STRUCTURE OF THE CULM BASIN: RAPID MAPPING OF THE TIVERTON SHEET AND THE LATEST VARISCAN INVERSION IN DEVON.

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Leslie, A.B., Burt, C.E. Chacksfield, B.C. and Waters, C.N. 2007. Structure of the Culm Basin: Rapid mapping of the Tiverton Sheet and the latest Variscan inversion in Devon. *Geoscience in south-west England*, **12**, xxx-xxx.

The Silesian (Upper Carboniferous) sedimentary rocks of the Culm Basin, to the west of Tiverton, belong to the Crackington and Bude Formations. These comprise turbidite and debrite sandstone, interbedded with mudstone. In the field the formations are differentiated on the basis of thickness and weathering characteristics of the sandstone packages.

In the study area although bedrock is commonly obscured by overlying superficial deposits, the character of these deposits can be used as an indicator of bedrock geology. Using both bedrock and superficial analytical techniques, the Crackington / Bude boundary has been mapped in the study area. Tracing of large scale structure has been helped by the use of shaded relief digital terrain models, however in areas of moorland the distinctive featuring is not present and there are no indicators of the underlying bedrock structure.

Geophysical data, in particular a recent gravity survey, provide considerable information on the structure of the Culm Basin. It is clear that the east-west trend of the Tiverton Trough, depicted by a negative gravity anomaly over the Permo-Triassic infill, continues westwards in the Silesian sedimentary rocks. Further west of the Tiverton Trough an area of relatively high gravity covers the area of Witheridge and Rackenford moors. North of this is a negative gravity anomaly whose northern boundary lies close to the crop of the basal Crackington Formation and whose southern margin follows the Crackington / Bude boundary. The strong east-west linear nature of the gravity anomalies indicates that the structure controlling the northern boundary of the Tiverton Trough was probably active during Variscan inversion. The gravity high over Witheridge is thought to be related to the presence of dense, earlier Palaeozoic rocks that form a structural high underlying the Silesian; given its linear nature and its alignment with the northern boundaries of both the Tiverton and Crediton troughs.

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INTRODUCTION

The Tiverton District is situated to the north of Exeter in Devon. In this paper references to "the district" are held to be contiguous with the boundaries of the Tiverton 1:50000 map sheet number 310 (Figure 1). The work described in this paper was carried out in large part as a rapid re-mapping exercise of the area, the majority of which was previously mapped by W.A.E Ussher in 1871-97, with some additions in the 1960s.

The District contains the boundary between Palaeozoic rocks deposited in the Culm Basin and the overlying Permian and Mesozoic cover (Figure 2). The Palaeozoic rocks in the District comprise Devonian-Lower Carboniferous limestones and black shales passing stratigraphically upwards into Silesian (Upper Carboniferous) sandstone and mudstone. The Silesian rocks underlie the majority of the area and are divided into the Crackington Formation and the overlying Bude Formation (Edmonds et al., 1968, Freshney et al., 1972). Both formations are part of the Culm Measures as described in Sedgewick and Murchison (1989).

Following the deposition of the Bude Formation the rocks were deformed by compression during the Variscan Orogeny. This deformation was complex, involving several phases of shortening through thrusting and folding (Lloyd and Chinnery, 2002) that might have begun during the latest stages of deposition. Deformation propagated northwards and it is probable that in the district the main period of compression followed the end of deposition.

After the culmination of the Variscan Orogeny in the Upper Carboniferous, uplift and extension allowed deposition of Permian sediments over the Tiverton district. Today these are best preserved in the Tiverton Trough, an east-west trending depocentre filled by Permo-Triassic sedimentary rocks. However, evidence suggests that Permian rocks covered a significant part of the district and have been subsequently eroded.

Although Ussher (1892) attempted to differentiate the Culm Measures, current maps of the district do not show this, simply listing the whole crop of Silesian rocks as “greywackes, sandstones and shaly mudstones”. There is no biostratigraphic control in the district and coupled with poor outcrop, a lack of distinctive lithologies and the complex structural history, this has made the tracing of beds particularly difficult. However, a combination of rapid mapping, examination of superficial deposits and use of topography images and geophysical data has allowed the construction of a geological model for the District.

SILESIAN SEDIMENTARY ROCKS

Differentiating and mapping the Crackington and Bude formations

Crackington and Bude formation sedimentary rocks cover much of the central and western Tiverton district (Figure 2). Both formations comprise interbedded sandstone and mudstone, with a regional dip towards the south. The older Crackington Formation is exposed north and west of the Tiverton Trough, with overlying Bude Formation rocks to the south. Both formations have been subdivided into sandstone and mudstone dominated packages.

The two formations are generally similar, and in small exposures cannot always be differentiated. Using a number of criteria (Table 1), however, they can be identified. In the area between Witheridge and the Exe Valley, where exposure is particularly poor, information from superficial deposits and topographic features (Figure 3) has been used to create a boundary. Outcrop data has also been used where available (Figure 4a & 4b). Soil produced from erosion of Crackington Formation rocks is commonly clay-rich and has a distinctive colouration, while Bude Formation sandstones weather to a free-draining, sandier soil containing rounded clasts.

Together the two formations show a broad coarsening and shallowing upwards succession, with progressive infill of the Culm Basin, leading to partially non-marine conditions during deposition of the Bude Formation (Edmonds et al. 1968; Freshney et al. 1979). Sandstone beds within the Crackington Formation are commonly <0.5 m in thickness and show regular interbeds of mudstone (Figure 4a). The sandstone is very fine to medium grained and linear bedforms are common. Palaeocurrent directions are variable. A strong east-west palaeocurrent trend in some parts of the Culm Basin has been related to axial flow along the depositional trough. Other areas are dominated by lateral flows from north and south (Edmonds et al. 1968; McKeown et al. 1973; Freshney et al. 1979). In the Bude Formation, sandstone beds have a maximum thickness >1.5 m, however larger, amalgamated, packages of sandstone are often found. Loading structures are common on bed bases. Some beds show contorted lamination interpreted to indicate slumping into the basin and debrite formation (Figure 4b; Edmonds et al. 1968; Freshney et al. 1979).

Fault Controls on Sedimentation

There is some evidence in the Exeter area that faulting controlled the distribution of sediments within the Silesian rocks, particularly in the Bude Formation (Edwards & Scrivener, 1999), and this pattern is also evident in the district.

Palaeocurrent evidence suggests that the common east-west faults controlling the geometry of the depositional basin were responsible for controlling the pattern of sedimentation in the Crackington Formation, but by the time Bude Formation sediments were being deposited the east-west control is not apparent.

Sediment controlling faults in the Bude Formation appear to have a north-south or northwest-southeast orientation. The sandstone packages have a common east-west orientation, reflecting the regional dip towards the south. In some cases the packages are truncated by faults with a north-south or northwest-southeast trend, but in other places thickening or thinning of the packages occurs across the fault.

Faults controlling the distribution of sediments in the Bude Formation were observed in the area to the north-west of Crediton (Edwards & Scrivener, 1999) where a significant fault subdivides sandstone rich rocks to the west from mudstones to the east. This fault can be traced into the district where a similar subdivision can be seen near Witheridge (F1 on Figure 2). Further east a northwest trending fault (F2 on Figure 2) has sandstones to the east but little evidence of their continuation to the west.

The question of whether the north-south and north-west-south-east fault trends were controlling sedimentation during the Silesian is difficult to answer. The truncation of sandstones against these structures is marked in both the district (Figure 2) and to the south on the Exeter sheet (Edwards & Scrivener, 1999). The fact that at Witheridge the boundary between the Crackington and Bude formations is displaced by <3 km (Figure 2) suggests that the sandstones several kilometres to the south do not continue eastwards across the fault and that there was syn-sedimentary control on sedimentation.

PERMIAN DEPOSITION AND FAULTING

Deposition of Permian sediments followed the ending of Variscan compression and uplift. Over much of south-west England the Permian overlies an eroded surface of older, deformed Palaeozoic rocks (Figure 2). The Tiverton and Crediton troughs, however, appear to be half graben structures, probably formed along the line of earlier Variscan, east-west orientated faults. The extensional regime was accompanied by some volcanic activity, with exposures of extrusive rocks around the northern boundary of the Tiverton Trough. This northern boundary appears to be, at least in part, fault controlled, indicating that the area was tectonically active during the deposition of the Permian sediments.

To the north of the Tiverton Trough a number of outliers of Permo-Triassic rocks indicate the original presence of another depocentre with an east-west trend, possibly also fault controlled. Strong red staining of the Crackington and Bude formation rocks throughout the district suggests that the Permo-Triassic cover was originally more extensive, but erosion has removed much of the sediment other than in the areas where deposits would have been thickest.

GRAVITY SURVEY DATA

While surface exposures provide little information on the large scale structuration of the pre-Permian rocks in the district, gravity survey data from southwest England have provided some indications of structure in the Silesian. The regional gravity field across southwest England, related to deep crustal sources, has been removed to produce a residual gravity map of north Devon that enhances the gravity effect due to geological structures at intermediate and shallow depths (Figure 5). Gravity data have been further processed to produce the residual anomaly map of the district (Figure 6) that shows in more detail anomalies associated with primarily the near surface geology.

The residual gravity map (Figure 5) shows that the structural trend across the Culm Basin in north Devon is predominantly east-west to west-northwest and confirms that the dominant structural trend is Variscan in origin. The strong linear and persistent nature of the gravity highs and lows are attributed to Variscan folding and faulting resulting in a series of relatively steeply dipping alternating sequences of high density mudstone and shale juxtaposed with lower density mainly sandstone rocks. Superimposed upon these features are east-west gravity lows (shown in blue) that are associated with the Tiverton and Crediton Troughs infilled with significantly lower density Permo-Triassic sediments.

Some of the linear highs are locally disrupted by northwest trending faults notably in the Chumleigh and Tiverton districts where three faults have been identified. These have a parallel trend to the major Sticklepath Fault and the Petrockstow basin (shown as an elongate gravity low in the southwest corner of the Chumleigh district).

In the northeast of the district, the positive anomalies (Figure 6) correspond to the area where relatively dense Lower Carboniferous and Devonian rocks are exposed The boundary of the positive anomaly corresponds closely to that of the Lower Carboniferous outcrop, indicating a significant density contrast between the lower density Silesian sedimentary succession and underlying denser predominantly mudstone and shale rocks. The anomaly pattern appears to reflect the kilometre-scale folding observed in the Lower Carboniferous. .

The eastern part of the district is dominated by the east-west gravity low associated with Permo Triassic rocks that lie within the Tiverton Trough (T on Figure 6). The trough appears to shallow abruptly to the west of the Exe valley as the gravity low here becomes less well defined and gradually dies out. The northern margin of the Tiverton Trough is defined by a strong east-west trending change in gravity which suggests the presence of a bounding fault. The southern margin of the trough has a more diffuse gravity gradient and is probably more shallow-dipping. Outside of the Tiverton Trough local isolated gravity lows occur over shallow pockets of Permo-Triassic rocks that indicate that the Permo-Triassic rocks were once more extensive.

The linear gradient along the northern margin of the Tiverton Trough continues further to the west where it forms the southern margin of an east west gravity low located over the outcrop of the Crackington Formation in the northern part of the district. This gradient is generally coincident with the Crackington / Bude boundary. The northern margin of the gravity low lies close to the base outcrop of the Crackington Formation and is bounded by a prominent gravity high that is probably caused by underlying relatively dense Lower Carboniferous and Devonian rocks that are exposed in the northeast part of the district.

A linear east-west trending gravity high in the central part of the district (Figure 5) occurs over the Bude Formation outcrop where a gravity low would be expected as this has a lower density than the Crackington Formation. This suggests that the gravity high may represent a structural high that is terminated along its northern margin by a basement fault that may be an extension of, or related to, the bounding fault along the northern margin of the Tiverton Trough. This fault might have been active during deposition of the Silesian rocks as the gravity low occurs where the Crackington Formation is at its thickest in the northern part of the district. If so, both the upper Crackington Formation and Bude Formation thin towards the south over the structural high across this reactivated and inverted active fault.

On a local scale the gravity high (M on Figure 6) appears to display minor northwest trending features that have the same trend as the set of northwest faults (F1 and F2 on Figure 2) which terminate local sandstone units S1 and S2; and F1 in particular is coincident with the south-west margin of gravity high M.

DISCUSSION

The new rapid mapping survey of the district has revealed a wealth of new data about the Silesian rocks in this important area of southwest England. Using a range of techniques the Crackington and Bude formations have been identified and subdivided into facies packages dominated by either mudstones or sandstones. By subdividing the formations in this way, end-users of the map will still be able to identify the primary lithology in their area of interest.

The sedimentology of the Silesian rocks in this area corresponds closely to surrounding areas of southwest England where the Crackington and Bude Formations have been identified. The features observed in the Crackington were consistent with deposition from deep marine turbidity currents, changing stratigraphically upwards into the Bude, which appeared to be more consistent with shallower, delta-slope deposition. This agrees with the basin model put forward for the Okehampton, Bude and Exeter areas (Edmonds et al. 1968; McKeown et al. 1973; Freshney et al. 1979; Edwards & Scrivener, 1999).

During the deposition of the Silesian sediments active faulting can be identified at both local and basin scale. The dominant direction of faulting through the deposition of the Crackington Formation is east-west, however during the deposition of the Bude the influence of north-south and northwest-southeast structures is apparent. Again these faults are present on both a local and basinal scale. Smaller (m-scale) faults appear within the sediments showing a growth fault structure indicating that they were syn-sedimentary, but large faults such as the one running from the south-west corner of the Tiverton sheet northwards towards Witheridge Moor (F1 on Figure 2), demonstrate that these seem to have an influence over sand and mud dominated deposition and therefore we conclude that these faults were active on a basin scale during the latter part of the Silesian. The north-south faulting may be related to the earliest part of extension in the Wessex Basin, which has been demonstrated to have controlled deposition from the Triassic, or might just represent an area of localised extension during movement on other faults in the area in parallel with the Variscan tectonic regime. More research into faulting would be required to prove the throws of the faults in this area, but due to the poor outcrop pattern it would be difficult to gather enough data to determine which theory would be more likely.

Permo-Triassic sedimentation in this area is preserved within earlier, large half graben structures. After deposition the dominance of northwest-southeast and north-south orientated faulting is clear. There is no evidence in the district to confirm that faulting was syn-sedimentary but this relationship has been observed to the south (Edwards & Scrivener 1999).

The gravity data shows the dominance of large east-west, Variscan, structures throughout the basement rocks. However, these are observed to be displaced by later faulting in a northwest to southeast orientation. The positive gravity anomalies appear to correspond to dense basement rocks near the surface, which are not exposed in the district. The pronounced negative anomalies in the east of the district appear to correspond to the Permian and later cover rocks. The westernmost extension of the Tiverton Trough is poorly imaged by the gravity data (Figure 6) which suggests that the trough west of the Exe Valley does not contain a significant thickness of Permo-Triassic rocks.

CONCLUSIONS

BGS has carried out a rapid survey of the Tiverton district, employing a combination of methods to generate new data for the revised 1:50 000 map sheet. During the new survey Silesian rocks have been subdivided to provide more accurate information for map users.

Studies of the structure in the district show a dominance of large east-west structures displaced in some areas by northwest-southeast orientated faults. These can be linked to the structural regime of the Variscan orogeny in southwest England. Large north-south orientated structures, which appear to have been active during sedimentation in the Bude Formation, might be linked to localised extension within the Variscan tectonic regime or may possibly be the earliest occurrences of structures related to the later extension in the Wessex Basin.

ACKNOWLEDGEMENTS

Many thanks to members of the BGS's mapping teams past and present including Richard Ellison, Ted Freshney, Brian Leveridge, Richard Scrivener and Colin Waters for discussion of the rocks in the Tiverton area. This paper is published by permission of the Executive Director of the British Geological Survey (NERC).

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FIGURE AND TABLE CAPTIONS

Figure 1. Map of SW England showing the location of 1:50,000 scale geological map sheets. The Tiverton district (map 310) is shaded.

Figure 2. Geological map of the Tiverton District showing the revised boundary between the Crackington and Bude formations, faulting and areas where there appears to be fault control on the distribution of sandstone-prone Bude Formation rocks (S).

Figure 3. Shaded topography image of the south-west part of the Tiverton district where sandstone-prone rocks are marked by east-west trending ridges.

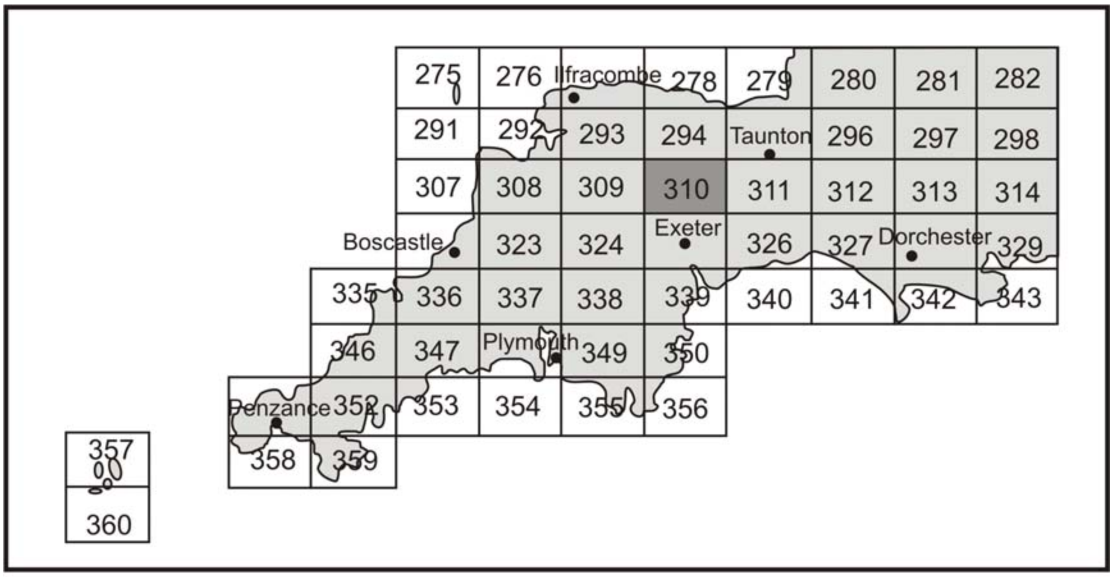
Figure 4a. Outcrop of Crackington Formation rocks at Cove Cleave Quarry in the Exe Valley south of Bampton (SS960204) showing interbedding of sandstone and mudstone.

Figure 4b. Outcrop of Bude Formation rocks at an unnamed Exe Valley quarry (SS944179) showing thick sandstone beds including a debrite (D) with uncommon mudstone.

Figure 5. Residual gravity map of SW England with the Tiverton district outlined. A strong east-west structuration is clear. The white dashed lines indicate displacement of the east-west structural trend.

Figure 6. Residual gravity map of the Tiverton district showing the gravity low associated with the Tiverton Trough (T) and the gravity high in the area of moorland in the west of the Tiverton district (M).

Table 1. Guide to differences between the Crackington and Bude formations identifiable at outcrop. The most useful distinctions are marked in bold.



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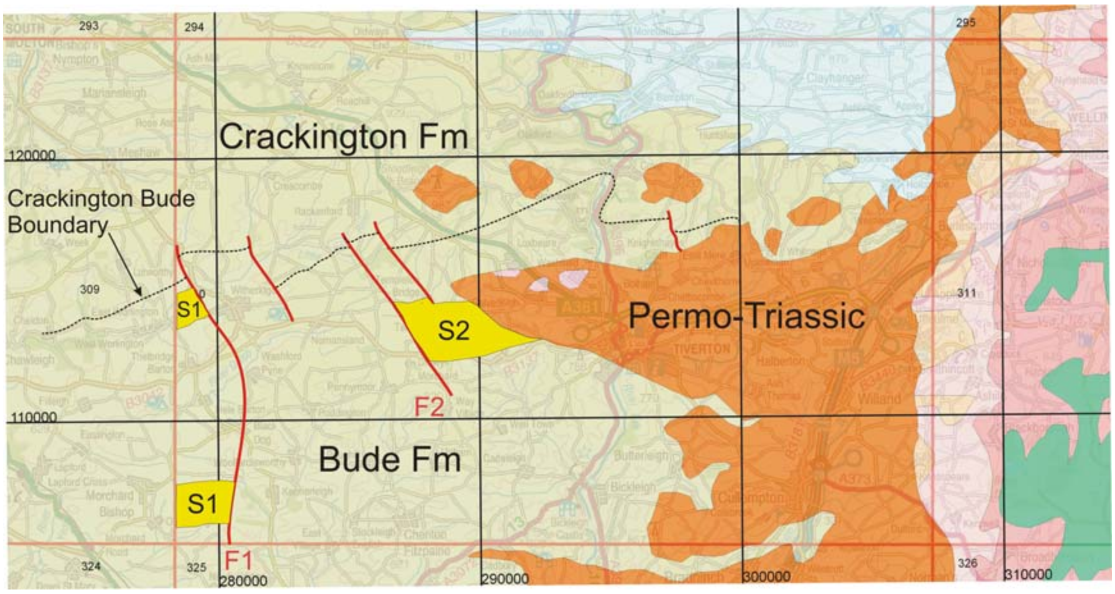

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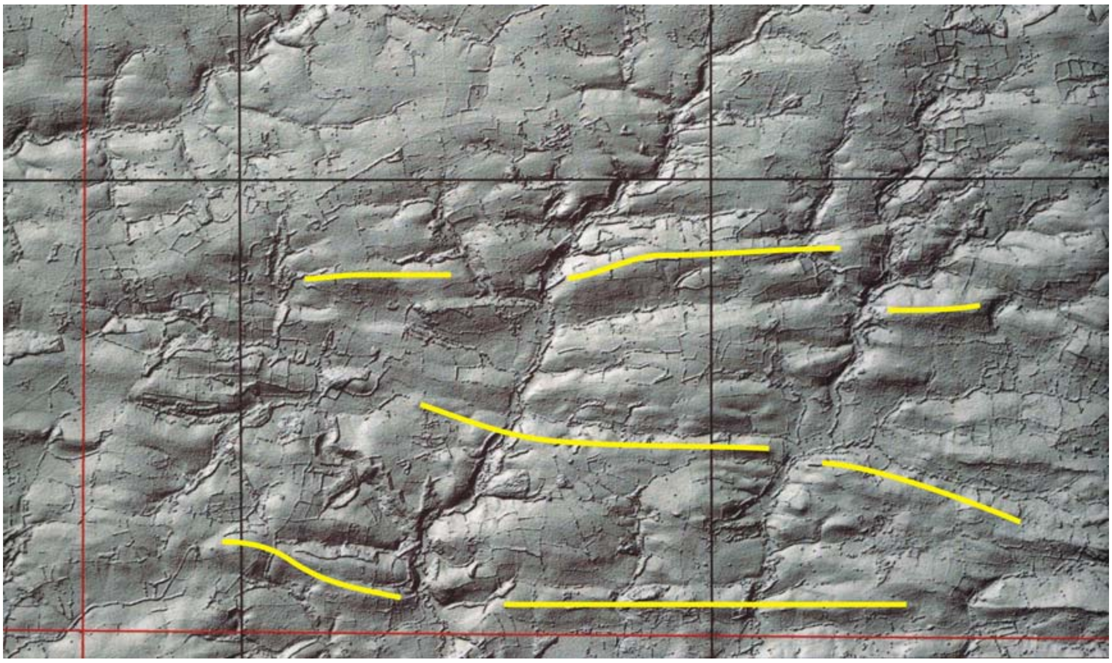

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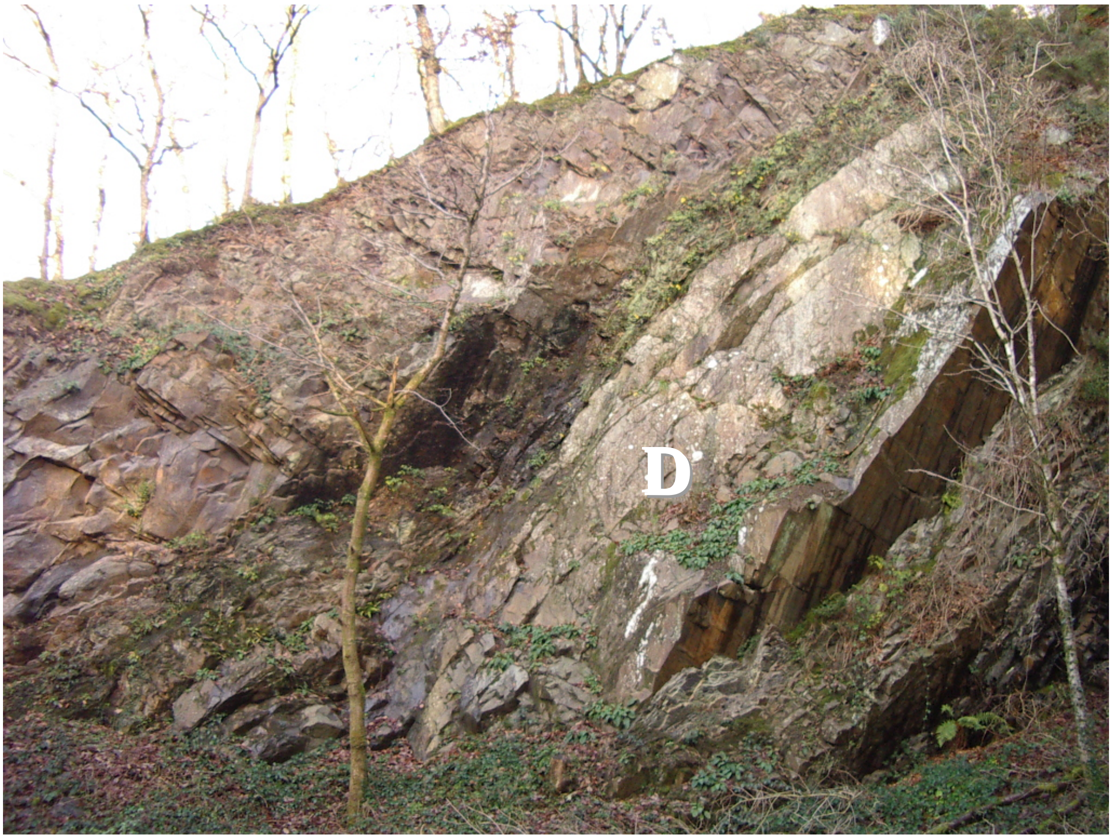

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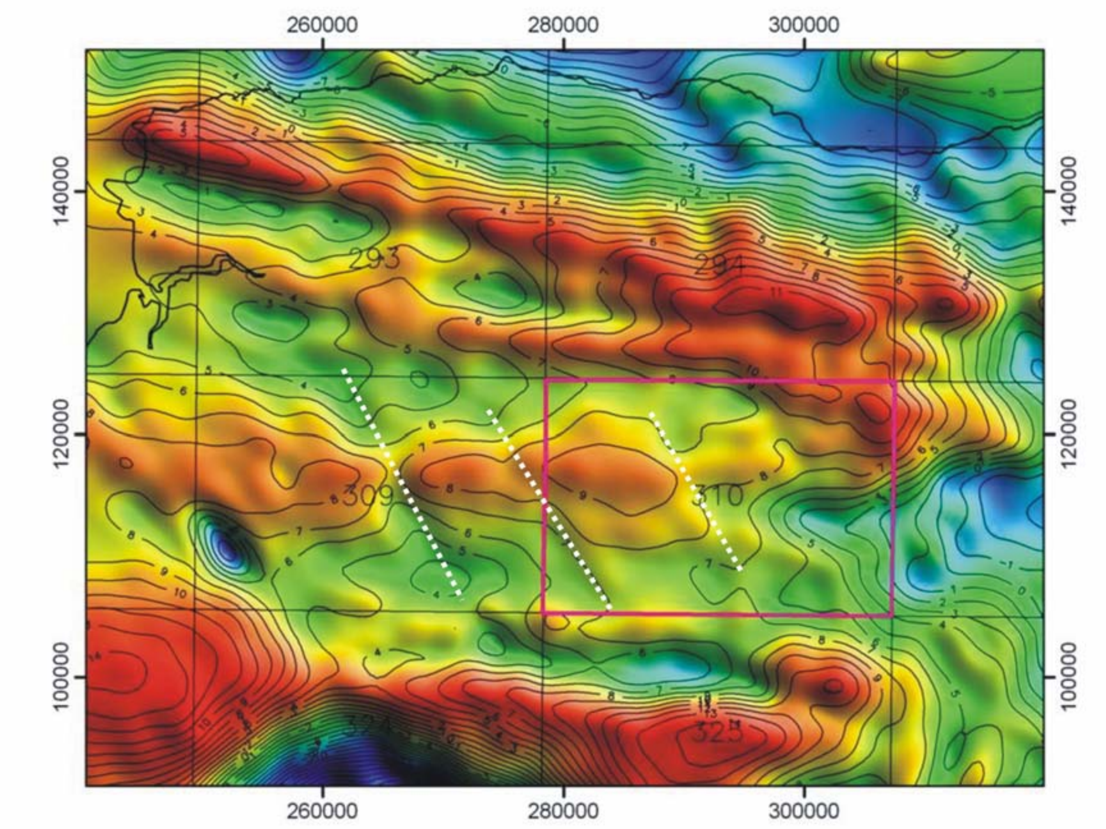

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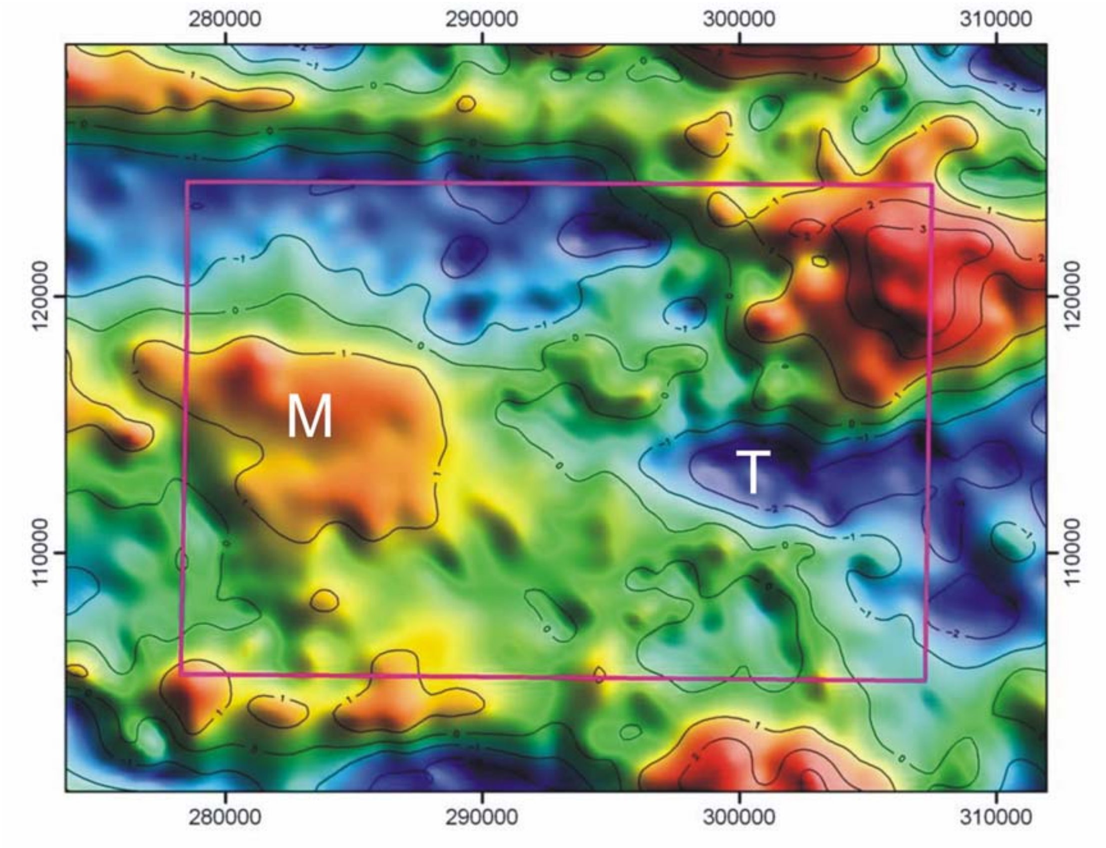

Figure 6. Residual gravity map of the Tiverton district outlined in red showing the gravity low associated with the Tiverton Trough (T) and the gravity high in the area of moorland in the west of the Tiverton district (M).

	Crackington Fm	**Bude Fm**
Beds:	***Interbedded shale and sandstone*** *Sandstone <0.5 m.* *Up to 60% sandstone.* *Fining up packages over ~10 m.*	***Amalgamated sandstone*** *Sandstone beds >1 m up to 20 m.* *Irregular bed variation.* *Slumped horizons with subtle deformation (can be marked by impact of cleavage).*
Bedforms:	*Linear groove, prod, flute, etc.*	*Commonly **loaded** enhancing sedimentary structures.* *Ripples.*
Environment:	*Basinal turbidites, marine but fossils uncommon.* *Basin axis transport east-west.*	*Basinal (but shallower) turbidites, debris flows, non marine with sporadic marine incursions - black shale with fossiliferous nodules.* *Transport from north into basin, some fault control.*
Structures:	*Possible extension along east-west faults.*	*Sands might thicken into faults both east-west and north-south.* *Possible expression of inversion to south.*
Features:	*Rolling countryside.*	*More pronounced topography related to thicker sand bodies.*
Drift:	***Buff / yellow clayey soil.*** *Pellets of yellow clay within soil.* *Angular clasts of sandstone.* *Arable cultivation uncommon.*	*Brown, silty, well-drained soil.* *Rounded clasts of sandstone are soft and can be eroded by rubbing.* *Arable cultivation common.*
Human:	*Squared block sandstone used in building generally under 0.5 m thick.*	*Some block sandstone used for bases of buildings with cob above.* *Rounded sandstone blocks up to 1 m.*

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