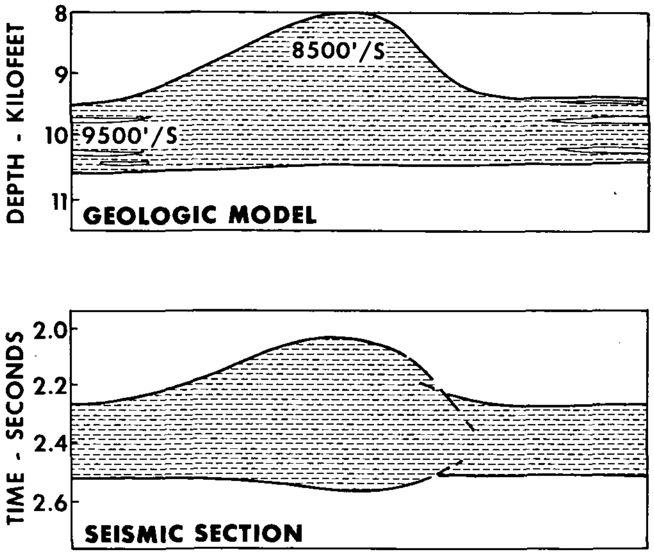
Observed Phenomenon



Example 5-A

Example 5-A shows a near-surface anticline that is interrupted by either folding or faulting in the upper bed. The lower horizon has a lesser reversal, with another fault indicated but opposite in throw from the upper horizon. These two faults in opposite directions suggest two periods of movement: first, a period in which the lower fault developed, then a period in which the lower fault acted as a buttress for later compressional movements that created the anticline above the fault and a fault trap below.

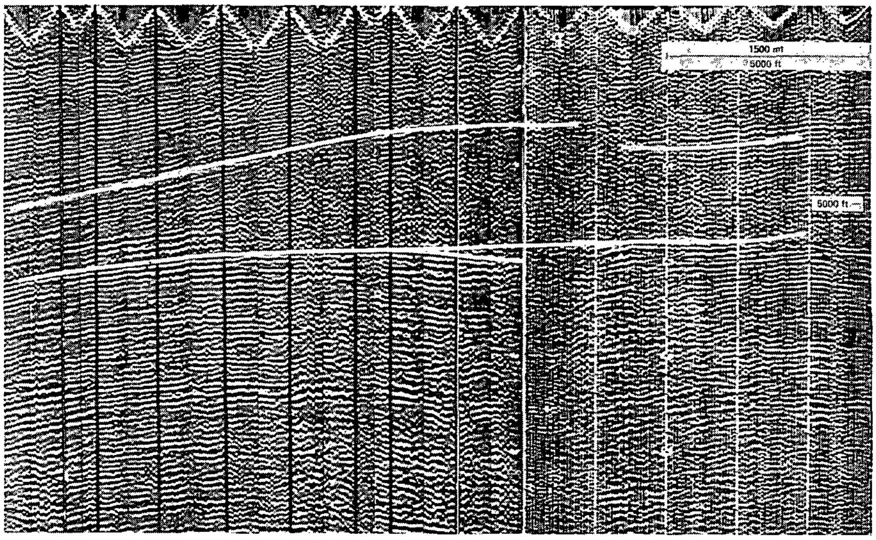
Model Study



Model 5. Shale flowage.

If we consider the velocity character of a structure of this type, we may find that the fault trap is a trap of another sort - a pitfall. A bulge like that shown in Model 5 is probably the result of plastic deformation, i.e., either salt or shale flowage. If it is shale flowage, the thicker mass of shale with lower velocity toward the center will create a velocity anomaly or downbowing beneath it. The change in thickness and velocity at the right edge of the bulge produces the apparent faulting in the deep reflection on Model 5. What test can be made to determine whether the structure on the deep reflector is real or a velocity anomaly?

Validity Check



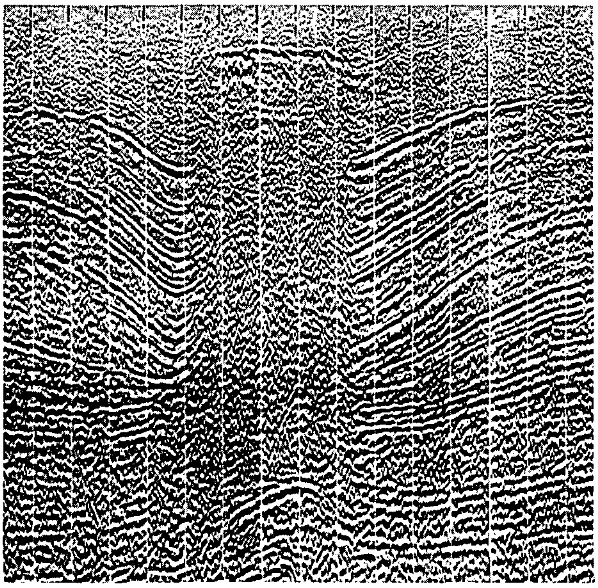
SHALE FLOWAGE

Example 5-B

Our best validity test in this particular example was the drill, which found that the lower horizon had neither the reversal nor the fault. The bulge was a high-pressure shale flowage, which caused a slower velocity. In fact, we could say of all shale bulges that "flowage is slowage." To check validity without drilling, we can use the ratio between the increase in interval and the downbending. Assume the lower horizon continues smoothly from the right into the regional dip on the left (Example 5-B). Plot the interval increases above this line against the departures below the line. If there is a velocity anomaly, these plots will approximate a straight line.

Example 6 - Salt Flowage

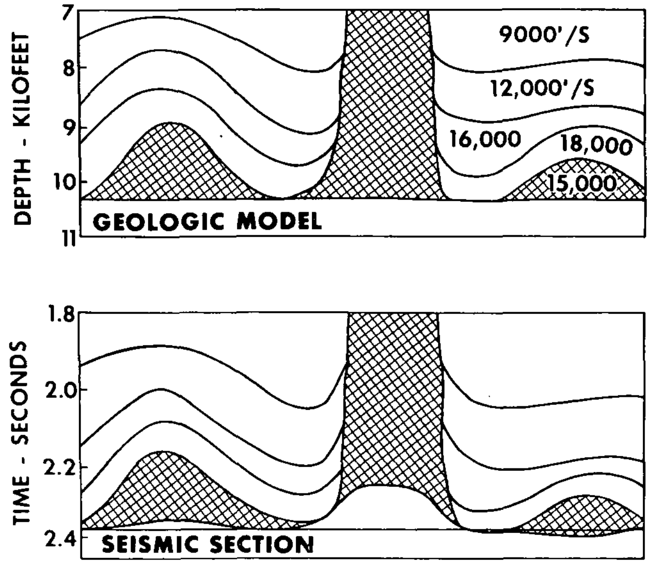
Observed Phenomenon



Example 6-A

Example 6-A is another type of flowage, in which salt is involved. The flowage was probably induced or triggered by the prominent pre-salt high. This could be a very attractive deep prospect.

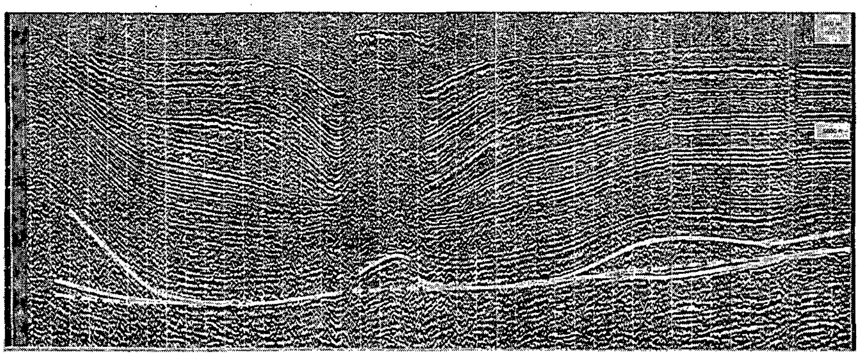
Model Study



Model 6. Salt flowage.

Attractive? Yes. Prospect? Perhaps. Let's examine the character of Model 6 for the pitfall, which is the differential between velocities. The travel time through the salt dome is less than that through the adjacent rocks. Consequently, reflections from beneath the dome appear upbowed. On the left side of Model 6 is a salt anticline in which, again, the travel time through the salt is less than that through the surrounding rocks. And again there is an upbowing of the base of the salt but on a smaller scale than with the dome. On the right side of Model 6 is a residual salt mass, where the travel time through the salt is greater than that through the adjacent zone. Here we find a downbow in the reflections from beneath the salt.

Validity Check



SALT FLOWAGE
Example 6-B

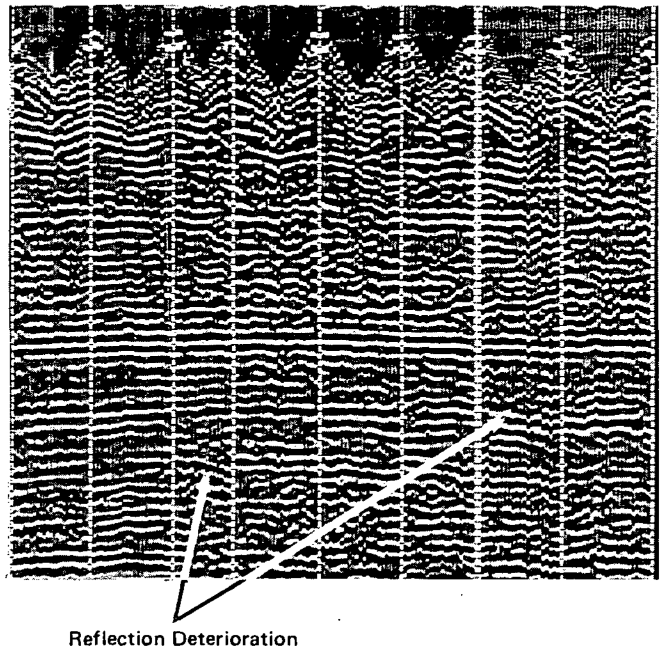
Validity checks? Again, the velocity tends to cause systematic changes. If the center of the salt dome is considered to be all salt as shown in Example 6-B (an extension of Example 6-A to conform to Model 6), the depth to the base can be determined. Assume the base to be flat at the computed depth and determine average velocities for various time values on the dipping basal reflector. If this assumption is correct, these varying average velocities will plot as a straight line on a V-T chart.

And coincidence, of course, plays its useful warning role. The syncline on the right matches exactly its overlying anticline, the basement high matches the intrusion, and there is a suggestion of coincidence for the anticline on the left.

The steeply dipping basal reflector beneath the salt dome can serve a useful purpose. The seismic waves travel more slowly on the left side than on the right side. This difference suggests an irregular shape for the salt body. Thus, a rough outline of the salt may be gained by merely observing the shape of the velocity anomaly.

Example 7 - Reefs

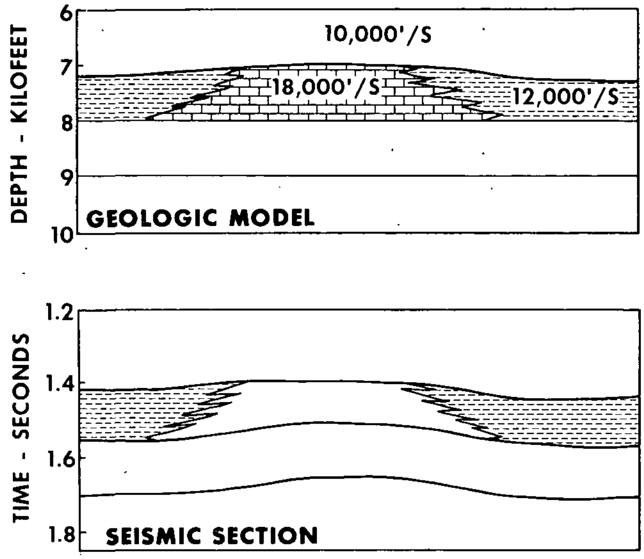
Observed Phenomenon



Example 7-A

Example 7-A is a classic supratenuous fold with gentle reversals in the shallower beds and increasing relief with depth. Reflection deterioration is seen in the deeper central basement uplift area. The structure appears to be basement involved and thus may have influenced the overlying beds through restricted deposition or differential compaction. A seemingly good geological interpretation, then, is a supratenuous fold. But the change in character and continuity of the lower interval is not explained.

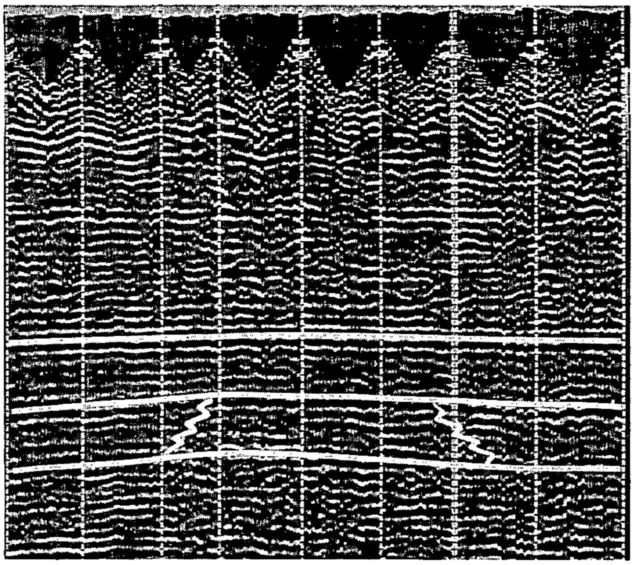
Model Study



Model 7. Reefs.

To settle for a simple basement uplift could be a pitfall. That subtle change in character and continuity of the reflections is a clue to the reef shown in Model 7. Seismic sections frequently show highs beneath reefs and these are often velocity anomalies. The character of such anomalies varies with the velocity composition of the on-reef and off-reef materials. The big problem is demonstrating for any specific example that all of the subreef structure is due to velocity.

Validity Check



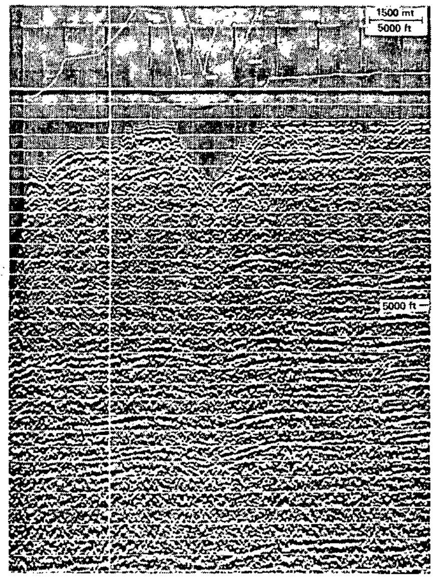
SERENDIPITY REEFS
Example 7-B

Although we cannot demonstrate that the sub-reef structure of Example 7-B is wholly due to velocity, we do have a validity check. That check is the coincidence of the deep high with the reflection deteriorations. A horizontal line drawn across the basal reflection will deviate from that reflection more or less coincidentally with the reflection deterioration.

The reef occupies the deterioration zone, and its higher velocity causes the basal upbowing. But this circumstantial evidence does not make the reef a unique solution; igneous tuffs have also been encountered in the same framework. If you drill for a reef and find igneous tuffs, that is tuff luck. But if you drill an anticline and find a reef - that is serendipity, as demonstrated in Example 7-B. Serendipity is the guardian angel of interpreters.

Example 8 - Channels

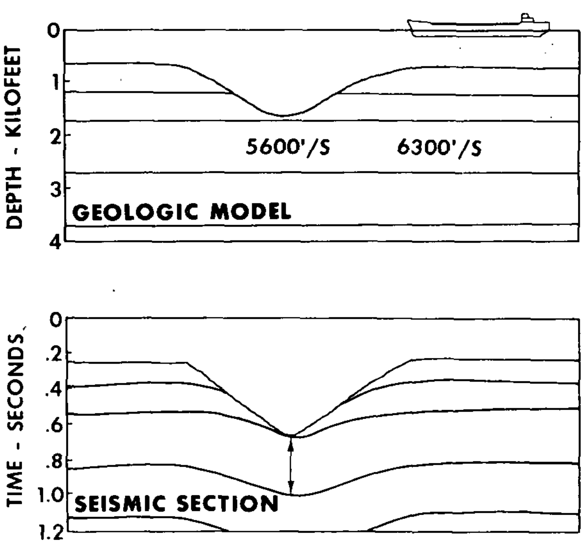
Observed Phenomenon



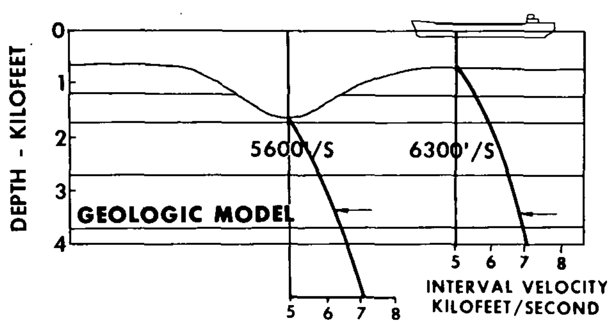
Example 8-A

Example 8-A shows a very marked indentation of some 1100 feet in the seafloor, and beneath it a very well developed syncline. A close examination of the various horizons of the syncline will show interval variations from top to bottom. It might logically be reasoned that this was a growing syncline extending up to the surface and thus localizing the initial erosion that created this canyon.

Model Study



Model 8-A.

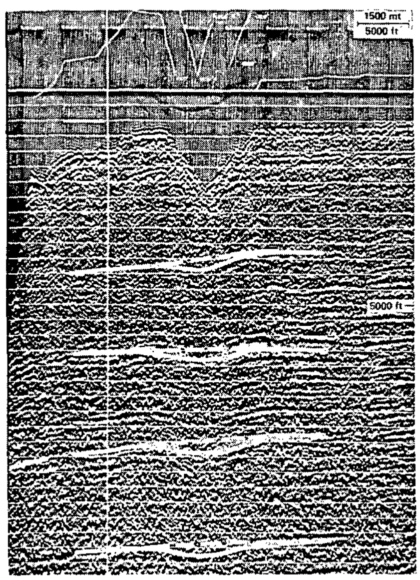


Model 8-B.

There are two pitfalls here. One, of course, is the apparent syncline beneath the channel. Most interpreters will recognize this as a velocity anomaly. However, it is not generally recognized that a waterfilled channel cut into recent sediments can increase the seismic time thickness of intervals beneath the channel as shown in Model 8-A. The difference in overburden pressure is responsible. Apparent synclines beneath channels generally widen with depth. The apparent thickening of intervals into the syncline tends to diminish with depth toward some limiting value. However, there may be considerable variation depending upon the character of the velocity-depth function.

The second pitfall is using a correction for topography based on replacing the water velocity with that of the adjacent sediments. In the seismic intervals beneath the channel, this type of correction will leave a thickening that could be misinterpreted as a growing syncline. Model 8-B demonstrates the proper method of estimating a correcting velocity. For channels that are not too deep, the same interval velocity–depth function may be used within and outside the channel, provided the curve is adjusted to the water bottom as shown in Model 8-B.

Validity Check

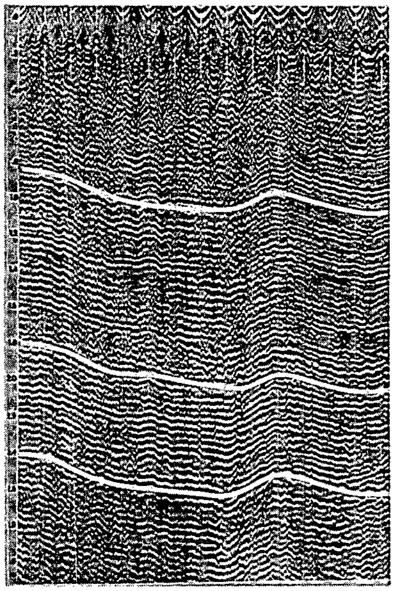


WATER-BOTTOM ANOMALIES
Example 8-B

Three quick checks can be made to test the authenticity of this type of syncline. One is the standard (by now) fact of coincidence. While the syncline could be real, again the coincidence strains credulity. A second check is the change in shapes of these synclines with depth. A close examination of the seismic section in Example 8-B will show a narrow, shallow syncline becoming broader with depth and varying in relief to some maximum value. These changes are both due to the velocity effect shown on Model 8-B. The third check will be discussed later under the category of "Geometry."

Example 9 - Near-Surface Velocity Anomaly

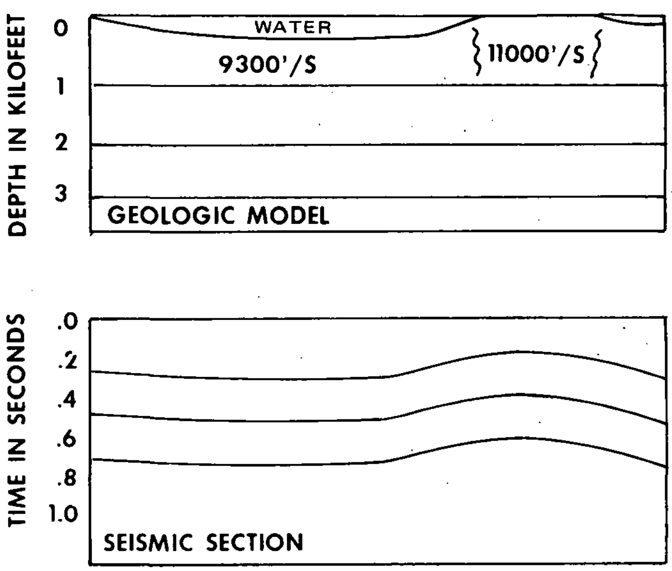
Observed Phenomenon



Example 9-A

Example 9-A shows a very young anticline. We know it is young because the amount of reversal is the same on each horizon and thus was folded later than the youngest horizon. This always raises the question, "Would a young anticline like this be prospective?"

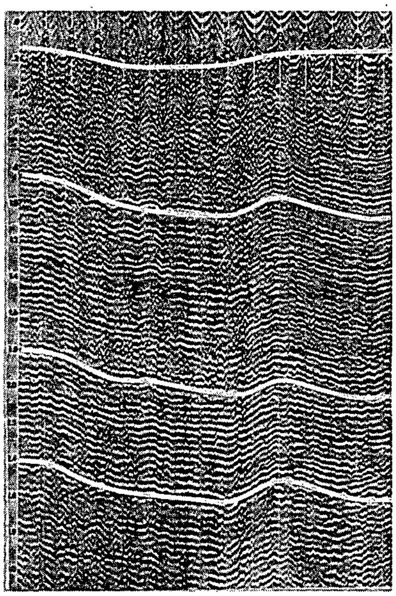
Model Study



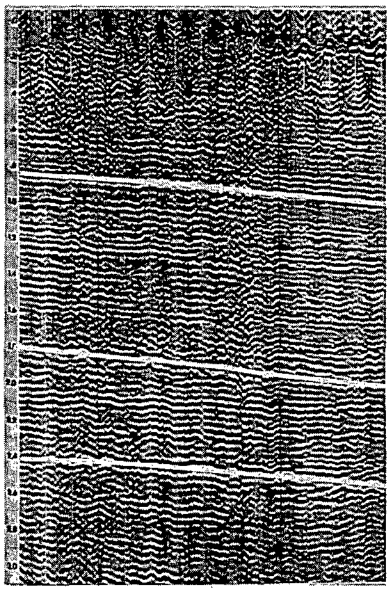
Model 9. Near surface effects.

But before we consider the prospectiveness of this anticline, we should first question its very existence. A structure in which all beds have the same relief will not produce a seismic section in which all reflections have the same relief. If the structure is not real, we immediately suspect a lateral velocity variation within the near surface. Model 9 represents a lateral velocity variation due to permafrost. The near-surface velocity varies from 9300 ft/sec in the water-covered area to 11,000 ft/sec within the permafrost. The seismic expression of the model shows the apparent structure resulting from the reduced travel time through the permafrost. Similar apparent structures can result from any localized, near-surface velocity anomaly.

Validity Check



NEAR-SURFACE
VELOCITY ANOMALY
Example 9-B



NEAR-SURFACE
VELOCITY ANOMALY
Example 9-C

Testing the validity of structural anomalies of this type is relatively simple. The best test is to plot the refraction first kicks, which will often show a coincidence between near-surface velocity anomalies and subsurface structure. But with CDP shooting these refraction first kicks are often smeared to the point where they cannot be seen at all, which is a pity because they can be so very valuable. In such cases, perhaps a singlefold write-out showing the refraction kicks would be helpful. In Example 9-B, a line drawn through the high-velocity break encountered in each of the refraction first kicks, takes a shape similar to the indicated subsurface. This is highly suspicious. When a correction is derived from the first kick data and applied to the anomaly of Example 9-B, the structure is eliminated completely, as shown in Example 9-C, and nothing but regional dip remains.

SUMMARY OF VELOCITY PITFALLS VALIDITY CHECK

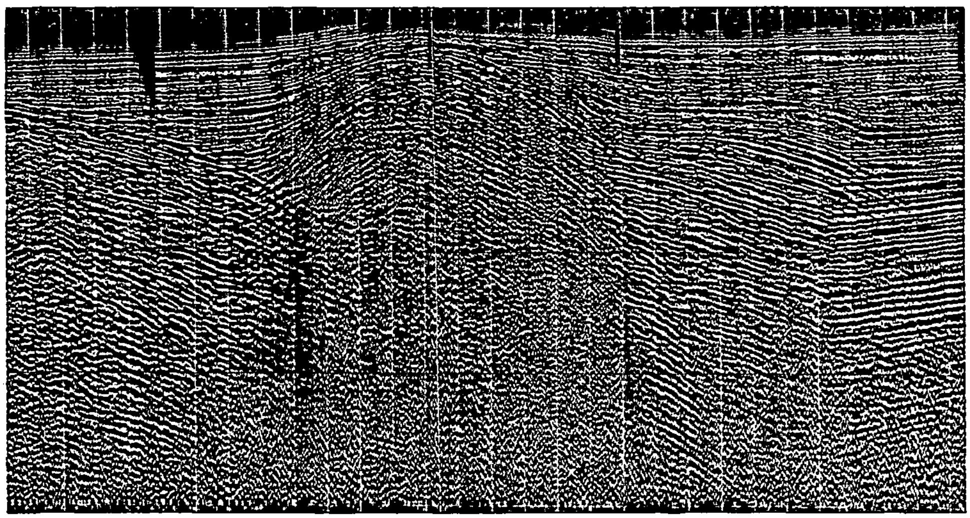
The validity check for the category of velocity pitfalls could be summed up with that one word used over and over again - "coincidence." A coincidence of surface, near-surface, and subsurface is a red flag to heed. A detailed velocity analysis may be required.

GEOMETRY PITFALLS

Our second category is geometry, the shape and steepness of the structures. We refer to anything over ten degrees as being in a steep dip category.

Example 10 - Anticlines

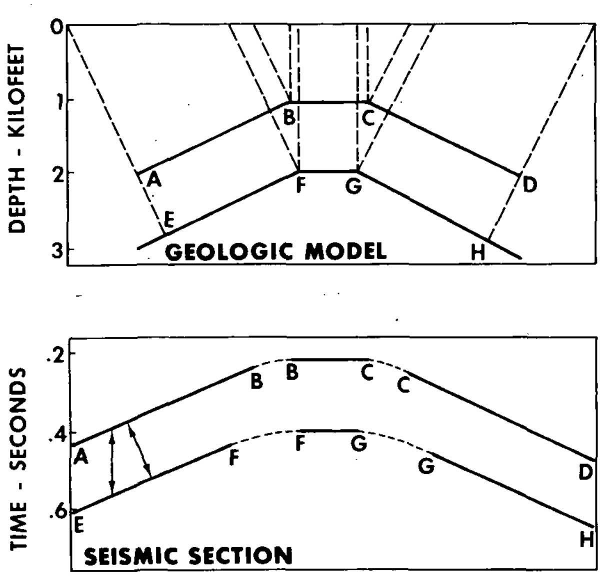
Observed Phenomenon



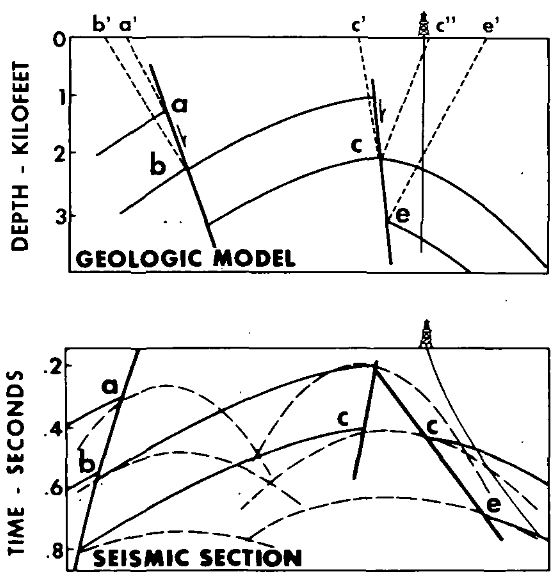
Example 10-A

In Example 10-A, a gentle anticline is readily seen near the surface. Little interruption or complexity is suggested in the near surface; basically, the anticline is a very simple rollover. But the deeper section quickly becomes a confused jumble of reflections.

Model Study



Model 10-A. Simple anticline.



Model 10-B. Complex anticline.

NOTE: These models are not representative of Examples 10-A and 10-B.

The Models 10-A and 10-B illustrate the seismic deception associated with complexly folded structures. To simplify the model, we consider straight ray paths constructed along perpendiculars to the beds from a common source-detector position on the surface. Note that reflections from dipping beds emanate from depth points which are updip from the surface detectors. Note further that the seismic section portrays these depth points directly beneath the surface detector location. The seismic section shows depth point A (Model 10-A) downdip from its position on the geologic model at a time which is equal to the slant path time 0-A rotated to a vertical orientation.

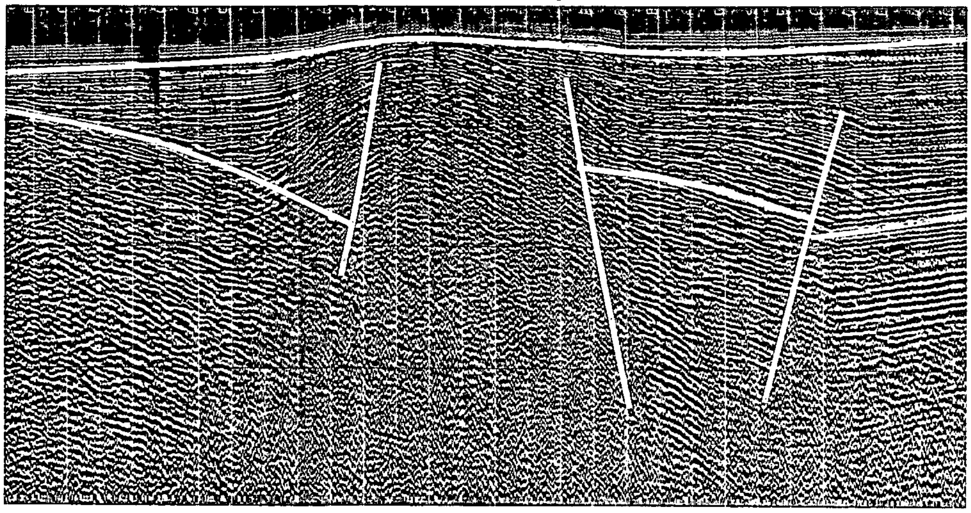
In a similar fashion, all points along the structure are displaced. The break in dip near the crest of the structure is a depth point common to many surface detector positions. Consequently, these depth points are repeated on the seismic section. The net result of the distortion is to present a seismic structure which is spread out, smoothed, and to some extent, simplified as compared with the corresponding geologic structure. Geologists should take special note of one feature of Model 10-A. Ray paths travel perpendicular to the beds but are presented on the seismic section in vertical orientation, as indicated by the arrows. Consequently, intervals on a seismic time section should be measured vertically and not along perpendiculars as is done on a geologic cross section. However, if the section has been migrated, intervals should be measured along perpendiculars.

Model 10-B shows the increasing complexity of the seismic structure as the geologic structure becomes more complex. The combination of steep dips and faulting can completely distort the subsurface geometry. Note how the intersections of the fault and the beds at "a" and "b" (Model 10-B) are shifted; if we locate these points on the seismic section, the normal fault appears as a reverse fault. Fortunately, we cannot ordinarily recognize these depth points and would use the apexes of the diffractions for locating the fault. Incidentally, the diffraction apex is a migrated (two-dimensional) position of the fault. Don't fall into the trap of remigrating at some later stage in the interpretation.

Faults at the crest of structures can present a special pitfall. Conceptually, they should be represented by a single diffraction at each bed-fault interface. However, spreading of the depth points as illustrated by point "c" may lead to the interpretation of multiple faults.

To illustrate further the geometric distortion of seismic structures, note (Model 10-B) how a vertical well bore would have to be deviated to portray it on the seismic section. This also illustrates the problem of tying seismic and well data in steep-dip areas.

Validity Check

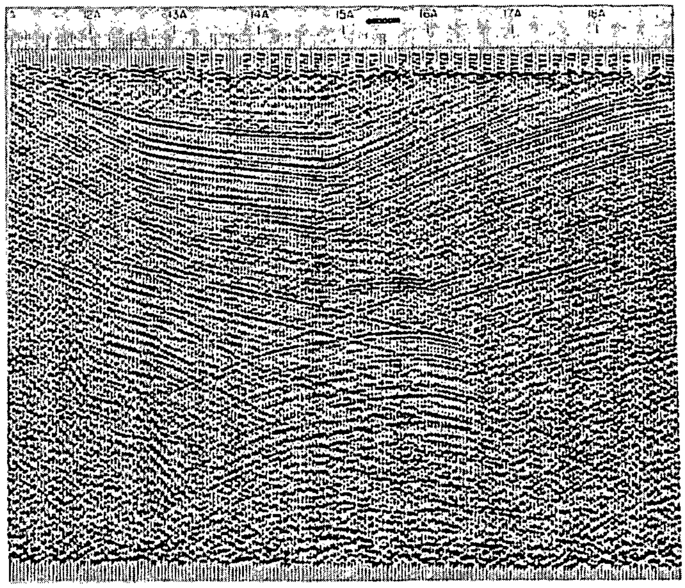


ANTICLINE - Example 10-B

Migration is the solution to the complexities discussed above. Some simple, easy method of hand-migrating (such as the diffraction overlay) should first be used to see how complex the structure really is and to see if a more definitive type of migration is needed.

Example 11 - Synclines

Observed Phenomenon

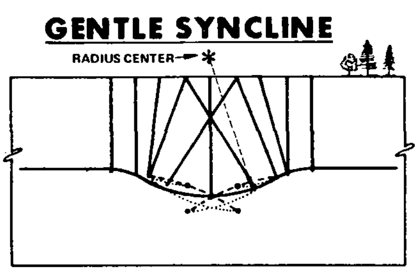


After Geocom

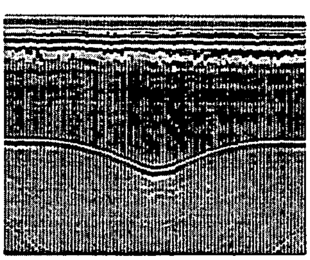
Example 11-A

Example 11-A, from Geocom, shows a simple, shallow syncline resting unconformably on top of a good rollover, or anticline. This positioning would require, of course, two periods of movement—the folding of the anticline and erosion, and then another period of deformation in which a syncline happened to be centered over what had previously been an anticlinal position.

Model Study

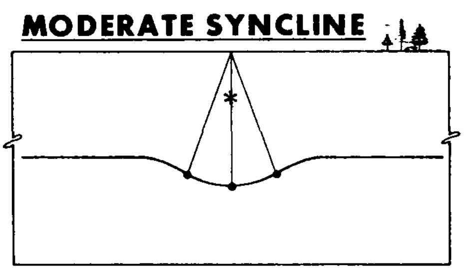


GEOLOGIC MODEL

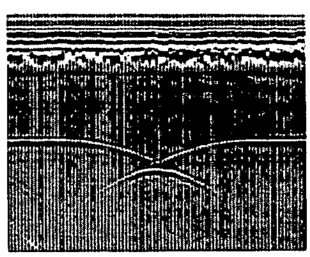


SEISMIC SECTION FROM MODEL

Model 11-A

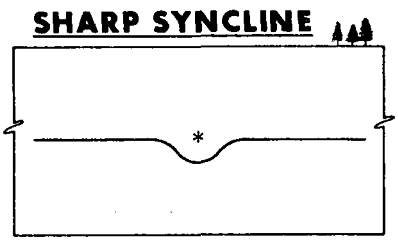


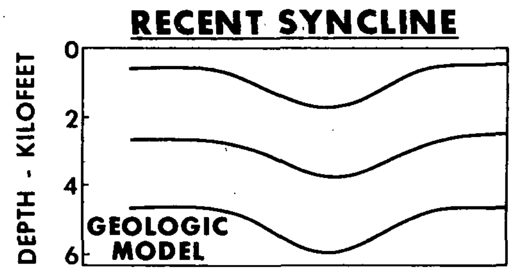
GEOLOGIC MODEL



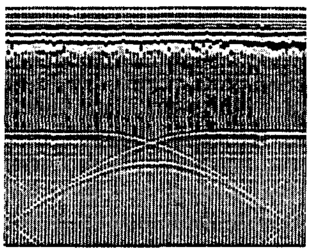
SEISMIC SECTION FROM MODEL

Model 11-B

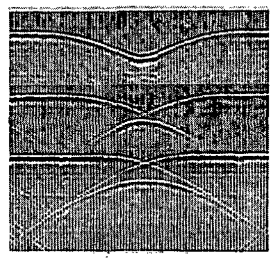




GEOLOGIC MODEL



SEISMIC SECTION FROM MODEL
Model 11-C

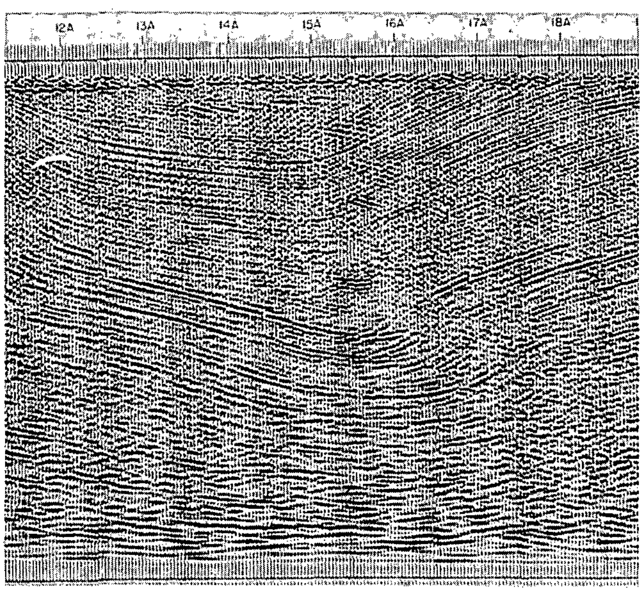


SEISMIC SECTION FROM MODEL
Model 11-D

But can we trust an anticline centered under a syncline? To answer this question, let us examine the seismic expression of a syncline as pictured in Models 11-A, B, C, and D. The portrayal of a syncline on a seismic section depends upon its arcuateness, which is expressed by the location of the center of curvature with respect to the earth's surface. A very gentle syncline having a center of curvature above the earth's surface appears on the seismic section as a relatively simple syncline, as shown in Model 11-A. As the arcuateness increases, Models 11-B and 11-C, the center of curvature moves below the earth's surface. At any surface position near the syncline, multiple depth points are detected and plotted one above the other as shown in the seismic models. The so-called bow-tie with apparent anticline centered below it is illustrated in Models 11-B and 11-C.

Examples 11-A, B, and C are combined in 11-D, in which the downbending on all beds is equal. The increase in depth shifts the center of curvature from above surface for the shallow syncline to below the surface for the deeper synclines. This effectively increases the arcuateness as the seismograph sees it. The seismic section will show a relatively gentle, shallow syncline–becoming progressively sharper with depth, then bow-tieing and finally inverting to form an apparent anticline. To answer the original question, then, anticlines beneath synclines cannot be trusted.

Validity Check



After Geocom

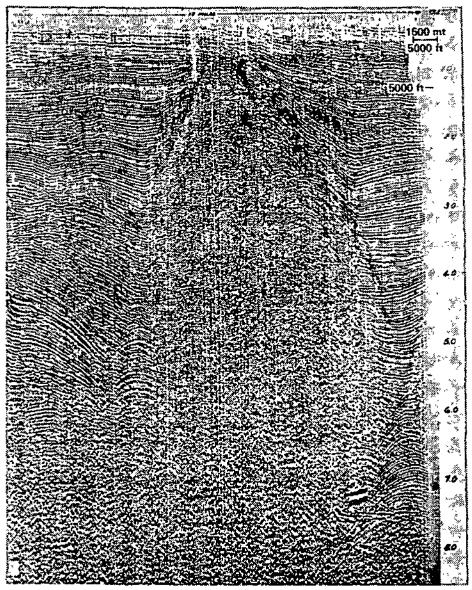
MIGRATED SECTION - Example 11-B

The check for validity of our suspected anticline is migration. The migrated section, Example 11-B, again courtesy of Geocom, completely eliminates any vestige of the anticlinal dip. The syncline now occupies the entire section.

You will recall now that for Example 8, p. 21, the velocity low beneath the sea-floor canyon, we gave two quick checks for identification of false synclines due to velocity pitfalls and promised a third, which is due to the geometry pitfall discussed above. Referring back to Example 8, we see no reflection crossover or bow-tieing. If the syncline had been real and not a velocity phenomenon, it would have had a reflection crossover on the deeper horizons as can be seen on Example 11-A.

Example 12 - Intrusion

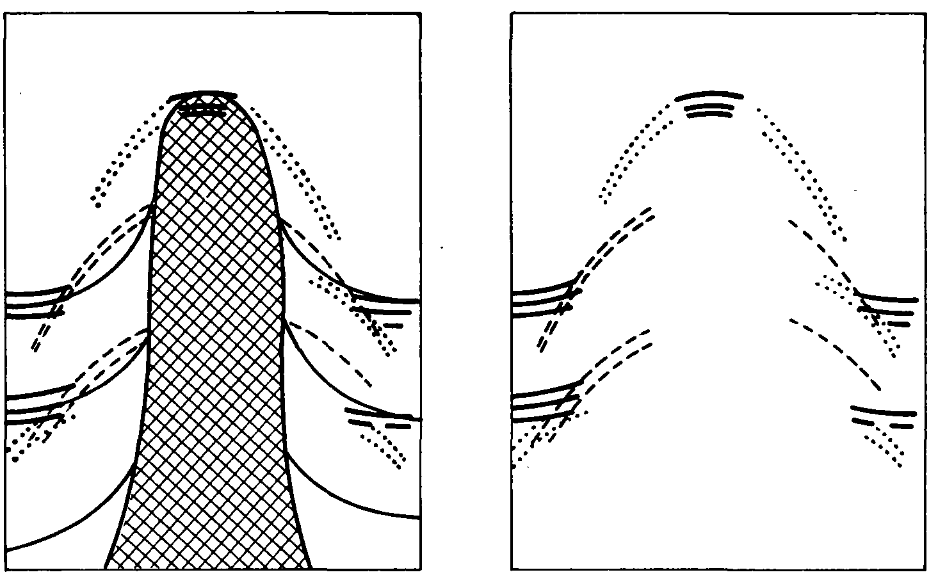
Observed Phenomenon



Example 12-A

Example 12-A is an intrusion, clearly outlined by the reflection terminations. It would be a simple matter to locate prospective wildcats against this intrusive.

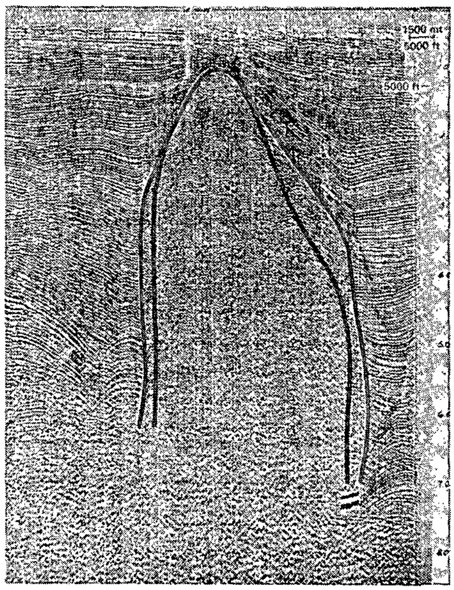
Model Study



Model 12. Salt dome with seismic expression.

Before making the location, though, note Model 12, which shows that the salt dome edge is not at the termination of the reflections. The dashed lines are diffractions and the dotted lines are multiple-branched reflections. You will note that the reflections terminate well out from the edge of the dome, and that the only direct seismic indicators of the dome edge are the apexes of diffractions. Normally, you will not see a diffraction leg within the dome.

Validity Check



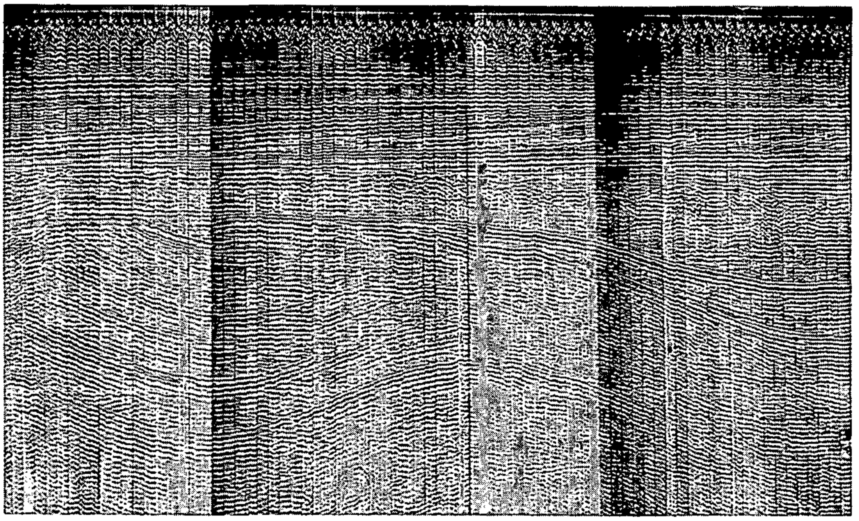
INTRUSION
Example 12-B

Migration is required to locate the actual boundary of the intrusive. The outer boundary shown on Example 12-B is drawn from the reflection terminations. The inner boundary is interpreted as the true outline of the intrusive. This interpretation is based on the migration of the adjacent dips and on a few scattered diffractions. We are assuming, of course, that these diffractions mark the termination of the intruded beds. Note the scale of the section; on the upper right flank there is a difference of over a mile between the reflection's termination and the interpreted edge of the intrusive. This difference is important when mapping the upturned edge of an intrusive for a well location. It is important to remember that the edge of the intrusive is not where the reflections terminate. The edge is somewhere inside.

Incidentally, on the lower left flank of the intrusive (Example 12-B) are some rollovers similar to those of Example 11-A. We now know that this is not an anticline, but a crossover caused by a deep rim syncline.

Example 13 - Sideswipe

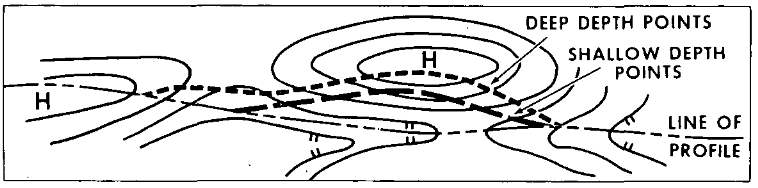
Observed Phenomenon



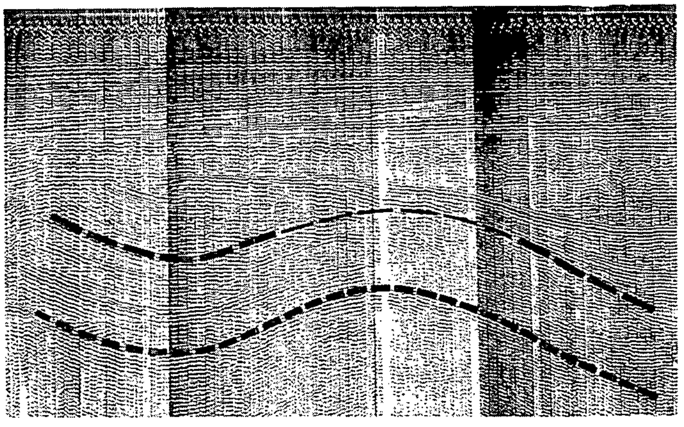
Example 13-A

Example 13-A is an enigma. The left side is easily interpreted, but the right side is confusing. On the left, a near-surface set of prograding reflections overlie an angular unconformity. The synclinal dips beneath the unconformity extend to the deeper section. The deep reflections rise to the right and develop into a deep anticline. But upward in the section, the anticline fades away into regional dip. Even the angular unconformity is less apparent.

Model Study



STRUCTURAL CONTOURS OF GEOLOGICAL MODEL



SEISMIC SECTION OF GEOLOGICAL MODEL

Model 13. Sideswipe.

An explanation of the anomaly is shown on Model 13. Displacement of the depth points to the side of the line of profile is called "sideswipe." As the line of profile passes the structure, the reflection depth points climb the flank of the structure. As in the normal migration problem, the deeper the horizon, the greater the amount of shifting of the depth point from beneath the surface position. Consequently, on the deeper horizons (indicated by short dashes), the depth points climb almost to the crest of the structure and the seismic reflection exhibits large reversal. On the shallow horizon (long dashes), the depth points are well down the flank of the structure, and the reflection exhibits subdued relief and is masked by reflections from the syncline directly beneath the line of the profile. Sideswipe then accounts for the unusual seismic structure in which the anticline dies out upward, but its companion syncline persists.

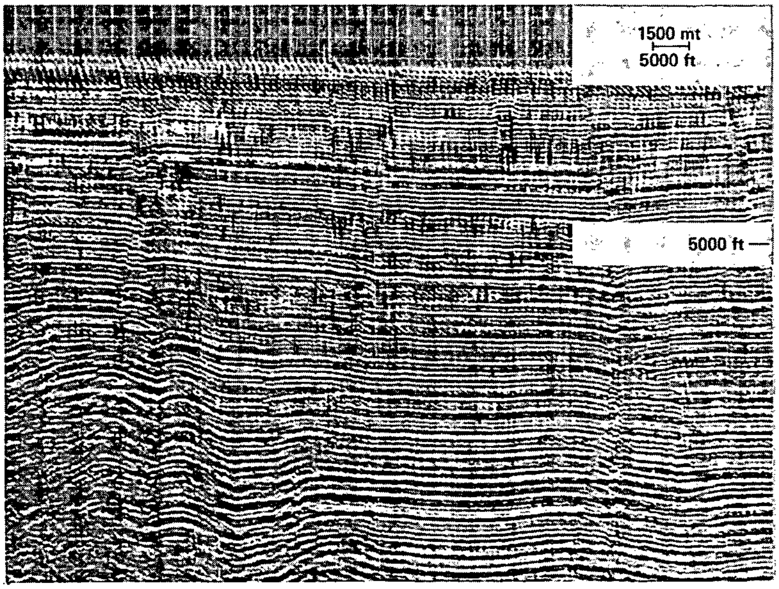
Validity Check

The validity check for sideswipe is sufficient cross lines to outline the structure. In tightly folded areas sideswipe is very likely, but so are front-swipe and back-swipe. In other words, energy will be recorded from a complete 360° circle around the shot point. If these tight folds are close enough together, reflected energy could be coming from one, two or even three anticlines at the same time, presenting a dilemma that could not be solved without some prior knowledge of the grain or trends of the folds.

Knowledge of the trend direction is important in laying out the seismic lines and in working the data. The dip lines would be worked first to get an idea of the complexity of these anticlines and then the horizons would be tied with the strike lines.

Example 14 - Diffractions

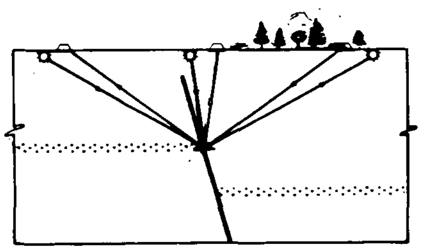
Observed Phenomenon



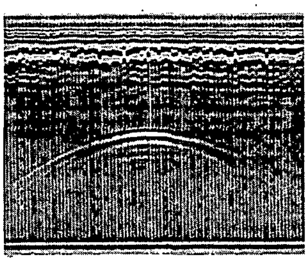
Example 14-A.

Example 14-A is a series of shallow terraces or homoclines which appear to be interrupted with monoclines about a mile in width. These monoclines could be interpreted as shallow expressions of the deep uplifts seen on the left of the section, and an even deeper uplift off the right of the section.

Model Study



GEOLOGIC MODEL

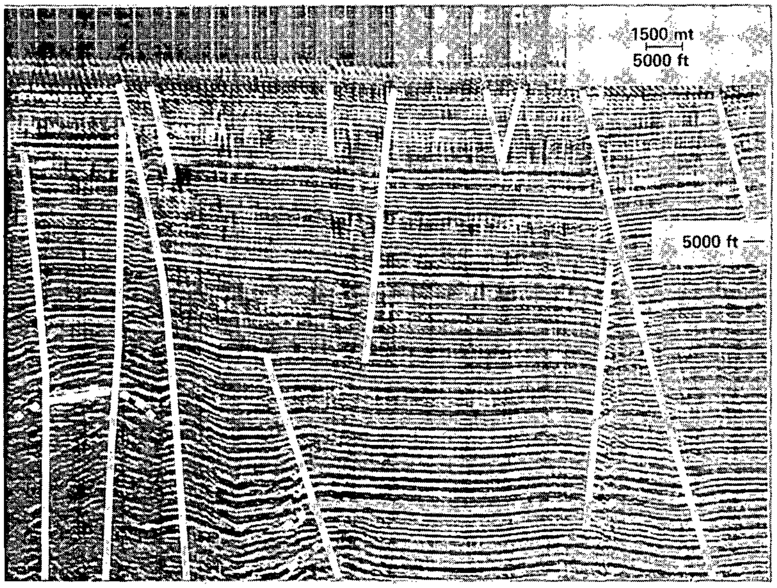


SEISMIC SECTION FROM MODEL

Model 14. Diffractions.

There is a good possibility that there is a fallacy in calling these features monoclines and uplifts; they might be diffractions. Model 14 shows how diffractions are generated. A diffraction source can be any object having dimensions on the order of a wavelength (150-300 feet). An example would be the intersection of a bed with a fault. For all practical purposes the diffraction source is simply a reflector which reflects energy from a series of shot points along the line of profile. Although the actual rays follow slant paths (except possibly at the apex), the reflections are presented vertically beneath the shot points and the typical hyperbolic diffraction pattern is generated. Point source diffractions from a shallow source are generally distinctly hyperbolic and highly arcuate and so readily recognizable as diffractions. However, a diffraction from considerable depth or from a fault which strikes at an acute angle with the line of profile tends to lose its hyperbolic character and assume the air of a respectable-looking anticline. How can we distinguish anticlines from diffractions?

Validity Check



FAULTS & DIFFRACTIONS
Example 14-B

An ideal medium for recognizing or suspecting diffractions is the diffraction overlay. In Example 14-B, the CDP processing has so smeared the true faults that they take on the appearance of a continuous bed or a monocline. Although a single-fold playback would best define the fault itself, a diffraction overlay is often sufficient to show where the fault really occurs. Notice particularly the "deep uplift" on the lower left; it is nothing but a fault with diffractions.

A second test for differentiating between diffractions and anticlines is their curvature. A diffraction is hyperbolic in that its maximum curvature is at the top and it straightens out with depth. An anticline, with its corresponding syncline, is a continuous convex-concave curve.

Diffractions originating from less than about 75° of the line of profile are a problem in recognizing. They may fit a diffraction overlay rotated from the vertical, the amount of skew being a rough measure of the angle of the line to the diffraction source. Where the structural trend is known, diffraction overlays should be made to satisfy the angle between the line of profile and the structural grain.

SUMMARY OF GEOMETRY PITFALLS VALIDITY CHECKS

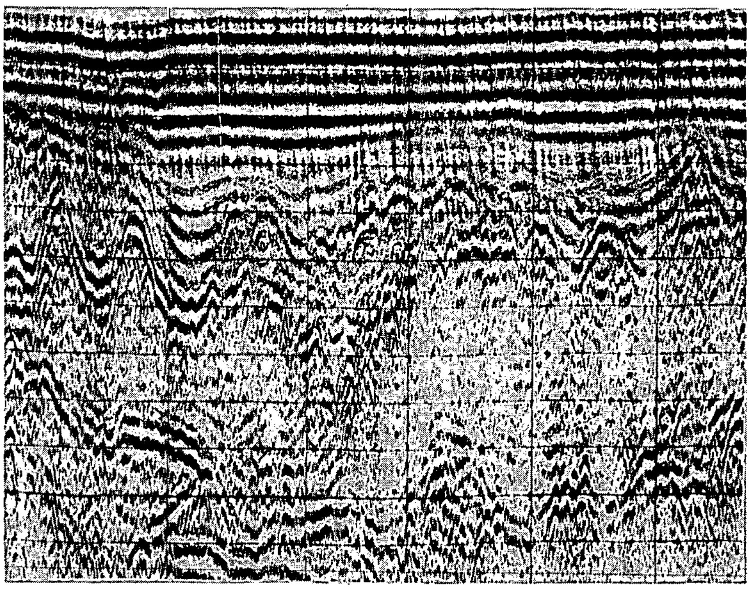
The validity checks for the category of geometry pitfalls may be summed up in two words: Geology and Migration. One must know what to expect in structural complexity and line orientation, and he must migrate for truer perspective.

DATA GATHERING AND PROCESSING PITFALLS

Our third category of pitfalls is Data Gathering and Processing. Processing is perhaps the most dangerous, because it is the newest and least understood. In the analog world of yesterday, shooting, processing, and interpretation often took place in one office in the field. Now, in the digital computer era, processing is generally separated from interpretation, and communications between interpreter, field operator, and data processor may not be adequate to maintain an optimum level of recording and processing. However, even high-quality recordings may contain pitfalls because of the presence of nongeologic reflection-like events.

Example 15 - Input Pulse

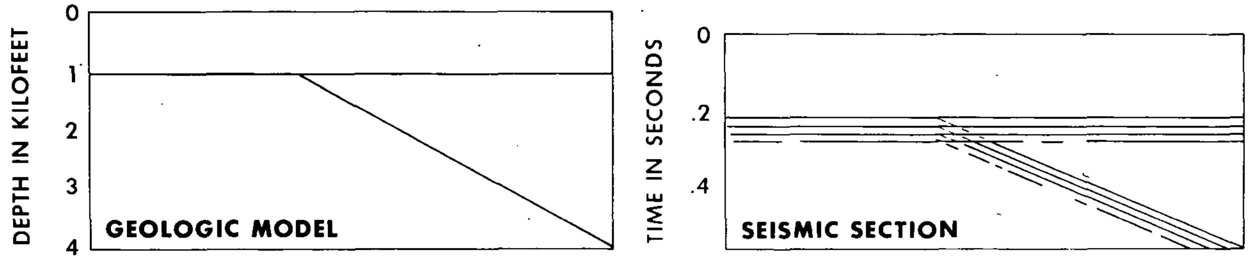
Observed Phenomenon



Example 15-A.

Example 15-A appears to be a very simple case of recent, many-layered bedding, beneath which are a couple of paleo unconformities – old unconformable, eroded surfaces. There are some scattered, confusing dips, but basically the unconformities can be very accurately mapped.

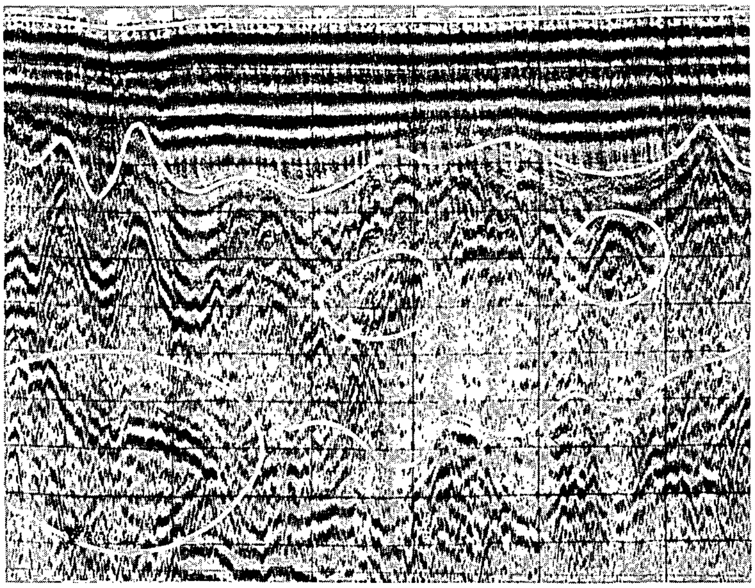
Model Study



Model 15. Elongated pulse.

"Accurately" may be a deceptive word to use here. Geologic Model 15 shows a simple condition, a flat-lying angular unconformity. But the seismic expression of this simple two-line model is complicated, since the seismic wave, the basic measuring device of the seismograph, is generally not a single cycle, but a train of as many as six cycles, as in Example 15-A. Each reflecting horizon generates multicycles, and the tailing cycles of the upper horizon may mask the correct position of features such as the unconformity in Model 15. Seismic reflections are distorted when the interval between reflectors is less than the length of the input signal.

Validity Check

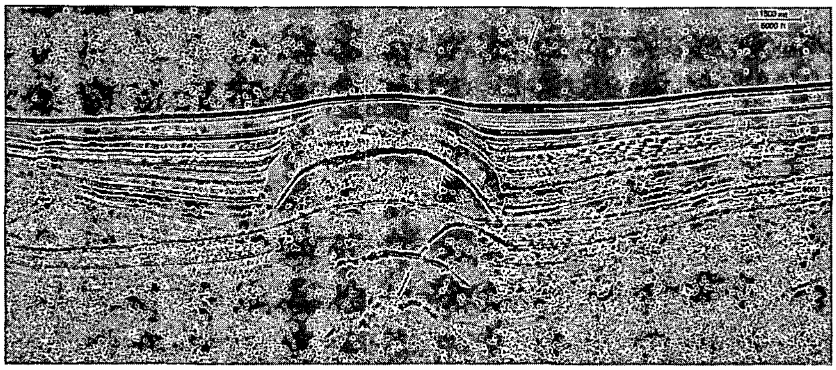


INPUT PULSE
Example 15-B

The crux of the validity check is to recognize the input signal. With deep marine shooting, this signal may be seen in the first arrivals and water-bottom reflection and verified in deeper, wide-spaced reflectors. With land and shallow-water marine shooting, the only clue will be in the wide-spaced reflectors. These will be seen as isolated reflections of a similar character. In Example 15-B, the circled areas are distorted – have no meaning whatever. If detailed mapping is required, extreme care must be maintained in the type of signal put into the ground.

Example 16 - Normal Multiples

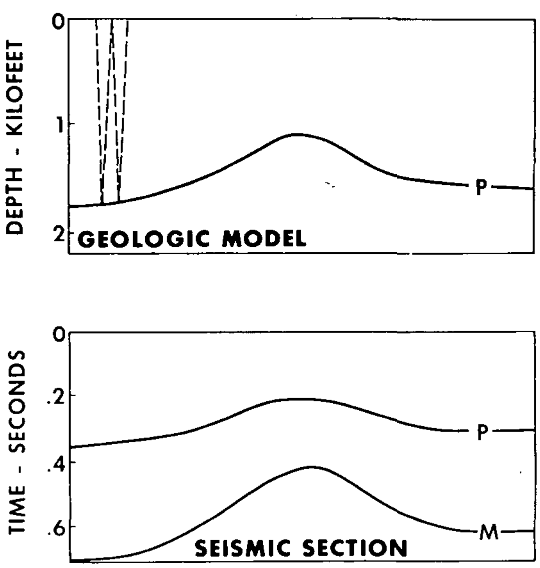
Observed Phenomenon



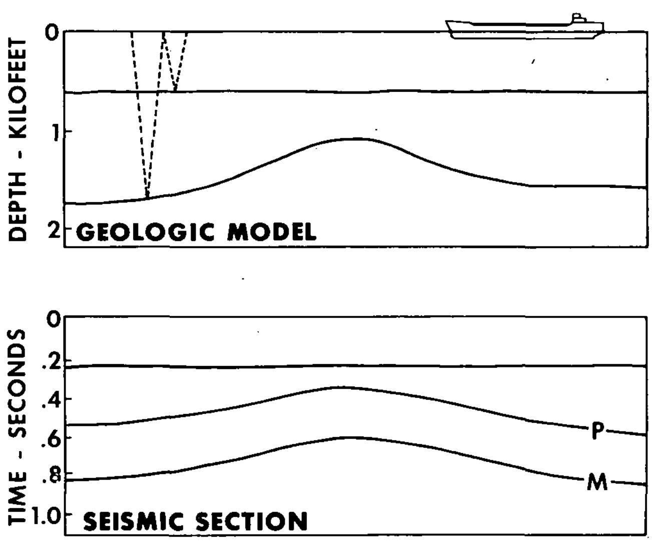
Example 16-A

Example 16-A has a central no-reflection zone reminiscent of the previously described reef. At the left there is also a nice wedge of sediments that gets progressively thicker with depth. This upper section is terminated by a very marked unconformity.

Model Study



Model 16-A. Simple multiple.

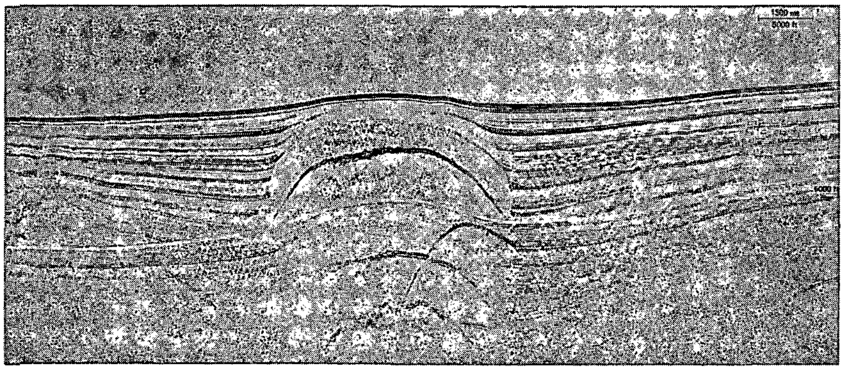


Model 16-B. Ringing multiple.

In sections of this type, one should suspect multiples. In discussing multiples, we will consider only the simpler types – those generated at the surface, at the base of a low velocity layer or a channel, or by standing waves within a near-surface or water layer. The simple multiple generated at the surface is shown in Model 16-A. Each bounce between surface and reflector is recorded, and the multiples appear on the seismic section at a time spacing equal to the two-way travel time between the primary reflector and the surface reflector. If the primary reflector is dipping and the surface reflector is flat, the seismic dips will be approximately double those of the primary for the first-order multiple.

The standing-wave multiple is demonstrated in Model 16-B. It develops when energy becomes trapped between two reflectors and reverberates. If the two reflectors are flat, primaries and multiples will exhibit the same dip. The standing-wave multiple is common on marine surveys, where the energy is trapped and reverberates in the water layer. If the layer is thin, the multiples appear close together and impart a ringing, or singing, character to the section. This type multiple is also called an interbed multiple.

Validity Check



MULTIPLES
Example 16-B

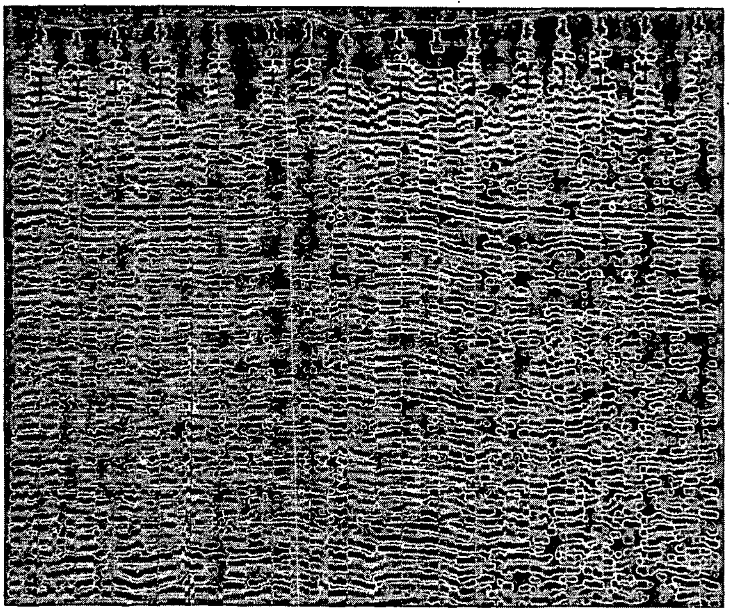
Many of the simpler multiples may be attenuated by filtering, which explains why this example is shown under "Data Processing." But how do we recognize multiples?

The simple multiple is easy to recognize. If the distance from one reflection (i.e. the water bottom reflection of Example 16-B) is duplicated by a second reflection, a multiple can be suspected. The sequences of wedges noted on the left of Example 16-B may be in part due to a special case of the interbed multiple. Some, if not all, of the wedging may be real, but a single wedge near the surface could in itself create a series of wedges.

Deconvolution may help with the ringing; selective dip filtering may remove some of the simple multiples; but no truly reliable method of eliminating multiples is available. While calculating multiple paths may be very helpful, a pessimist can "multiple" himself completely out of a prospect. A healthy skepticism is a virtue.

Example 17 - Inverted Multiples

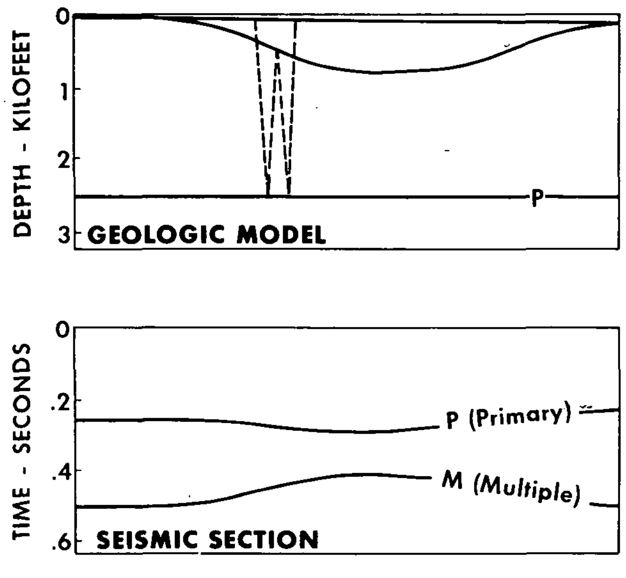
Observed Phenomenon



Example 17-A

Example 17-A exhibits a very shallow anticline. As in Example 9-A, it is shallow, so it obviously must be a young anticline representing recent folding. But in the explanation of Example 9-A, we learned our shallow anticline was really a low velocity correction problem. Is that what we have here?

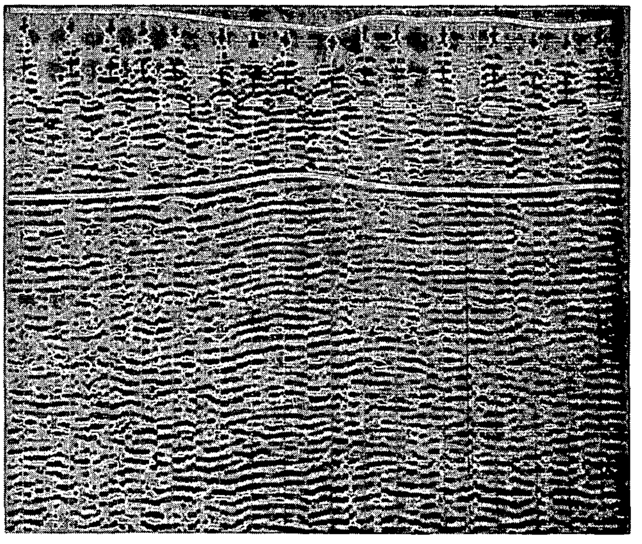
Model Study



Model 17. Multiple from base low velocity layer.

Yes and no. Yes, it is caused by a low velocity layer, but it is not a correction problem. Again, multiples are our pitfall. In Example 17-A, the prominent reflections at 0.5 sec and others parallel to it are multiples. Unlike the multiples of Models 16-A and 16-B, the multiple of Model 17 is an accentuated mirror image of its primary. It is also a mirror image of the base of the low velocity layer from which it originates.

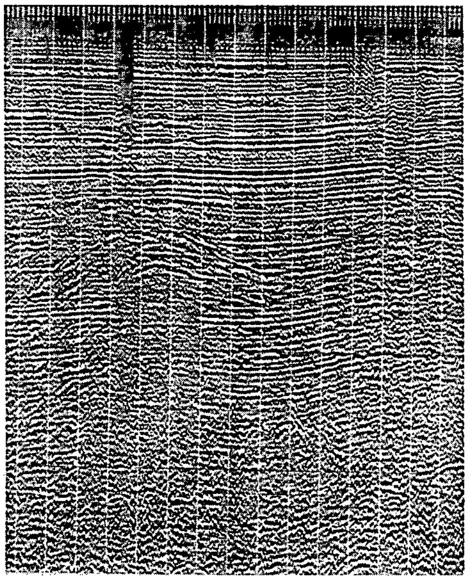
Validity Check

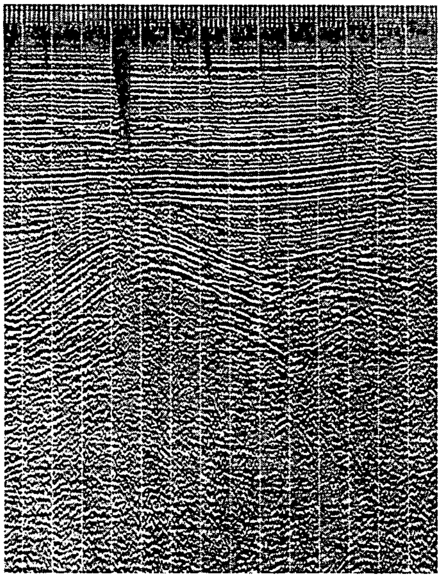


MULTIPLE REFLECTIONS
Example 17-B

The multiple style of the anomaly in Example 17-A is suggested by the surface topography marked on Examples 17-A and 17-B. The validity check is the coincidence of the topography with the structural anomaly. This time, however, the low velocity zone becomes a reflector producing a multiple. The true dip is indicated by the primary reflector, the horizontal dashed line in Example 17-B.

SUMMARY OF DATA GATHERING AND PROCESSING VALIDITY CHECKS





MULTIPLES OR DIP?
Example 18

Example 18 summarizes the category of Data Gathering and Processing. It shows two versions of the same seismic data. On the left section, the horizontal dips are very strong, with a faint rollover in the background. We might explain the rollover as sideswipe, or we might consider the horizontal dips as multiples. The predominant feature on the right section is the anticline. Which of these two is correct – the structure or the horizontal dip with the faint indication of sideswipe – can be determined only by the Data Processor, the Geologist, and the Geophysicist, working together. This rapport must be established in our digital world today. Otherwise we will all be suppressing structures and missing prospects. Communication between Operations and Geology and Geophysics is essential to successful data gathering and data processing.