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Bringing Complex Salt Structures into Focus – a Novel Integrated Approach

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Gravity:

The gravity data set consists of a densely surveyed grid with a station density of about 7 per km^2. Gravity stations and the Bouguer gravity image in the area of interest are shown in *Fig. 3*. The black box outlines the area of reliable results from the 3-D gravity interpretation and also the displayed area of Fig. 7. The Bouguer gravity is dominated by a prominent gravity low above the salt structure caused by the lower salt density compared to the density of the surrounding sediments. The darker the grey colours, the lower the gravity field.

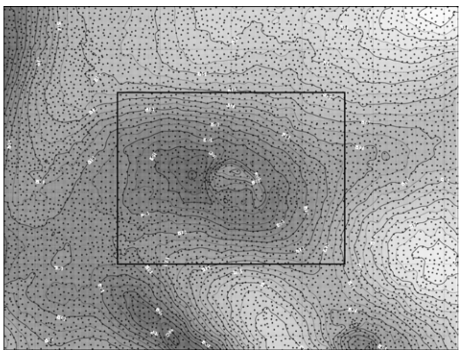

Fig. 3: Bouguer gravity map with location of gravity stations

High resolution magnetotellurics (HRMT):

The general objective of the application of MT to an exploration program is the determination of the subsurface electrical resistivity. The resistivity data are then used for the interpretation of geologic stratigraphy and structure, utilizing the resistivity information as part of a cooperative interpretation. The extension of MT to higher frequencies, the audio frequencies used by AMT, leads to the investigation of the very shallow subsurface. For this project, a novel high-resolution array (HRMT) was deployed to improve resolution of the salt structures. The salt boundaries show strong resistivity contrasts with the surrounding sediments and thus represent a good target for electromagnetic measurements. The acquisition setup and a field view of the MT instruments are displayed in *Fig. 4*.

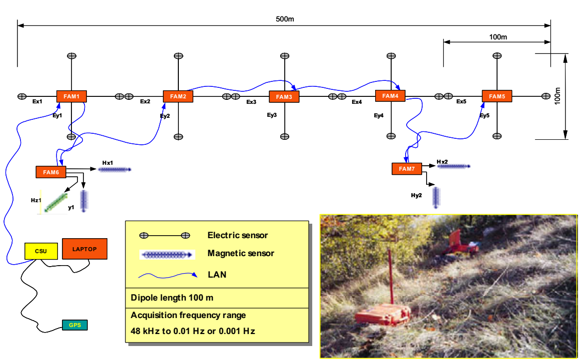

Fig. 4: HRMT acquisition setup

Data were acquired by multi-dipole "setups" using a 24 bit networked system. The "Setups" acquired six (6) frequency bands at: 48 KHz, 9600, 4000, 1000, 500 and 25 Hz sampling. The full tensor continuous coverage and the wide frequency band (0.01-20,000 Hz) allowed for the reconstruction, via multi-dimensional inversion technology, of an impressive high-resolution model from ground surface to depths of the order of 2,000 meters and deeper. Innovative data processing procedures were developed to handle the huge daily data flow and the strong local noise contamination. Advanced depth imaging capable of inverting efficiently huge amounts of data and unknowns was applied, based on 2^{nd} order finite-element forward computation and robust constraints inversion.

The Wedehof salt dome area is outlined in *Fig. 5* together with the HRMT profiles and the contoured second vertical derivative (SVD) of the Bouguer gravity.

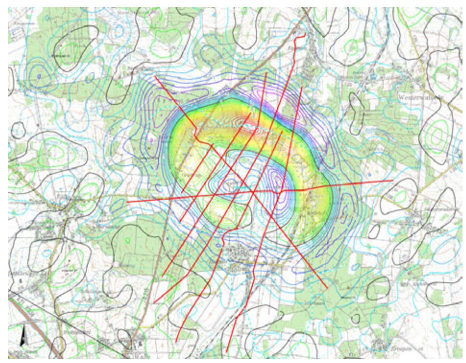

Fig. 5: HRMT profiles and contoured SVD of gravity

Shallow wells:

Seven shallow water wells down to a maximum depth of 200 m provided information about top salt and the thickness of salt covering crest of anhydrite.

Bringing the complex salt structure into focus

Fig. 6 shows the cooperative data interpretation workflow that was applied to the Wedehof salt imaging.

Gravity:

Gravity data analysis was carried out starting with wavelength filtering for anomaly separation into regional and residual field components. A 0.3-50 km bandpass filter (Fig. 7) was selected as reference field for this 3-D modeling into depth of up to 6 km.

Beside the NW-SE extended salt related gravity low a gravity high located around the centre of the salt dome is clearly visible with highest peaks occurring at the northern margin of the salt dome. This gravity high is due to the steepness of the sediments below the salt overhang. The areal boundaries of the Wedehof salt dome were defined by the second vertical derivative (SVD), where the 0-contour line clearly marks the salt-sediments boundaries (Fig. 7).

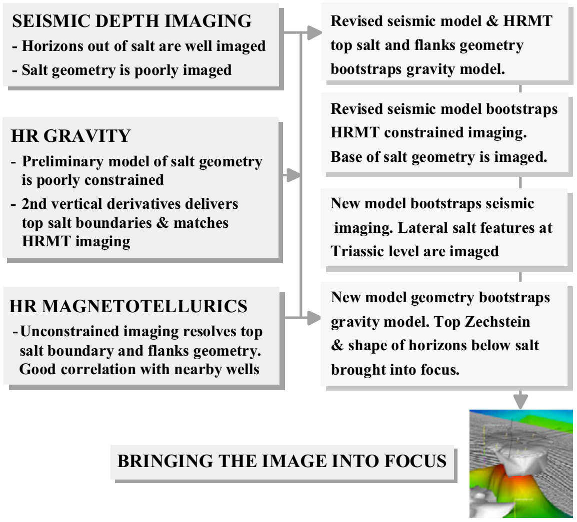

Fig. 6: Wedehof salt dome data integration work flow

These lateral boundaries match the HRMT imaging very well. The cooperative imaging of gravity and HRMT was also instrumental in determining the depth and extension of the top salt geometry and the thickness of the anhydrite crest (see Fig. 10).

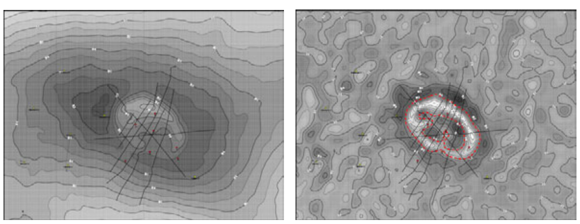

Fig. 7: Bouguer gravity: Wavelength filter 0.3-50 km (left) and second vertical derivative (right)

High-resolution magnetotellurics (HRMT):
The HRMT depth imaging shows a high degree of accuracy in resolving the top of salt and salt flank geometry. HRMT data samples are displayed below (Fig. 8), showing the response when salt is absent and when HRMT measurements are made above the salt body. The sample shows high quality data resulting from advanced processing techniques that were instrumental in reducing the very strong background noise. The advanced processing and interpretation tools applied, delivered an impressive high resolution image of the salt dome in the upper 2,000 meters (Fig. 11).

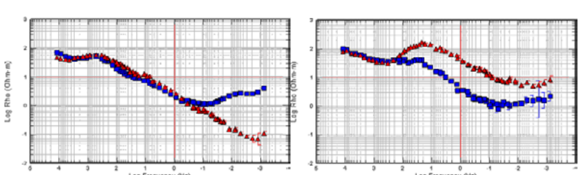

Fig. 8: HRMT data sample: no salt (left) above salt body (right)

Fig. 9 shows two HRMT depth imaging slices down to a depth of 1200 m. Red colors indicate high resistivity up to 800 Ohm m (salt), green to blue colors indicate low to very low resistivities (sediments).

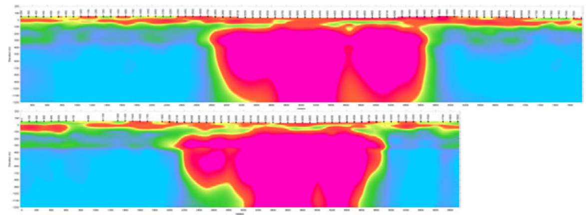

Fig. 9: HRMT depth imaging slices (oriented SN)

Seismic:
Seismic depth imaging defines the geological horizons outside the salt structure very well. Additionally the maximum lateral extension of salt is determined. These are essential constraints for the gravity- and HRMT-modeling. The well defined shallow salt geometry and the model gravity lead to a new seismic imaging of a lateral salt feature at Muschelkalk and Keuper level. The introduction of this salt pillow results in a better match of the gravity data.

The cooperative interpretation model

The cooperative interpretation of high resolution gravity, HRMT and seismic data has produced a phenomenal increase in quality of complex geometry imaging of the Wedehof salt structure. By taking full advantage of the strength of each individual tool and their proper integration the shallow features of the salt dome could be accurately imaged first. The depth and geometry of the anhydrite crest was mapped by proper integration of the HRMT and gravity information (Fig. 10).

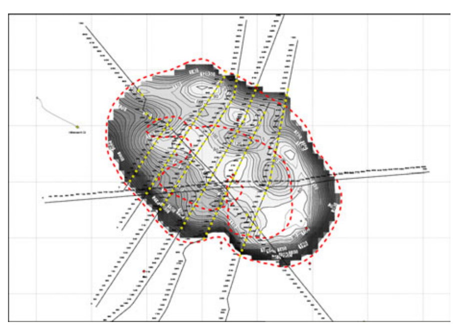

Fig. 10: Top of anhydrite crest, MT lines and 0-contour line of 2^{nd} vertical derivative of gravity

HRMT depth imaging was then used to derive an enhanced seismic depth model resulting in an improved subsalt depth image. With the help of seismic imaging and the gravity field the shallow part of the salt dome could be well defined. Fig. 11 shows the geometry of this upper part of the salt dome, viewed from SW.

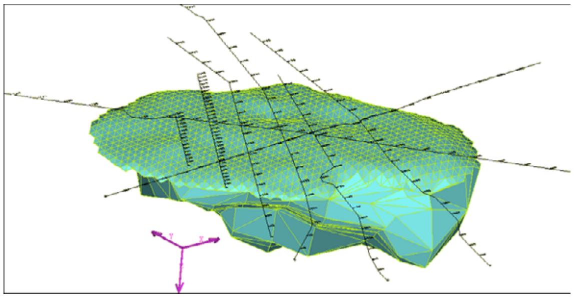

Fig. 11: Upper salt dome and HRMT lines (SW view)

This new shallow geometry was used to constraint the gravity modeling which is now enabled to determine the size and shape of the salt carrying Zechstein horizons below the salt dome. In Fig. 12 a NW view of the upper part of the salt dome and the top Zechstein horizon is shown.

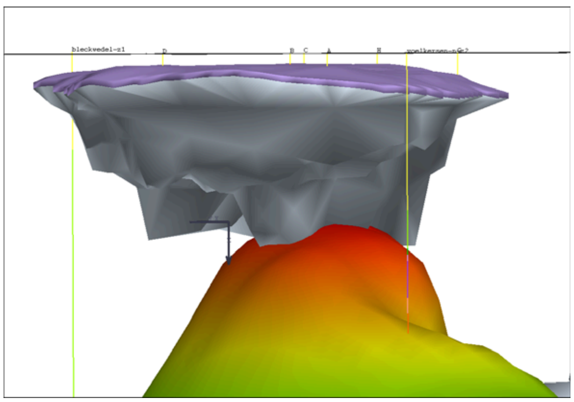

Fig. 12: Salt dome and top of Zechstein horizon (NW view)

Fig. 13 displays the salt geometry and the top of Zechstein-horizon viewed from SE, a seismic inline and two density slices of the 3-D gravity model. The lateral salt feature at Muschelkalk- and Keuper-level was presumed by matching the model gravity and verified by seismic depth imaging.

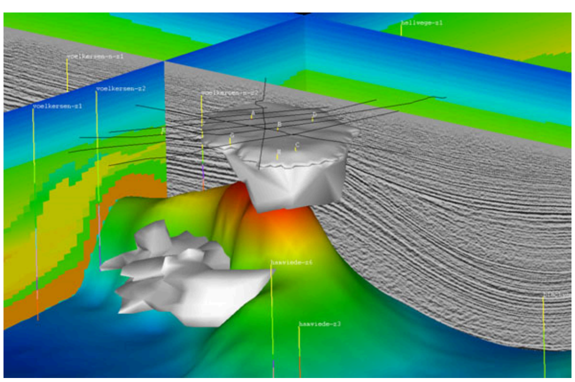

Fig. 13: Salt structures, top of Zechstein horizon, HRMT coverage, seismic inline and 2 density slices (SE view)

Conclusions

The cooperative interpretation of high resolution gravity, HRMT and seismic data has produced a phenomenal increase in quality of complex geometry imaging of the Wedehof salt structure. The new integrated model shows dramatic improvements over the previous model based on seismic data alone. This interpretation technology is now ready to be applied to the toughest imaging problems.

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Acknowledgements

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