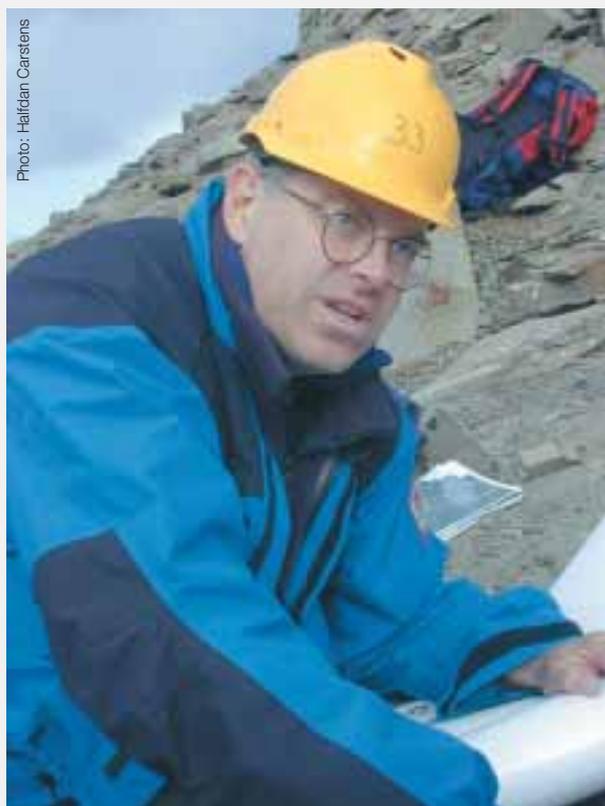


The same PRINCIPLE as in borehole logging

Reservoir rocks have much lower electrical conductivity if they are saturated with oil rather than salt water. This is the principle, well known from borehole logging, which is exploited in Sea Bed Logging.



Ståle Johansen emphasizes that Sea Bed Logging only records the electrical conductivity of the rocks. It is, therefore, necessary to interpret the results in order to predict the presence of hydrocarbons in the sedimentary layers. To do this in the best possible way it is decisive to have good geological knowledge about the area where the investigation has been carried out. Such knowledge is mainly obtainable from geological studies based, among other things, on seismic data.

Halfdan Carstens

The same physical laws apply for mobile telephone technology as for Sea Bed Logging. Mobile telephones send out signals – electromagnetic waves – which are received by the person one is ringing. The difference is first and foremost in the scale and the medium through which the signals travel. While the antennae of mobile telephones become smaller and smaller we operate with transmitters which are several hundred meters long

and with a current intensity which is vastly stronger. We make use of much lower frequencies than in mobile telephone technology, explains Ståle Johansen in Electromagnetic Geoservices (EMGS).

The principle works

Sea Bed Logging (SBL) is based upon the fact that all geological media have some sort of electrical conductivity. The difference in conductivity between, for example, shale and sandstone which are common rocks in sedimentary basins the

world over, is relatively small when they are saturated with saline water. When, however, we fill sandstone with oil its conductivity falls markedly (its resistivity increases). This is the principle utilised in well logging. Measurements of the conductivity of a rock based on a transmitter and receiver built into a small instrument lowered into a drillhole, can say whether the reservoir contains water or hydrocarbons. It is so accurate that the values obtained can be used to estimate the hydrocarbon saturation percentage in the reservoir.

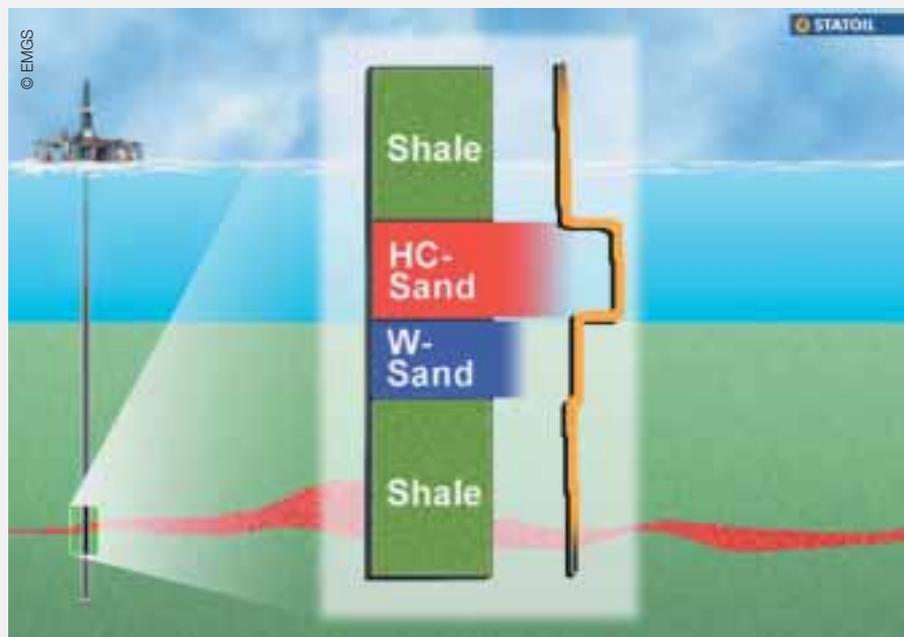
EMGS has now shown that the principle also functions on a much bigger scale. With the electromagnetic field generated from a transmitter pulled *along* the sea bed and registered by a receiver placed on the sea bed it is now possible to "view" the reservoir from above and not just from an instrument in a borehole. The signal used in well logging has frequencies between 16 kHz and 2 kHz and gives little spatial depth in resistivity measurements. High frequency signals like this quickly lose energy and will only penetrate a few decimetres into a formation. To achieve deep penetration – several thousands of metres down through the sedimentary layers – it is necessary to have significantly greater current strength and much lower frequencies (<1 Hz) in the outgoing signal.

Amplitude and phase

The operations start by placing receivers on the sea bed. The usual distance between them is 0.5-2 km. Then a boat sails along the line of receivers emitting electromagnetic waves from a transmitter towed along the sea bed. The electromagnetic fields will disperse in all directions. The energy we are mainly interested in penetrates the bedrock, travels along the layering before returning to the receiver. At the same time the unwanted energy passes directly through the water from transmitter to receiver and in the air/water interface. These contributions must be reduced to enable the results to be interpreted in the best possible way.

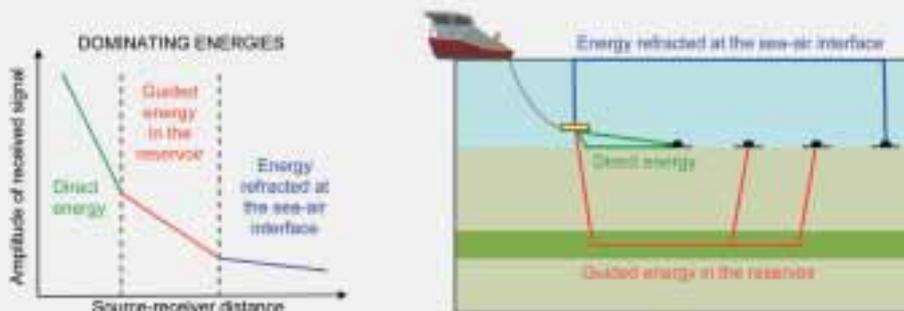
- The principle resembles a to a certain extent the acquisition of seismic data. It is, however, important to note that the receivers remain permanently on the sea bed whilst the power source is pulled behind a boat, as in 4C seismic, says Johansen.

- The most important difference from seismic surveying is that we do not use two-way time from transmitter to receiver



Sedimentary rocks with salt water in their pore spaces are good conductors of electricity. If the rocks are filled with oil or gas, media which in a pure state are electrical non-conductors, the conductivity will be lower (the resistance greater) and the electromagnetic energy will transmit much easier in the medium. This is the principle utilised in Sea Bed Logging to determine whether a reservoir is filled with hydrocarbons or not.

Interpretation Methodology



The receivers are first placed on the sea bed. Then a vessel with a transmitter passes over them registering signals arriving directly through the water (green line), through air (blue line) and through the reservoir (red line).

in the interpretation. SBL uses instead mainly the amplitude and phase of the signal received for interpretation of changes in resistivity in the subsurface. With a given, continuous and harmonic signal from the transmitter the amplitude will depend on the distance from transmitter to receiver and also on what sort of medium – what sort of rocks - it has passed through, explains Johansen.

Measuring the difference

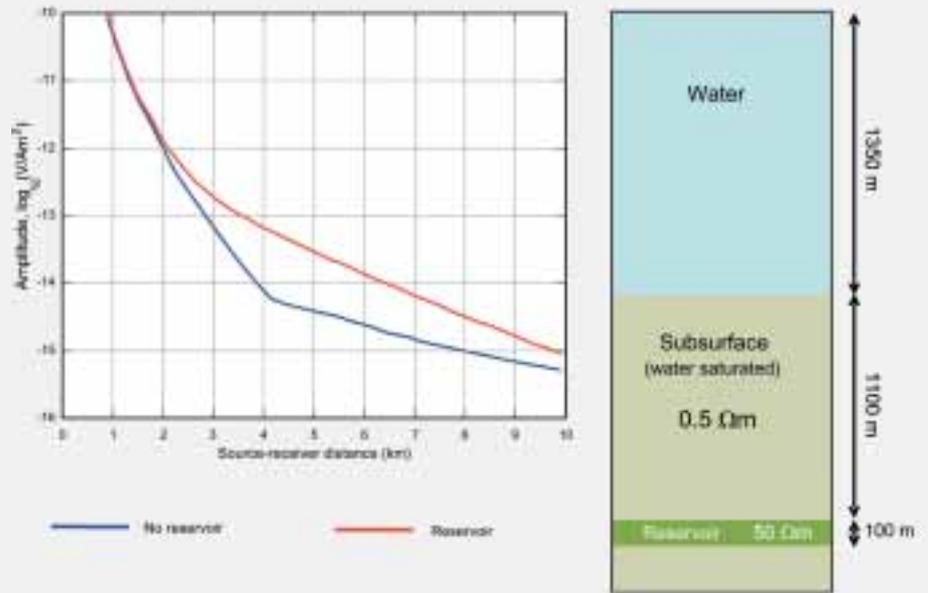
The strength of the electric field, for a specific receiver placed on the sea bed is measured and registered as a function of distance between transmitter and receiver ("offset"). When the distance from the transmitter to the receiver increases (the boat moves away from the receiver) the signals diminish in strength. All measurements above the reservoir are compared

with reference measurements outside it. The blue curve (see figure) is the modelled response for a reference measurement outside the reservoir. If the receiver instead is placed over an oil-saturated reservoir the curve will have a different course (shown by the red curve). It is the difference between these two curves which can tell us if there are hydrocarbons in the reservoir. The registrations are therefore compared with each other where water-saturated reservoir rocks form the reference. To obtain good statistical data there should be just as many receivers outside as inside a prospect.

- We measure the electrical conductivity of the rocks and are talking about a method of measuring which can only tell us indirectly if a given reservoir contains water or hydrocarbons. Therefore the results from an investigation must be interpreted by geologists who know the geological conditions in the area. Salt and volcanic rocks are, for example, very poor conductors and must be taken into consideration when interpreting the acquired data. Geologists, however, have the advantage that there are few "candidates" which can explain a clear-cut anomaly, points out Ståle Johansen, who also believes that a combination of Sea Bed Logging and 4C seismic – two techniques both of which measure on the sea bed – can be a good combination in the future.

Interpretation Methodology

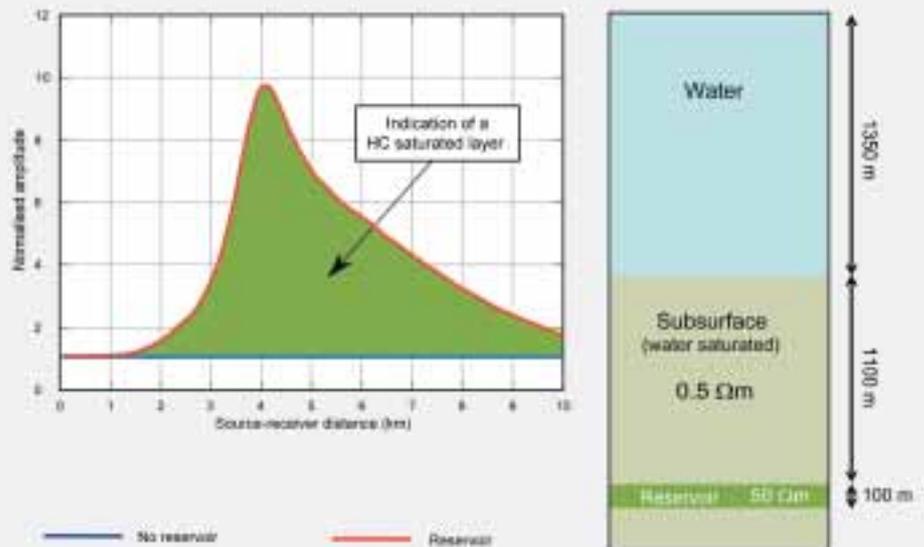
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Sea Bed Logging takes place when a transmitter is pulled along the sea bed emitting electromagnetic fields which are then registered by receivers lying on the sea bed. Measurements from a given receiver can be expressed in amplitude strength as a function of distance between transmitter and receiver ("offset"). In this example we have a geological model where a 100 m thick reservoir lies at a depth of 1100 m. Water depth is 1350 m. The blue curve shows modelled signals from a receiver which lies above a water-saturated reservoir rock. Here the signals, have therefore, only passed through a "dry" reservoir. The red curve shows the amplitude strength from a receiver which lies above an oil-filled reservoir.

Interpretation Methodology

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The difference can be expressed more clearly by normalizing the measurements recorded where the reservoir is water-saturated.