Extraction of *P*- and *S*-Wave Velocities from a 3-D Reflection Data Set and Its Application to Direct Hydrocarbon Detection

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SUMMARY

A 3D seismic data set over the F-A/F-AR gas fields offshore South Africa has been interpreted for direct hydrocarbon indicators, processed using both conventional techniques and the GEOSTACK process. GEOSTACK is a direct hydrocarbon detection method utilising amplitude versus offset concepts to generate weighted stacks. The method is based on the extraction of P-wave and S-wave reflectivities from reflection data. The purpose of this study was to evaluate the GEOSTACK process over a known gas field and to determine how closely the extent and quality of the gas sands established by drilling correlated with the amplitude anomalies apparent on the GEOSTACK sections. Interpretation was done on the 'F-stack', which is designed to be sensitive to the presence of gas-bearing sandstones. Two distinct high amplitude events of opposite polarity could be traced, representing the top and base of the gas-bearing reservoir sands. Contoured amplitude maps of the two anomalies show a very good correlation with the known extent of the gas sands, with the highest amplitudes occuring at the positions of best reservoir quality. The study has shown that using weighted stacks, in particular the F-stack, gas-bearing sandstones can be detected and a qualitative assessment made of their reservoir characteristics.

Introduction

Amplitude versus offset concepts can be used to generate weighted stacking schemes which can be used in an otherwise standard seismic data processing sequence to display information about rock properties (Smith and Gidlow, 1987). Using approximations to the Zoeppritz equations, which describe the variation of P-wave reflection coefficients with the angle of incidence of a P-wave as a function of the P-wave velocities, the S-wave velocities and the densities above and below an interface, time- and offset- variant weights are generated which are applied to each time sample in a CDP gather. The properties which are most usefully displayed by GEOSTACK are: P-wave reflectivity (or true zero-offset reflectivity) and the so-called F-stack, which highlights the presence of gas. If we have a clastic section uncomplicated by carbonates or other lithologies then on the F-stack all reflections will disappear except those associated with gas. The complete discussion of GEOSTACK is given in Smith and Gidlow (1987)

Geological Setting

The FA gas field is situated in the north eastern rim of the Bredasdorp basin, one of several arcuate basins on the Agulhas bank, formed during the continental breakup of Gondwanaland. Initial rifting began in the Jurassic, followed by succesive periods of graben infill. The major marine incursion associated with final separation, resulted in a major unconformity at seismic horizon C. The field consists of two structurally high areas, F-AR in the north west and F-A in the south, separated by a graben. Basement rocks consist of metamorphic slate, Devonian in age, and are overlain by four depositional cycles. The first two cycles comprise predominantly red claystones and siltstones with poorly sorted fluvial sand- stones and conglomerates, with very limited reservoir potential. The following two cycles form the shallow marine sandstone reservoir, Upper Jurassic in age. These sands grade upwards from poorly sorted nearshore sandstones to clean, well sorted medium to coarse grained barrier bar sand-stones. Deposition of the sandstones was controlled to a large extent by movement on the major faults bounding the horsts. Erosion at the time of the horizon C unconformity resulted in the removal of most of the sediments on the horsts and caused deep channelized erosion in the grabens. Overlying the reservoir is a succession of post-continental separation Lower Cretaceous and younger shales and siltstones, deposited in open marine conditions.

Seismic Data

a) Acquisition - The 3D survey consisted of 175 lines, 50m apart shot in the strike direction (this orientation was selected to reduce strong swell noise). The acquisition system comprised a 2 780 cu. in. gun array and a 2875m long streamer consisting of 230 linear hydophones of 12,5 m separation. Shot point interval was 25 m, resulting in a recorded 57-fold CDP stack. Bin size used during acquisition was 6,25 m in the in-line direction and 50 m in the cross-line direction; during processing an "intelligent" interpolation technique was used to reduce the cross-line trace interval from 50 m to 12,5 m.

b) Processing - a conventional processing route was followed with attention being given to the preservation of true amplitudes with offset. GEOSTACK weights were applied to CDP gathers prior to stack.

Interpretation

The interpretation of the 3D data set was done on a SIDIS workstation. The original interpreted horizon picks from the conventionally processed data set were transeferred into the GEOSTACK data set and were used to correlate the GEOSTACK anomalies with the established geologic model. Only the F-stack was used in the interpretation, selecting every twentieth line and crossline i.e a 250 m by 250 m grid. Two distinct high amplitude events of opposite polarity could be mapped over the established extent of the gas-bearing reservoir sands. Figure 1a shows a typical F-stack section through three boreholes. Two high amplitude events at 2,0 s (a trough and peak), extending from CDP 721 to 1021 can be clearly seen on this section. Figure 1b shows the same section processed conventionally. The gas event is not an anomalously bright event. Contoured two way time and amplitude maps for the high amplitude events were produced, figures 2, 3, 4. The upper event (trough) - correlates throughout with seismic horizon C, the unconformity forming the top of the marine sandstone reservoir. The lower event, H1, which should trace the base of the gas-bearing section, can be tied to the gas/water contact in the boreholes intersecting the reservoir. Three distinct anomalous areas could be defined; two occur at the horizon H1 level and are centered on the F-A and F-AR gas accumulations(fig. 2). The third anomaly occurs to the north east of F-AR at a lower statigraphic level in an area untested by drilling. Reservoir thickness above the gas-water contact in boreholes F-A10 and F-A13 (Fig.1) was 45 m and 110 m respectively, whereas in F-A5 the reservoir sands have been eroded by a channel, with only 5 m of gas sand being intersected. The abrupt termination of the anomaly at this point is very clear. In the central graben between the F-A and F-AR structural highs deep channelized erosion has removed much of the reservoir interval, reflected in the lower amplitude of H1. The coincidence of the anomaly and the mapped extent of the gas reserves based on structure and drilling results is striking.

Conclusion

In this study we have shown that weighted stacks, based on amplitude versus offset concepts can be successfully used in direct hydrocarbon detection. The GEOSTACK process was applied to a 3D seismic data set over an established gas field offshore South Africa. Amplitude maps generated from the F-stacks clearly delineated the areal extent of gas bearing reservoir sands and gave an indication of relative reservoir quality. This is of significance not only in the search for gas accumulations but also in oil exploration as many oil deposits have associated gas caps.

REFERENCES

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SMITH, G.C. and GIDLOW, P.M. 1987, Weighted Stacking for Rock Property Estimation and Detection of Gas, Geophysial Prospecting 35, 993-1014.

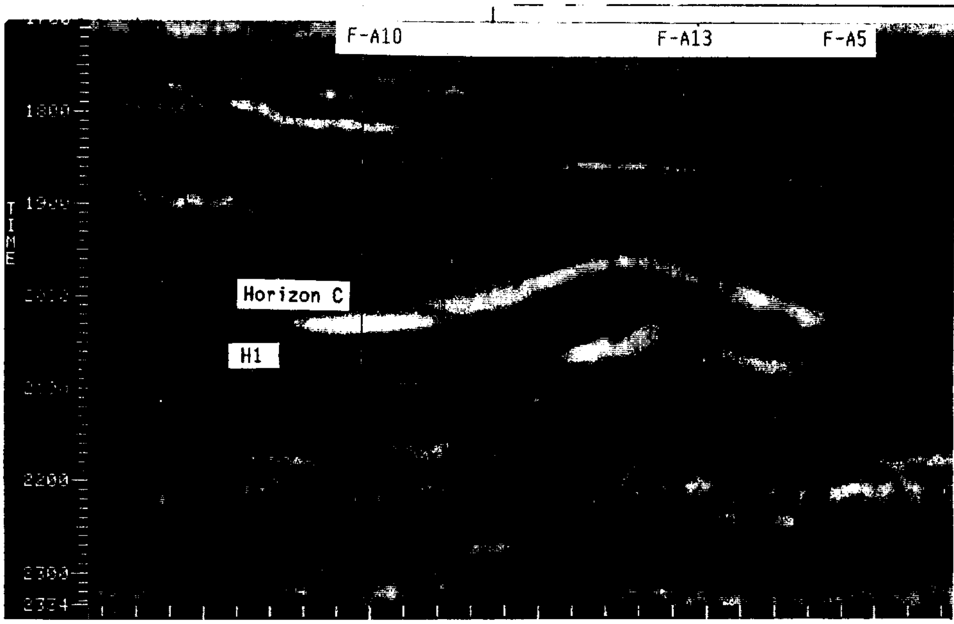

Fig 1a. F-stack through the FA gas field - GEOSTACK processing.

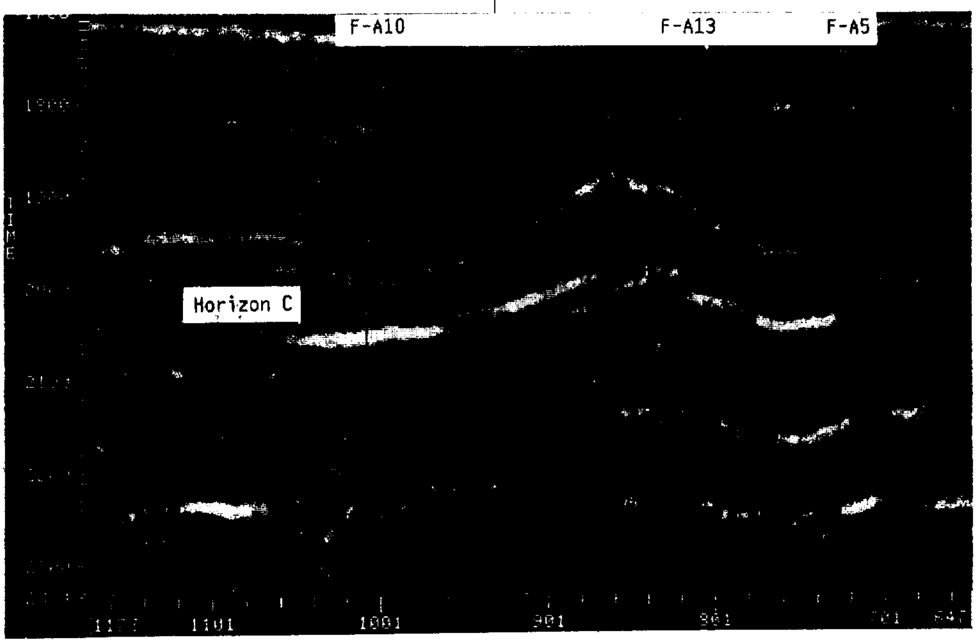

Fig 1b. Migrated section as in Fig 1a. - conventional processing

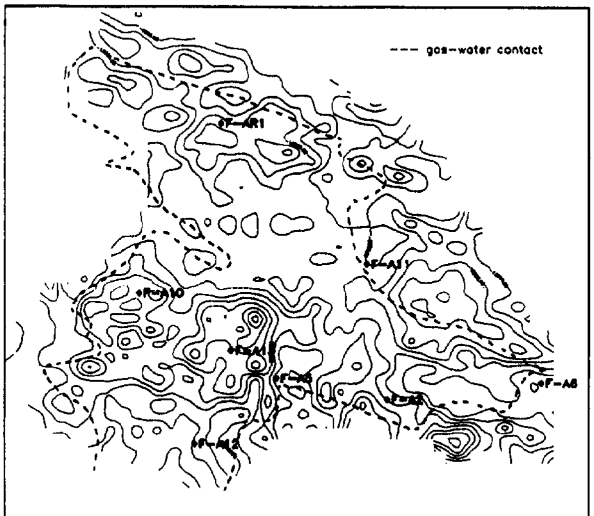

Fig 2. Amplitude map – base of gas reservoir
contour interval 4000

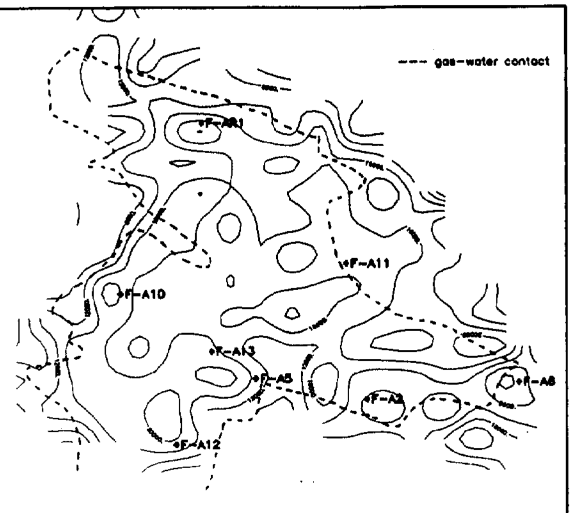

Fig 3. Amplitude map – top of gas reservoir
contour interval 4000

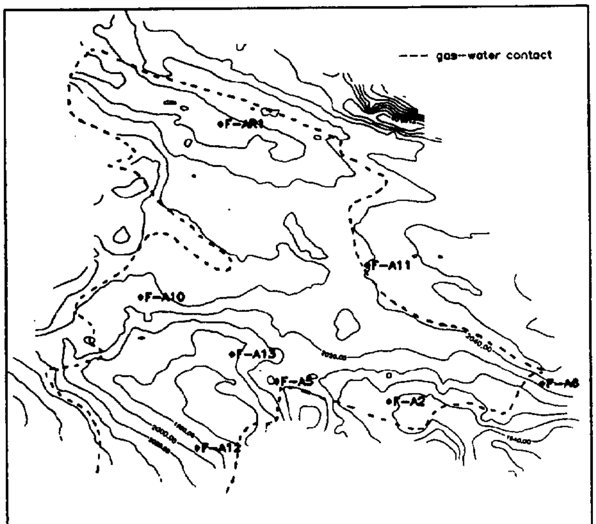

Fig 4. Two way time Horizon C
contour interval 20ms

Scale
0 1,5 3,0km