KMS Technologies – KJT Enterprises Inc.

Publication

Buehnemann, J., Henke, C. H., Mueller, C., Krieger, M. H., Zerilli, A., Strack, K.-M.

2002

Bringing Complex Salt Structures into Focus – a Novel Integrated Approach

Society of Exploration Geophysicists, Annual Meeting, Salt Lake City, Invited Paper in workshop “Recent Advances and Road Ahead”

Bringing complex salt structures into focus – a novel integrated approach

Jan Buehnemann and Christian H. Henke (RWE-DEA AG, Hamburg, Germany),
Christina Mueller and Markus H. Krieger (TERRASYS Geophysics, Hamburg, Germany),
Andrea Zerilli and Kurt M. Strack (KMS Technologies, Houston, Texas)*

Summary

Advances in seismic imaging have changed the way we view salt bodies. Once seen as impenetrable barriers to geophysical probing, many salt structures are now proving to be thin blankets or complex geometries shielding rich reserves. Prestack depth imaging and interpretative processes have advanced to a point, where, in many cases, subsalt horizons are imaged as clearly as the areas outside the salt. Subsalt structural as well as stratigraphic interpretations are possible using this technology that is being rapidly adopted by oil companies as a key to reduce risk and improve data accuracy. Currently, its full potential is far from being completely realized. Issues limiting the success of PSDM have included poor data, incorrect geologic models and associated velocity fields, inaccurate processing algorithms, anisotropy, near-surface and topographic effects, lack of a true amplitude solution, computer power and overall cost. In this paper we discuss how alternative geophysical data can be fully integrated in the cycle of iterative depth migration anisotropic model updating to develop a higher resolution earth model, that can be used for improved seismic imaging.
We illustrate in a case history of a salt structure in densely populated Northern Germany how additional geophysical measurements that focus on density and resistivity contrasts can significantly improve the seismic interpretation. The integrated modeling of high resolution gravity and magnetotelluric data leads to a new and more reliable model.

Enhancing complex salt imaging

De-risking of subsalt exploration is presently being done by advancing seismic technology and application of integrated interpretative processes focused on seismic data. Integration of non-seismic information is confined to conventional gravity and emerging 3D Full Tensor gravity Gradients that have shown great potential in reducing the alternative and equally viable seismic interpretations. Other independent geophysical techniques, which respond to the same (or are linked to the same) lithological parameters as the seismic method, can be used to provide additional input and greatly enhance the imaging of complex salt structures. A novel cooperative multi dimensional imaging of high-resolution gravity and high-resolution magnetotellurics data integrated in the cycle of iterative seismic depth migration anisotropic model updating (Fig. 1) has been tested to improve depth imaging of the Wedehof salt dome, located in the Northern Germany. This approach has proven of enormous benefit, in that we were able to bring the salt geometry into focus improving the model prior to the PSDM and consequently reducing the cost and the time required to complete the depth imaging while increasing the likelihood of success.

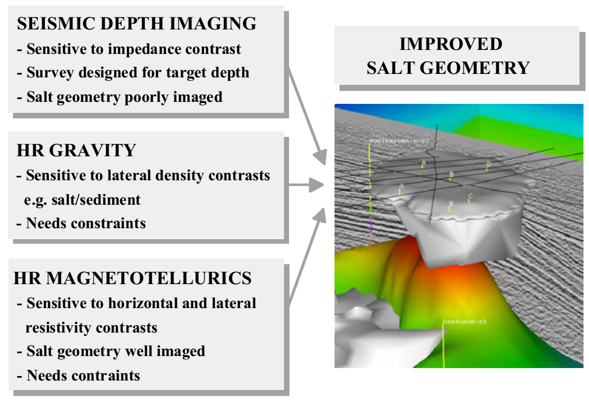

Fig. 1: Data integration workflow

Data Base

Located among many others, at the southern edge of the South Permian Basin in Lower Saxony, the salt dome Wedehof has been the subject of intense geophysical search for hydrocarbon structures and gas exploration drilling. The main objective has been the search for hydrocarbon direct below the salt structure.

3-D Seismic:
3-D seismic has been acquired to obtain data in the deeper flanks and their downward extension into the Triassic series. This survey was designed in a conventional 400x400 m acquisition grid, and was therefore not suitable to image reflectors in the shallow subsurface. The large uncertainty in the top salt imaging leads directly to large uncertainties (imaging, depth conversion) at the base of salt *(Fig. 2)* .

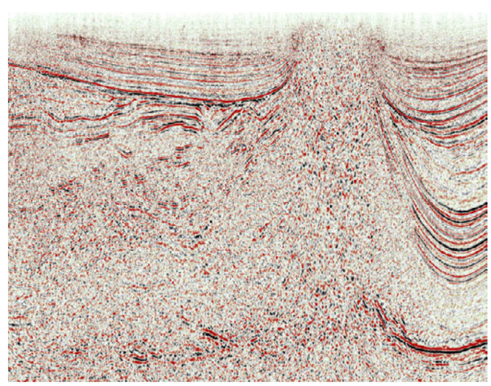

Fig. 2: Seismic section, central salt dome

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.

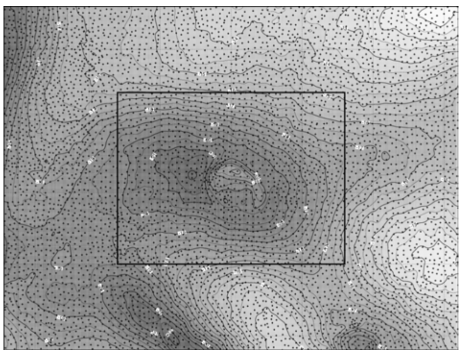

Fig. 3: Bouguer gravity map with location of gravity stations

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*.

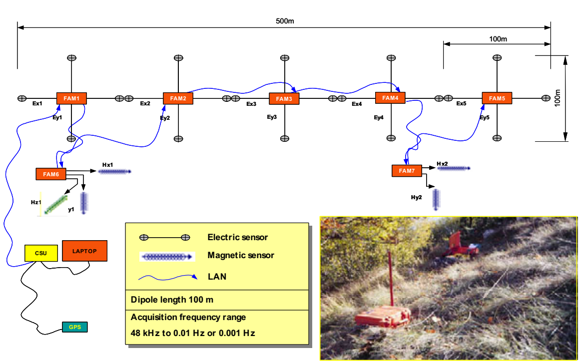

Fig. 4: HRMT acquisition setup

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 2nd 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.

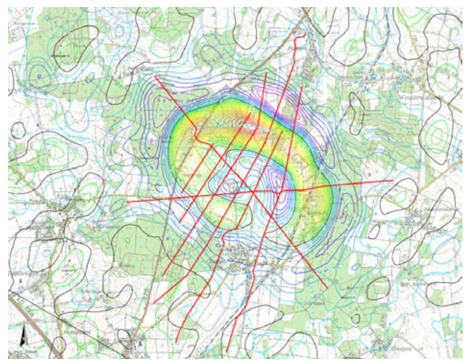

Fig. 5: HRMT profiles and contoured SVD of gravity

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).

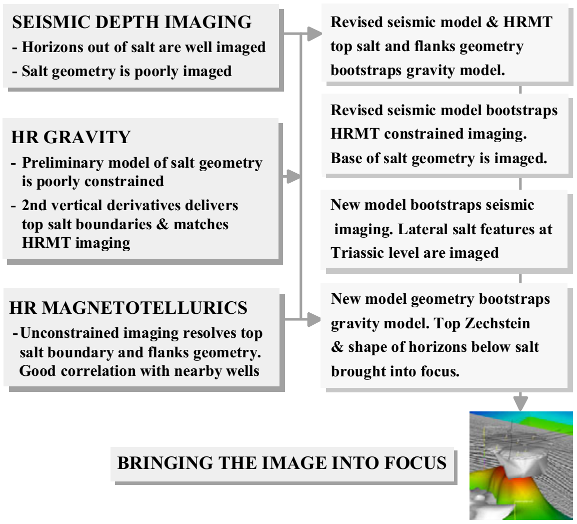

Fig. 6: Wedehof salt dome data integration work flow

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).

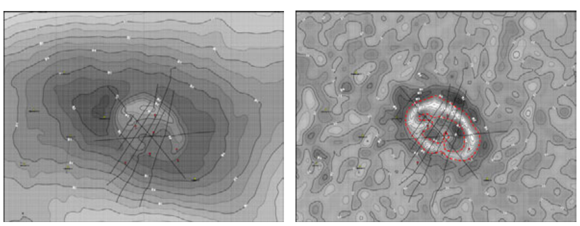

Fig. 7: Bouguer gravity: Wavelength filter 0.3-50 km (left) and second vertical derivative (right)

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).

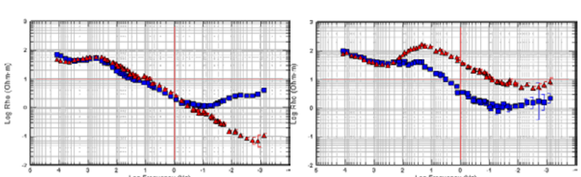

Fig. 8: HRMT data sample: no salt (left) above salt body (right)

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).

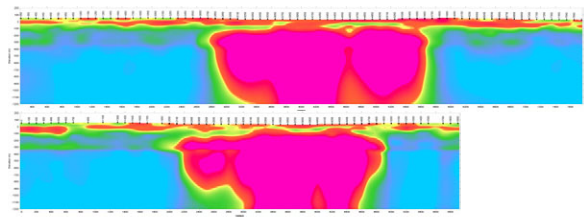

Fig. 9: HRMT depth imaging slices (oriented SN)

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).

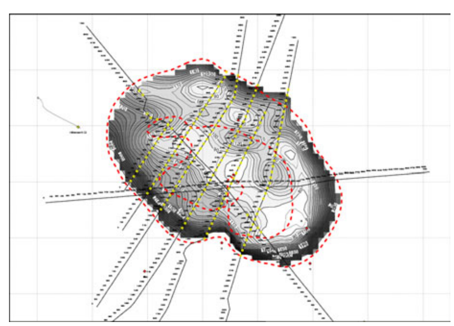

Fig. 10: Top of anhydrite crest, MT lines and 0-contour line of 2^{nd} vertical derivative of gravity

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.

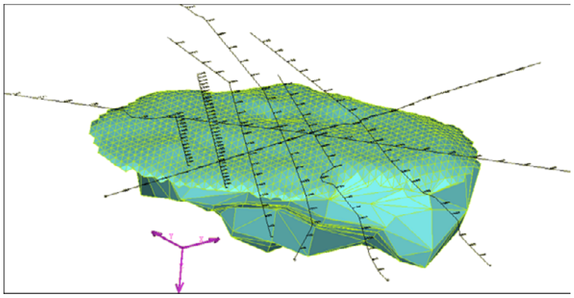

Fig. 11: Upper salt dome and HRMT lines (SW view)

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.

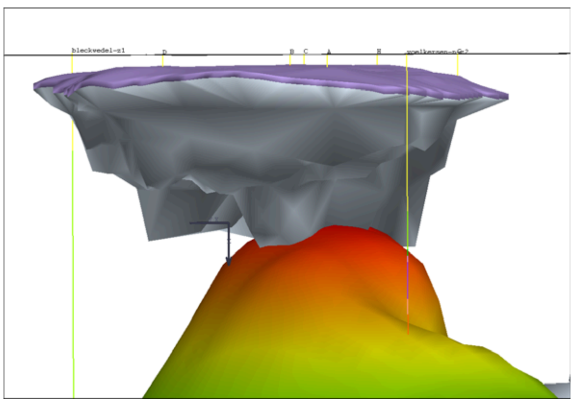

Fig. 12: Salt dome and top of Zechstein horizon (NW view)

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.

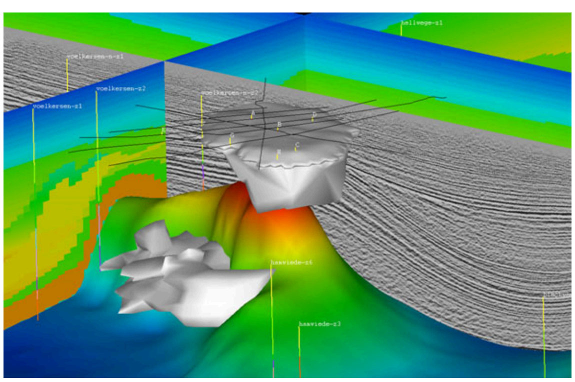

Fig. 13: Salt structures, top of Zechstein horizon, HRMT coverage, seismic inline and 2 density slices (SE view)

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.

References

[1] Henke, C.H., Krieger, M.H., 2000. High-Resolution Potential Field Data: Solutions and Limitations. In: 20th Mintrop Seminar, Conference volume, 101-131.

[2] Jaritz, W., 1973. Zur Entstehung der Salzstrukturen Nordwestdeutschlands. Geol. Jb., A, 10, BGR, Hannover.

[3] Krieger, M.H., Henke, C.H., Zoch, H.J., 1998. Seismo-Gravity – an example from NW-Germany: Salt dome Verden. J. Seism. Expl. 7, 319-328.

[4] Krieger, M.H., Henke, C.H., Müller, C., 2001. Static corrections derived from ultradense gravity surveying, inversion and 3-D modeling of shallow salt and caprock structures. 70th annual SEG meeting, Calgary, Expanded Abstracts.

[5] Marschall, R., Zoch, H.J., Henke, C.H., Krieger, M.H. and Kockel, F., 1999. Successful imaging below salt: technique and two case histories. AAPG International Conference and Exhibition, Birmingham. Extended Abstracts, 347-351.

[6] Zerilli, A., Botta, M., Apolloni, B., 1997. Improving Magnetotelluric data degraded by coherent noise by robust regression analysis and recurrent neural networks. 67th SEG meeting, Dallas, Expanded Abstracts, 366-369.

[7] Zerilli A., Botta, M., 1998. Advances in Magnetotellurics applied to extreme noise environments. 68th SEG meeting, New Orleans.

[8] Zerilli A., Botta, M., 2000. High-resolution continuous MT imaging: At last! Data from the Southern Apennines. in “Advances in Electromagnetic Methods for Petroleum Applications” 70th SEG meeting, Calgary.

Acknowledgements

We thank RWE-DEA AG for the kind permission to publish this work.

KMS Technologies – KJT Enterprises Inc.
6420 Richmond Ave., Suite 610
Houston, Texas, 77057, USA
Tel: 713.532.8144

info@kmstechnologies.com

Please visit us
http://www.kmstechnologies.com//