Chapter 6 Seismic Structural Mapping and Basin Evolution

6.1 Introduction

This chapter describes the geometries of structures interpreted from seismic sections, with the aim of synthesising this structural information and reconciling the interpretation with previous geophysical modelling within a basin evolution context.
Most of the seismic sections in the TBO1 survey are orientated in a NE-SW direction and therefore, most seismic-interpreted faults trend NW. Structures have exaggerated dips on TWT sections and have been depth converted for analysis. The base of the Tertiary, as well as selected horizons, is tied throughout the seismic grid permitting the production of time structure maps for the basin. Introduced in this chapter are Western Graben (WG) and Eastern Half-Graben (EHG) referred to as the western sub-basin and eastern sub-basin of previous chapters.

6.2 Previous work

Carey (1947) was the first to propose a detailed structural interpretation of the Longford Sub-basin, at the time referring to the area as Lakes Cressy and Tamar. He speculated that a Miocene peneplain was broken by normal step faulting, producing a graben structure. The Tiers Fault and Ben Lomond Highlands were uplifted, while the Midlands became a low-lying trough with a central horst from Mt Arnon to Hummocky Hills.

Hinch (1965) undertook the first gravimetric survey of the area and defined the gross structure as a half-graben. This interpretation was supported by Longman (1966), and Longman & Leaman (1971), who proposed a southwest dipping surface that was fractured by normal step faulting.

The most detailed study on the basin to date is a groundwater study by Matthews (1983). Integrating all previous work, Matthews argued in favour of the half-graben interpretation, postulating the basin symmetry from drilling data.

A comprehensive study by Direen (1995) using stratigraphic data, gravity, magnetics and electromagnetic surveys, modelled the basin as a series of half-grabens with blocks down thrown to the east.

6.3 Faults

Faults were interpreted on the basis of breaks in reflector continuity and displacement of seismic sequence packages. Interpretation of faulting below the Longford Sub-basin is made difficult by the poor quality of seismic data. All fault interpretations are in some way based around dolerite displacement or Tertiary reflector termination. Below this stratigraphic level, fault geometry can only be inferred. Major faults are interpreted as planar but may become listric at depth. A major fault previously identified and clearly recognisable from the seismic profiles is the Bracknell Fault. Previous geophysical interpretations and structural mapping have identified many more faults within the Longford Sub-basin (Direen 1995). Even though these faults are not recognised via seismic methods, they may still exist (Brown 1997).

6.3.1 Bracknell Fault

The major fault, previously referred to as the Bracknell Fault by Leaman (1971, 2002), bounds the western margin of the Longford Sub-basin. On seismic sections, Tertiary sediments appear to onlap this structure.
The Bracknell fault is relatively straight, NW trending and dips 60-70^0 to NE. It exhibits normal displacement and forms the western boundary of the WG. It is the largest mappable fault in the study area, in excess of 17km and is clearly recognizable on seismic lines TB01-SA, SB, PM, PU and PG (figure 6.1).

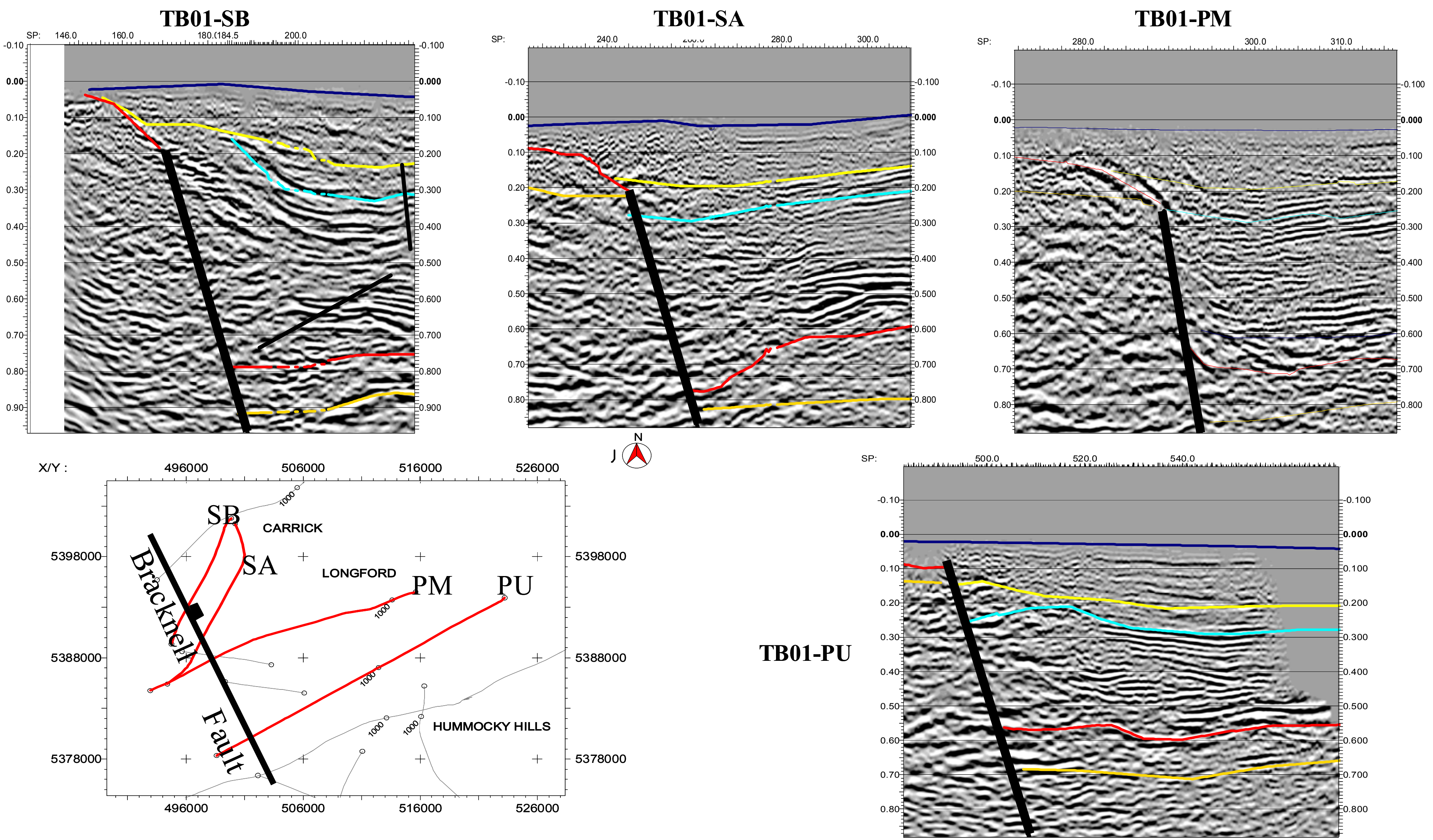


Figure 6.1: Seismic character of the Bracknell Fault (black line) on lines TB01-SB, SA, PM and PU.

Figure 6.2 illustrates variation in throw along the strike, ranging from 0.80sec(TWT) too less than 0.52sec(TWT). To enhance accuracy of seismic interpretation, faults are depth converted (figure 6.3). This reveals displacement range of 800m (TB01-SB) to 490m (TB01-PG). From the seismic sections it is unclear whether the Bracknell Fault is segmented by cross-strike faults or if movement was diachronous along strike. Figure 6.2 would support a ramped displacement by the even displacement along strike.
The eastern boundary fault of the WG is not clearly identified from seismic sections.

Interpretation

Dolerite outcrops west of the Bracknell Fault, while Tertiary deposition occurred on the downthrown block to the east. A thick sequence of Triassic sediments is presumed to have eroded from the downthrown block before the basin opened (pre-Palaeocene deposition), suggesting incipient rifting occurred in the Late Cretaceous to early-Palaeocene. The occurrence of coal deposits (low energy environment) immediately succeeding rifting, suggests the rate of movement along the Bracknell Fault was slow. The footwall has not been cut back nor do large wedge shaped deposits occur on the downthrown side, which are indicators of rapid displacement and erosion of uplifted footwall causing coarse-grained fan deposition. The uniform thickness of Tertiary sediments suggests that movement along the Bracknell Fault was synchronous with the deposition. The graben interpretation is based on the symmetrical form of basin-fill, seen from seismic section TBO1-SB(figure 4.3a) and Tertiary isopach map (Appendix 2).

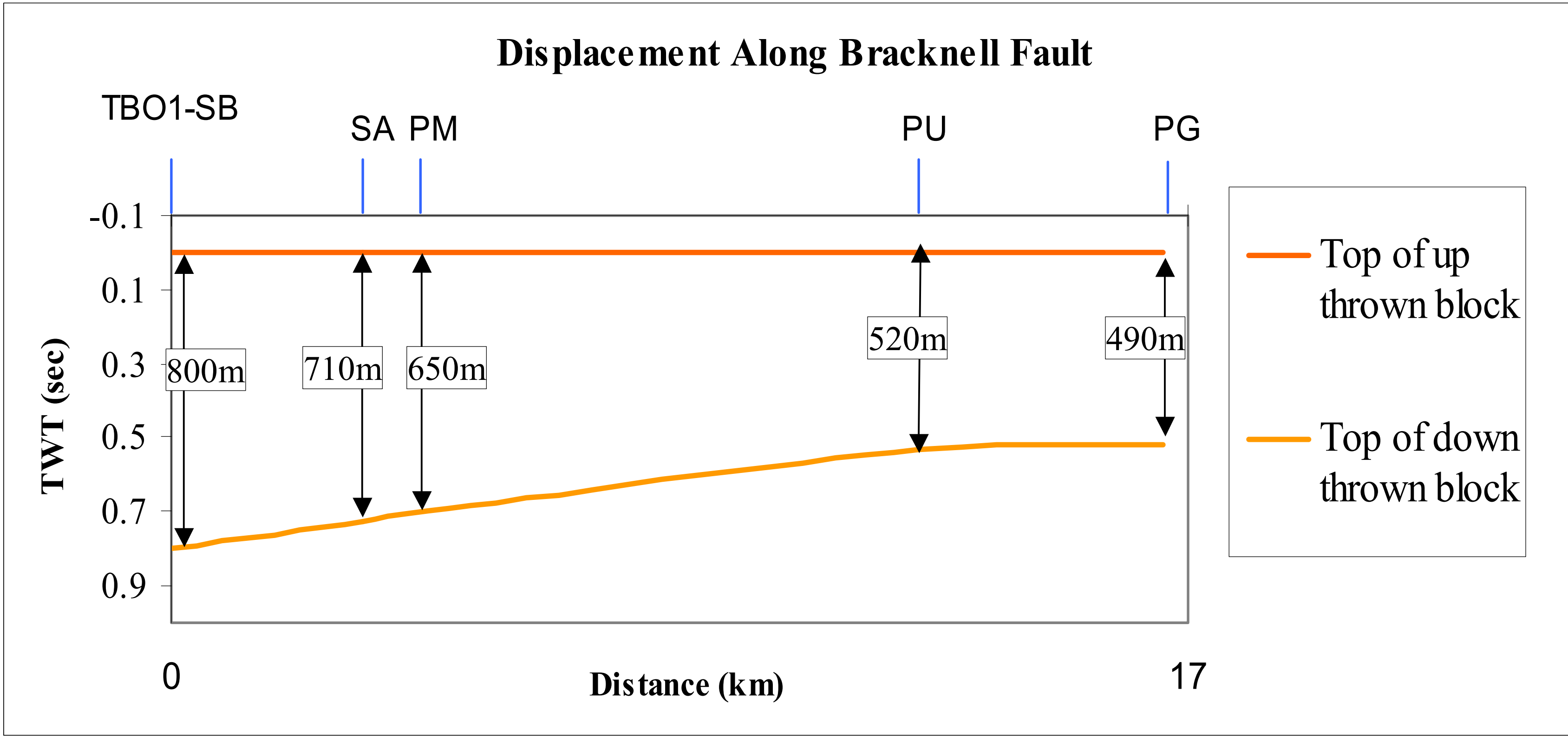


Figure 6.2: **Displacement of the Bracknell Fault along strike in TWT at top basement event (reflector).**

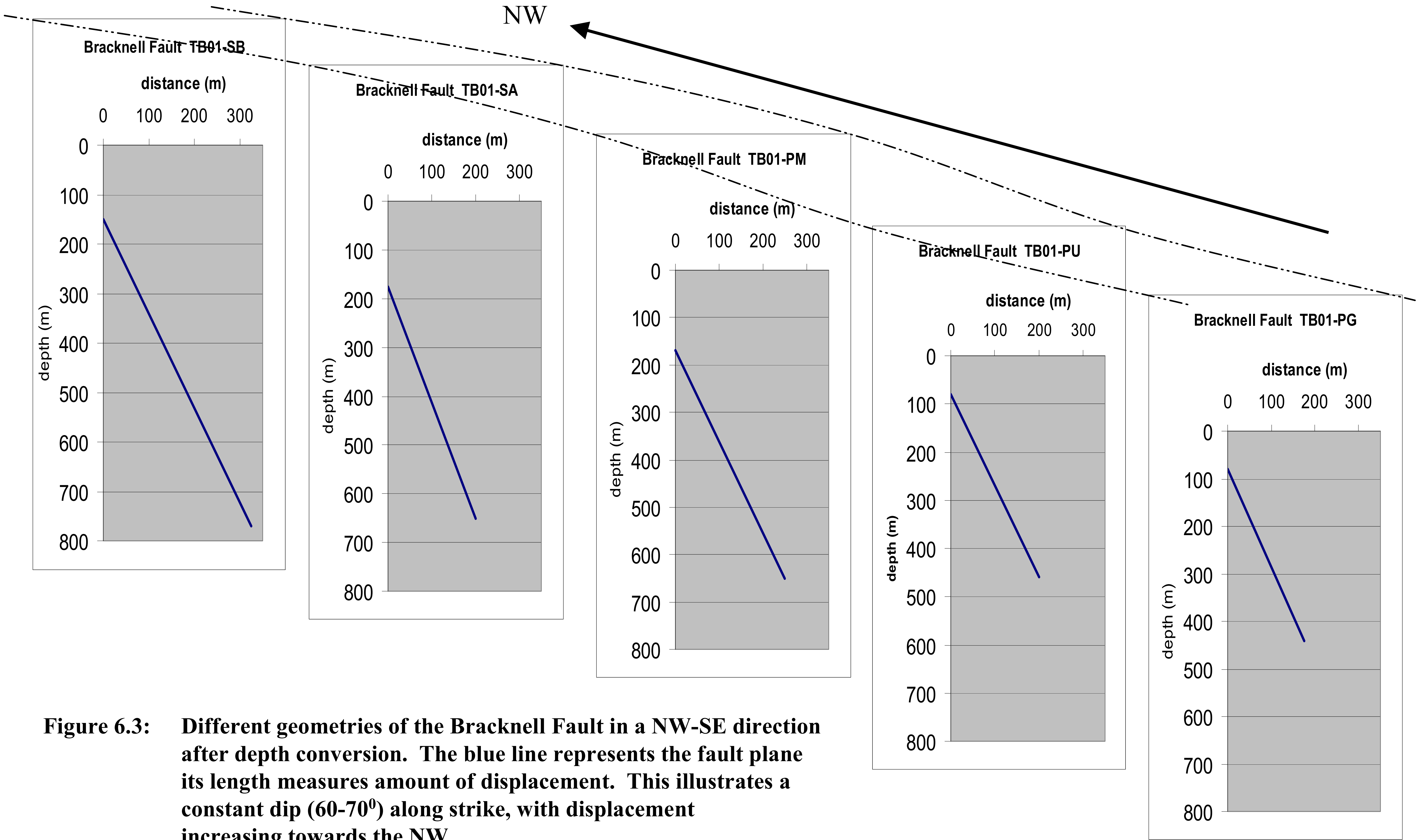


Figure 6.3: **Different geometries of the Bracknell Fault in a NW-SE direction after depth conversion. The blue line represents the fault plane its length measures amount of displacement. This illustrates a constant dip (60-70^0) along strike, with displacement increasing towards the NW.**

6.3.2 Unnamed Faults

On line TBO1-PG a number of faults are identified that have not been previously named. There is evidence the structural geometry changes from a graben in the west, to a half-graben in the east (figure 6.4). The two troughs are separated by a horst, west of Hummocky Hills. Previous investigations (Carey 1947; Hinch 1965; Longman 1966; Longman & Leaman 1971; Matthews 1983 & Direen 1995) have suggested Hummocky Hills is the horst block separating the two sub-basins. From the geology map (Matthews 1974) horst blocks and internal basement highs are difficult to interpret because of the lack of continuous topographical signatures. West of the horst lies the WG composed of a series of tilt blocks dipping less than 3^0 towards the west. The major boundary fault of the WG is referred to as Fault A, it is interpreted on lines TBO1-PG and TBO1-PT (figure 6.5). Figure 6.5 clearly shows the structure at Hummocky Hills to be a tilted block, dipping 3^0 toward the west. Fault A dips at approximately 68^0 to the east with displacement decreasing to the south.

Synthetic Faults

West of Hummocky Hills along line TBO1-PG, the frequency of 'down-to-basin' faults increases. Faults B-E have been interpreted as synthetic growth faults. The synthetic faults have similar dips (approximately 65^0) to major bounding faults with displacement decreasing to the south of Hummocky Hills. To the north, on line TBO1-PG, the number of interpretable faults decreases significantly. In the north structure complexity decreases perhaps representing a later stage of sub-basin development (figure 6.6).

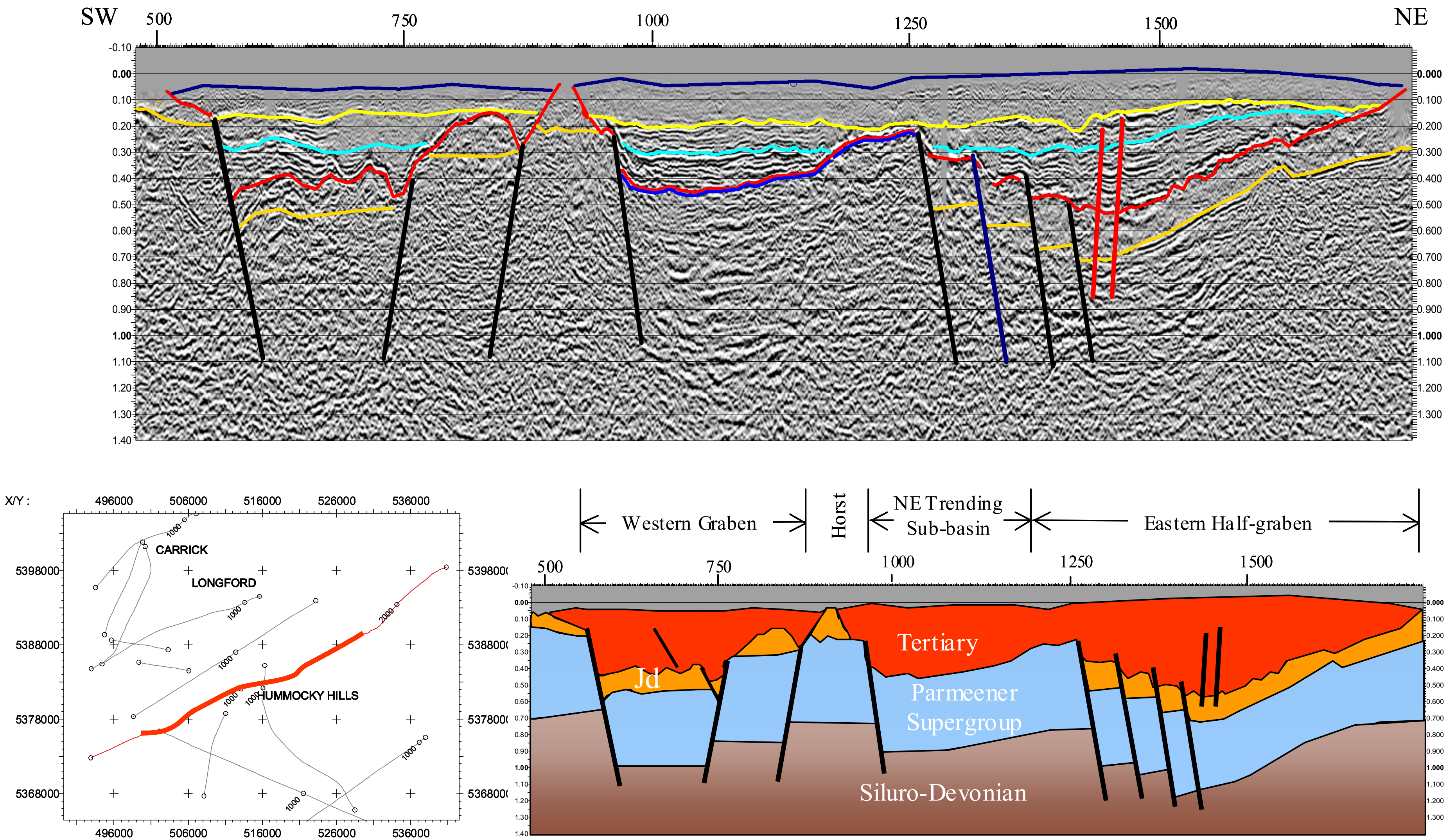


Figure 6.4: **Structural interpretation of seismic line TB01-PG. The structural geometry changes from graben to half-graben eastward.**

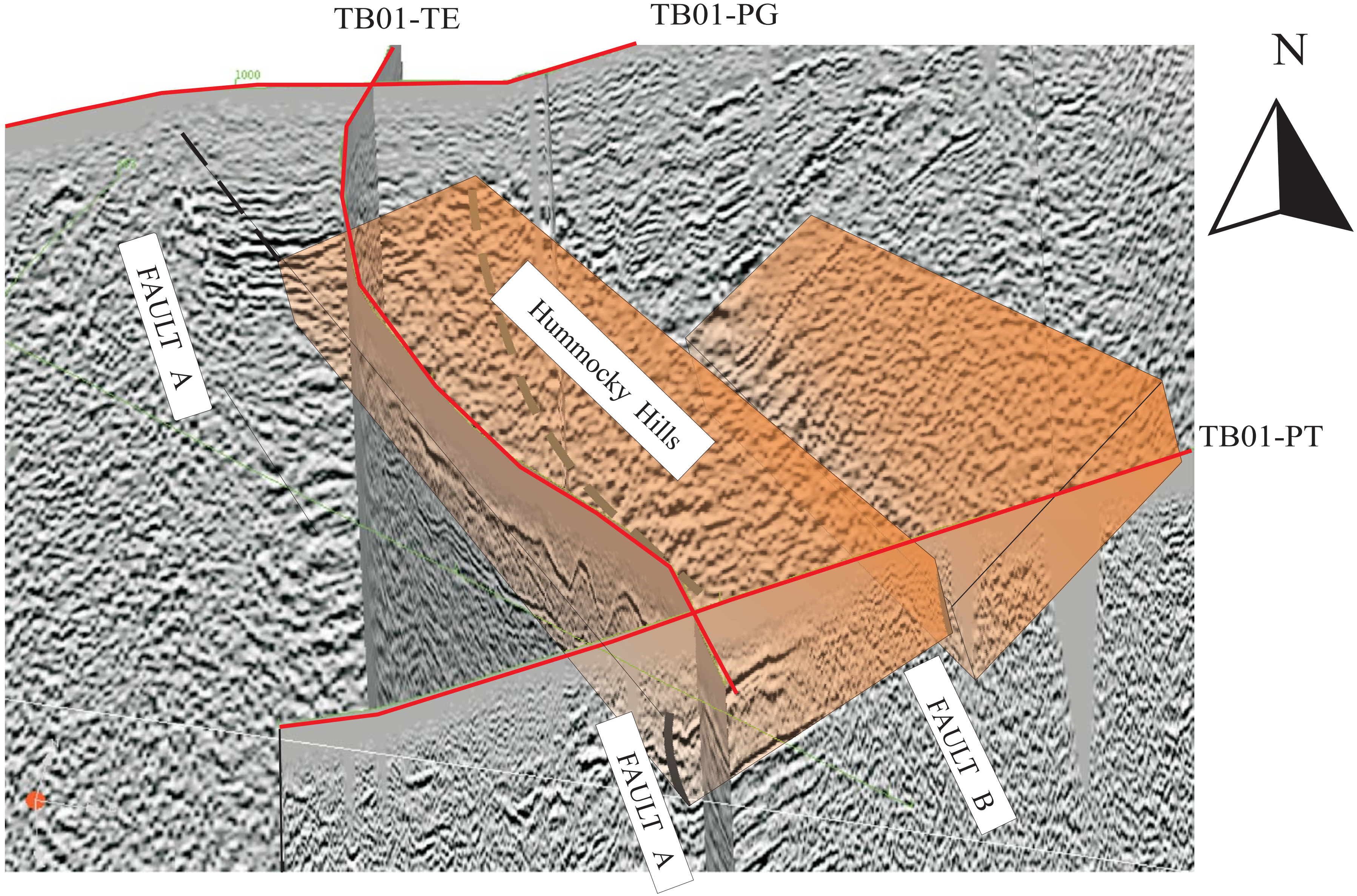


Figure 6.5: Seismic sections TB01-PG, TB01-TE and TB01-PT. Using all three sections, A simplified 3D model of the southern end of the Longford Sub-basin. Hummocky Hills is identified as a large dolerite (orange) capped tilted block, bound by Faults A and B.

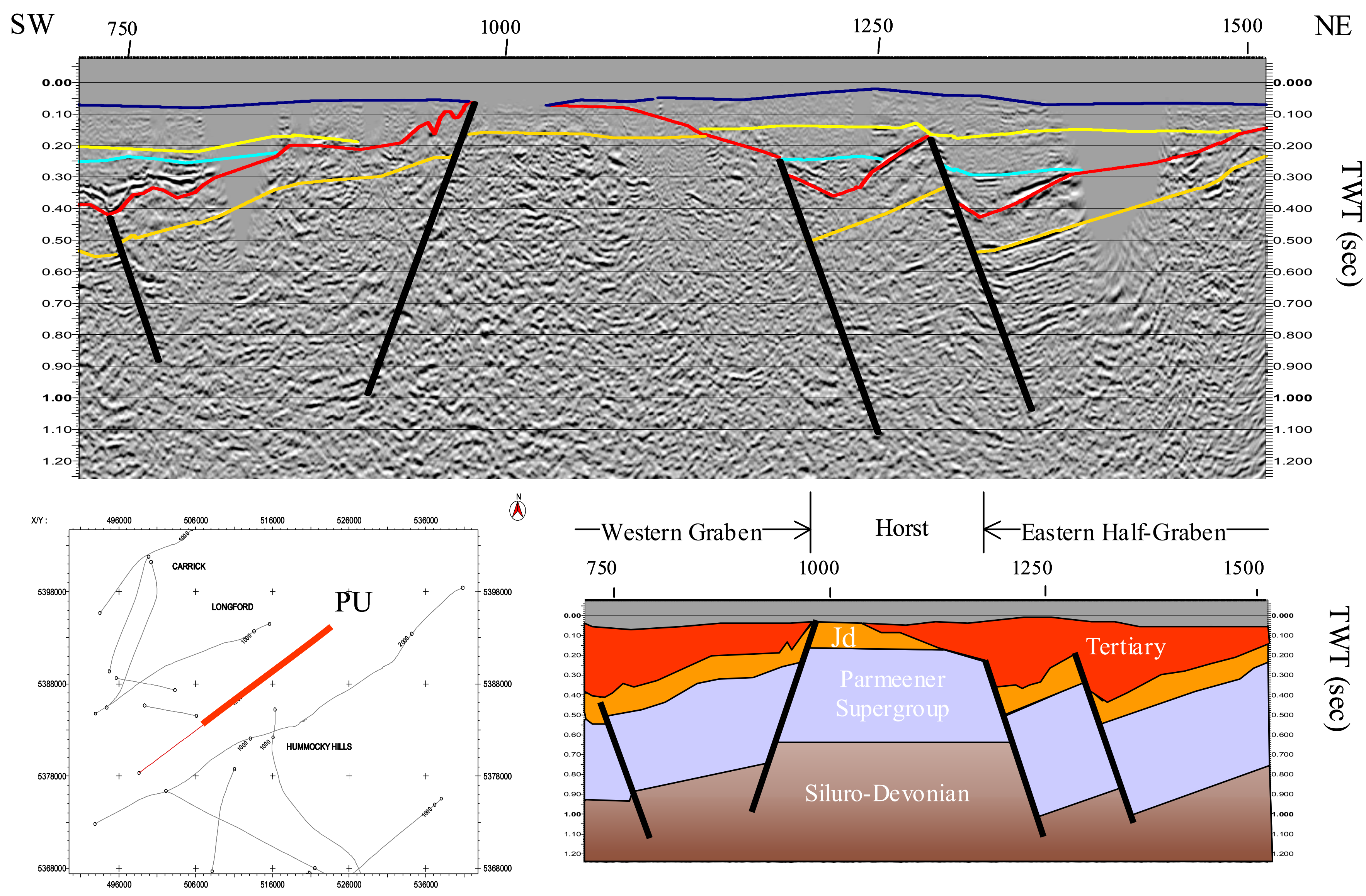


Figure 6.6: **Decreased structural complexity in the north of the Eastern Half-Graben, indicating late stage structural development.**

Syn-depositional growth faults of the EHG are the likely cause of thickness variations in seismic packages overlying tilted blocks. As packages step down the basin, they thicken indicating subsidence during deposition (figure 6.7). Sediments to the north (lithological log IH44) have been dated at middle-late Eocene (Matthews 1983). This suggests rejuvenated faulting throughout the mid-Tertiary.

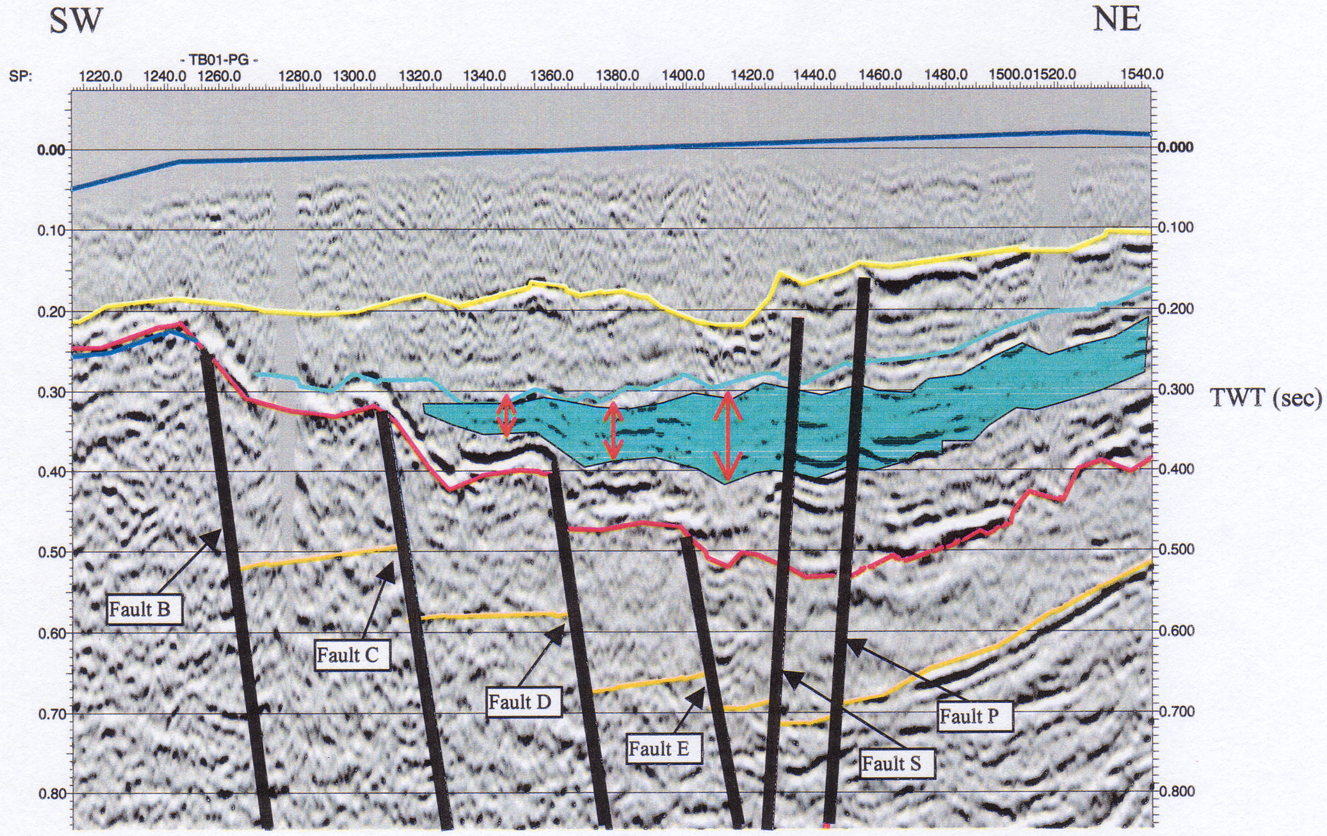


Figure 6.7: **Western end of seismic line TB01-PG. Tracing prominent reflectors within S4, showing the internal packages becoming thicker as they step-down towards the depocentre, indicating syn-depositional fault growth during the mid-Tertiary.**

Faults B-E may become listric at depth, joining a detachment surface (Tiers Fault, Bracknell Fault or Fault A), but the current seismic data cannot confirm this hypothesis.

Anthetic Faults

In the EHG two anthetic faults, Faults S and P, are well imaged on line TBO1-PG (figure 6.7). They extend to the S1 unconformity level, indicating active movement until the late Eocene. These faults are interpreted as planar, dipping 60^0 to the west.

Cross Strike Faults

A cross cutting structure, Fault Q, can be seen on section TBO1-TE due to the north-south orientation of this seismic line. This fault is a minor structure displacing the southern end of the Hummocky Hills tilt block by <100m. Fault Q coincides with a sharp decrease in area of surface dolerite and Upper Parmeener sediments south west of Epping Forest (Matthews 1974). Figure 6.8 outlines the movement by which Fault Q and the surface relationship are achieved. Fault Q is interpreted as a late to mid-Tertiary structure.

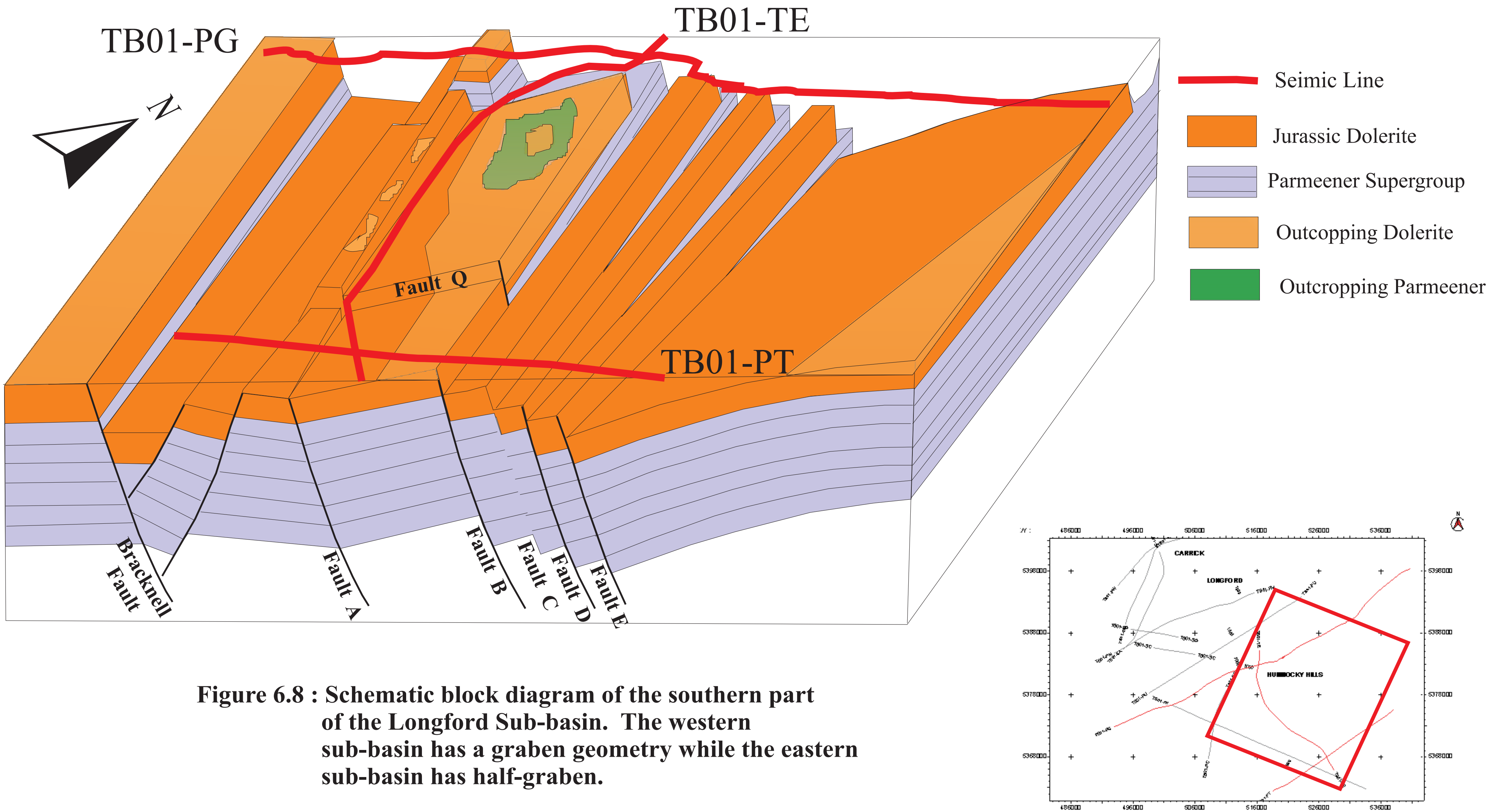


Figure 6.8 : Schematic block diagram of the southern part of the Longford Sub-basin. The western sub-basin has a graben geometry while the eastern sub-basin has half-graben.

6.4 Folds

The Longford Sub-basin, together with the Bass Basin to the north, lacks the anticlinal structures that occur in the Otway and Gippsland Basins. A single anticlinal structure has been interpreted, on lines TBO1-PM and TBO1-SA that marks the position of a dome (figure 6.9).

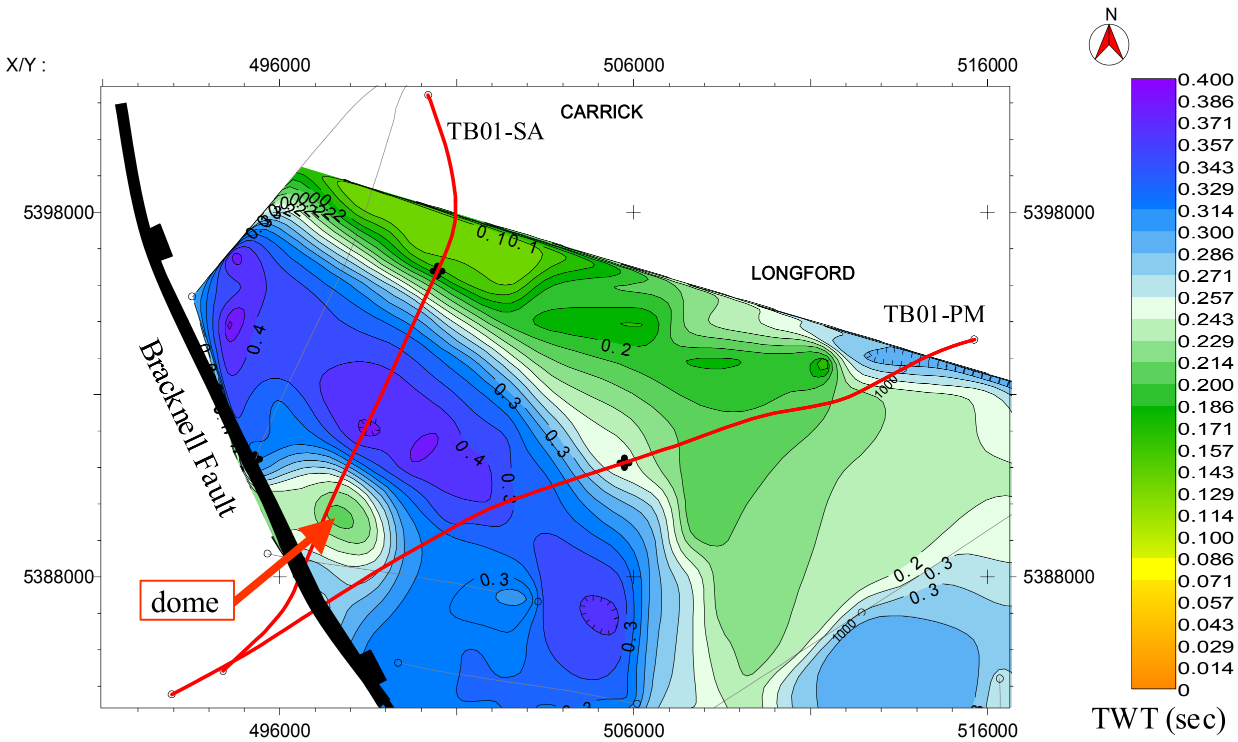


Figure 6.9: The top of S4 TWT structure contour map of the northern part of the Longford Sub-basin. At this level the dome is well represented, occurring on the down-thrown side of the Bracknell Fault.

The dome is situated at the foot of the Bracknell Fault, and extends throughout the entire Tertiary section. To determine if the structure was created by drape or compression, a seismic section was flattened to permit visualisation of basin evolution. The flattened section (figure 6.10) supports a late Eocene compression.

6.5 Potential Field Datasets

Previous investigations have constrained the gross structure of the basin using gravity and magnetic data. Combining seismic interpretations with new and old geophysical interpretations a basin model can be developed.

6.5.1 Magnetics

The Geoscience Australia aeromagnetic datasets over the western sub-basin were interpreted by Direen (1995) and are shown in figure 6.11. A NE trending zone of low magnetic intensity occurs to the north of Hummocky Hills (figure 6.11).

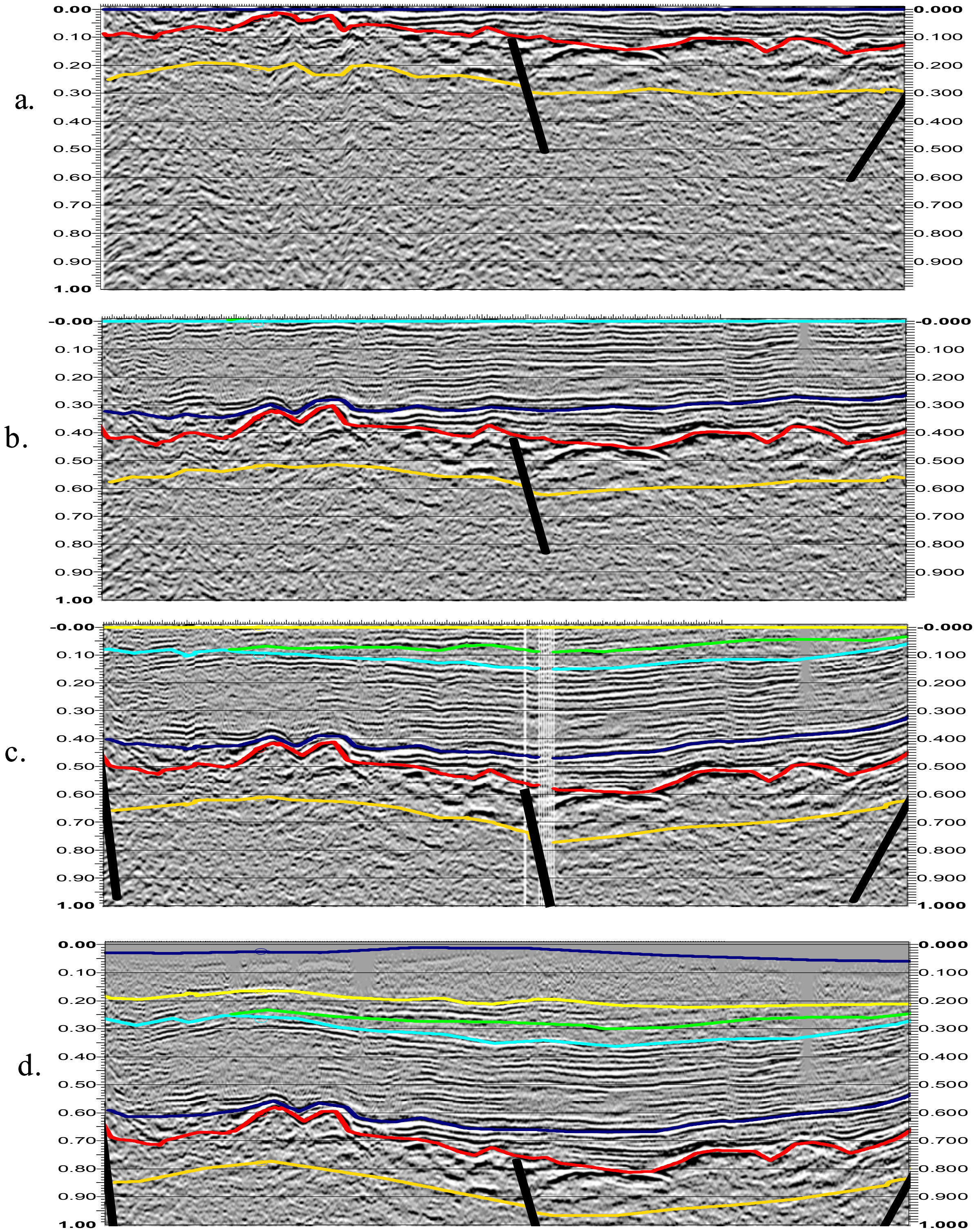


Figure 6.10: **Seismic line TB01-PM flattened at 3 horizons. a) Section flattened at S5, basal sequence is flat lying. b) Section flattened at S4, sequence remains flat lying. c) Section flattened at S2, underlying sequence begins to fold. d) Section at present day, significant doming of the S4 and S2 sequences, indicating uplift continuing during the deposition of S1. The pinch-out of S3 and erosional unconformity above S4 may represent uplift initiation. A second phase of rapid uplift may have produced a regional unconformity at S1.**

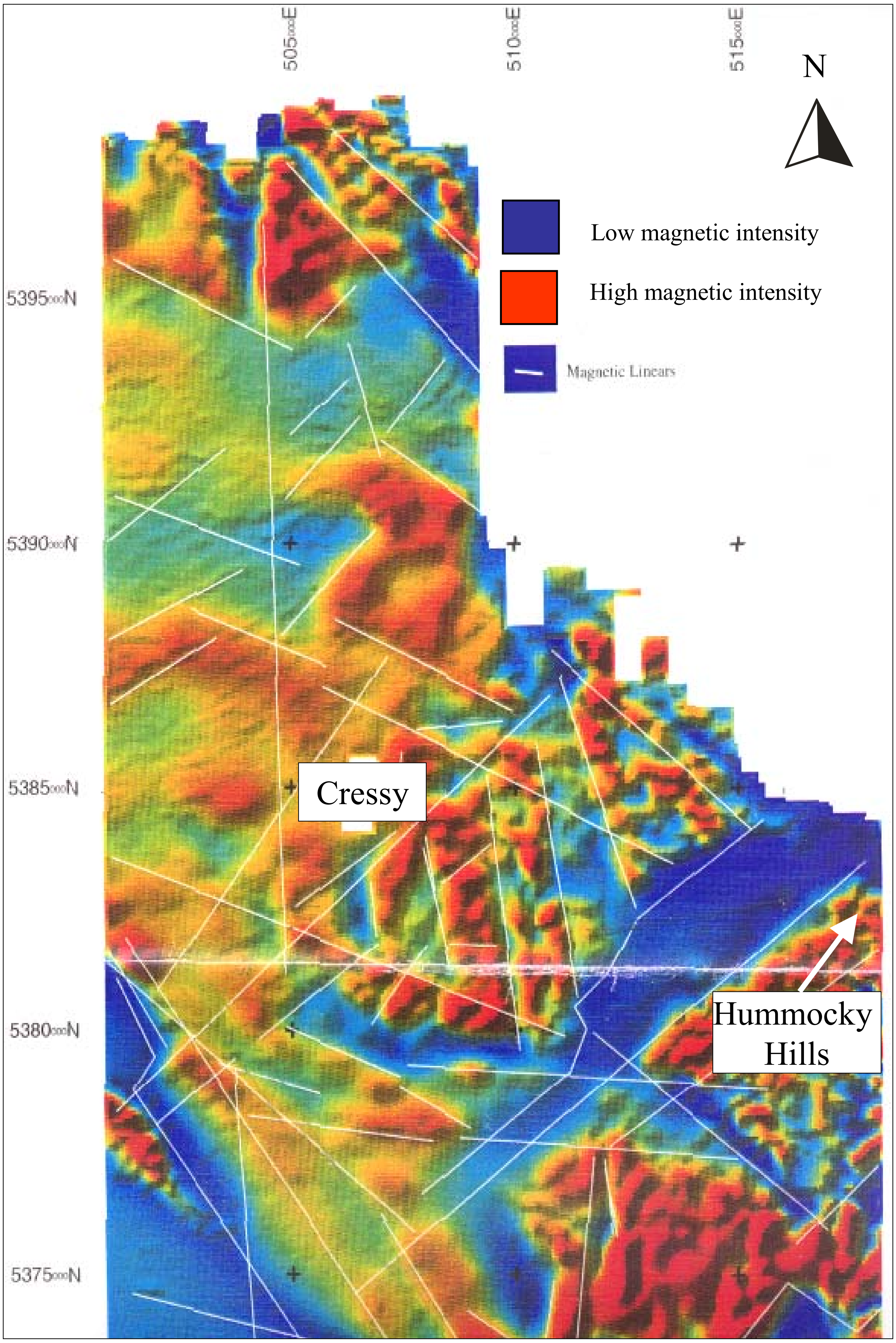


Figure 6.11: Total magnetic intensity pseudocolour image shaded with the first vertical derivative of the magnetic intensity(east sun angle). Linear features shown (from Direen 1995, figure7.7).

Dolerite has a high magnetic intensity (red), whereas the Parmeener Supergroup is neither magnetic nor magnetised (Leaman 2002). Therefore, the margins of this zone represent linear boundaries of dolerite intrusion. Line TBO1-TE intersects the zone clearly showing the abrupt termination of dolerite (figure 6.12).

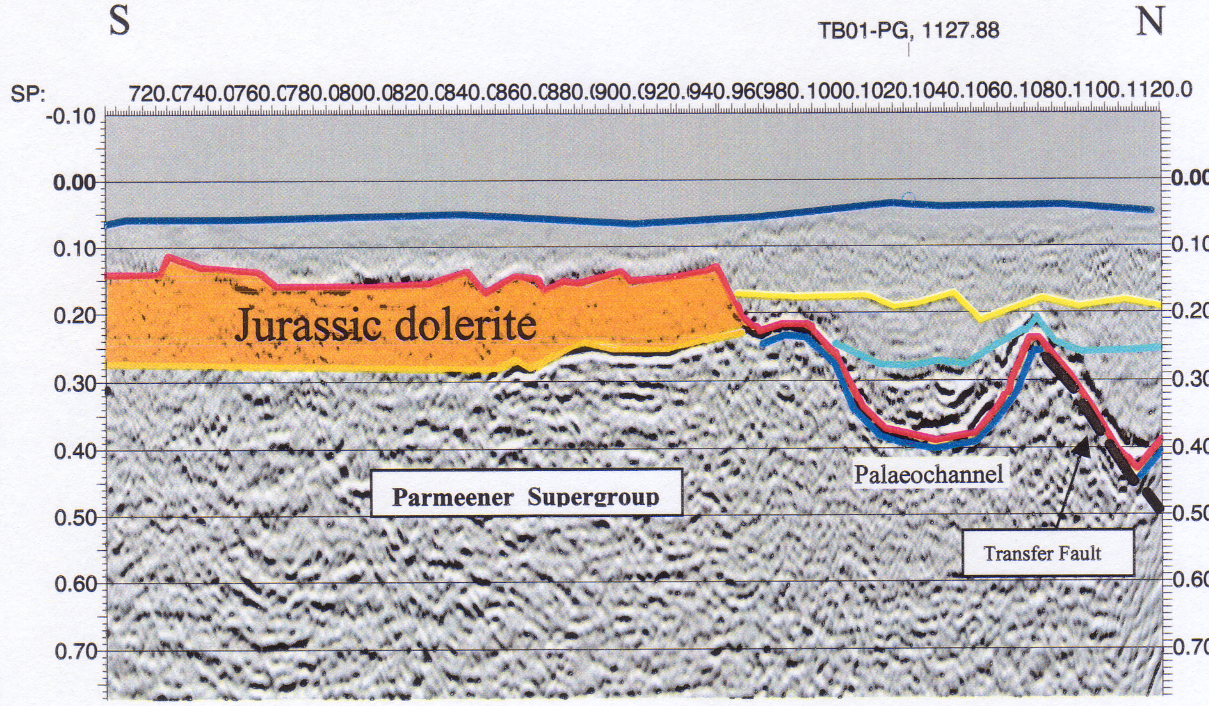


Figure 6.12: N-S seismic line TBO1-TE. The Sub-surface dolerite sheet which is a continuation of outcropping Hummocky Hills, shown here to stop abruptly at the junction of the NE trending zone of low magnetic intensity. Parmeener sediments form the base of Tertiary deposition to the north and possible transfer faulting is indicated at the extreme north of this seismic line. Interpreted palaeochannel containing onlapping Tertiary fluvio-lacustrine sediments in the north.

The linear geometry would indicate some form of structure has controlled the dolerite emplacement. Parmeener sediments probably underlie the non-magnetic zone and today forms a NE trending sub-basin. The sub-basin is defined between shot points 950-1200 on line TBO1-PG (figure 6.13)

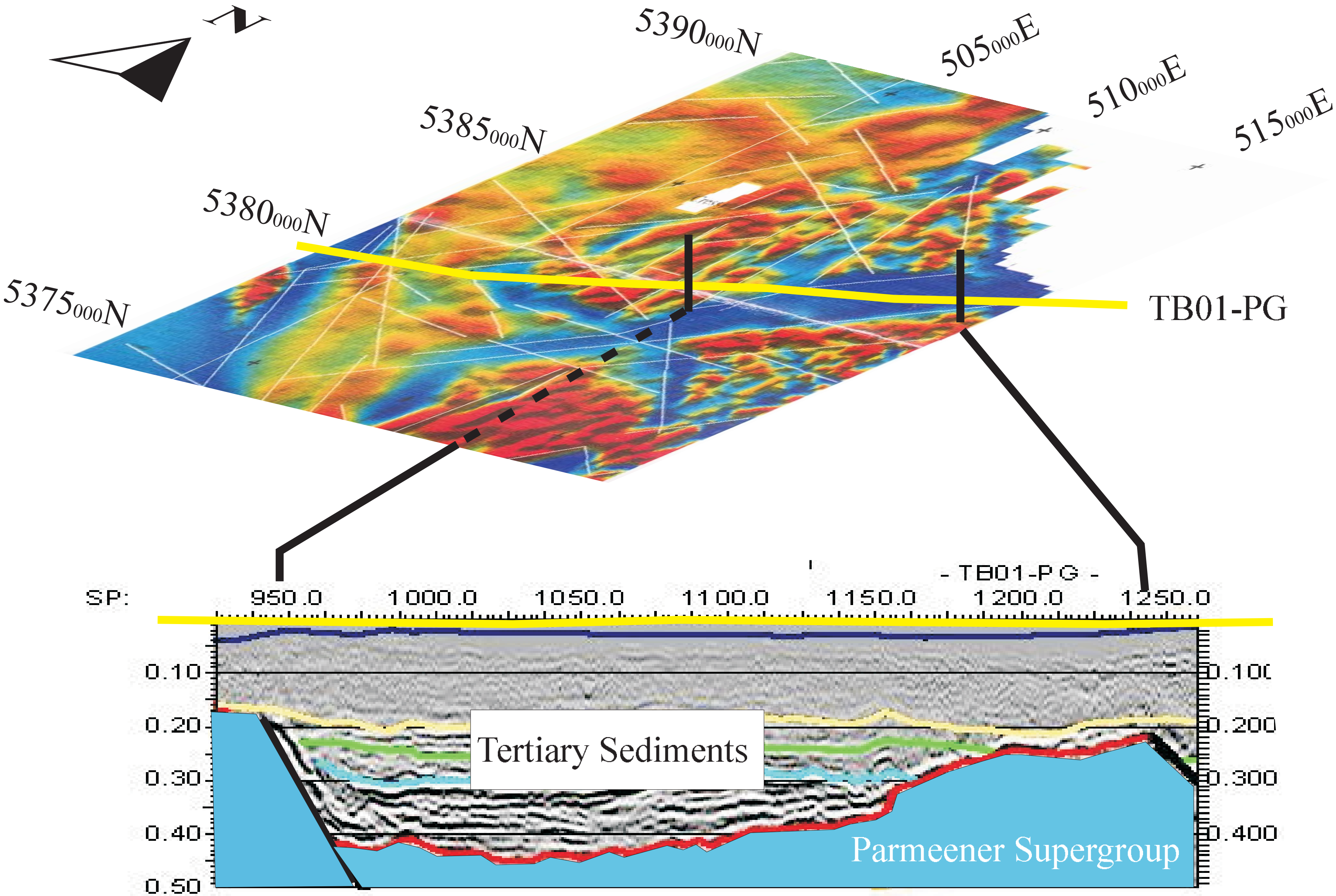


Figure 6.13: The NE trending zone of low total magnetic intensity corresponds to a sub-basin between shot points 950 and 1250 on seismic line TB01-PG. Parmeener Supergroup sediments are interpreted as the the reason for the low magnetic anomaly, whereas elsewhere in the basin dolerite forms the immediate basement for Tertiary deposition.

The sub-basin has been interpreted to form due to accelerated denudation of Parmeener sediment compared to the surrounding dolerite. However, without more north-south trending seismic lines over the zone, transfer faulting cannot be discounted, with possible evidence for transfer faulting seen on the extreme north of seismic line TBO1-TE (figure 6.12). Transfer zones are associated with topographical breaks, which provide entry points for large fluvial systems (Morley 1995). An interpreted palaeochannel coincides with the NE trending sub-basin (figure 6.12)

6.5.2 Gravity

The gravity data used in this study was from a pre-existing MRT database that was infilled over the Longford Sub-basin by GSLM. A pseudocolour image of the residual Bouguer anomaly with structural interpretation is shown in figure 6.14.

The major structures interpreted from seismic data clearly correspond to gravity anomalies. The major linear NW trending Bracknell Fault produces a distinct change in gravity data, from a gravity low trough to gravity high. North of the seismic grid, the Bracknell Fault swings to strikes N-S.

A number of NE trending linear anomalies are identified from gravity data as linear extrapolation and troughs between gravity highs, and indicate a secondary NE structural trend. A feature of these NE structures is that they are bound along strike changes in basin geometry, indicating transfer faults. However, this geometry contradicts the relay ramp interpretation along the Bracknell Fault. The transfer structures have a movement imposed from major NW faults. As a result, sense of movement on transfer is likely to be oblique slip that may change sense along strike. The NE trending zone identified from aeromagnetic data coincides with a negative gravity anomaly, which favours the argument that this area is underlain by Permo-Triassic basement. The different structural geometries either side of this zone identified from seismic data are also evident in the gravity data. Based on the gravity data, a structural interpretation of the basin is shown in figure 6.15.

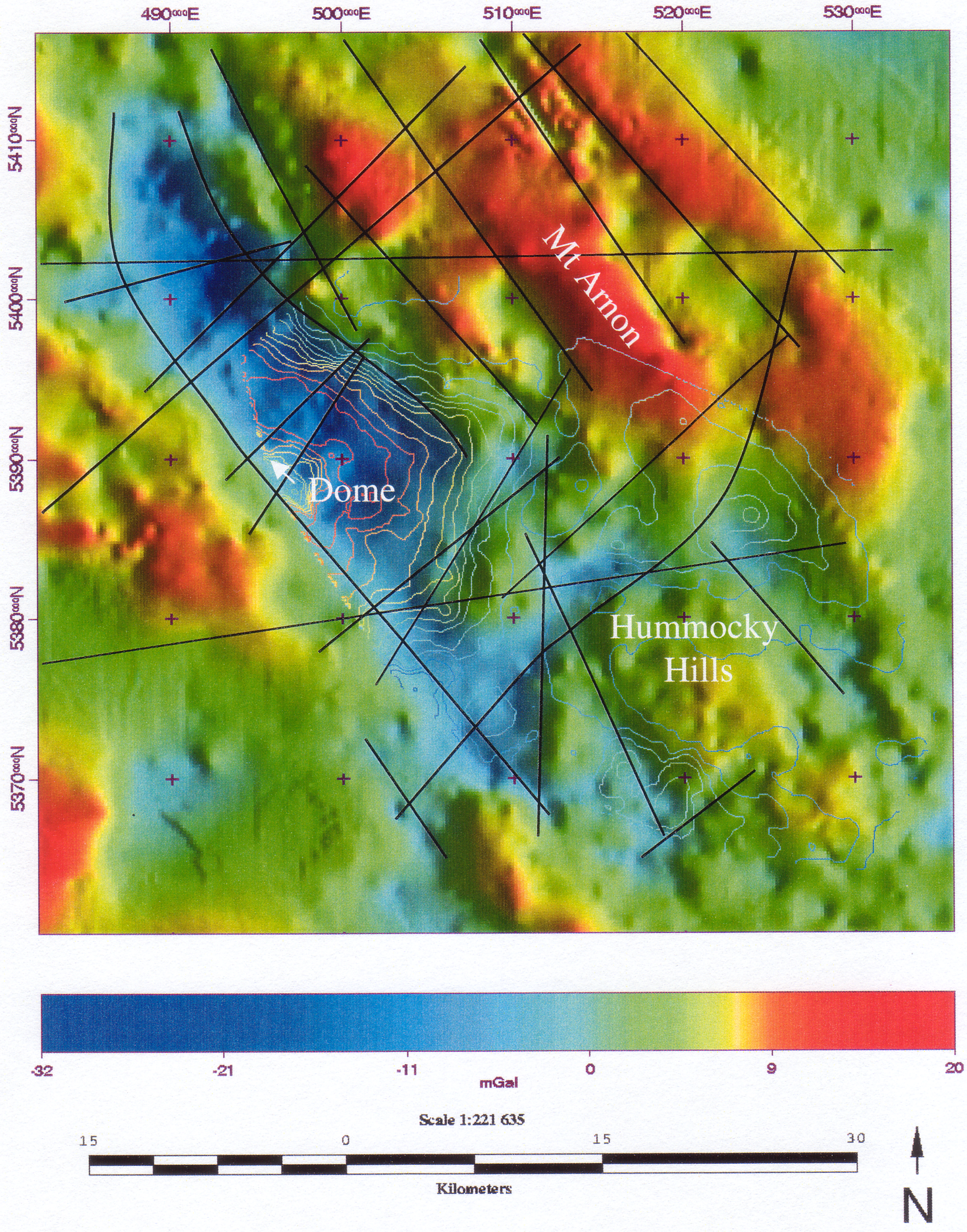


Figure 6.14: Residual Bouguer anomaly, pseudocolour image with NE sun angle. Linear features are shown.

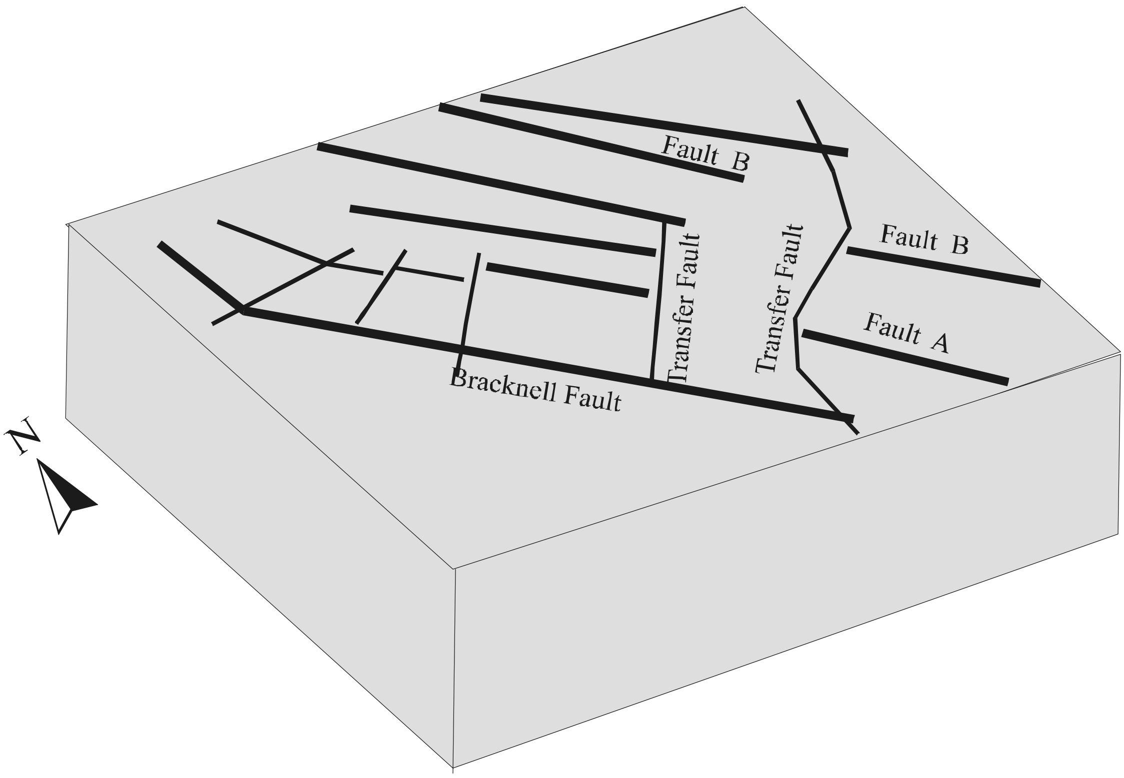


Figure 6.15: Interpreted fault movements based on the gravity data of the Longford Sub-basin.

Interpreting the basement architecture assists in understanding the gross structure of the Longford Sub-basin. Figure 6.16 is the residual Bouguer anomaly with an overlay of seismic interpreted TWT (sec) contours of the base of the Tertiary. The seismic interpreted depocentres and basement highs correlate extremely well with the gravity map. Therefore, the gravity supports seismic interpretations of the base of the Tertiary.

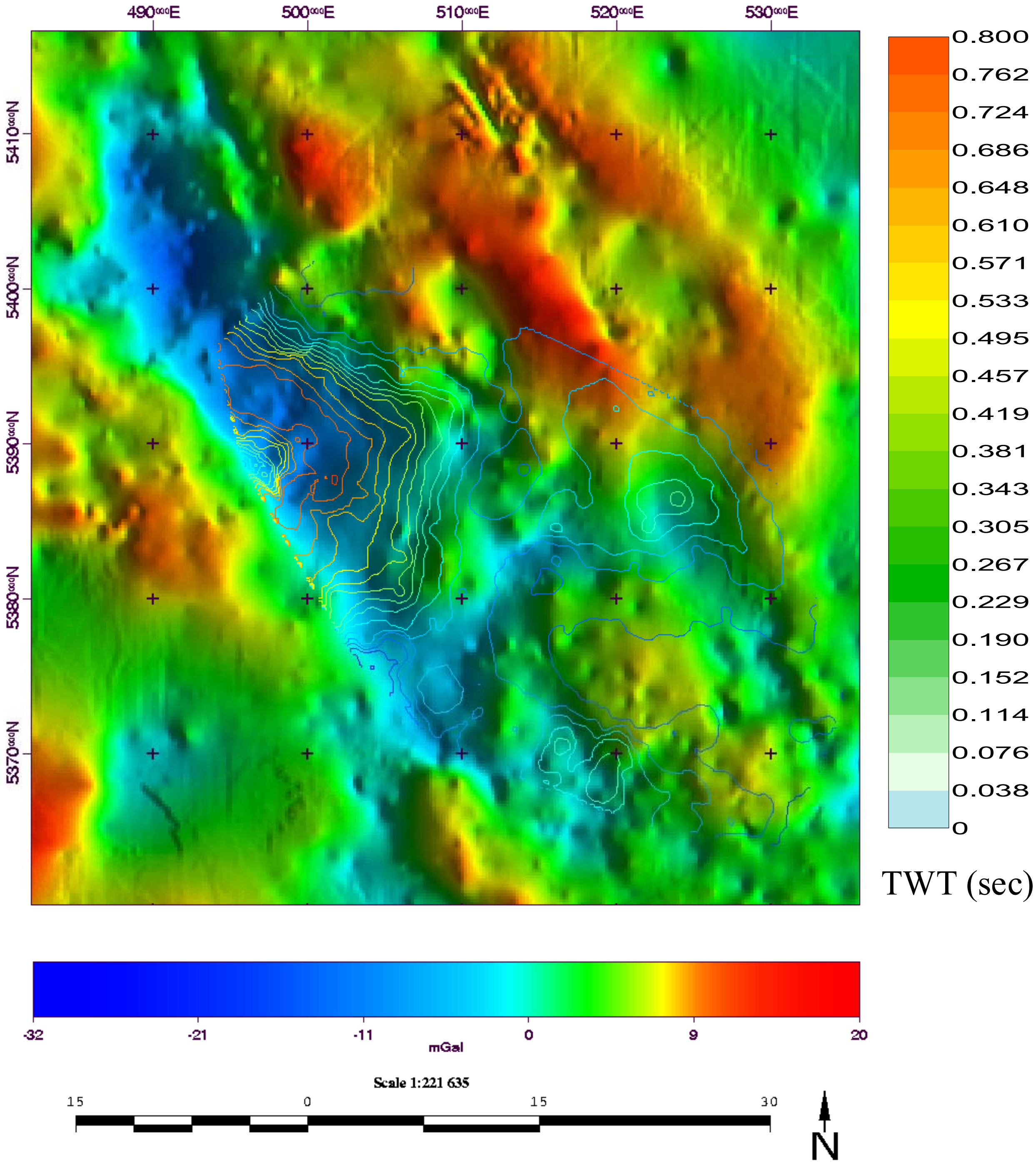


Figure 6.16 : Residual Bouguer Anomaly Gravity Map with an overlay of TWT contours of the base of the Tertiary

6.6 Structure Contours

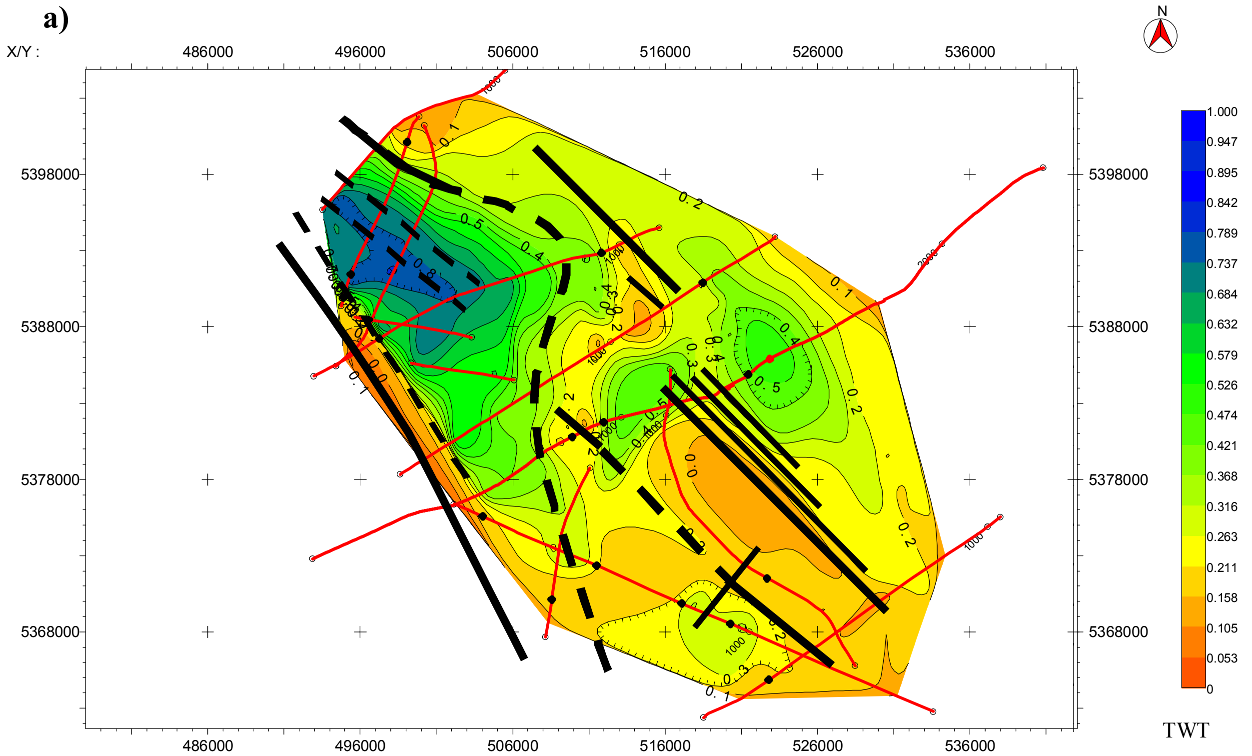
TWT structure contours have been generated from the seismic interpretation. Areas between seismic lines have been corrected on the basis of Matthews (1974) and drill hole information. Contours have been gridded using an inverse distance squared algorithm, and displayed in 3D.

6.6.1 Base of Tertiary Unconformity Level-Basement Map (Figure 6.17)

Fault trends over the basin consistently strike NW-SE, implying NE-SW extension during the Late Cretaceous to early Palaeocene. Structural relief is more pronounced along the Bracknell Fault and conjugate graben fault. The Bracknell Fault forms a steeper margin compared to the eastern boundary (figure 6.17(a)). Interpreted structural highs occur on footwall blocks of the WG, the flexural margin of EHG and Hummocky Hills tilt block.

6.6.2 Mid-Tertiary Unconformity Level-S4 Map (Figure 6.18)

By the mid-Tertiary structural formation of the Longford Sub-basin was complete, faulting intensity decreased over time, with higher frequency minor faulting taking place. The structural highs and low-lying areas mimic the underlying basement. However, doming has superimposed a local high over what was previously, one of the lowest lying areas of the basin. The position of the dome, 15 km south of a major bend in the Bracknell Fault, may indicate a transpressional origin for this dome. Alternatively, from the gravity (figure 6.14), two NE transfer faults enclose the dome and may cause uplift of an isolated block a)



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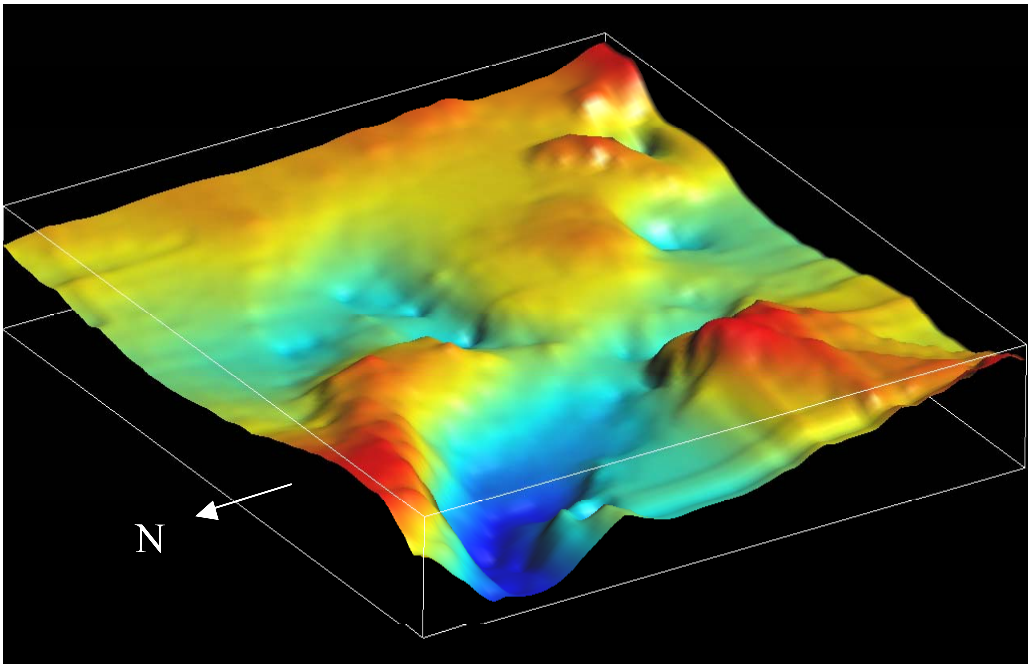
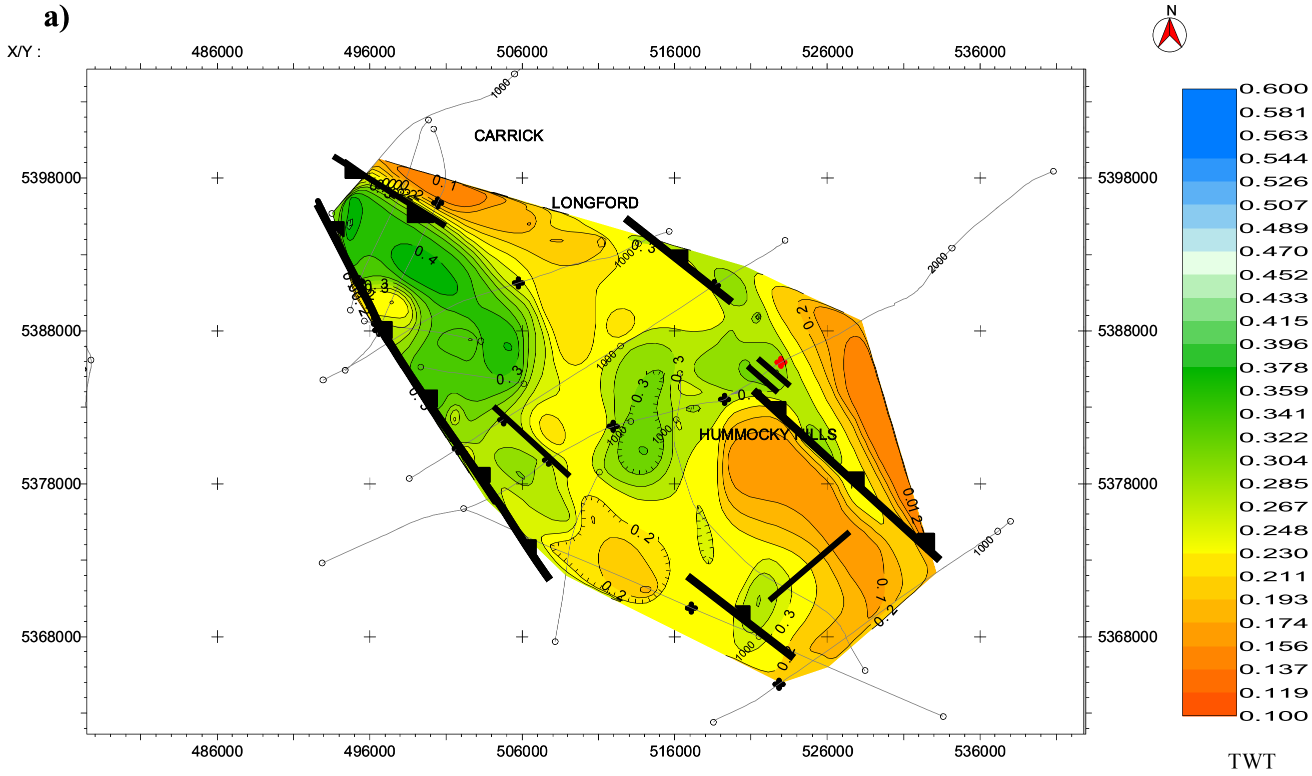


Figure 6.17: a)Base of Tertiary unconformity level-Basement Structure Contour Map.

b) Basement contour grided using inverse distance squared, shown in 3D looking SE. (Note:Time scales are the same).

a)



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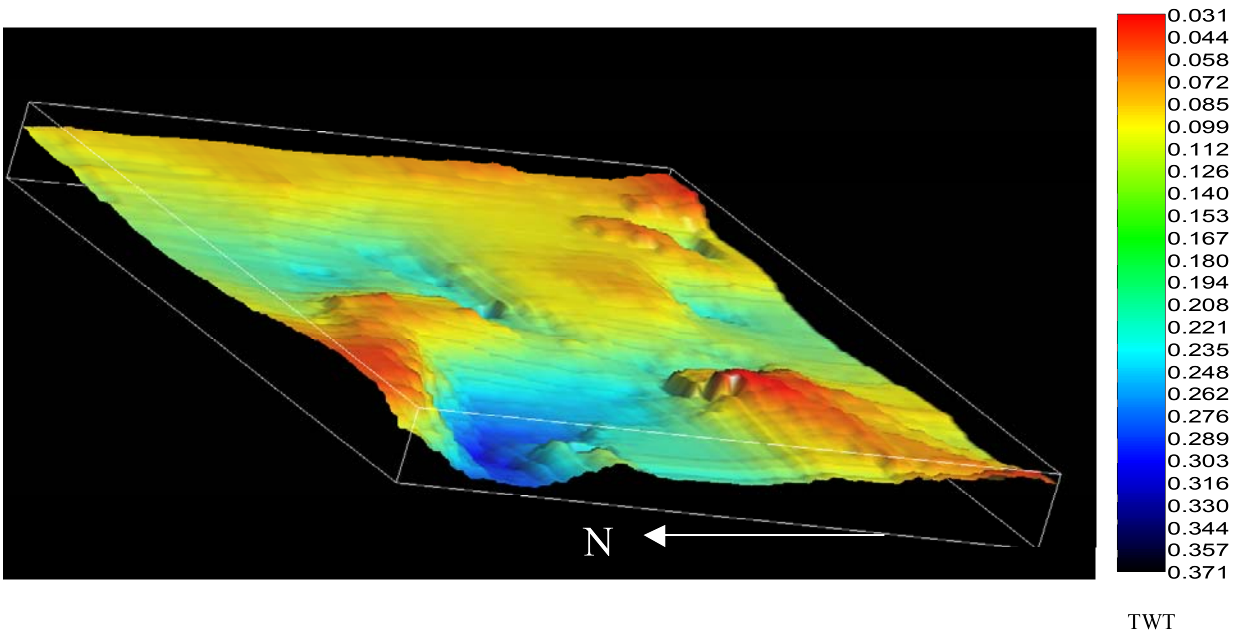

Figure 6.18: a) Mid-Tertiary unconformity level-S4 Structure Contour map.

b) S4 Contour map grided using inverse distance squared and displayed in 3D (Note:Time scales are not the same).

6.7 Basin Evolution

Episodic rifting controlled basin development of the Bass Strait basins in the Late Jurassic to Early Cretaceous, ceasing in the mid Cretaceous (Geary; Konstantine & Reid 2001). These basins were subjected to rifting during continental break-up between Australia and Antarctica during the Late Cretaceous (95± 5 Ma)(Veevers et al. 1991). During the Early–mid Cretaceous Tasmania was undergoing regional uplift, erosion and transporting fluvial material into the Bass Basin (Hill 1995; O'Sullivan et al. 1997). In support the palaeotopography of the basement is highly irregular. NW-SE trending faults fractured Northern Tasmania one of which was the Bracknell Fault. Graben formation began in the north and progressed southward along the Bracknell Fault (figure 6.19). Since the geometry of NW faults change, NE transfer faults were active during initial extension. The initial depositional environment was restricted to lacustrine in the far north with coarse-grained slope deposits at the margins. The rate of movement along major faults in the western graben is interpreted as slow, but synchronous with deposition. The basin forming faults of the EHG (Fault A&B) are interpreted to have formed post WG formation and pre mid-Eocene. This is due to the absence of Palaeocene and late-Eocene sediments in the EHG. Throughout the early-Eocene basin accommodation continued allowing a lake to develop in north of the Western Graben.

During the mid-Eocene, the WG continued to subside. However, faulting in the EHG commenced at this time. Down-to-basin faulting generated a series of small, gently dipping tilt blocks. The fault system of the EHG has maximum complexity and displacement at the junction of a NE trending zone (magnetic low) near Hummocky Hills. To the north of this junction fault frequency and displacement decrease, while to the south, faulting dies out. Likewise to the south of the NE trending zone, the WG dies out. The stress acting along the Bracknell Fault has been interpreted to transfer to the EHG via NE transfer faults to produce late fault development in the east.

The first extrusion of basalts into the basin is in the mid-Eocene (Matthews 1983). The timing and distribution of volcanism coincides with the mid Tertiary faulting of the EHG. The two are therefore probably related. Similar relationships have been noted within the Bass Basin (Robinson 1974).
Extruded basalts flowed along river channels, impeding basin drainage, preventing the exit of sediment and water to lower accommodation areas. The result of such an event would cause a dramatic increase in accommodation space and water within the basin. Evidence of drainage restriction within the Longford Sub-basin is: lake persistency, increased base level and back stepping of shoreline (refer to figure 4.7b), which are all attributes of mid-Eocene sedimentation.

From mid to late-Eocene lacustrine deposition continued. Basin architecture suggests the WG was subject to thermal sag, whereas the EHG experienced tectonic subsidence. This interpretation is based on the bow-shaped geometry of S4 in the west and syn-depositional growth faulting in the east.

By the late Eocene the basin was experiencing uplift. However, uplift may have been initiated earlier in the late mid-Eocene as evidence by S3 pinchout and decreasing base level causing coarser grained S2 deposition (figure5.7). Accelerated uplift during the late-Eocene caused local doming near Bracknell and a regional unconformity above S2. With only a localised doming event and no reverse reactivation along major structures, there is a lack of supporting data to suggest uplift produced the basin wide unconformity.

Alternatively, failure of drainage barriers allowing the escape of large volumes of water may produce a regional unconformity. With uplift a possible catalyst, emptying the basin would cause dramatic changes to the geomorphology. Meandering rivers and creeks would migrate across the surface cutting new and/or following ancient paths. The surface once covered by water becomes exposed to atmospheric conditions. Direen's (1995) stratigraphic investigation was concentrated above the unconformity level and has been consistent in this model. He interpreted a sub-aerial fluvial regime.

With depositional environments varying from braided streams, meandering rivers, oxbows, bogs and lakes. Tertiary volcanic activity appears unabated from the mid-Eocene to Pliocene (Sutherland 1966). Volcanics interfinger with Oligocene sediments, before becoming the dominant lithology during the Pliocene (Matthews 1983). Laterite formation is common in the Pliocene. Soil formation and the development of aeolian dunes occurred during the Quaternary.

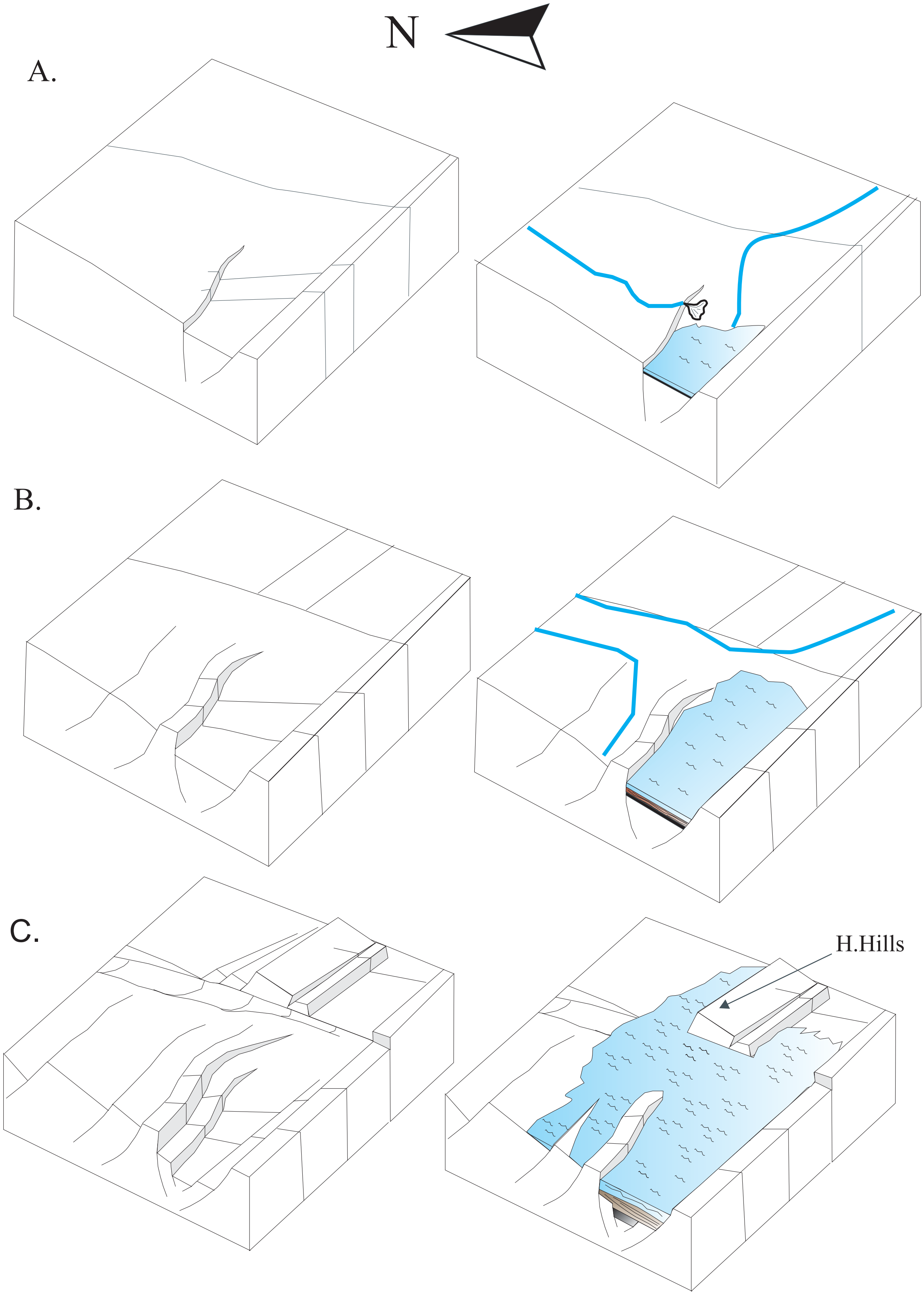

Figure 6.19: Generalised summary of basin development. a. Palaeocene basin intiation and lacustrine environment . b. Early-Eocene lacustrine deposition in the western graben. c. By mid Eocene the structural development of the eastern half graben had begun and a large lake connected the two sub-basins.