Igneous Bodies that look like Sedimentary Features in Seismic Data: A Way to Avoid Pitfalls in Seismic Interpretation

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Summary

In the past decades, many exploration wells have drilled into igneous rocks by accident because of their similar seismic expression to the common intended targets such as porous carbonate mounds, sheet sands or deepwater sand-prone sinuous channels. In cases where sedimentary features such as channels or fans cannot be clearly delineated, the interpretation may be driven primarily by bright spot anomalies, and a poor understanding of the wavelet polarity may compound this problem. While many wells that are drilled into igneous rocks were based on interpretation of 2D seismic data, misinterpretation still occurs today using high quality 3D seismic data. We propose an in-context interpretation workflow in which the interpreter looks for key clues or parameters above, below and around the target of interest to confirm the interpretation.

Introduction

Using modern 3D seismic surveys, significant work has been achieved over the past two decades in accurately imaging the geometry of igneous bodies (Hansen and Cartwright 2006; Holford et al., 2012; Jackson et al., 2013; Magee et al., 2014). We now have many documented examples of igneous bodies that mimic common sedimentary exploration targets such as carbonate mounds, sinuous channels, and bright spots. To avoid such pitfalls, the interpreter needs to place the interpretation in context, identifying clues that may indicate the presence of igneous features. For example, in the Faroe-Shetland Basin, North East Atlantic, exploration companies looking for Carboniferous/Devonian, Jurassic, and Lower Cretaceous sandstones have drilled mafic igneous sills based on high amplitudes observed in seismic data (Mark et al., 2017) (Figure 1). Similarly, in the San Jorge Basin, Argentina, exploration/development wells targeting sand prone meandering channels have drilled mafic lava flows filling a preexisting meander valley (Figure 2a). In the Bass Basin, Australia, basaltic volcanoes were drilled by at least two exploration wells which were originally intended to test the hydrocarbon potential of a Miocene "reef complex" at a depth of 790 m., (Holford et al., 2017;Reynolds et al., 2018) (Figure 2b).

Given these examples where clastic, carbonate and igneous bodies exhibit similar characteristics, it is clear that we should not limit our interpretation solely on the geometry or seismic expression of our preconceived or desired model, doing so, would make us a victim of confirmation bias. Krueger and Funder (2004) define confirmation bias as "actively looking for opinions and evidences that support one's own beliefs or hypotheses" (see Bond et al., (2007) for examples of confirmation bias in seismic interpretation). Such confirmation bias concept was unconsciously executed in the previous examples from Argentina, Faroe Shetland and Australia (Figures 1 and 2) where the explorationist believed to have found in their seismic data the expression of the conceptual geological target model they had in mind. Counterintuitively, the best way for an interpreter to avoid confirmation bias is to gain a deeper understanding of features they are *not* interested in drilling, which in this paper, is a better understanding of the seismic expression and geomorphology of igneous intrusive and extrusive features.

Method

To help mitigate the confirmation bias concept, we examine a seismic amplitude section of the Akira 2007 2D seismic survey acquired over the Taranaki Basin, New Zealand. The seismic data depict a series of cone-to-mound geometry with chaotic internal reflection configurations and moderate to high amplitudes on the top. Immediately below the mound-like features there is a disruption in the reflections. The mounds exhibit base lengths of approximately 2000 meters with "steep" flanks and appear to be laterally interconnected. Based only on their geometry, these features are similar to "carbonate mounds" (Holdford et al., 2017; Reynolds et al., 2018;) or even to mud volcanoes. The only unequivocal way to determine the composition of these mounds would be to drill a well through them and study an extracted core or cuttings. An alternative way would be to use potential field methods to differentiate between generally magnetic igneous rocks and non-magnetic sedimentary rocks. However, remnant magnetization may confuse the interpretation (e.g. Pena et al., 2009) while diagenesis may result in magnetic volcanic tuff being converted to nonmagnetic montmorillonite (personal communication with former colleagues at AGIP). An alternative and inexpensive method *is to apply* ***in-context interpretation***. In this study, *in-context interpretation* refers to the concept implemented by Posamentier (per. Comm., 2018), in which he looks at the pattern of the features of interest as well as the surrounding elements (e.g., what's below, what's above and what's around). To illustrate this concept, we cite *National Geographic's Brain Games TV show* analogy illustrated in Figure 3a. In this image, we see headshots of two former U.S.A leaders. We can easily recognize former vice president Dick Cheney on the left and former president

George W. Bush on the right side. Detailed examination of this image shows that they both have the same face (analogous to the ambiguous pattern of interest in geology e.g., carbonate mounds, or volcanic mounds) with minor alterations. So, how is it that the same face gives two completely different persons (analogous to two different interpretations)? It is the context, (what's above, what's below and what's around) where the key to differentiation lies. In this case, the context is given by the glasses, the different hair style, as well as hair and skin color that allows us to distinguish ex-vice president Cheney from ex-president Bush in Figure 3a.

Applying the same in-context interpretation concept to Figure 3b, we recognize other key clues that would help infer the composition of the mound-like features. Among these clues are: (1) saucer-shaped high amplitude sills around the mounds (2) forced folds that are formed due to the emplacement of the sills (Hansen and Cartwright 2006; Holford et al., 2012; Jackson et al., 2013; Magee et al., 2014; Infante-Paez and Marfurt, 2017; Schmiedel et al., 2017; Magee et al., 2017; Schofield et al., 2017) (red arrows) and (3) a sub-vertical narrow low amplitude pattern in the section below these mounds that appears to disrupt the reflectors for significant vertical distances (2250-3500 ms TWT, or more than 1km) just below the mounds. Implementing the before mentioned strategy of *in-context interpretation*, the presence of all these elements (saucer shaped sills, forced folds) indicate an igneous composition of the mounds (Figure 4). In contrast, an interpretation driven by confirmation bias where the objective is to identify carbonates build-ups to test their reservoir potential might misinterpret the mound-like features to be pinnacle reefs, as appeared to be the case documented by Holford et al., (2017) and Reynolds et al., (2018) in the Bass Basin, Australia. Figure 5 summarizes a proposed workflow to avoid interpretation pitfalls in the presence of igneous intrusions and extrusions. Key to this workflow is not to stop when we find what we are looking for (finding the feature of interest from our conceptual geological model), thereby confirming our bias. Rather, we perform in-context interpretation to try to match the evidence of the context to our exploration target, like the igneous evidence found in Figure 3b. Further examination of the literature supports the igneous interpretation where Jackson et al. (2013) and Magee et al. (2013) found similar features in the Ceduna sub-basin of Australia to be volcanoes.

Conclusions

Igneous bodies can mimic the geometry and morphology of important exploration targets such as carbonate mounds, sinuous channels and bright spots. For this reason, the interpreter cannot rely on seismic morphology and geometry alone. Whenever possible, seismic data should be complemented with other geophysical methods such as gravity and magnetic surveys to avoid drilling features like volcanic cones. An alternative and inexpensive method to avoid such pitfalls is in-context interpretation where the interpreter examines not only the pattern of the features of interest but also the patterns of the surrounding elements, in simpler terms, we need to not only identify features we want to find, but also to identify neighboring features we don't want to find.

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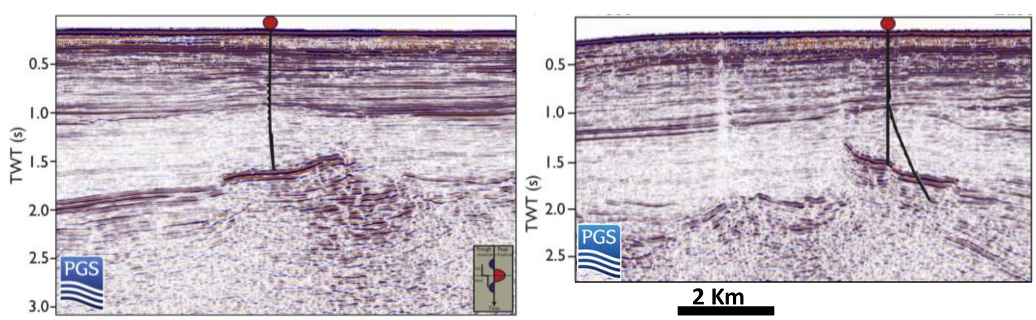

Figure 1. Exploration well drilled into mafic igneous sills, Seismic data courtesy of PGS. Reprinted from Igneous intrusions in the Faroe Shetland basin and their implications for hydrocarbon exploration; new insights from well and seismic data, In Press N.J. Mark, N. Schofield, S. Pugliese, D. Watson, S. Holford D. Muirhead R. Brown D. Healy,1-21, Copyright (2017), with permission from Elsevier.

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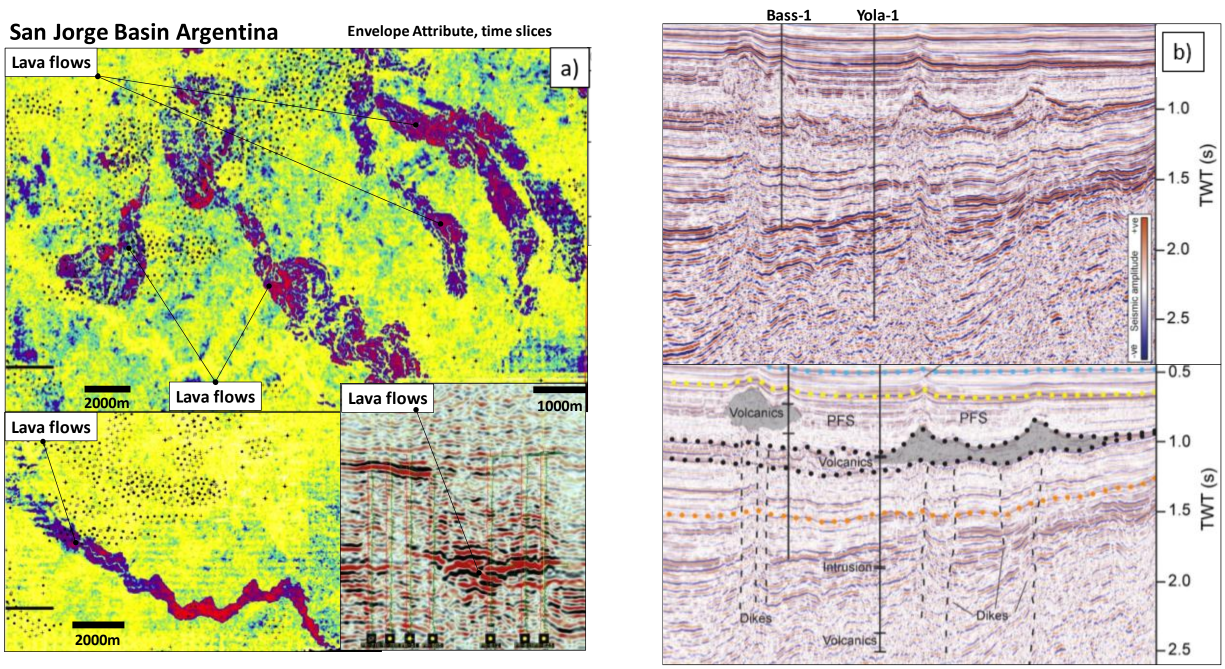

Figure 2. a) Envelope attribute in time slices and amplitude vertical section showing development wells drilled into channel-like features. The wells ended up drilling basaltic lava flows that filled previously formed meander valleys. (Courtesy of Luis Vernengo, Pan American Petroleum). b) Above, vertical amplitude section showing exploration wells drilling into mound-like features. Below, interpreted seismic section. The wells drilled basaltic volcanoes rather than carbonate build-ups. (After Holdford et al., 2017).

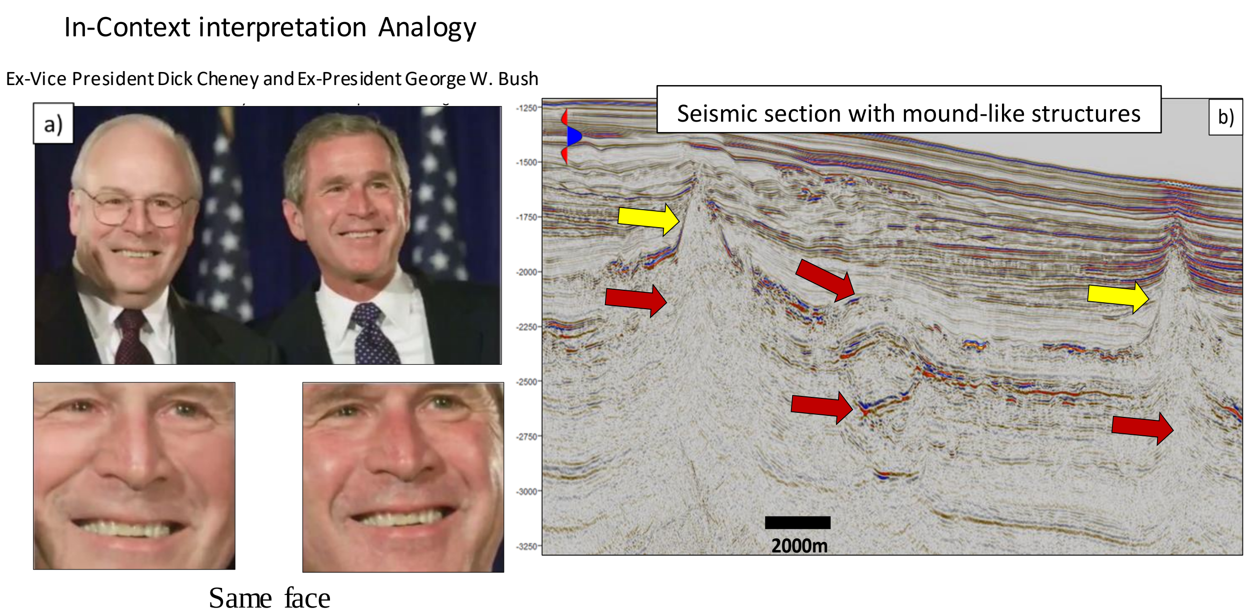

Figure 3. a) Former U.S.A leader headshots captured from National Geographic's Brain Games TV show. b) Seismic amplitude section showing mound-like structures (yellow arrows) with similar geometry to the ones in Bass, Basin Australia in Figure 2b. Red arrows represent clues for in-context interpretation.

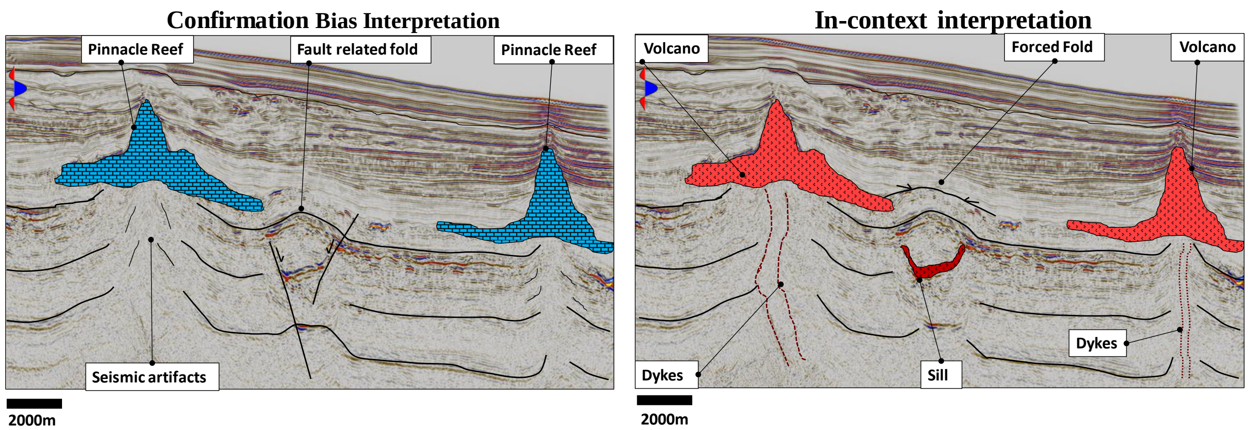

Figure 4. In-context vs Confirmation Bias Interpretation from Figure 3b. Notice the different outcome in each approach. Confirmation bias "sees" Pinnacle reefs whereas in-context interpretation "sees" the sills, forced folds and interprets an igneous composition for the mounds.

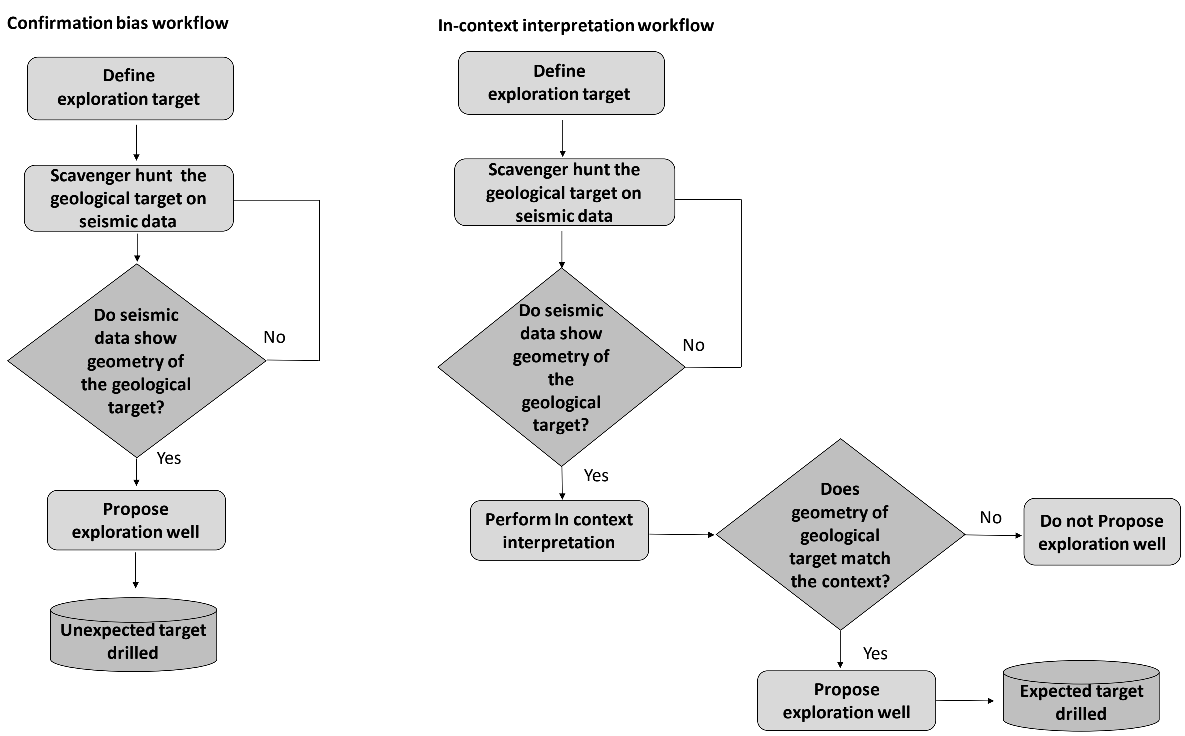

Figure 5. In-context interpretation vs confirmation bias approach workflow.