GC Deciphering Seismic Amplitude Language*

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General Statement

Interpretation of seismic amplitude anomalies could be a direct solution to finding hydrocarbons, or defining lithology, but is usually a tricky problem. Isolated seismic amplitude values higher than the average background amplitude levels are termed as “seismic amplitude anomalies.”

It is quite common to see confusion prevail in G&G study groups when discussion is going on about seismic amplitudes anomalies. The anomalous behavior of seismic amplitudes may arise due to some peculiarities in the subsurface, which may be due to a number of reasons, including the following:

● Clean wet sands with high porosity and thickness greater than the tuning thickness at the target level may exhibit low acoustic impedance, and thus show up as an amplitude anomaly.

● Thin layers of salt, volcanics and carbonates, which are usually associated with high interval velocities when sandwiched between sand or shale layers, may exhibit strong reflections in otherwise continuous reflection campaigns. Similarly, coal or soft shales sandwiched in sands may show up as high amplitude reflections or anomalies.

● Thin geologic formations with varying thicknesses may give rise to amplitude variations due to tuning phenomenon. There may be other situations such as absence of reservoir sands updip or downdip causing seismic amplitude variations.

● Seismic amplitude anomalies may be generated as artifacts during processing of seismic data if data are not processed optimally, e.g. concave or convex geologic bed shapes in the subsurface may give rise to focusing or defocusing effects respectively, and in turn produce stronger or weaker reflections. Similarly, when using neural networks for reservoir property determination, artificial seismic anomalies may be generated as artifacts as a result of overtraining data.

● Low-impedance gas sands sandwiched between shale layers can give rise to strong amplitude anomalies. However, as a low-gas saturation may exhibit a similar seismic amplitude response as a high gas-saturation, a strong seismic amplitude anomaly may be associated with "fizz gas," instead of a hydrocarbon-bearing sand.

Seismic Amplitude Anomalies

Seismic amplitude anomalies have been found in sand formations of all geologic ages ranging from the older (Cretaceous, Triassic) to the younger (Tertiary). But besides compaction, depth of burial, porosity, lithological composition and the presence of fluids (gas, oil) are other factors that may influence the impedance contrast shown by an anomaly. It is difficult to distinguish oil from gas in a direct hydrocarbon detection workflow, as oil may contain dissolved gas. Also, low-gravity oil may show less of an impedance contrast than high GOR (gas/oil ratio) light oil. By making use of the available dipole sonic and density logs from the area under investigation, the seismic response can be forward-modeled. The elastic gathers so generated can help understand what kind of response to expect from the target reservoir levels, and if a seismic anomaly would be associated with gas or oil.

It is important to understand the geologic setting of the target formations and their depositional environment, so the interpreter has a feel for the kind of formation consolidation to expect. This will have a bearing on the type of amplitude variation with offset (AVO) anomaly to expect. For example, consolidated sands may exhibit a class 1 anomaly, a moderately consolidated sand, a class 2 and an unconsolidated sand a class 3 anomaly. A class 4 anomaly is generally seen for lower-impedance sands below high-impedance shale or carbonate rocks.

These anomalous class variations are examined on prestack seismic data, i.e. gathers, which are stacked to generate seismic traces. Seismic gathers allow investigation of the amplitudes as a function of offset or angle. Near-, mid- and far-offset or angle volumes are created to study the seismic amplitude anomalies, and if they show an amplitude response as seen on the modeled response, confidence is gained in the analysis.

For reducing uncertainty in the seismic anomaly interpretation, the seismic data should be put through true-amplitude processing, i.e., seismic amplitudes should be preserved at each step in the processing sequence. The phase of the seismic data being interpreted should be understood well so that impedance contrasts can be interpreted properly. Examining the seismic phase and polarity of the data being interpreted, and keeping it consistent for all data under investigation can be helpful in confidently carrying out amplitude anomaly analysis.

The strength of an anomaly may be measured by normalizing it to the background amplitude levels. Also, comparing the strength of hydrocarbon-charged anomalies in an area with the strength of the other anomalies associated with lateral geologic variations can be very helpful.

Tuning prevents meaningful interpretation of amplitudes in terms of lateral property changes. Should the data have tuning problems, the frequency content of the seismic data can be enhanced in an amplitude-friendly way and the data can be detuned.

There may not be any one unique way to carry out a foolproof analysis of seismic amplitude anomalies. Developing a consistent workflow for interpreting seismic amplitude anomalies and de-risking them may not be straightforward, but sustained efforts at examining the amplitude strength and the character of its lateral terminations in the light of what has been mentioned earlier could be helpful. This can be important, as the prospect evaluation may not be just the prediction of the presence of the reservoirs and their areal distribution, but also the prediction of possible hydrocarbons within the reservoirs.

Examples

In spite of taking adequate precautions and following a logical workflow, we may encounter exceptions that demand answers. We illustrate this by citing some examples below from the San Jorge Basin in Argentina.

In Figure 1a we show an arbitrary profile through the relative P-impedance volume generated using colored inversion passing through two wells, 1 and 2, as shown in the inset.

The higher impedance values indicated with the yellow arrows do not necessarily imply productive reservoirs. In fact, the high impedance corresponds to the tuffaceous sandstone at that level, and the variation in impedance there is reflective of lithology change. Another arbitrary profile through the same impedance volume, but tracked along the signature of the impedance anomaly is shown in Figure 1b. The seal rock is mainly tuff but has sandstone component present as well.

In Figure 2 we show the horizon slices from the seismic (Figure 2a) and the relative P-impedance volumes (Figure 2b) for the same data shown in Figure 1. The anomaly seen on the seismic amplitude in red and yellow is seen better defined on the impedance. Well 1 came out oil bearing and well 2 was tested dry, perhaps being too close to the edge of the anomaly. The other wells seen on the displays did not encounter the reservoir.

Figure 3 shows the same arbitrary profile as shown in Figure 1, but now from the (a) near-offset, (b) middle-offset and (c) far-offset seismic volumes. The yellow arrows indicate the amplitude response of the anomaly on these displays. We notice that even though we see an anomalous response for these amplitudes in Figure 2a, there is no AVO effect seen here for the oil reservoir encountered in well 1, being more prominent for a gas reservoir.

An arbitrary profile passing through two wells from a seismic volume acquired in a structurally complex (fold and thrust belt setting) area falling to the west of the data shown in Figure 1 , Figure 2 and Figure 3 is shown in Figure 4. The well to the left encountered a gas reservoir, but the well to the right came out dry. The geological level and strength of the amplitudes seem to be similar for both wells. The black peaks at the location of the two wells indicated with cyan arrows in Figure 4 seem to be related to the same reservoir behavior, but while the first well to the left was gas bearing, the well to the right and drilled after the first one came out dry, with no reservoir but a hard rock instead. Post-mortem analysis indicated a class 4 AVO anomaly for the target level to the left, with no AVO anomaly at the target level to the right.

In Figure 5 we show an equivalent arbitrary profile to the one shown in Figure 4, but passing through the reflection strength volume instead of the seismic amplitude data. The geological level for the reservoir seems to be associated with similar reflection strength amplitudes, but the well to the left encountered a gas reservoir at that level, and the one to the right came out dry (bad reservoir).

Conclusions

The recognition of seismic anomalies and their interpretation requires a systematic and consistent workflow or a series of steps. Beginning with gaining knowledge about the general geology of the area and the depositional environment of the target formations, one could go on to making use of the required well data and generating modeled elastic gather response at appropriate frequencies, comparing with processed seismic gathers, studying the signature characteristics of the anomalies, analyzing the various seismic anomaly scenarios and understanding the geologic risk factors are some of the salient steps that could be followed. Examination of amplitude anomalies from adjoining areas with similar geologic environment and the subsequent drilling results could help. All these steps, if performed logically and critically, could help lower the uncertainty in prospect evaluation. Exceptions may still surprise us.

Acknowledgements

The help extended by M. Garcia Torrejón in fixing the image shown in Figure 2 is gratefully appreciated.

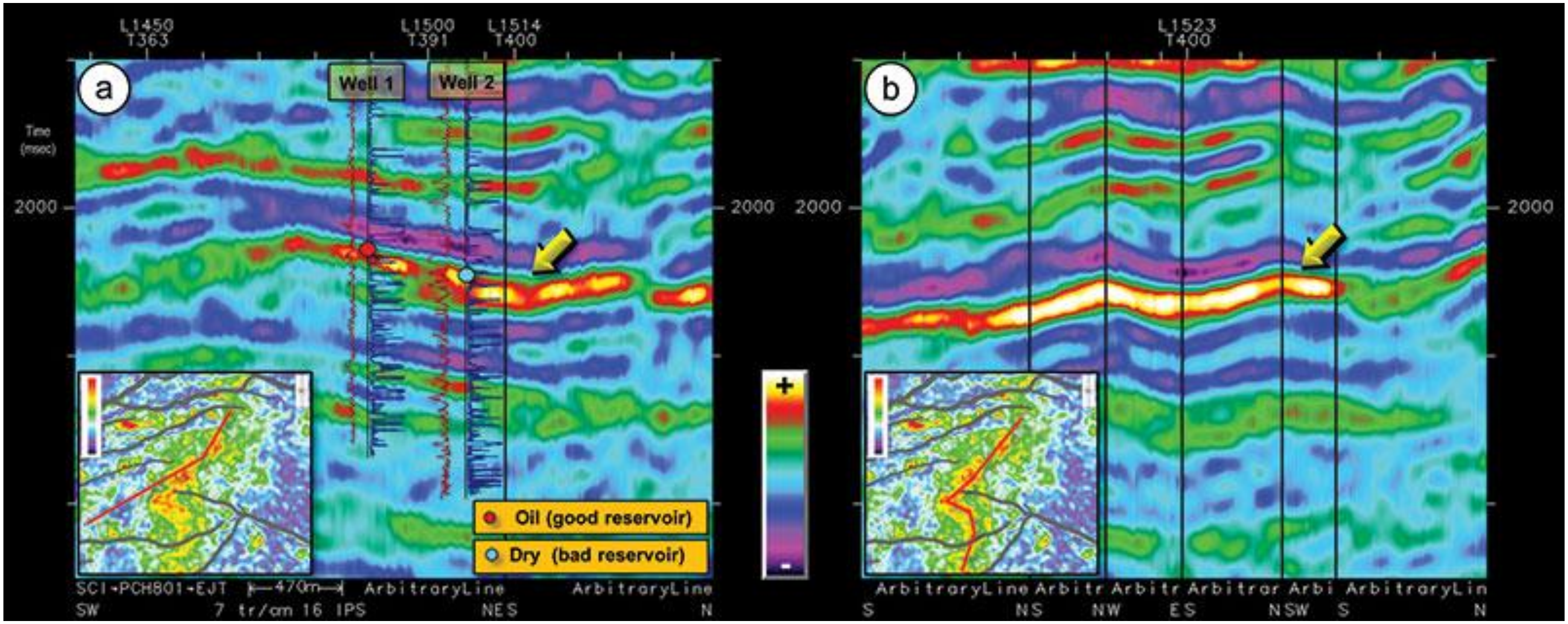

Figure 1. Arbitrary profiles passing through the relative P-impedance volume through wells 1 and 2 as shown in the inset. The two overlaid curves are the spontaneous potential in red and the resistivity in blue.

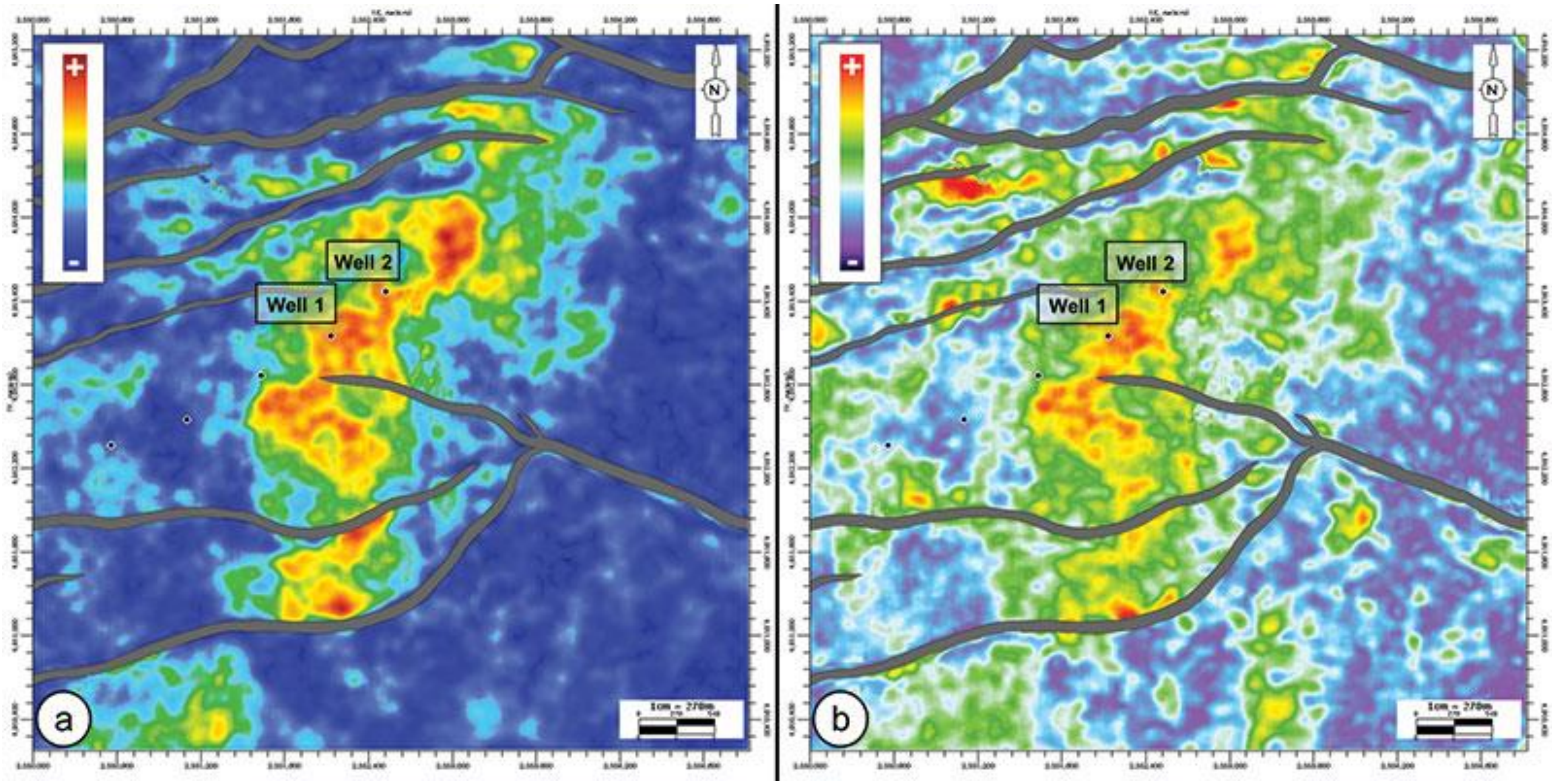

Figure 2. Equivalent horizon slices from (a) seismic amplitude volume, and (b) relative P-impedance volume. The two overlaid curves are the spontaneous potential in red and the resistivity in blue.

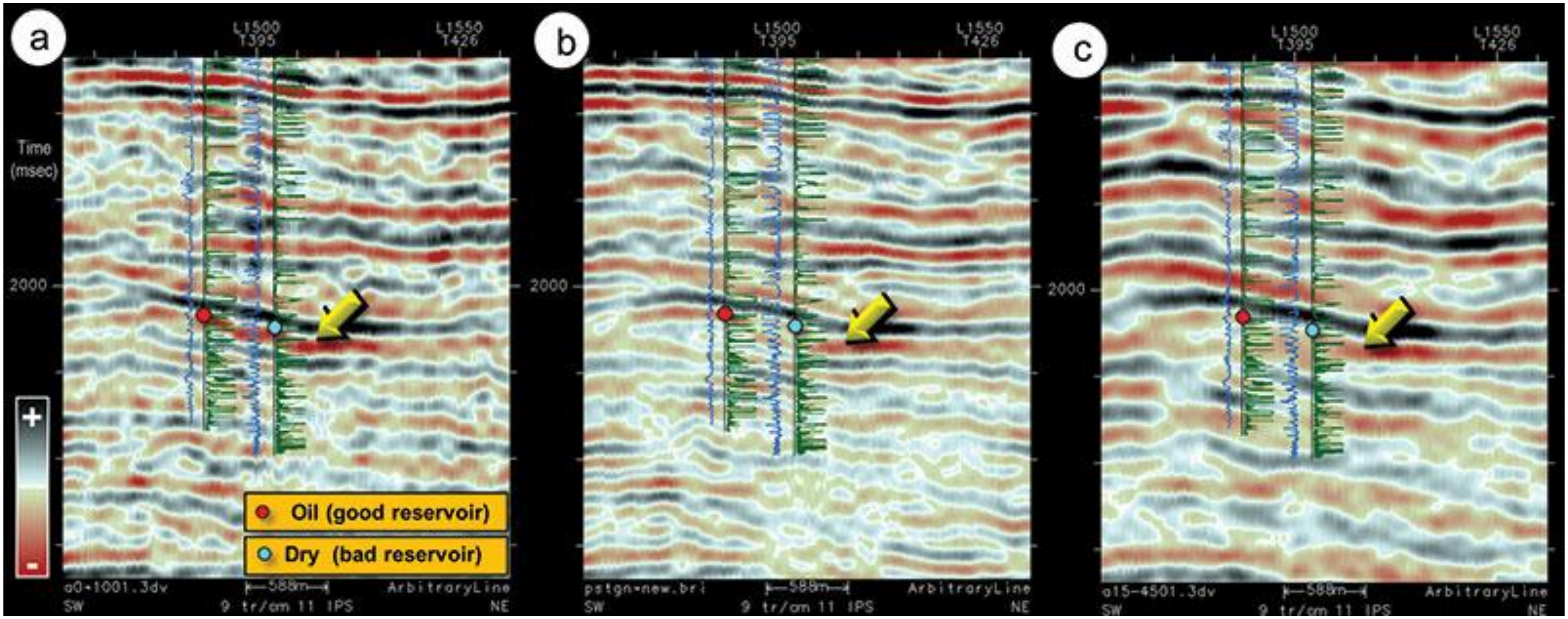

Figure 3. An arbitrary profile similar to the one shown in [Figure 1](#), but passing through the (a) near-, (b) mid-, and (c) far-offset seismic volumes. As indicated with the yellow arrows, even though the reservoir seems to be at the same geological level, no AVO signature is seen. The overlaid curves are the spontaneous potential in light blue, and resistivity in green.

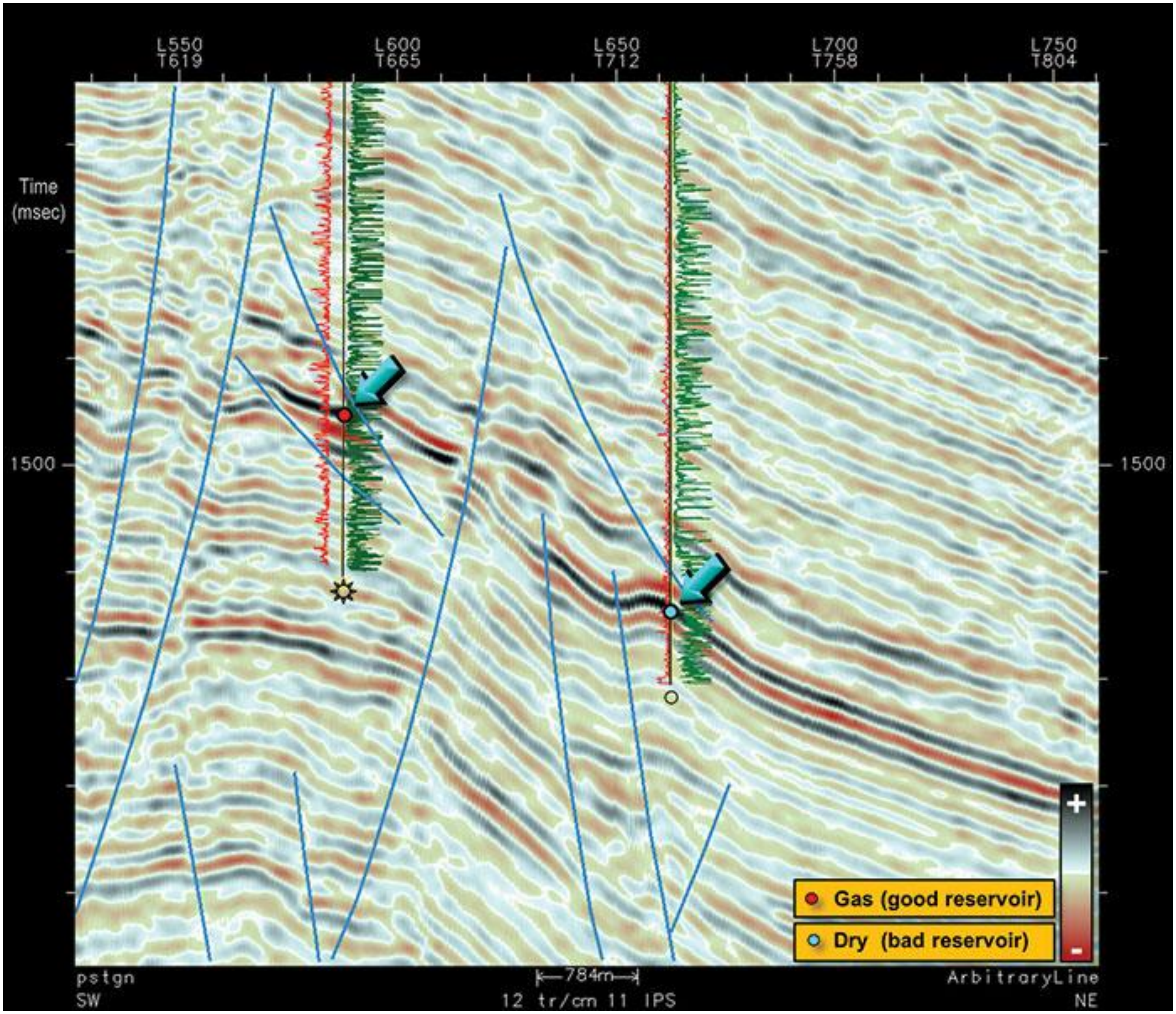

Figure 4. An arbitrary profile from a seismic data volume and passing through two wells. The well to the left is gas-bearing and the one to the right is dry. The reservoir level seems to be associated with similar geological and seismic amplitude levels. The overlaid curves are the spontaneous potential in red, and resistivity in green.

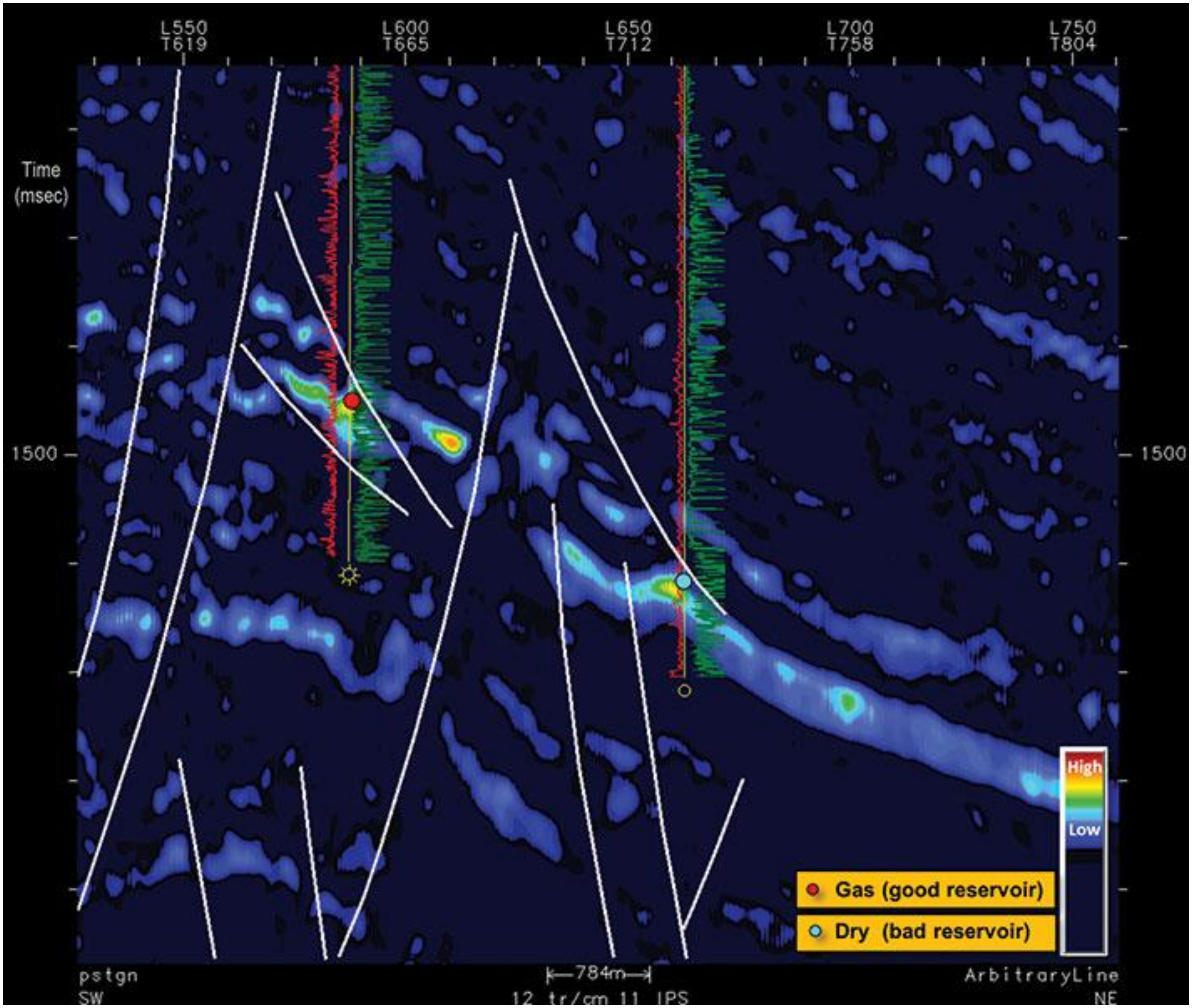

Figure 5. An arbitrary profile equivalent to the one shown in Figure 4 from the reflection strength volume and passing through two wells. The reservoir in both the wells has similar reflection strength signatures even though one is gas-bearing (left) and the other is dry (bad reservoir). The overlaid curves are the spontaneous potential in red, and resistivity in green.