SUMIC: Multicomponent sea-bottom seismic surveying in the North Sea—
Data interpretation and applications

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SUMMARY
A new concept, named SUMIC (subsea seismics), of acquiring four component data at the seabottom has been developed. The development stage included an offshore acquisition of a 2D SUMIC seismic line using seismic detectors deployed at the seabottom. The survey was undertaken over a reservoir in the North Sea where the main objective was to image the deep reservoir units through a gas chimney in the overburden above the reservoir. This has been an insoluble mapping problem for previously acquired conventional towed streamer 3D survey data.

The image produced of the reservoir intervals from the vertical velocity component Vz data showed similar distortion to that obtainable from the conventional towed streamer data, because of P-wave misfocusing and attenuation introduced by propagation through the gas chimney. A more reliable image and interpretation of the reservoir intervals was produced from the X-component data which predominantly consist of inline S-waves. A Graben structure was identified at the top of the reservoir structure using S-waves for the first time from a marine seismic survey. Shear-waves are less affected by the presence of gas than P-waves. Statoil has demonstrated that SUMIC surveying is an effective tool with significant advantages over conventional marine seismic methods. The results have very interesting strategic implications for the use of this technology for structural and stratigraphic definition of reservoirs and exploration prospects.

INTRODUCTION
A new concept, named SUMIC, of acquiring four component seismic data at the seabottom has been developed since 1988 and is the subject to four patents owned by Statoil. The SUMIC method involves measuring the X, Y & Z components of the velocity field at the sea-bed using three component geophones, and the pressure field using hydrophones. Assuming a homogeneous plane layered earth, the Z component is dominated by P-wave energy and the X and Y components by S, and S, shear-wave energy respectively (Aki and Richards, 1980).

The development stage included a series of major experiments at many locations in the North Sea. We have gained much knowledge about S-wave generation and the applicability of SUMIC technology in the North Sea environment. We have also learned how to interpret best SUMIC data to enhance our structural interpretation in difficult data areas and directly detect hydrocarbons through the use of interpretation tools such as Vp/Vs-ratios (Ensley, 1984, Robertson and Pritchett, 1985, Tatham, 1985).

The SUMIC concept's main goals concern the utilization of pressure (P) and shear (S) waves to: (1) reduce exploration costs by increasing the find rate through improved detection and mapping of stratigraphic traps, (2) reduce the number of dry exploration wells for both structural and stratigraphic prospects, (3) reduce reservoir estimate uncertainty at an earlier stage in the field development programme by improving the reservoir description, and (4) reduce the number of appraisal wells during field development.

The data acquisition procedure required a two boat operation (see Figure 1). One boat, the receiver boat, remains stationary beside the seabottom geophone detector array taking care of geophone stick deployment, retrieval and data recording. The second boat, the shooting boat, tows and fires an airgun array along the shooting line to give a split-spread inline common- receiver gather.

A North Sea reservoir was chosen by Statoil, as part of its on-going SUMIC development programme, to measure the potential of SUMIC seismic surveying as a means of providing cost effective solutions to specific geophysical problems which cannot be solved using conventional seismic methods. The chosen reservoir has an exploration target which lies beneath a gas chimney. Previous conventional towed streamer seismic surveys, which rely on PP energy propagation, produced untenable images, because of the distortion and misfocusing introduced as the P-waves passed through the gas chimney where some of the rock pore fluid has been replaced by the gas.

During previous SUMIC experiments (Berg et al., 1994), we found that PSS energy was the dominant mode of propagation observed on the X and Y components in the North Sea, where the conversion from P to S takes place either at, or within the near surface of, the sea-bottom. The propagation velocity of such PSS energy is less affected by the presence of gas than that of PP energy. The seismic image resulting from a SUMIC PSS survey would, therefore, be less distorted than that from a PP survey by propagation through a gas chimney.

A continuous and regular 2D seabottom line of 12 km length passing over two wells was acquired. The well data will enable us to correlate and calibrate our multicomponent data, improving the reliability of our interpretations. Pressure data from a conventional towed hydrophone streamer were also acquired over the same seismic line to provide a direct comparison with the SUMIC seabottom survey.

The data from the SUMIC acquisition phase were somewhat oversampled, with respect to fold, inter-trace spacing within each common-mid-point gather and offset range, when compared with conventional marine 2D and 3D surveys. One of the purposes of our survey, however, was to provide an oversampled SUMIC dataset so that a number of degradations could be undertaken during data processing, to test their impact on the structural and lithological interpretability of the data. A fairly conventional data processing sequence was applied to the full dataset to achieve the main geophysical objective of the survey, namely to "see through" the gas chimney lying above the reservoir's target level. The conventional towed streamer dataset, which provided the benchmark, was processed using a similar sequence with only necessary data dependent parameter changes.
RESULTS

In general, the quality of the multi-component data was excellent at all locations along the 2D line as the seabottom, geological conditions and water depth varied.

The seabottom data were of significantly better quality than the surface towed hydrophone data. Observations of the seabottom geophone components: the vertical particle velocity \( V_z \) and the horizontal particle velocities \( V_x \) and \( V_y \) indicate a clear and distinct separation of the pressure (P) and shear (S) wave modes in their respective common receiver gathers. The common receiver gathers of the vertical particle velocity \( V_z \) are dominated by pressure wave data while the inline \( V_x \) horizontal particle velocity gathers are dominated by shear waves. The other horizontal component, \( V_y \), shows mainly weak out of plane shear wave energy with a low signal/noise ratio.

Low frequency and dispersive boundary waves (Scholte waves) propagating along the seabottom, similar to 'ground roll' seen during land seismic exploration, were found to be extremely weak on all SUMIC components.

The component separated data have undergone a conventional processing sequence and CMP velocity analysis. The SUMIC and conventional data reflection events have been calibrated and correlated using well log data. We have been able to identify major lithological boundaries and the SUMIC survey had enabled us to extrapolate our detailed log interpretations to more distant locations.

It is quite clear from these analyses that the main shear wave mode is S-S and conversion of pressure energy from the airgun source takes place at the seabottom.

Figure 2 shows a migrated stacked section of the conventional 2D towed streamer data. The reservoir targets of interest are the reflections between 3s and 3.5s in the Top Ekofisk chalk interval and possible Jurassic prospects below 3.7s in the mid-part of the section. But as illustrated, it is quite difficult to produce reliable structural interpretations from these data. The reflections loose continuity and are completely broken up the middle part of the section. The reflection collapse is caused by the gas chimney which rises from the domed and faulted reservoir sediments above an intruding salt dome and extends to approximately 1.0s in the shallow section. These effects of the gas chimney are caused by propagation of the P-waves through sediments with only 2.4% gas saturation which heavily misfocuses the ray paths because of the rapid and "stochastic" behaviour of the velocity field above the reservoir level.

On Figure 3, the \( V_z \) component SUMIC data acquired in the surveyed area is shown as the migrated stacked version. As in Figure 2, the distortions of reflectivity pattern in the reservoir interval of interest are the same even if the gas chimney influenced area is narrower than on the conventional section. This is achieved due to more optimal acquisition with the split-spread configuration compared to the surface conventional data. Otherwise, outside the disturbed gas chimney, the data quality and continuity of the reflections are comparable and in parts better than the surface conventional data shown in Figure 2. All events observed on the surface conventional data are recognized on the \( V_z \) P-wave section in Figure 3. The structural image quality in Figures 2 and 3 is comparable to that seen from the conventional 3D survey data.

In Figure 4, the stacked \( V_z \) component SUMIC data illustrates clearly another situation compared with Figures 2 and 3. The first 9s of the data are shown, but they are plotted at half scale with respect to the conventional data shown in Figure 2. Even if we didn't have well control with S-wave logs, the correlation of events between the P-wave section (Figure 2) and S-wave section (Figure 4) is easily seen for the main events and structural features.

In the reservoir zone a more reliable image from S-wave data in the central part of the section is achieved. The reservoir zone lies between 5.5s to 6s and a faulted pattern can be indicated across the crest of the dome. Shear wave propagating will only be slightly distorted by the presence of gas, their velocity of propagation through a given medium being affected only by the density changes occurring when the "fluid" within the medium is altered.

Figure 5 shows the stacked migrated version of the \( V_z \) component SUMIC data with the improved structural definition of the reservoir zones at 5.5s in the middle part of the section. The top of reservoir, the top Ekofisk horizon (A), can be interpreted through the reservoir with a downfaulted Graben structure at the top of the dome.

The results of our SUMIC experiments and surveys show that this technology can be used to solve a series of related mapping problems in bad data areas where for instance we have hard seabottom, shallow gas and gas chimneys.

In other experiments, we have also experienced that multicomponent SUMIC data have a potential to be used to predict lithology and directly detect hydrocarbons, even in stratigraphic traps with limited well control. We are continuing to develop further and implement novel applications of SUMIC technology.

CONCLUSIONS

The results from the application of the SUMIC concept of acquiring multicomponent seismic data at the seabottom have demonstrated that it is possible to "see through" gas chimneys and produce a more reliable seismic interpretation of a Graben structure at the top of the reservoir for the first time from a remote seismic survey.

The seismic quality of the multicomponent seabottom data, as also confirmed by other experiments, is better than conventional marine seismic surveys with respect to S/N-ratio and resolution.

As the main objective of the SUMIC method is to reduce risks in the exploration phase and reduce uncertainty in reservoir mapping, the data results demonstrate that the first application of the SUMIC technique has shown significant advantages over conventional seismic methods.

The results from the experiments demonstrate the tremendous potential of SUMIC technology. SUMIC can be used to address a series of related mapping problems where pressure waves have so far been the only data upon which to provide structural and stratigraphic definition of reservoirs and exploration prospects.
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REFERENCES


Figure 1. Two boat operation for SUMIC 2D-line data acquisition.

Figure 2. Migrated stacked section of the conventional towed 2D streamer data acquired over the surveyed reservoir.

Figure 3. Migrated stacked section of the SUMIC \( V_p \) component.
Figure 4. Stacked section of the SUMIC V_c-component.

Figure 5. Migrated stacked section of the SUMIC V_c-component with interpretation of the top of the reservoir reflector.