[GC]Vertical Seismic Profiling at Eldfisk Field *

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General Statement

Vertical seismic profiling (VSP) began to be popular among non-Soviet scientists in the late 1970s, about the time that my previous employer, Phillips Petroleum Company, and our partners were trying to determine development strategies for newly discovered fields in the Greater Ekofisk area of the Norwegian North Sea. Resource evaluations and development planning at Ekofisk and Eldfisk had to be done with 2-D seismic data at that time – and one of the controversies regarding development of these fields centered on the famous "collapsed zone" atop each structure.

One 2-D seismic profile of 1970s vintage that crosses Eldfisk field is displayed here as Figure 1 and shows a classic example of the apparent collapsed structural crest that had to be factored into early field development plans. Two camps existed among the partner teams that had to decide how to proceed with development drilling:

Camp 1 said, "The anticline has a true collapsed top and reserves are reduced."

Camp 2 said, "There is a low-velocity chimney in the thick shale above the structure that creates a velocity pull down and there is no collapsed top."

Camp 1 wanted to interpret a fault where one is drawn on the profile; Camp 2 believed that there was no fault, just a velocity-generated time sag.

VSP Project

A VSP project was designed to acquire information to help resolve these two opposing structural interpretations – the VSP geometry that was used is illustrated as Figure 2. An obligated field-evaluation well (Figure 1) had to be drilled and was used as a VSP receiver well to decide where to place the next evaluation well. The VSP source was offset 2.5 kilometers from the well, so that if there were a low-velocity gas cloud above the crest of the structure, the down-going VSP raypath would pass under the velocity anomaly (Figure 2). Up-going reflected VSP raypaths to the borehole receivers would still pass through part of the low-velocity zone.

Because only a small part of the total VSP travel path traverses the low-velocity zone, any time delays introduced into VSP reflection events would be much less than the time delays associated with two-way travel paths through the low-velocity interval when towed-cable data are acquired. One combination of down-going and up-going towed-cable raypaths is shown in Figure 2. The VSP image that was produced is inserted into the 2-D towed-cable image in Figure 3; the VSP data show that the top of the Ekofisk Formation climbs smoothly and continuously to form an unbroken anticline crest at this location.

Although Camp 2 won the argument at this well location, the controversy of collapsed anticline crests remained in other parts of the greater Ekofisk development program. Not unexpectedly, some graben collapses were found at some crestal well positions (and were again verified by VSP imaging). The moral of this story: Properly designed VSP surveys can answer numerous questions about geological complexity near a receiver well. VSP imaging is often the best way to undershoot a shallow geological complexity to see a deeper target.

Conclusion

In this example, cost of the VSP survey was repaid many times over by the value of the information provided by the VSP data. The presence or absence of several million barrels of oil was at stake when field developers had to decide whether Eldfisk lost a big part of its structural crest.

With modern 3-D seismic technology we can do a much better job of creating reliable images of structure beneath complex velocity layering than was possible in the 1970s.

However, there will still be locations – even today – where VSP imaging can provide information that is difficult to acquire using surface-based receiver technologies.

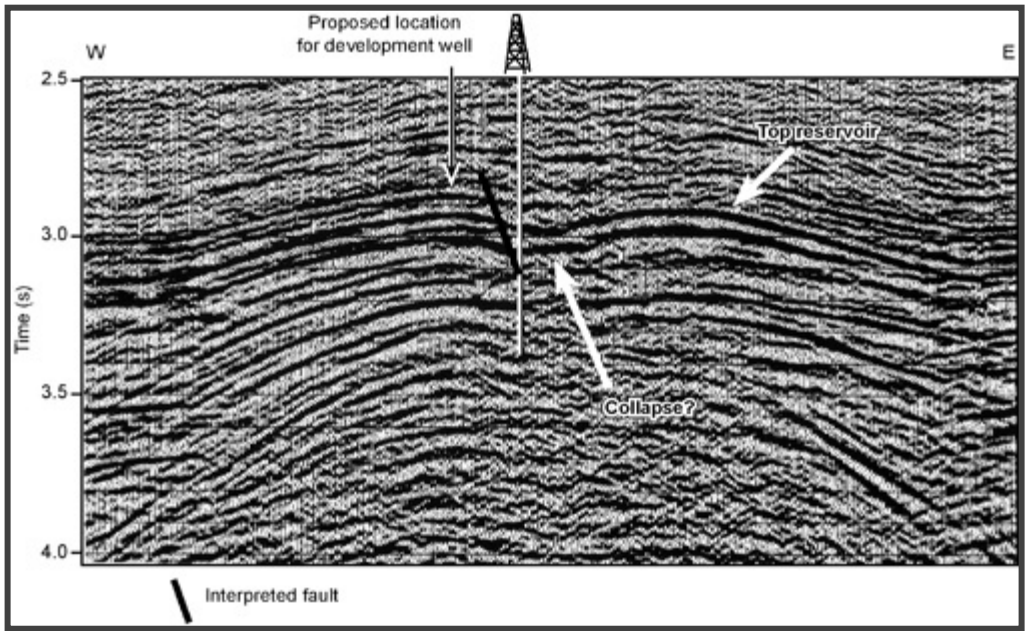

Figure 1. 2-D seismic profile, 1970s vintage, traversing Eldfisk field. The data show an apparent structural collapse across the crest of the structure near the well location. Is the graben real? Is the interpreted fault really there?

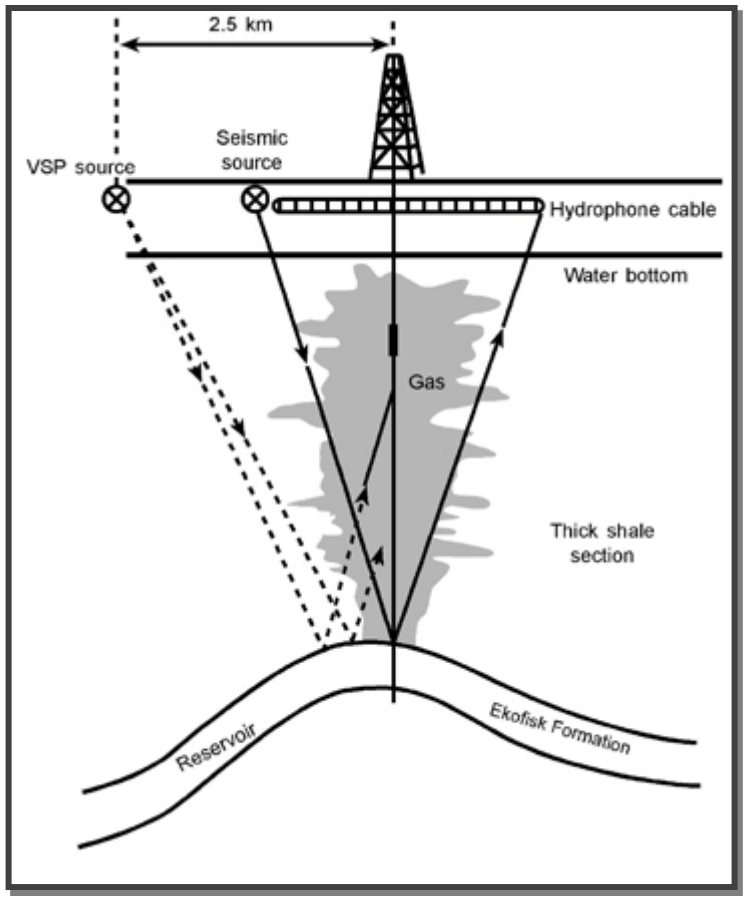

Figure 2. Assumed low-velocity gas chimney extending through the thick shale interval above the Ekofisk Formation. Towed-cable seismic data have significant time sags when their two-way raypaths have to pass through the low-velocity chimney. In contrast, offset-VSP data have minor time delays, because only short segments of each VSP travel path have to traverse the low-velocity zone.

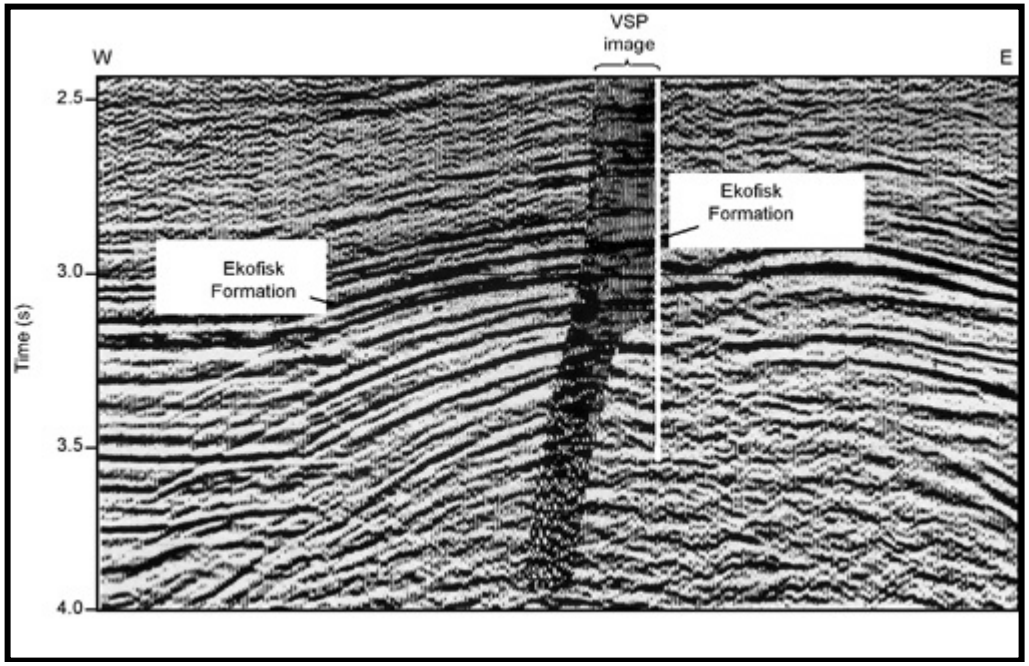

Figure 3. Comparison of VSP image and towed-cable image: The VSP data show that there is no significant structural collapse, which was the correct answer at this well location.