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# Are bright spots always hydrocarbons? A case study in the Taranaki Basin, New Zealand

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| Complete List of Authors: | Reilly, Peter; University of Oklahoma, School of Geosciences<br>Clairmont, Roberto; University of Oklahoma, Mewbourne College of Earth and Energy<br>Bedle, Heather; University of Oklahoma, School of Geosciences |
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# Are bright spots always hydrocarbons? A case study in the Taranaki Basin, New Zealand

**Funny Looking Thing (FLT):** Submarine Gullies
**Seismic Appearance**: High amplitude spotted features
**Alternative Interpretations:** Lithologic anomalies, gas seeps, bright spots
**Features with similar appearance:** Gas accumulation, sediment fills in limestone paleocaves
**Formation**: Giant Foresets Formation
**Age:** Pleistocene
**Location:** Taranaki Basin, New Zealand
**Seismic data**: Nimitz 3D (cropped volume)
**Contributors:** Peter Reilly, Roberto Clairmont, Dr. Heather Bedle, University of Oklahoma

## SUMMARY

In the shallower regions of the 3D Nimitz seismic survey, there exist multiple interesting bright seismic amplitude anomalies. These anomalies, or Funny Looking Things (FLTs), occur in a confined spatial and temporal region of the seismic. They have a concave up seismic appearance along cross section. Bright seismic amplitudes can be a direct hydrocarbon indicator, or representative of strong lithological contrasts, and/or acquisition artifacts. We set out to investigate misinterpreted seismic anomalies along cross sectional lines. Therefore, we apply seismic attributes to indicate these bright spot features, which we interpret to be submarine gullies looking along time slice intersections, can possibly be mistaken for hydrocarbon anomalies in cross sectional view. However, we cannot fully rule out the presence of hydrocarbons since it is common for gas sands to create similar anomalies. Previously drilled wells within the survey (Korimako-1 and Tarapunga-1) point towards a lack of hydrocarbon potential in the subsurface. While it is possible these bright spots are due to hydrocarbon presence, we present a more likely hypothesis: the lithology of the interfluve sediments is similar to the gully-margin drapes but differs from the gully sediment fill.

## SEISMIC SURVEY & GEOLOGY

The Nimitz 3D survey is located along the western continental shelf of the Northern Island of New Zealand (Figure 1), in the northernmost region of the Taranaki Basin, just south of the Northlands Basin. It covers an area of approximately 432 $km^2$ and trends NNE to SSW. The seismic data has zero-phase, positive standard polarity, in which the red to yellow denotes a positive reflection coefficient and dark to light blue indicates a negative reflection coefficient (see Figure 2 inset; ocean/seabed reflector). Additionally, using an average velocity indicated by the well drilling reports (O'Leary *et* al., 2010) in the area of interest and the observed dominant frequency of around 20Hz, a vertical resolution/tuning thickness is calculated to be ~21m.

Within this survey lies one of the most notable geological features; the stacked clinoform successions known as the Giant Foresets Formation (GFF). The GFF is the result of rapid progradation and aggradation in the late to early Pliocene to relatively recent succession of the continental margin that underlies the modern shelf and slope (Hansen and Kamp, 2002). The Taranaki Basin originated in the Mid-Cretaceous as a rift basin associated with the breakup of Zealandia from Gondwana and was later deformed by compressional and extensional tectonics driven by onset of subduction along the Pacific-Australian plate boundary in the late Paleogene (King, P., Thrasher, G., 1996). Erosion of the Southern Alps supplied sediment during the Pliocene into Pleistocene, resulting in northwestward/westward migration of the continental margin across the Taranaki Basin; thus, influencing the progradational patterns of the GFF clinoform packages observed in the seismic data (Shumaker *et al*., 2016). In this study, observations of the Funny Looking Things (FLTs) are located above the GFF.

## APPEARANCE ON SEISMIC DATA

The dataset consists of bright spots of limited spatial extent that are temporally confined within 0 to 3 seconds two-way-travel time (TWTT) (i.e. from the seabed to the lowermost sections of the GFF). However, the majority of the anomalies are seen in the shallow subsurface around 450ms (See Figures 2 & 3). Figure 2a/3a shows a seismic amplitude section (Inline 1185) identifying the bright spots which appear to have a concave up geometry. Figure 2b shows a cross section along crossline 2177 of the bright spots. Viewing along crossline shows the spatial/temporal extent of the anomalies, and inline shows distribution amount. In this region, we expect a Class 3 AVO (Amplitude Versus Offset) response, with a direct hydrocarbon indicator (DHI) that appears as a bright spot in the full stack data.

Conventionally, geophysicists describe data using seismic appearances such as velocity effects and attenuation. Velocity pulldown/pushup effects due to velocity differences above and below an anomaly are commonly found, but due to the size of the features in this study, they are not sufficiently large enough to produce this appearance (Wood, L. and Treitel, S., 1975). Similarly, hydrocarbon accumulation can cause observable seismic attenuation in data, but any seismic attenuation due to the loss in transmission of acoustic waves through the anomalies is not easily seen since the thickness of the features are not sufficiently large enough to produce underlying shadow zones (White, J., 1975)

The seismic anomalies occurring concave up in cross section (Figure 2a/3a), appear to be in channel shaped geometries in time slice/horizon (Figure 4a). These features most likely represent gullies with widths ranging between 30m to 100m, and further interpreted in previous studies




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above and below the GFF (Clairmont et al., 2020; Shumaker *et al*., 2016; Hansen and Kamp, 2006; Hansen and Kamp, 2002) and supports the hypothesis that these high amplitude anomalies present themselves in buried submarine gullies. Assuming these features are gullies, the fill of the gullies have a negative amplitude response and the base of the gully where it transitions back into surrounding strata is a positive response (Figure 3a).

Additionally, geophysicists have observed in seismic data that low gas saturation can create large amplitude reflections (Domenico, 1974). This effect can create an appearance of bright spots in data where a small amount of gas is trapped in a rock. The drilling reports indicate there are no minor oil and gas shows evident in either wells (Korimako-1 & Tarapunga-1) within or above the Giant Forsets Formation (O'Leary *et al*., 2010). We observe minor oil and gas shows intermittently about 1,000m below the Giant Foresets Formation, which were attributed to be primarily biogenic methane. The underlying minor gas shows create a possibility of vertical gas migration through the GFF and possibly gas accumulation in the sandier fill of the buried submarine gullies.

The termination of relative amplitude values in data can also be used for interpretation. Uniform down dip terminations of high amplitudes can indicate hydrocarbons since this would represent a fluid contact or boundary, similar to flat spots (Sheriff, R., Geldart, L., 1995). The bright anomalies observed within this study do not seem to have a uniform termination of brightness; in other words, the anomalies start and end at differing times and occur for varying lengths (seen in Figure 5). Since the high amplitudes do not uniformly begin/end neither temporally nor spatially, this indicates the bright spots do not conform to structure. The absence of structural conformity is likely due to a non-existent fluid boundary table that would be present in the data if there were to be a transitional contact between a saturated and unsaturated zone of water, oil, or gas. To further investigate the reason behind the proposed gully bright spots, we will investigate geologic history and seismic attributes.

## SUBMARINE GULLY FORMATION

The processes dictating gully formation and the role of gullies in deep-water sediment transport are poorly understood. There are many current hypotheses for the formation of submarine gullies. Hypotheses can be broken down into erosional (Izumi, 2004; Micallef and Mountjoy, 2011), depositional (Field *et al*., 1999; Spinelli and Field, 2001; Chiocci and Casalbore, 2011), or a combination of erosional and depositional (Fedele and Garcia, 2009; Lonergan *et al*., 2013). Sea-level fluctuations, sediment gravity flows, mass wasting events, hyperpycnal flows, internal waves, and dense shelf-water cascades can all be attributed to the initiation of submarine gullies (Spinelli and Field, 2001; Canes *et al*., 2006; Chiocci and Casalbore, 2011; Gales *et al*., 2012).

Shumaker *et al.* (2016) stated the gullies in the Giant Foresets Formation of the Taranaki Basin formed over time through large, dilute, sheet-like turbidity currents. These turbidity currents produced net-aggregational, shallowly incised submarine gullies with variations in erosion and deposition. Erosion initiated the gullies and had maintained presence through a combination of incision and aggradation. Many gullies do not preserve levees and are bounded by interfluve areas. Since there was re-incision of the filled or sediment-draped gullies (Shumaker *et al.*, 2016) subsequent erosive flows must have been preferentially routed along similar paths and that the gullies had maintained topographic expression along the seafloor.

## HIGH AMPLITUDE OCCURENCE

To aid in describing these bright amplitude anomalies, we used seismic attributes such as curvature, sweetness, and instantaneous frequency. Conventional seismic amplitude (Figure 2) shows these bright spots are found in buried submarine gullies. Regional context and exploratory wells drilled within the Nimitz 3D survey point towards a lithologic reason for the anomalies. Lithology contrasts between the interfluve sediments, gully-margin drapes, and gully sediment fill are likely causes of high amplitudes. More specifically, the lithology of the interfluve sediments is like the gully-margin drapes but different from the gully sediment fill.

Though it is unlikely there are limestone paleocaves in this area, it is important to note that Zeng *et al*., (2011) showed elsewhere that lithologic variations related to sandstone/shale sediment fills in collapsed limestone paleocaves and paleo-drainage systems can also create similar looking bright spots in seismic data which has no occurrence of hydrocarbons. This study used several attributes to further investigate the anomalies (Figures 3 and 4).

Roberts (2001) describes the geometric attribute, curvature, as the reciprocal of the radius of a circle that is tangent to a given curve at a point. Most-positive curvature defines the curvature that has the greatest positive value and will thus show anticlinal/domal features. Most-negative curvature defines the curvature that has the greatest negative value and will highlight synclinal/bowl features (Chopra and Marfurt, 2007). Geophysicists have demonstrated that the curvature attribute is effective at aiding identification of channel/gully geometry (Roberts, 2001; Luo *et al*., 1996; Marfurt, 2006; Sigismondi and Solda, 2003; Hakami *et al*., 2004). Though vertical resolution may not be sufficient to make definitive conclusions, the curvature attribute shows the gully-like geometry in both inline cross section (Figure 3) and time slice (Figure 4).

Hart (2008) describes sweetness as a seismic attribute used as an interpretation aid for identifying sands and sandstones and acoustic reflection strength anomalies. The sweetness attribute calculation divides the envelope by the square root of the instantaneous frequency. The sweetness attribute indicates sand detection if the sands have a lower acoustic impedance than the surrounding shales (Li *et al.*, 2017). Large seismic amplitudes with low frequencies produce high sweetness values. High sweetness can also be an indicator for oil and gas (Radovich and Oliversos, 1998). Sands are not the only lithology that generates high sweetness values; shaly condensed sections can also produce the same sweetness value (Li *et al.*, 2017). Since the anomalies in this study have high sweetness values (Figures 3 & 4) and are bounded by gully-like geometry, the lithology fill is likely sand-rich.

Instantaneous frequency is the time derivative of phase and relates to the centroid of the power spectrum of the seismic wavelet (Taner *et al.*, 1979). Wave propagation and depositional characteristics determine values of instantaneous frequency. This defining feature makes instantaneous frequency an effective discriminator for physical properties. Values of instantaneous frequency should be low beneath a highly attenuating zone like sands or gas sands (Barnes, 1992). Looking at Figure 3d, the lowest instantaneous frequency values (orange/red) appear both within the gullies as well as beneath the gullies. Vertical resolution/tuning thickness of the data may be the reason for the discrepancy of frequencies within and below the high amplitude anomalies. Frequency shadows beneath the anomalies points towards a sandy lithology, but low frequencies within the gully point towards a sandy lithology above the gullies.

Figure 5 shows 3D rendering of the cropped volume with an additional opacity filter to only show high amplitudes. 3D visualization of the data can help identify the reason behind the occurrence of the bright spots. Figure 5 shows the geometry, spatial/temporal extent, and occurrence of the bright spots. As expressed previously in the paper, bright spot terminations can be used to identify hydrocarbons. There is neither a uniform initiation nor termination of the bright spots, supporting the evidence that trapped hydrocarbons unlikely caused these bright spots.

## MODERN ANALOGUE OF MARINE GULLIES

Present day gullies along continental slopes are quite common existing along ocean bottom surfaces. San Francisco Bay and Portugal show clear examples of modern gully formations off their coasts. Submarine gullies are not identical around the globe though; gully density, length, and direction can vary depending on physical properties of the sediments moving down the continental slope.

## CONCLUSION

Given the processes that define gully formations and the regional geologic history of the Taranaki Basin, it is evident there can be variations in lithology due to initial sediment infill and succeeding sediment deposition outside of the gully formations. Variations in lithology can be a likely cause of the amplitude anomalies observed in this study's data. It is unlikely the gully-margin drapes are different from the interfluve sediments, rather, the drapes are similar to the interfluve sediments. A strong hypothesis explaining the reason behind the anomalies is that the lithology of the interfluve sediments is similar to the gully-margin drapes but different from the gully sediment fill. High sweetness values of the gullies point towards a sand dominated lithology fill, and low instantaneous frequency values in and below the anomalies point toward either a sand dominated fill or sand dominated upper stratigraphic unit. The likely contrasting interface between the sandy fill against the finer grained interfluve sediments can explain the bright anomalies.

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Figure 1. Nimitz 3D seismic acquisition geometry & geography, offshore New Zealand within the Taranaki Basin. Figure 2a/b crossline and inline locations overlaid on Nimitz 3D area.

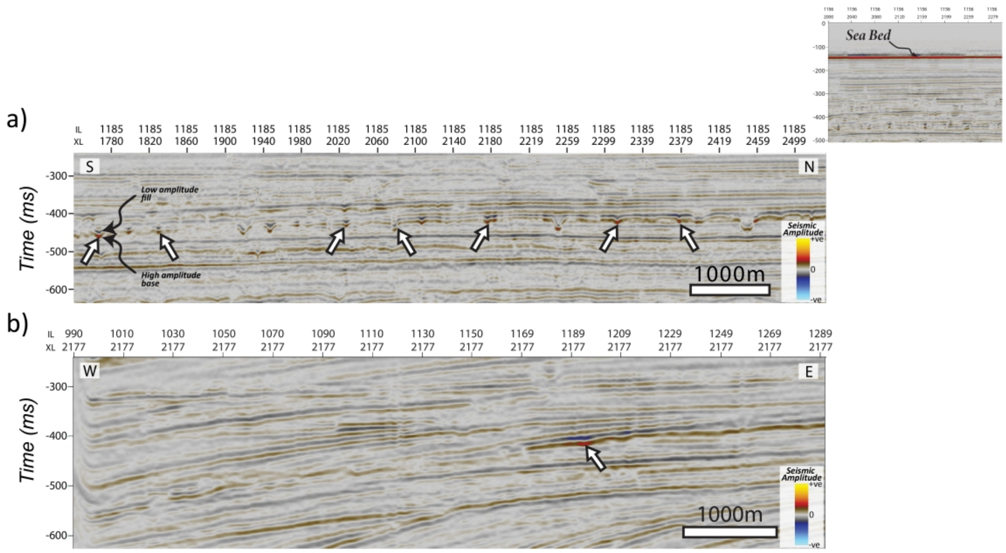


Figure 2. Showing seismic amplitude images at (a) inline 1185 where arrows show high amplitude anomalies in concave up geometry and (b) crossline 2177 where an arrow shows the anomaly perpendicular to the concave feature in Figure 2a.

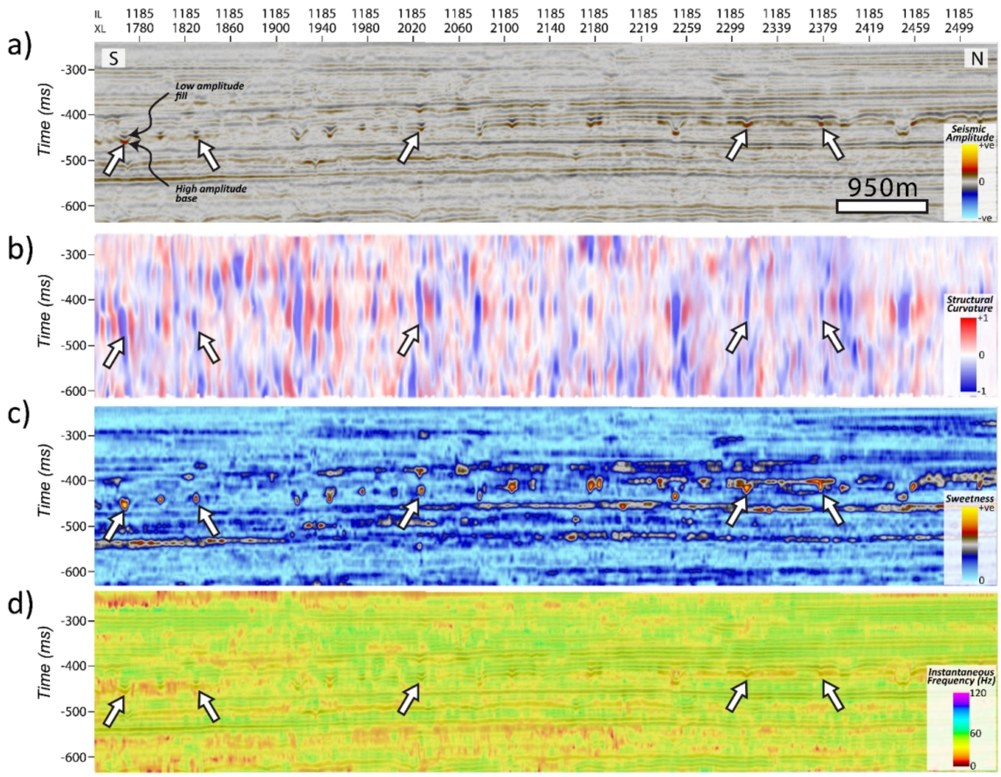


Figure 3. Showing seismic amplitude images at inline 1185. (a) Showing seismic amplitude responses where arrows point out high amplitude anomalies. (b) Showing curvature where arrows correspond to most-negative curvature. (c) Showing sweetness where arrows point out high amplitude anomalies. (d) Showing instantaneous frequency where arrows indicate low frequency zones.

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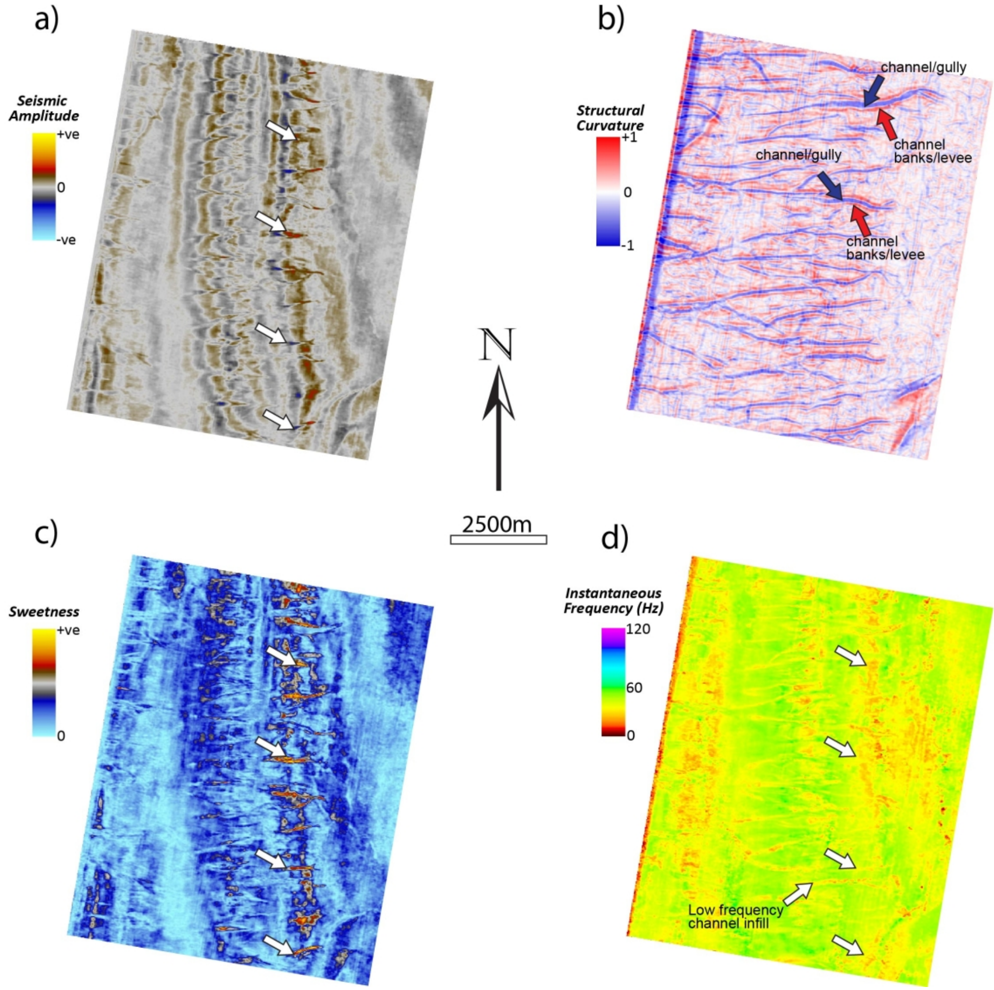


Figure 4. Time slices at -416ms. (a) Showing seismic amplitude where arrows point out high amplitude anomalies. (b) Showing curvature where blue arrows indicate areas of most-negative curvature, interpreted as gully concave up feature, and red arrows indicate areas of most-positive curvature, interpreted as gully banks/levee. (c) Showing sweetness where arrows point out high amplitude anomalies. (d) Showing instantaneous frequency where arrows indicate low frequency zones within and beneath features.

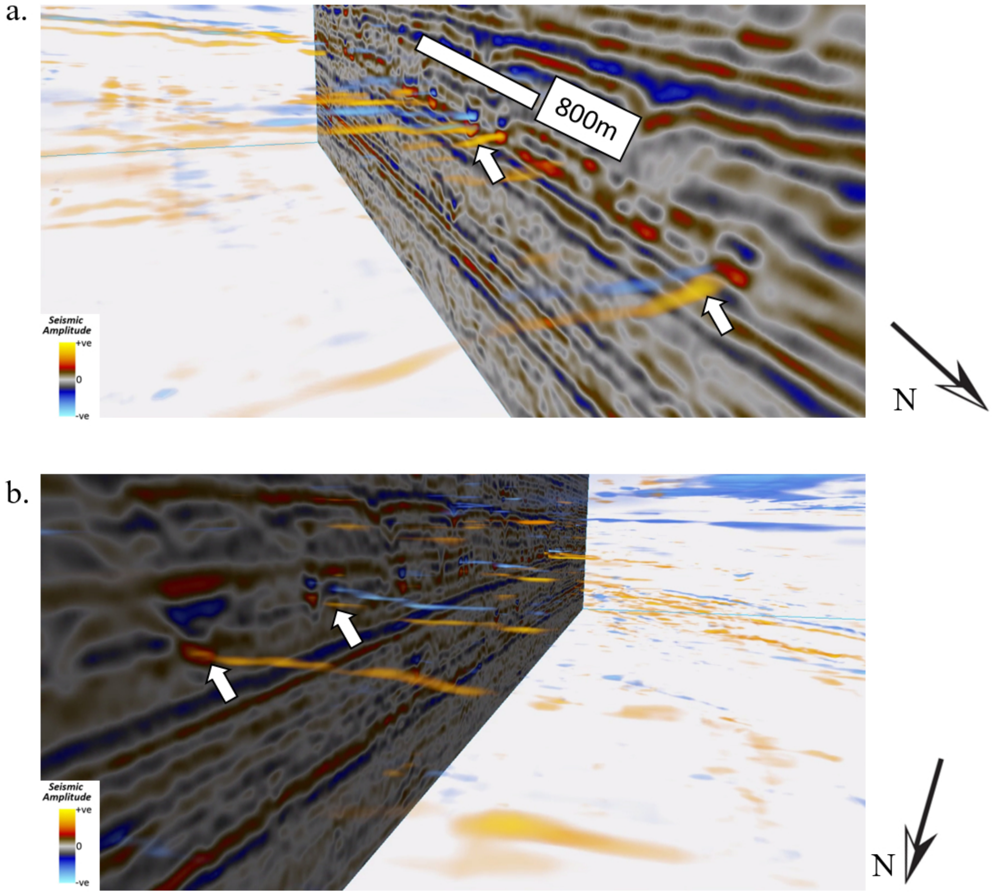


Figure 5. Inline 1146 intersecting 3D volume. (a) Eastern half of data, (b) western half of data. 3D volume has an applied opacify filter to allow only high amplitudes to appear. Bright spots are clearly observable, and examples have been pointed out by arrows. Bright negative response (interpreted as gully fill material) above a bright positive response (interpreted as boundary of gully fill and underlying strata).

DATA AND MATERIALS AVAILABILITY

Data associated with this research are confidential and cannot be released.


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