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Comment on "The three-dimensional geometry and growth of forced folds above saucer-shaped igneous sills" by Hansen and Cartwright

Keywords: Forced folds; Sill emplacement; Volcanic centres

Hansen and Cartwright (2006) describe a number of <5 km wide domal features at the top Balder Formation level (late Palaeocene/early Eocene) within the Rockall Trough (Fig. 1) and have interpreted them forced folds that are the result of roof uplift above inflated saucer-shaped sills. Although forced folding is a common phenomenon associated with movement on blind faults or the emplacement of igneous intrusions the interpretation provided by Hansen and Cartwright (2006) contradicts the previous interpretation of the Rockall Trough domes as small volcanic centres (Thomson, 2005a,b). In order to confirm that the features are domal forced folds, as opposed to small volcanic centres, several criteria must be met. Firstly, and most obviously, horizons above the intrusions need to show clear evidence that they are folded. In addition, as an interpretation as volcanic centres requires the presence of a volcanic edifice the data must demonstrate that there is no thickening of the potential volcanic sequence across the domal structures and that the syn-intrusive surface provides no evidence for eruption (e.g. the presence of lava flows) if the forced folding mechanism is to be accepted.

Fig. 2 contains two seismic sections through the proposed 'Fold B' of Hansen and Cartwright (2006). Although the precise correlation of the reflectors (Horizons B and C of Hansen and Cartwright, 2006) across the structure is open to some debate the crucial observation is that the sequence is significantly thicker in the 3.5 km wide zone of the proposed fold compared to that in the surrounding region. Furthermore, both the vertical thickness and the bedding (reflector) normal thicknesses within the proposed fold are greatest in the centre of the structure and decrease towards the flanks. This evidence for stratigraphic thickening demonstrates that the dome at the Horizon C level is not the result of folding but a constructional edifice and consequently that another mechanism needs to be invoked.

Fig. 3 is a seismic section across 'Fold C' of Hansen and Cartwright (2006). The seismic sections across this structure provided by Hansen and Cartwright (2006) are orientated NE–SW and traverse the flanks of the structure. In contrast, Fig. 3 is orientated NW–SE and passes through the summit of the structure. This line orientation is important as the structure is located in the hangingwall of an NE–SW trending normal fault (Thomson, 2005a,b) and consequently Fig. 3 shows the proposed fold in its full structural context. Again the seismic section demonstrates that the topographic anomaly is associated with significant stratigraphic thickening of the Horizons B–C interval. The Horizons B–C interval shows no evidence for folding but instead dips gently to the northwest. Seismic sections perpendicular to Fig. 3, as presented by Hansen and Cartwright (2006), also show that the Horizons B–C interval is relatively flat within the proposed fold. Consequently, there is no evidence for folding within the Horizons B–C interval. Furthermore, Fig. 3 demonstrates that the strata into which the sills were intruded maintain their dip to the northwest. In particular, Fig. 3 shows relatively shallowly dipping reflectors terminating against the top of the sills that

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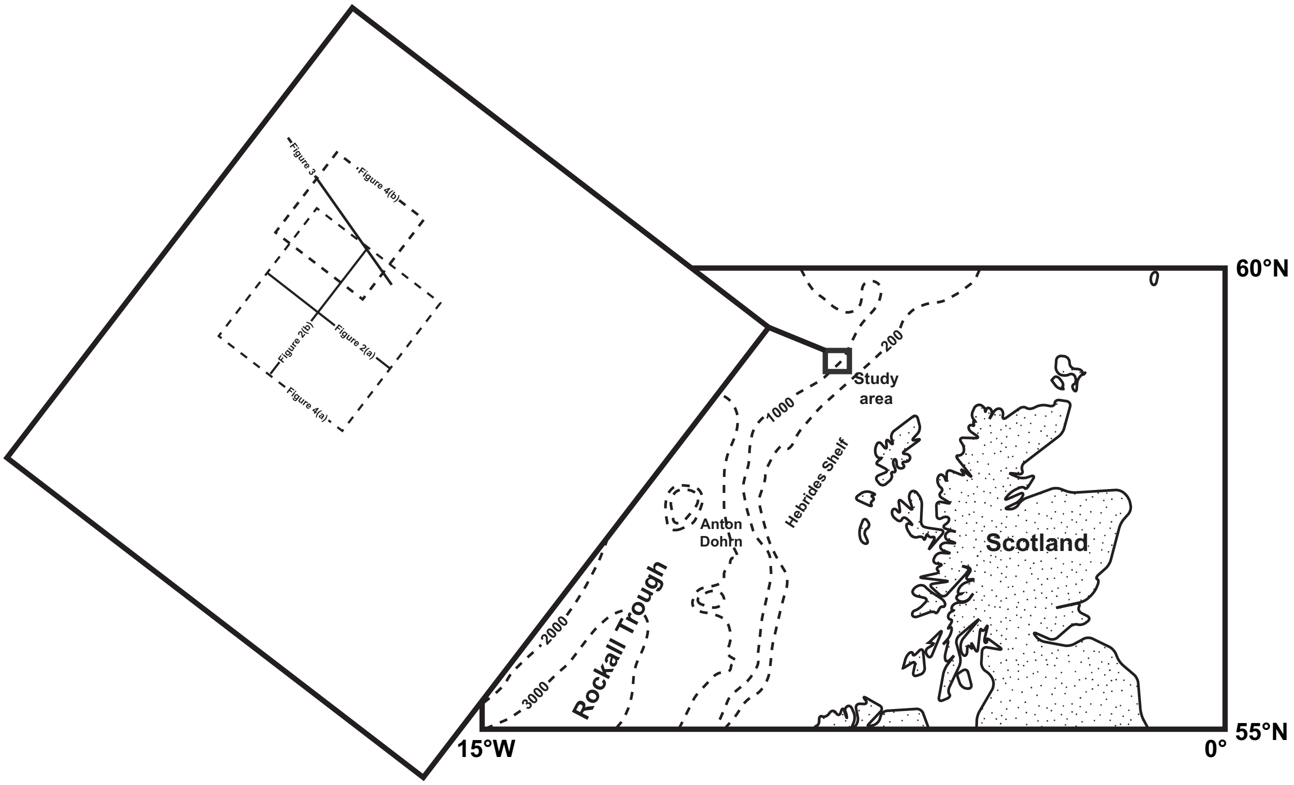

Fig. 1. Map showing the location of seismic sections and artificially illuminated two-way travel time maps described in this discussion.

underlie the proposed fold and consequently do not support the folding proposal.

Fig. 4(a) is an artificially illuminated two-way travel time map of the proposed ‘Fold B’ and equates to Horizon C of Hansen and Cartwright (2006). The map demonstrates that the topographic anomaly is radially symmetrical and approximately 3.5 km wide (c.f. Fig. 2 and Hansen and Cartwright’s Fig. 10). Surrounding the proposed fold are elongate features radiating as spokes from the topographic anomaly and extending up to 2.5 km beyond it (Fig. 4(a)). These features originate close to the summit or on the upper slopes of the topographic anomaly and in some cases broaden away from the structure to reach maximum widths of approximately 1 km. Given the evidence for stratigraphic thickening and the high seismic amplitudes associated with the reflectors in the Horizons B–C interval these elongate features can, with some confidence, be interpreted as lava flows originating from a 3.5 km wide volcanic centre as previously proposed by Thomson (2005a,b).

Fig. 4(b) is an artificially illuminated two-way travel time map of the proposed ‘Fold C’ of Hansen and Cartwright (2006). The map shows, particularly on the eastern flank, a number of elongate, downslope broadening features that originate on the upper slopes of the topographic anomaly. Although less well defined than the examples in Fig. 4(a) the evidence for stratigraphic thickening and the high seismic amplitudes associated with the reflectors in the Horizons B–C interval suggests that the features can be interpreted as lava flows from a volcanic centre situated in the hangingwall of a normal fault (Thomson, 2005a,b).

The examples provided here demonstrate that the proposed forced folds of Hansen and Cartwright (2006) fail to meet the necessary criteria to be validated. In particular, the features involve stratigraphic thickening towards the centre of the proposed folds and in some cases the proposed folds are composed of unfolded strata. In addition, the kinematic model proposed by Hansen and Cartwright (2006) involves the presence of outward dipping normal faults. In contrast, inflation of a 300 m thick sill or laccolith would be associated with inward dipping reverse faults that develop during the forced folding (Pollard and Johnson, 1973). These observations make the case for forced folding difficult to reconcile with the data. However, the architecture of the proposed folds and the surface morphologies are entirely consistent with the development of small volcanic centres and their associated lava flows. Furthermore, the outward dipping normal faults described by Hansen and Cartwright (2006) would be compatible with the partial collapse of the volcanic edifices.

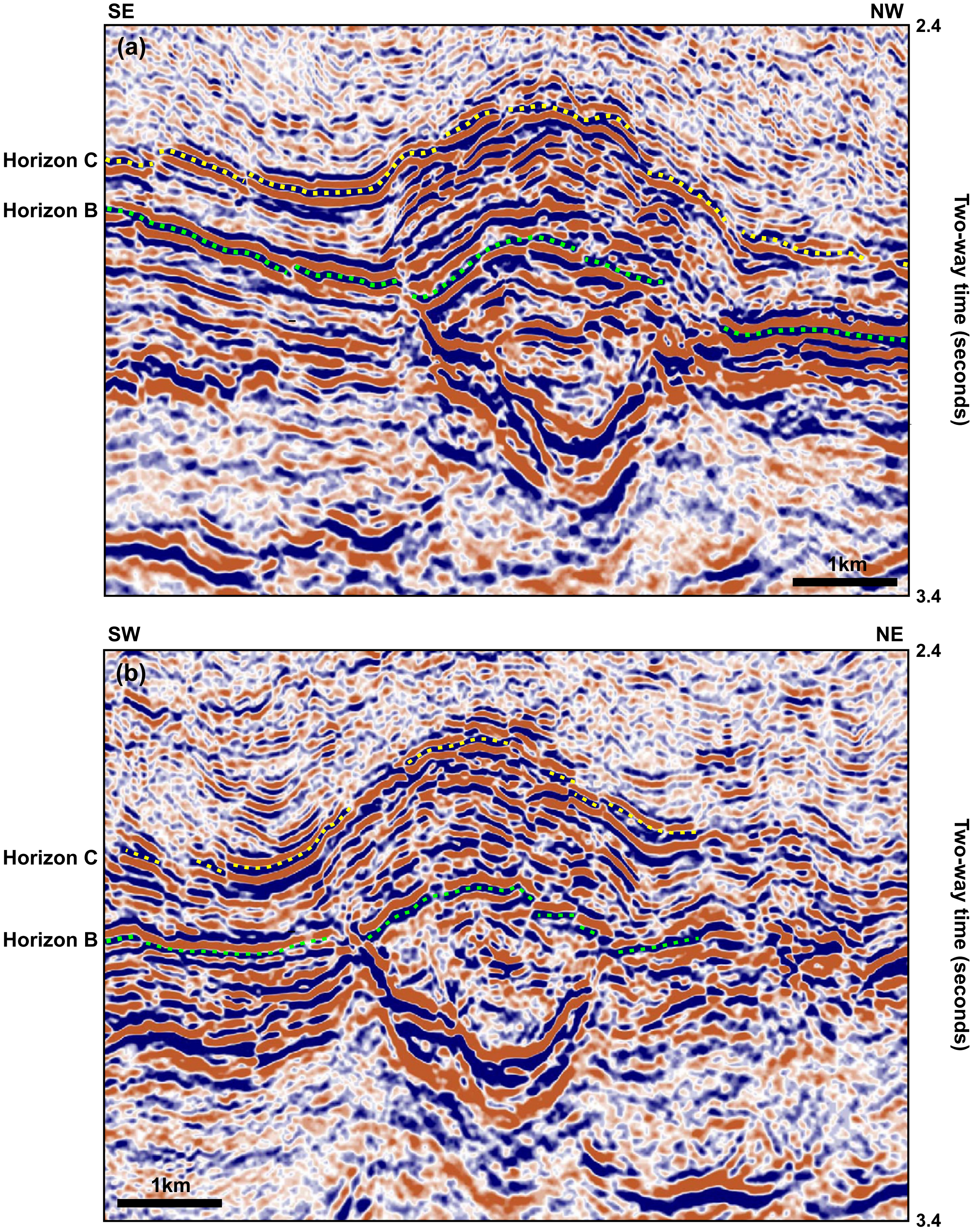

Fig. 2. Seismic sections across the proposed 'Fold B' of Hansen and Cartwright (2006).

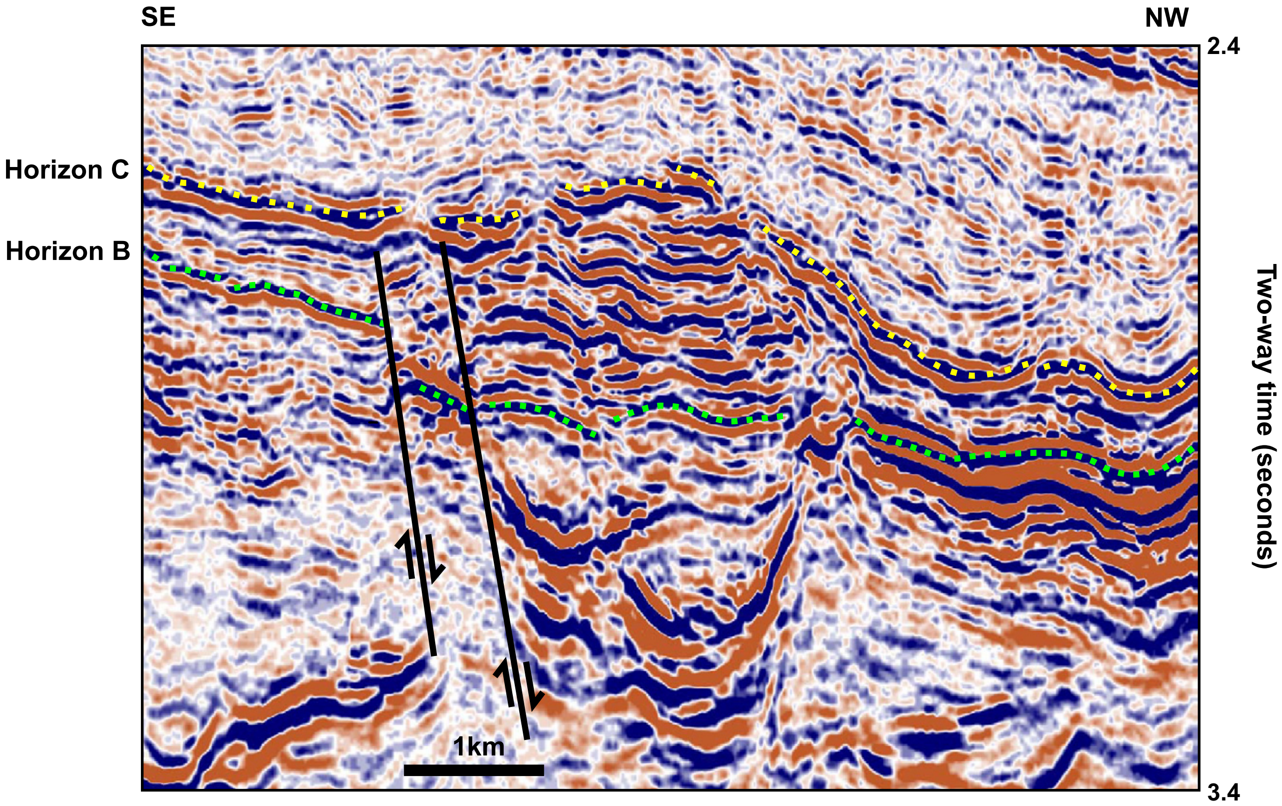

Fig. 3. Seismic sections across the proposed 'Fold C' of Hansen and Cartwright (2006).

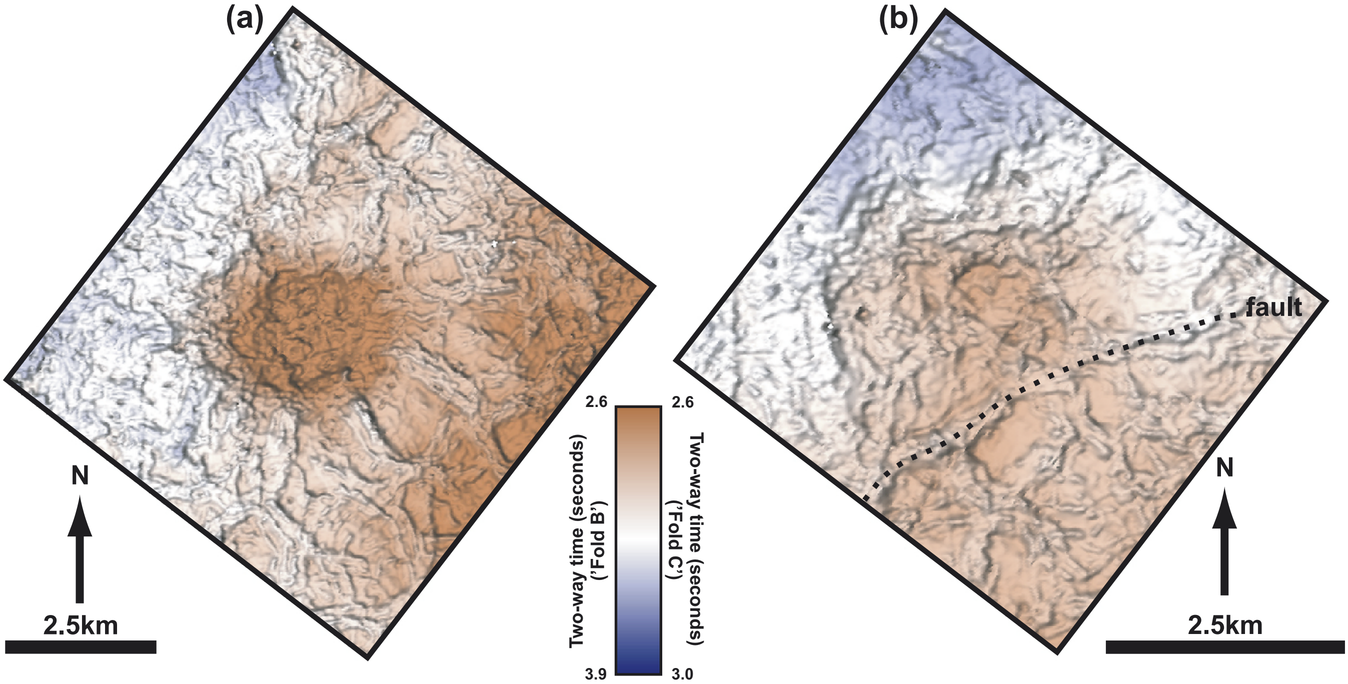

Fig. 4. Artificially illuminated two-way travel time maps of the near Top Balder Formation surface (Horizon C of Hansen and Cartwright (2006)). (a) The region of the proposed 'Fold B' of Hansen and Cartwright (2006). (b) The region of the proposed 'Fold C' of Hansen and Cartwright (2006).

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