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Quantitative Integration of Measurements in Near Surface Characterization

M. Mantovani* (Schlumberger)

SUMMARY

A valid support to seismic in shallow anomaly detection is offered by additional geophysical measurements such as potential fields or electromagnetic induction soundings. In fact, gravity and electromagnetics (EM) measure complementary properties and, even though they do not sense any quantity directly related to P-velocity, they can be successfully used to improve the statics solution. Since the different geophysical domains are sensitive – to a large extent – to the same geometry structure of subsurface rock formations, there exists a structural link between the properties measured by the various methods, which are supposed to sense consistent anomaly shapes.
A high confidence solution for the near surface is therefore derived through a Simultaneous Joint Inversion (SJI) process (De Stefano and Colombo, 2007). Within this process, seismic and non-seismic data are inverted simultaneously together with the structural (or petrophysical) link established between the corresponding physical properties (velocity, density, resistivity, etc.). The solution explains seismic as well as plenty of logging information other than the simple sonic curve. Moreover, EM and potential field data are also explained by the output model simultaneously with seismic and borehole data. Thus, each of the measurements complements the others, as each is affected by different and uncorrelated noise.

Introduction

A valid support to seismic in shallow anomaly detection is offered by additional geophysical measurements such as potential fields or electromagnetic induction soundings. In fact, gravity and electromagnetics (EM) measure complementary properties and, even though they do not sense any quantity directly related to P-velocity, they can be successfully used to improve the statics solution. Since the different geophysical domains are sensitive – to a large extent – to the same geometry structure of subsurface rock formations, there exists a structural link between the properties measured by the various methods, which are supposed to sense consistent anomaly shapes. The concept, as many others used in geophysics, is actually valid for a restricted bandwidth of wavelengths, as well as circumscribed in areal-depth extent. The assessment of the extent of such validity often requires direct subsurface measurements as benchmark, or even the constitution of a rock-level relationship. The need to account for possible exceptions to the validity of this link in certain areas of the model, both in space and wavelengths, discourages any direct conversion strategy of any non-seismic result into P-velocity. Instead, an accurate solver for the problem accounts for similarity and data prediction in least squares sense, to allow any possible local exception in the model. Thus the main drivers for inversion parameterization and quality control of the results are the similarity metrics: the similarity of the inferred structure through each of the various properties in output, as well as the similarity of inverted properties to the borehole information.

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Direct applications of simultaneous joint inversion

The application of such concepts to exploration data presents a number of potential benefits. First, the integration of disciplines is performed ahead of data inversion to obtain a consistent earth model and associated image. It is formulated in a statistical and quantitative manner, so that the derived properties are in mutual agreement and allow a direct interpretation. As all of the available information is inverted and fitted simultaneously, the output model is the best possible predictor of the actual lithology, given the available information. The self-consistency of the solution is also obtained while maximizing the model's capability for data prediction, in contrary to the many manual searches for tie of the available heterogeneous information normally operated in reservoir geoscience.

Each of the Seismic, EM and Gravity methodologies is non-unique and can outline several possible structural geometries that predict the data. However, only a few of them can be mutually consistent and explained by all three domains and the borehole measurements. SJI is therefore a concordance searcher and, in principle, a reduction of the overall non-uniqueness is achieved with its execution.

Locally in space, geophysical data from the various methodologies may be in disagreement, and a similarity across them might not be established without a major impact on the measured data fit. In near surface, it is often the case for a highly water-saturated weathered layer, appearing as a high resistivity anomaly within a sedimentary sequence of normally increasing velocity. In deeper areas, the presence of hydrocarbon fluids or gas has similar effects. Hence, a least-squares solution of data fit and similarity constraint grants the freedom to the inversion for fitting the data rather than the similarity constraint in an anomalous locations. This formulation enables SJI to be used as high-level rock-physics anomaly locator. If the anomalies are known through any of the available borehole measurements, dedicated workflows can be implemented to sharply define their edges.

Data examples

In recent years, the potential of quantitative integration of near surface measurements has been explored in many publications. In Colombo (2012), SJI is shown to resolve localized outcropping basalt, whose irregular base causes distortion in seismic time imaging. The failure in time processing statics impacts any imaging of the area. A similar approach is presented in Colombo, (2010): the shallow carbonate dissolution at the base of the formation is compensated by under-datuming the seismic wave-field below the shallow complexity (Berryhill, 1979). SJI can also invert for various wave propagators out of the same elastic source. This is the case shown in Speziali, (2014), where a successful solution is reached by combining the information content of refractions and ultra-shallow surface waves.

The de-risking capability of SJI is acknowledged in Mantovani (2013), where SJI is used to avoid over-fit of seismic refraction picks that contain systematic errors. In this case, the correct solution is obtained when erroneous picks are somehow disregarded. Conventional tomography assesses on lateral consistency and tends to confirm any slip if wide enough in space. This is avoided in SJI by the action of complementary information that pushes for a rejection of the erroneous solutions, under the action of the similarity metrics (Figure 1).

Conclusion

A robust and increased uniqueness near surface solution can be obtained by quantitative integration processes such as simultaneous joint inversion, with application on seismic data in complex areas.

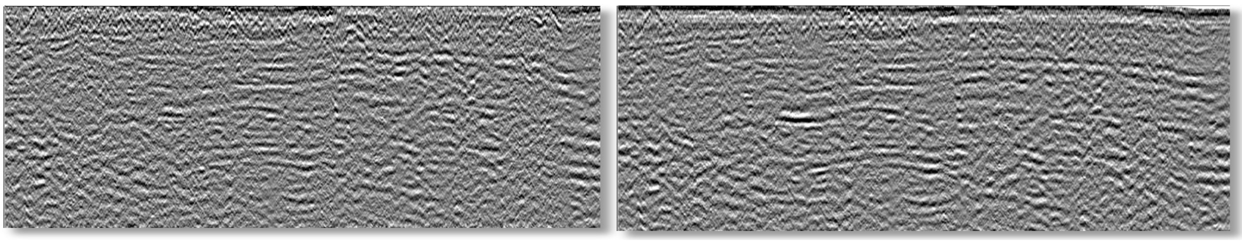

Figure 1 *Static response comparison between a refraction based diving wave tomography (left), and a simultaneous joint inversion solution of seismic refraction, surface waves, EM and gravity.*

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