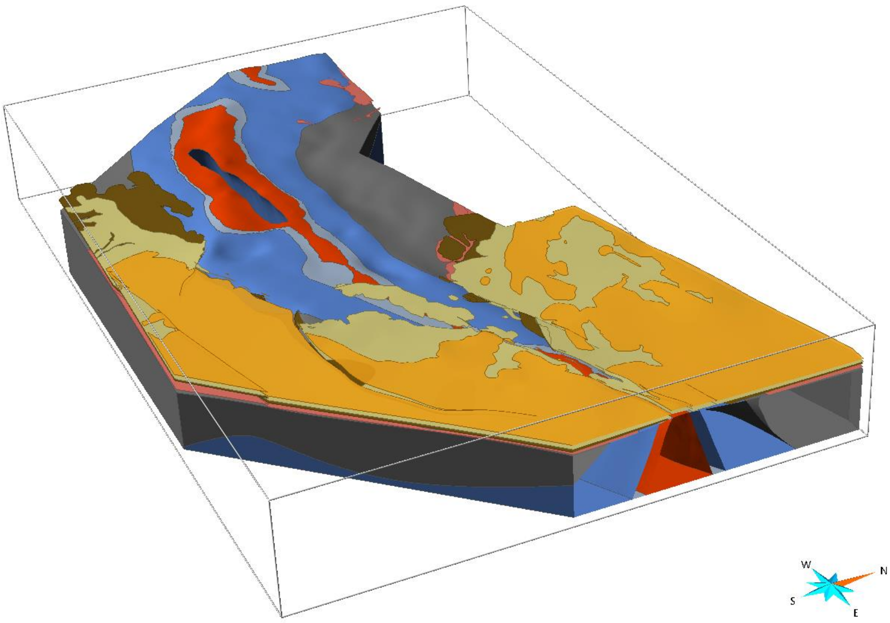
3D Geological Model and Field Observations of the Eastern Mendips

National Geoscience Programme

Open Report OR/25/024



BRITISH GEOLOGICAL SURVEY

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Dewald, N., Lajo-Yáñez, J., Farrant A.R., Newell, A., Morgan, D., Heath, J., Unwin, H.

Keywords

Report; 3D Geological Model; Fieldwork; Seismic.

Front cover

Oblique view of the model in Aspen SKUA™

Bibliographical reference

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Foreword

This report is the published product of a study by the British Geological Survey (BGS).

Acknowledgements

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Contents

FIGURES

TABLES

Summary

This report was produced by the British Geological Survey (BGS) on behalf of the Environment Agency (EA). It provides background and methodological information on the development of a 3D geological model as well as field passive seismic survey observations of the Eastern Mendips.

The 3D geological model covers an area of approximately 225 km^2 and comprises selected horizons from regional Palaeozoic and Mesozoic bedrock strata as well as selected faults and a major unconformity. It was constructed using historical data including borehole records, geological maps and structural data held by the BGS and seismic data provided by Heidelberg Materials.

The model was built in two parts, separated by the major unconformity. The stratigraphically upper part consists of horizons ranging from Triassic to Middle Jurassic, whereas the stratigraphically lower part consists of horizons ranging from Silurian to Carboniferous. Both parts, but especially the stratigraphically lower part of the model were constructed using relatively sparse data resulting in significant uncertainties, especially at greater depths. The modelled stratigraphical horizons are provided as ASCII grids and TSurfs.

The modelling was augmented by the collection of additional field data, principally in the large active working quarries (Torr Works, Whatley, Westdown, Colemans, and Halecombe quarries), and passive seismic transects across the eastern Mendips north of Frome. These data were used to assess the quality of the current geological mapping hat was used as input to the 3D geological model. The results confirmed that the existing geological data at surface, and thus much of the input data to the 3D model, is of good quality.

The 3D geological model provides an overarching architecture of the major geological units in the east Mendips area. As such, it cannot be used to predict flow pathways because these will be guided by sub-model scale heterogeneities within the modelled strata. However, it provides estimates of where important aquifer units may be present at depth and where there may (or may not) be likely groundwater connectivity between recharge zones and springs.

1 Introduction

The British Geological Survey (BGS) has created a 3D geological model of the bedrock strata and major faults in the Eastern Mendips area (Figure 1) as part of commissioned study for the Environment Agency (EA). The bedrock model shows the 3D structure of selected formational boundaries, selected faults and a major regional unconformity. The purpose of the model is to aid understanding of the movement of groundwater in the subsurface and provide input data to hydrogeological models.

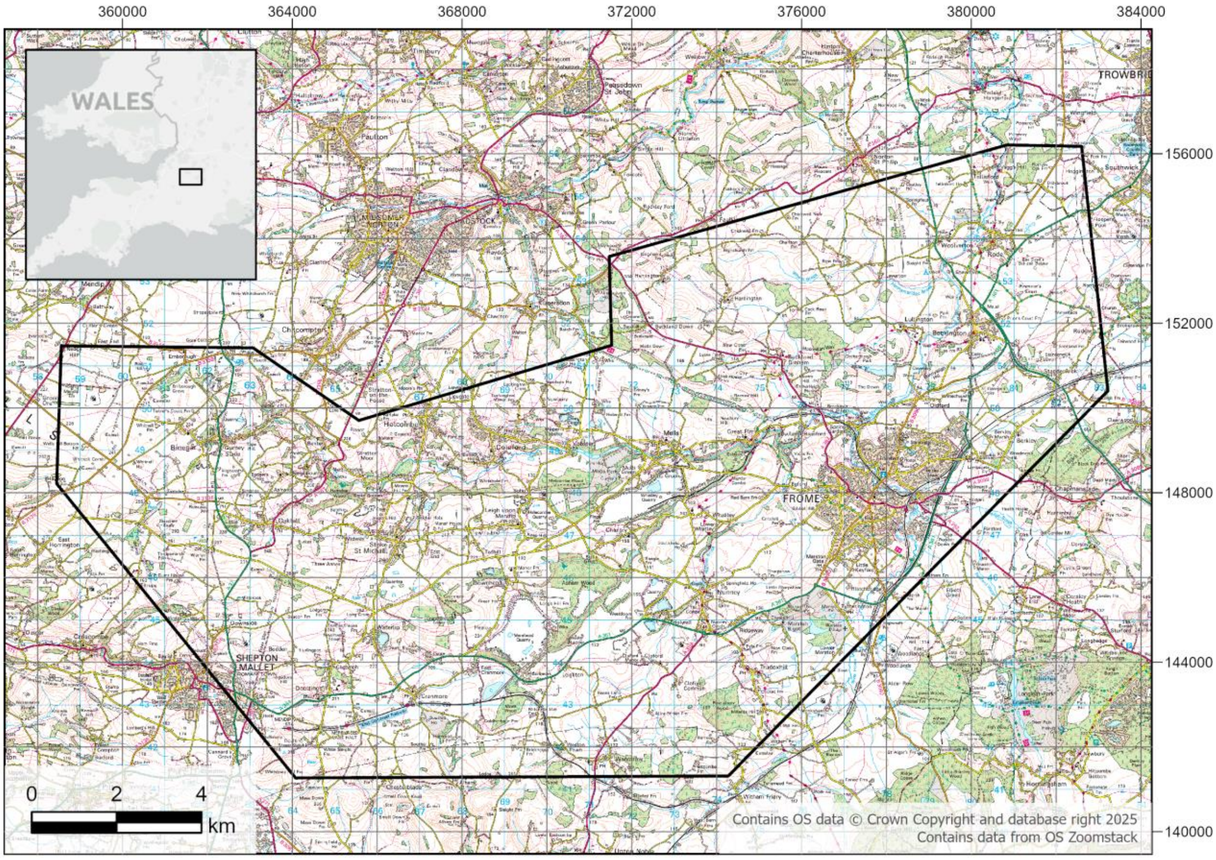

Figure 1 Location of the study area. Contains Ordnance Survey data © Crown copyright and database rights 2025. Ordnance Survey Licence no. OS AC0000824781. Contains data from OS Zoomstack.

The model is based on 1:50 000 scale geological map data, however, the modelling process sub-samples that information, so the final model is applicable for use at scales between 1:100 000 and 1:200 000 and is not suitable for city or site scale assessments. Also, the modelling software has geological rules built in so if there are geometric errors in the mapping the model will not honour them. Not all the faults shown on the geological map can be included in the model and the units have been modelled at group level. Due to intense deformation in many geological units in the area of interest (AOI), the uncertainty in this model will be higher than for models built entirely for flatter lying strata.

This report details background information and the methodology used for the development of the 3D bedrock geological model underlying the Eastern Mendips project area (see Figure 2). This includes a reinterpretation of legacy deep seismic data which informed modelling of the deeper strata in the study area. Additionally, the report provides details on data collected during field surveys involving targeted quarry visits and passive seismic surveys using Tromino® instruments. These data were used to assess the quality of the existing input data but were not used as input for the model themselves due to significant scaling differences between field data and modelled volume.

The model was developed using Aspen SKUA™ software which provides a highly customisable, integrated software suite for geological modelling and reservoir characterisation, bridging the gap between interpretation and simulation. The report also describes established BGS model Quality Assurance procedures, methodology, limitations of the model and uncertainty of the modelled surfaces. Derived model outputs are provided in the form of elevation grids compatible with common GIS software and complemented by 3D views (images), taken from the 3D modelling software platform (Appendix 1).

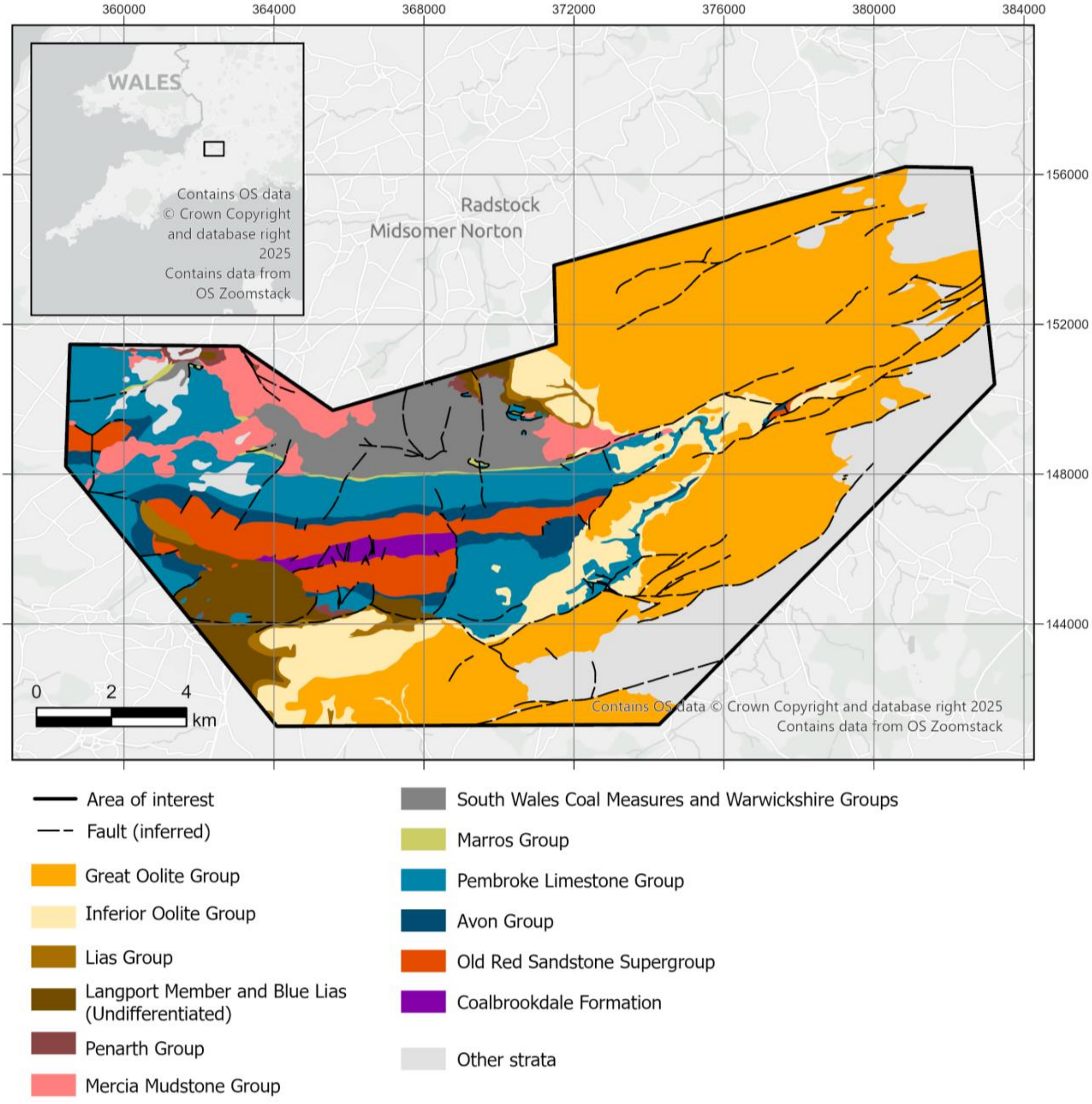

Figure 2. Simplified geological map (1:50 000) and location of the AOI. Contains BGS Geology 50k © UKRI 2025. Contains Ordnance Survey data © Crown copyright and database rights 2025. Contains data from OS Zoomstack.

2 Geology and Modelled Surfaces

The bedrock geology of the Eastern Mendips comprises a sequence of heavily deformed Palaeozoic rocks overlain by a gently dipping sequence of Mesozoic strata (Figure 2). The Palaeozoic rocks include Silurian volcanic rocks and mudstones, Devonian sandstones, Lower Carboniferous limestones and mudstones and the Upper Carboniferous Coal Measures mudstones and sandstones. The Mesozoic cover consists of Triassic conglomerates and mudstones as well as Lower and Middle Jurassic mudstones and limestones. A small outlier of Cretaceous strata overlies the Silurian strata at Tadhill but is not shown on the map. Both the Lower Carboniferous and Jurassic limestones contain important aquifers in the region.

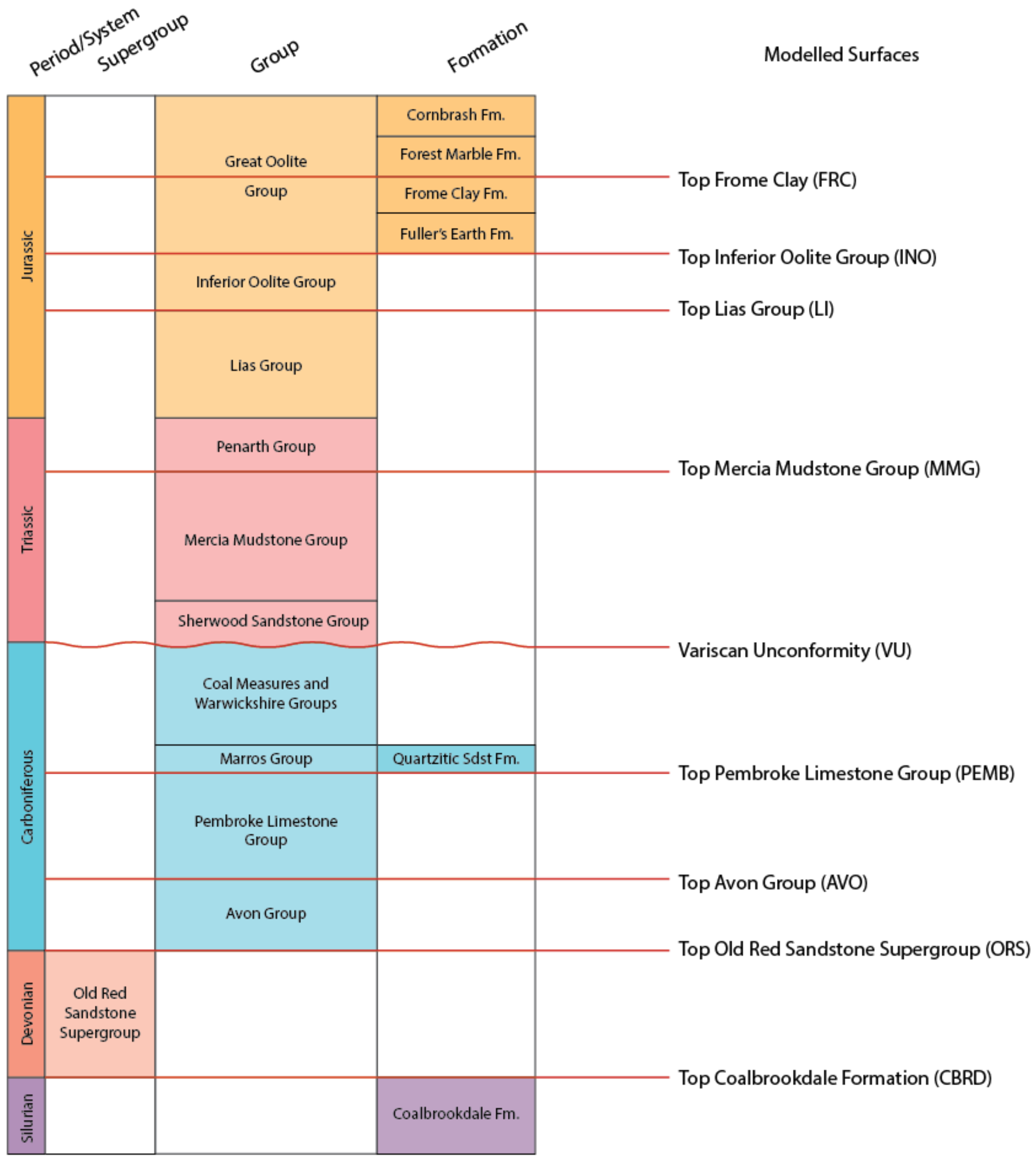

Figure 3. Simplified stratigraphic column showing the regional geological units (Barron et al., 2012; Newell, 2018; Waters et al. 2007). Note that not all units shown are found in the study area.

Modelled surfaces are indicated as red lines and associated labels. Abbreviations in brackets are BGS Lexicon codes (exception: VU), which are also used in file names (see section 13).

The contact between the Palaeozoic and Mesozoic sequences is marked by a major regional unconformity resulting from deformation of the Palaeozoic strata during the Variscan orogeny and subsequent deposition of Mesozoic strata onto the post-Variscan palaeo-landscape. The folded and thrusted Palaeozoic strata of the Mendips Hills is exposed in a series of east-west striking, en-echelon periclines with the study area including the Beacon Hill Pericline and the eastern limb of the Pen Hill Pericline to the NW. Extensional movement during the Mesozoic resulted in most strata being affected by faults of varying ages and orientations reflecting the multiple phases of deformation (e.g. Ates and Kearey, 1993; Wall and Jenkyns, 2004).

The model is a 3D representation of the bedrock geology comprising key stratigraphical horizons (Table 1), selected faults and the regional unconformity. It is based on 1:50 000 scale geological map data, but the modelling process sub-samples that information, so the final model is at a coarser scale. Also, the modelling software has geological rules built in so if there are geometric errors in the mapping the model will not honour them.

Table 1. Stratigraphic horizons included in the model. Note that colours in this table deviate from the official BGS colour scheme.

Modelled surface	**Lexicon Code**	**Equivalent/Obsolete names**
Top Frome Clay Formation	FRC	Upper Fuller’s Earth
Top Inferior Oolite Group	INO	Inferior Oolite Series, Under Oolite, Redbourne Group
Top Lias Group	LI	Lyas
Top Mercia Mudstone Group	MMG	Keuper Marl(s), Red Marl(s), Skerry Band, Stanwix Shales Formation
Variscan Unconformity	-	-
Top Pembroke Limestone Group	PEMB	Carboniferous Limestone, Main Limestone Group, Clifton Down Group, Hotwells Group
Top Avon Group	AVO	Lower Limestone Shale (Group), Cefn Bryn Shales, Maesbury Mudstone Formation
Top Old Red Sandstone Supergroup	ORS	Orcadian Old Red Sandstone Supergroup.
Top Coalbrookdale Formation	CBRD	Wenlock Shale Formation

3 Fieldwork

To test the geological understanding derived from a desk study review and acquire new data to quantify sub-model heterogeneity, some targeted fieldwork was carried out. The emphasis was on examining new geological sections and acquiring structural data in the major quarries in the region that were not available when the published 1:50 000 map was compiled. The data gathered during this survey were not used in the modelling process because they are below model resolution.

Five quarries were visited, and new dip and fault data was collected. In addition, some fieldwork was carried out in the area north of Frome to test the existing mapping and to identify any new outcrops that could provide new evidence for the geological structure in this area.

3.1 QUARRY SURVEYS

Five quarry site visits were conducted during late November and early December 2024. The sites visited are detailed in Table 2. Details of the lithology and structural measurements were recorded at observation points in the field. Structural measurements taken with a compass-clinometer include the orientation and dip of bedding planes, faults, fractures, and 'Neptunian' dykes (sediment filled fissures in the Carboniferous limestones, usually infilled with Mesozoic sediments), and the plunge and plunge direction of fold axial planes. The quarry faces could not be approached for safety reasons and the majority of measurements were therefore estimated from a distance or taken from outcrops away from large faces. The remote measurements were collected by taking a compass bearing from the best safe position that could be accessed. Measurements of the direct rock surface were taken wherever safe to do so. The height of the unconformable contact between the Lower Carboniferous strata and overlying Jurassic Inferior Oolite Group was also plotted where the contact was present.

Table 2. Quarry sites visited.

Site	Operator	Approximate location (BNG)	Date visited (DD-MM-YY)
Whatley Quarry	Heidelberg Materials	372916, 148056	25-11-24
Westdown Quarry	Heidelberg Materials	371774, 145863	26-11-24
Torr Works Quarry	Aggregate Industries	369892, 144174	04-12-24
Colemans Quarry	Aggregate Industries	372636, 145034	05-12-24
Cloford Quarry	Aggregate Industries	371640, 144440	05-12-24
Halecombe Quarry	Tarmac	370219, 147442	06-12-24

The data collected was captured geospatially using either the BGS Geological Data Capture System in QGIS with a Panasonic Toughbook or the Mergin Maps application with a Samsung Android tablet. Images of features of interest were also collected using a camera. Data collection was limited to areas of quarries which could be safely accessed whilst normal working operations took place, though good spatial coverage was achieved (Figure 4).

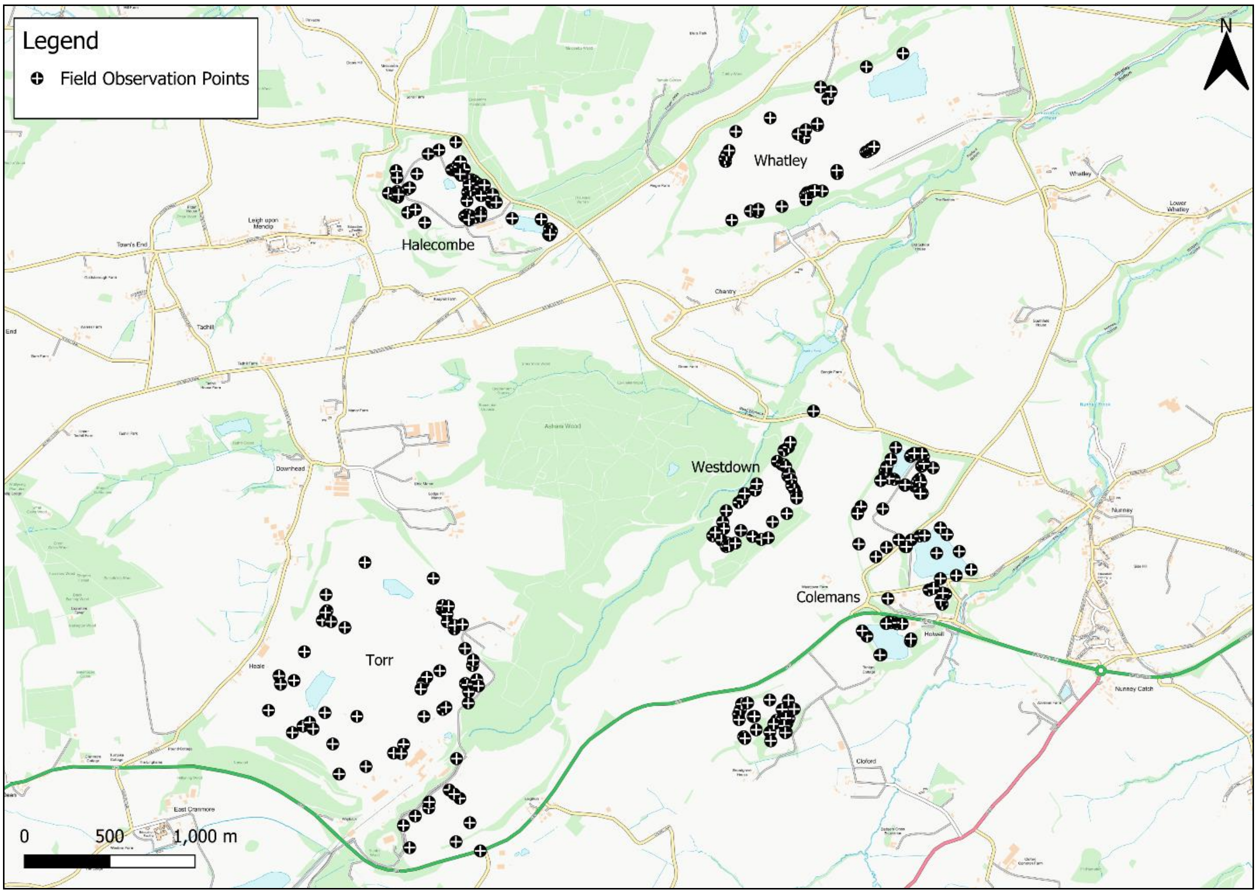

Figure 4. The locations of field observations made during fieldwork for this project. Map data from OpenStreetMap available under the Open Database License.

The basemaps used for mapping were a combination of Ordnance Survey 10 000 scale maps, Environment Agency LiDAR Digital Terrain Model (DTM), Bing Satellite imagery and screenshots from a drone model (provided by Tarmac for Halecombe quarry). Imagery and DTMs of quarries become quickly out of date due to continuous extraction. Where the quarry at the time of mapping differed from the available basemaps, the location of features mapped was estimated using the Panasonic Toughbook or Samsung Tablet GPS and bearings from consistent features. The field data collected was used to inform the modelling of faults and stratigraphical surfaces within the region, ratifying and complimenting data that exists on published BGS map sheets which were produced prior to the extent of quarrying seen today.

3.2 KEY OBSERVATIONS.

The targeted quarry surveys identified numerous faults which are not present on previously published BGS geological maps (Figure 5). Visible rock faces within the quarries also allowed faults that were previously inferred in the geological map data to be seen, increasing the certainty of the map data and allowing map linework to be refined.

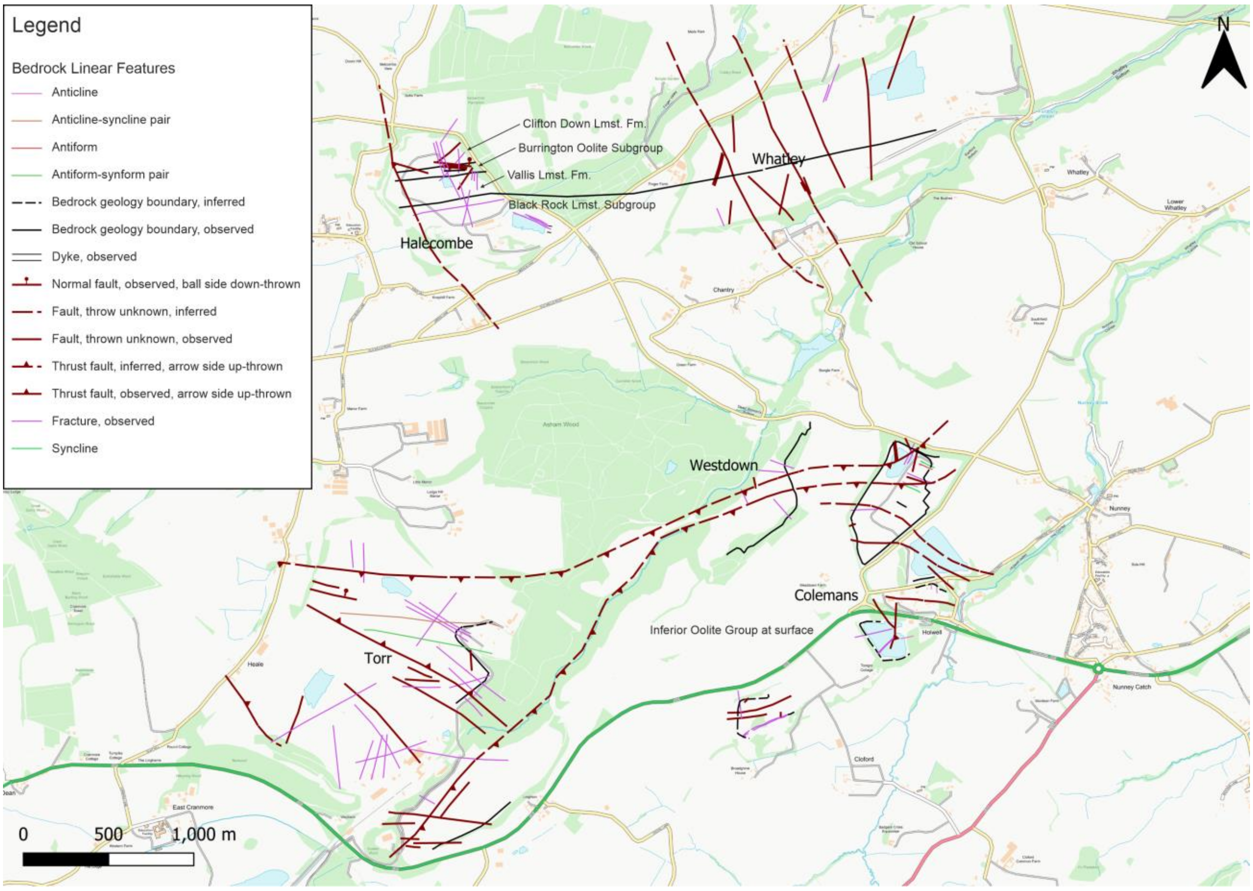

Figure 5. Linear bedrock features mapped during fieldwork for this project. Numerous faults and bedrock contacts can be traced between quarry sites. The geological units exposed in the eastern wall of the main pit at Halecombe Quarry are labelled as in Figure 9. Map data from OpenStreetMap available under the Open Database License.

There is evidence that some faults identified in the quarries are extensive over kilometre scales, evidenced by their presence at outcrop in multiple adjacent quarries, such as those which can be traced eastward from Torr Works, through Westdown Quarry, to Colemans Quarry (Figure 5). The location of quarries is likely to bias the mapping of faults towards these areas, and it is therefore probable that there are numerous unmapped faults within the area which are not currently intersected by quarrying.

A high density of point data was collected from the quarry exposures, either by sighting from a safe distance or from direct contact with bedrock exposures (Figure 6). This enables a greater, higher resolution understanding of the dip of bedrock strata in the region, as well as the trends of other structural features, than can be gained from current published maps of the area.

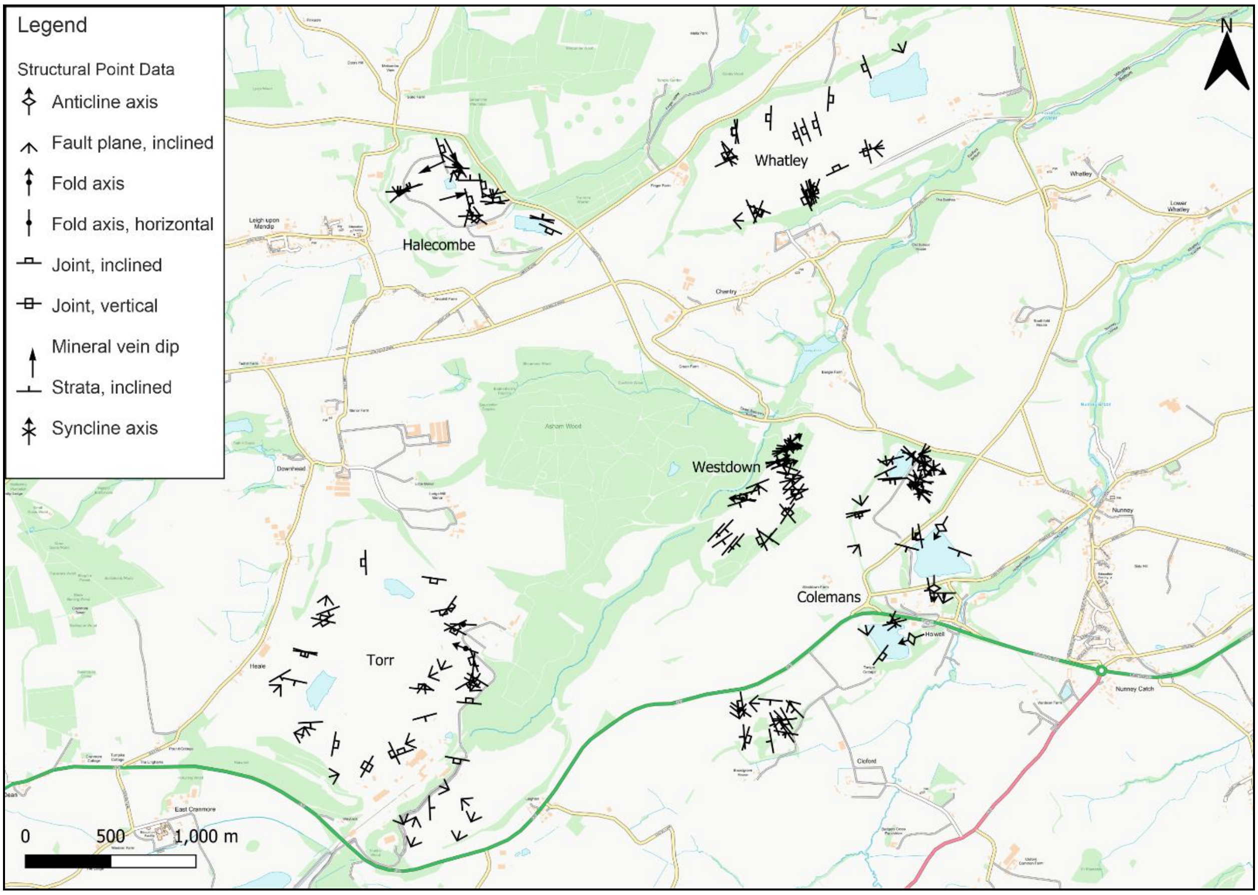

Figure 6. Structural point data collected during fieldwork for this project. Quarry exposures, and the continual expansion of these sites, have enabled a high density of structural data to be gathered from previously un-surveyed areas. Map data from OpenStreetMap available under the Open Database License.

Water ingress into the quarries is in some instances associated with fault or fracture zones, probably fed by discrete conduits. Notable examples of this are a steady flow of water emanating from a fault in the north-western wall of Torr Works (Figure 7) around [369181, 144994]; and shortly following a routine blasting operation at Whatley Quarry (around [372028, 147575]; Figure 8B) that took place whilst BGS geologists were on site. In the case of the water ingress at Torr Works, anecdotal evidence from quarry employees and the presence of vegetation and significant quantities of sediment suggest that this flow is continuous over periods of several months at least. This ingress is likely to be related to the nearby Downhead Fault and the numerous stream sinks (locally known as 'slockers') that lie along it to the immediate west of the quarry (Newton, 2019). Orange to red staining of the Black Rock Limestone in the region of water ingress at Halecombe Quarry also suggests that this water flow is either a discontinuous but frequent, or continuous occurrence (Figure 9B).

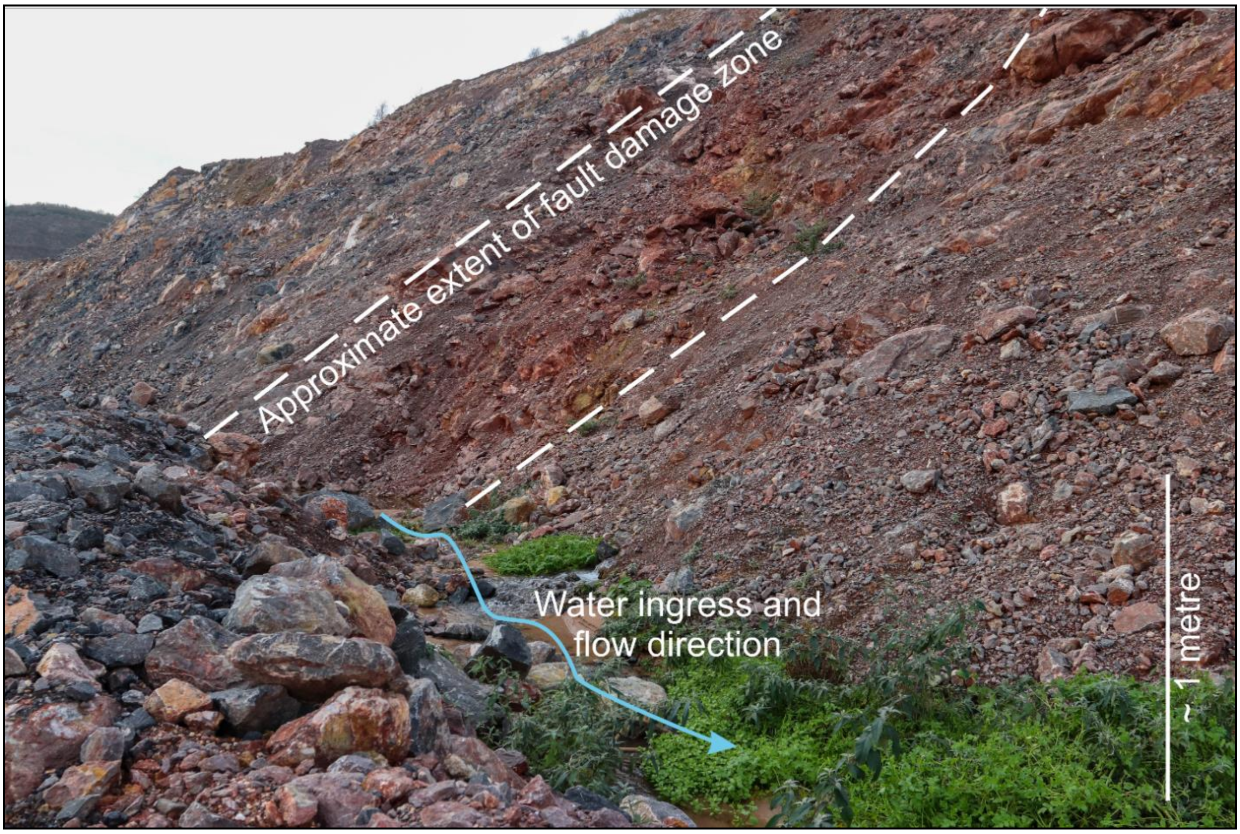

Figure 7. A fault zone associated with a point of water ingress on the north-western wall of Torr Works Quarry (369181, 144994). Note the vegetation which implies either a continual or frequent flow.

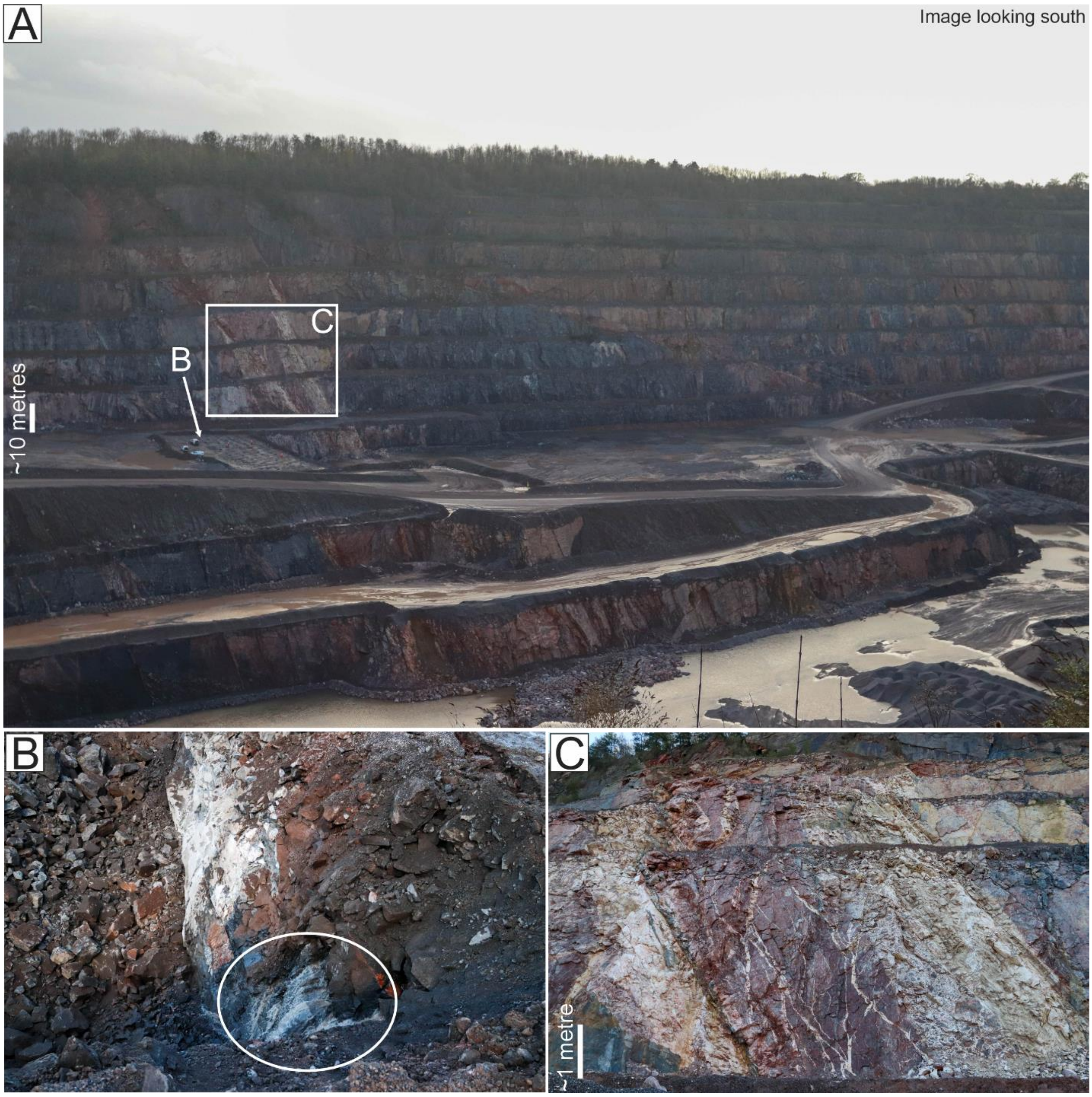

Figure 8. Images gathered during fieldwork at Whatley Quarry. A) A view of the southern wall of the quarry from the public viewing platform. B) Water emanating (circled) from within the Black Rock Limestone Subgroup shortly following a blast. C) A mineralised fault damage zone with a width of over 10 metres. The fault is in close proximity to the location of the water ingress.

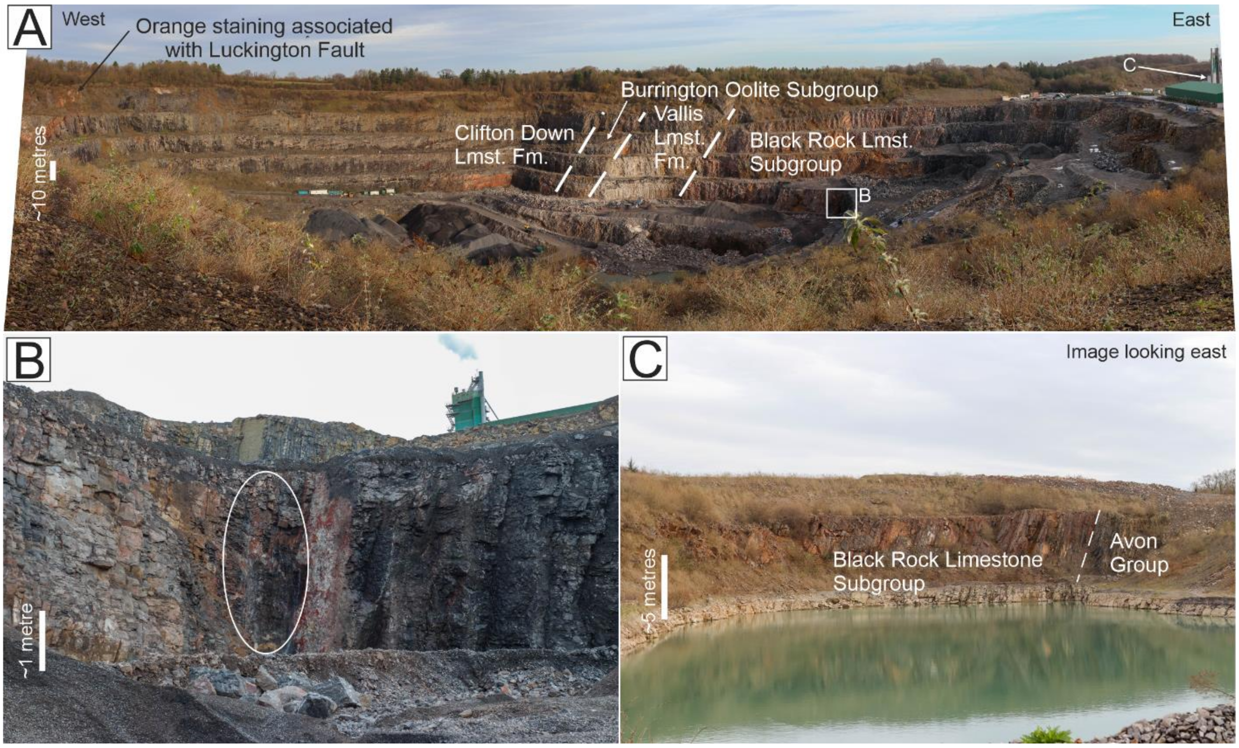

Figure 9. Images taken during fieldwork at Halecombe Quarry. A) A panorama looking north at the main pit. Numerous steeply-dipping bedrock contacts (dashed white lines) can be seen in the north-eastern wall of the quarry, whilst a large fault zone, likely to be the Luckington Fault, is visible in the far west. B) Water ingress (circled) and tufa formation within the Black Rock Limestone Subgroup strata. C) The contact between the steeply-dipping Black Rock Limestone Subgroup and underlying Avon Group (dashed white line) exposed in an old, flooded pit in the far east of the site.

Quarrying operations have enabled the widths of previously mapped and unmapped fault zones to be measured, and these were found to be significant, in some cases exceeding 10 metres (Figure 8C). These zones are characterised by pervasively damaged and fractured bedrock, and in some cases the mineralisation of fracture walls. Tufa formation is common at sites of prolonged water flow, and is characterised by orange staining, such as is visible in close proximity to the mapped location of the Luckington Fault at the far south-western edge of Halecombe Quarry (Figure 9).

3.3 FIELD SURVEYS IN THE FROME AREA.

In addition to the quarry visits, some reconnaissance fieldwork was undertaken to assess the veracity of the published geological maps. This was focussed on the area to the north of Frome between Hapsford and Oldford. Outcrops here are limited but the field data observed corroborates the published 1:10 000 scale maps. Numerous outcrops of the Inferior Oolite were noted on the interfluve between the Mells River and the River Frome, notably around Spring Gardens, along the line of the old canal, and in the Mells River valley where the unconformity between the Inferior Oolite and the Carboniferous limestones can be observed in many places, not least at the classic De la Beche unconformity section in Vallis Vale [ST 7556 4917]. The Penarth Group outcrop can also be seen at several localities, including the section at Hapsford Bridge [ST 7599 4940], recently written up by Ronan et al., (2020). The Devonian sandstones of the Portishead Formation were observed in a track off Cuckoo Lane, near Spring Gardens at [ST 7744 4964], confirming that the Carboniferous limestones on the northern side of the Beacon Hill pericline lie north of the River Frome at this point. The available field evidence and geomorphology backs up the current interpretation of the faults in the area; their position could possibly be altered by a few tens of metres in some areas, but there was no evidence suggesting a wholesale reinterpretation was necessary. It was not possible to check for new outcrops in the bed of the River Frome or the Mells River as water levels were too high at the time of fieldwork.

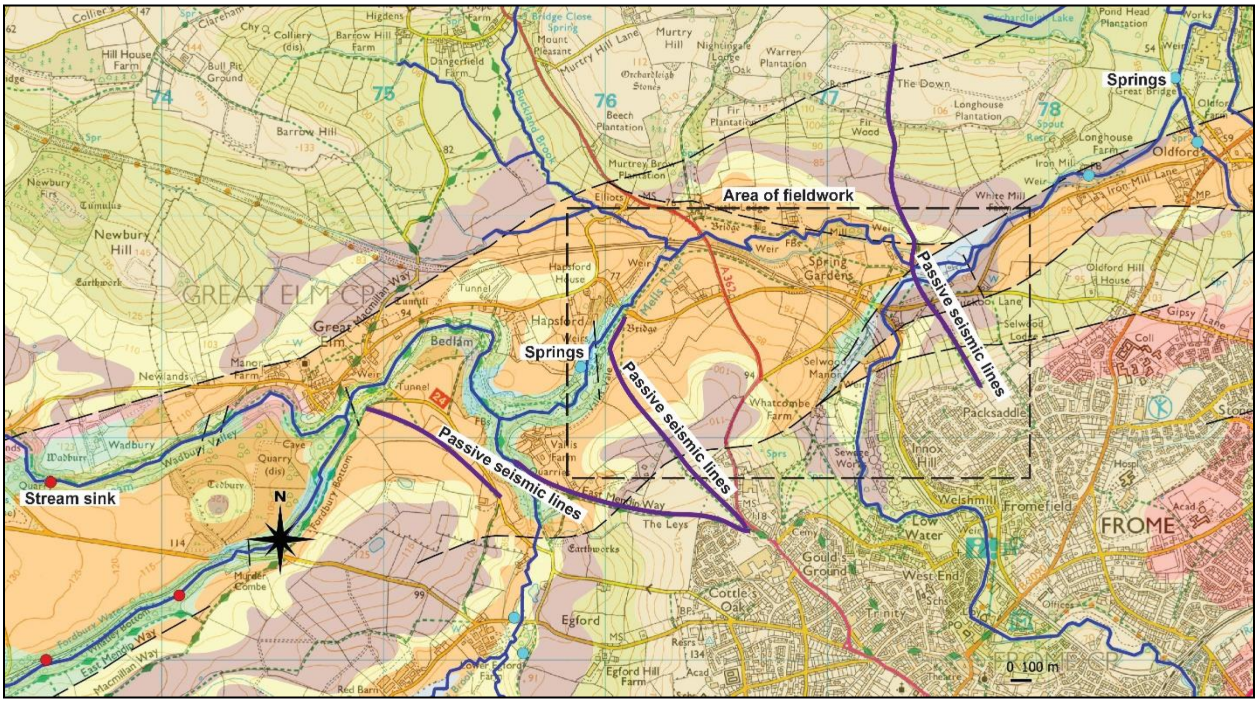

Figure 10. Area of fieldwork north of Frome, in relation to the passive seismic surveys and key stream sinks and springs. The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights 2025. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.

4 Passive Seismic Surveys

In order to test the quality of the published geological map and potentially improve the understanding of the faulting and 3D geometry of the geology in the Spring Gardens-Vallis Vale area northwest of Frome, geophysical data were acquired. Four transects to the north and northwest of the town were surveyed in September/October 2024 using the HVSR passive seismic technique with a Tromino® instrument. The location of the survey is shown in Figure 11. The data gathered during this survey were not used in the modelling process because they are below model resolution.

The Tromino® uses background seismic energy to create seismic profiles. The data were used to help constrain the geometry and depth of the shallow geology. Given uncertainties in the seismic velocity profiles of the various deposits, the sections should not be used to predict the absolute depths but can be used to as an overall guide to the structure. The profiles are documented in Appendix 4.

4.1 THE PASSIVE SEISMIC METHOD

The H/V ambient noise seismic method is a non-invasive technique that was initially developed for earthquake microzonation studies. However, it is increasingly being used to estimate structure and depth of the bedrock below sedimentary layers (Chandler and Lively, 2014). The energetically dominant part of seismic noise which consists mainly of surface waves and traditionally regarded as a nuisance by seismologists, is rich in information, especially in the structure of the near-surface. As this noise is ever present and everywhere, it appears a convenient exploration tool (Castellaro et al., 2005).

One way of analysing seismic noise is the horizontal-to-vertical spectral ratio method. The method computes the ratio between the horizontal and vertical (H/V) components of seismic noise measurements at a single station. The underlying assumption is that ambient noise consists mainly of surface waves (Rayleigh and Love) and/or body shear wave waves reflected and refracted inside shallow layers characterised by strong impedance (velocity x density) contrast. Because seismic noise varies largely in amplitude as a function of the noise "strength", the spectral ratio remains essentially unaffected and is tied to local subsoil structure.

The H/V method uses a single, broad-band three-component seismometer, in this case a Tromino Zero and a Tromino 3G, to record low-amplitude ambient vibrations of the ground. These vibrations are produced by local surface sources such as traffic and other industrial/human activities, normally at frequencies > 1 Hz, or from far-distance sources such as oceanic waves, winds and other meteorological sources below 0.3 Hz (Bonnefoy-Claudet et al., 2006 and Acerra et al., 2004). The instrument itself is a small, portable device approximately 140 x 100 x 80 mm in size (the small red box in the foreground of the photo, Figure 12), and is powered by 2 AA batteries or equivalent internal battery. It sits directly on the ground surface, and measures the natural, ambient vibrations in the earth. Each measurement usually takes between 10 and 30 minutes.

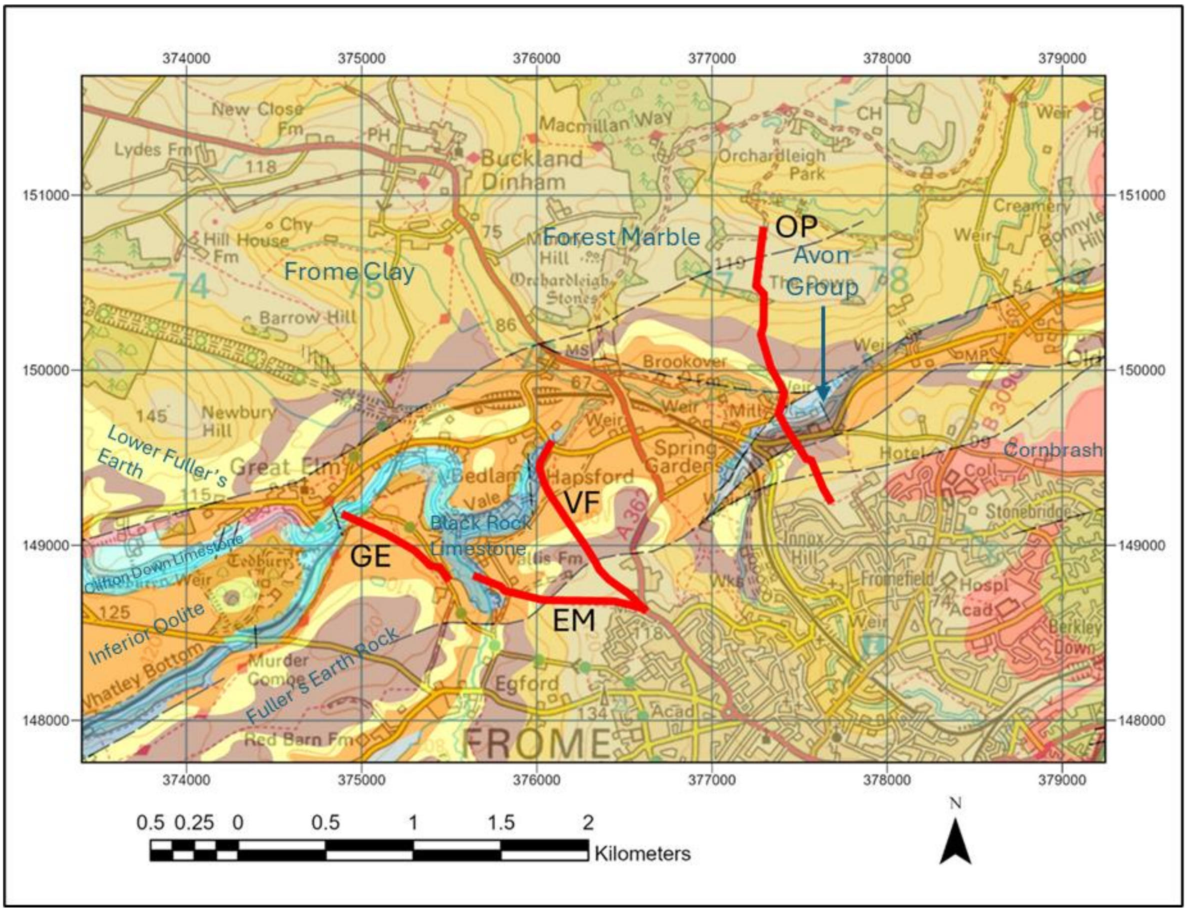

Figure 11. Map showing the locations of passive seismic transects and 1:50K scale bedrock geology. Geological formations are labelled in blue text. Contains Ordnance Data © Crown Copyright and database rights 2025. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.

Figure 12. Tromino passive seismic instrument in operation next to a water observation borehole.

Processing of the passive seismic data was undertaken in three stages:

(i) an initial screening to ensure that the data were valid
(ii) filtering of artificial noise from the data, and
(iii) the depth of the frequency peaks was determined from the assumed bulk shear wave velocity for the profile, using Equation 1:

$$h = Vs/4f \qquad \text{[Equation 1]}$$

Where h = depth; Vs = shear wave velocity, and f = frequency (Hz)

The greatest area of uncertainty in the interpretation of the data comes from the requirement to assess the shear wave velocity of the near surface strata for modelling, as the Grilla Software is designed to model from the surface shear wave velocity. Whenever possible shear wave velocity profiles are validated against measurements of shear wave velocity using such techniques as Multi-Channel Analysis of Surface Waves (MASW); or calibrating the results using borehole data. In the absence of ground-truthed data the approach is to select appropriate shear wave velocities from the literature.

4.2 SURVEY

The survey was carried out in late September / early October 2024 by taking measurements at c. 50-100 m intervals along selected transects, which crossed the mapped faults. A limited number of readings were taken in the vicinity of boreholes; and SoilSpy® MASW soundings were undertaken at four locations on profile OP, which helped to provide some constraint on the seismic velocity profiles. The locations of the measurement points were recorded using hand-held GPS which generally had a precision of about +/-10 m. Elevation data with a precision better than 1 m were derived from a DTM in ArcGIS Pro.

4.3 PROCESSING

The Tromino and SoilSpy data were processed using Grilla® software, a propriety package designed specifically for these instruments. Colour contour plots of the horizontal to vertical ratio (log H/V) values were generated in HeeVee®. An example is shown in Figure 13, and the full set of plots is given in Appendix 4. The higher values of H/V ratios, in yellow, orange and red colours represent zones of high acoustic impedance contrast (i.e. a transition from weaker to more competent rocks). The zone of high H/V values has been interpreted as the base of superficial deposits / top of chalk or the top of unweathered chalk.

The processing relies on representative values for the shear-wave velocity and its rate of increase with depth. This can be verified by MASW surveys, taking Tromino measurements over known geology (e.g. borehole location), or using typical values from literature.

It should be noted that there are lateral changes in mapped surface geology along many of the profiles. The SoilSpy MASW data show that the shear wave velocity (Vs) profile also varies, so the parameters used in processing the Tromino data used averaged values which were assumed to be reasonable given the composition of the underlying strata. Should other data show that the values are incorrect, then the depths of the profiles should be adjusted accordingly. An increase in the Vs or exponent values used in processing would result in an increase in the interpreted depths of strata. The processing algorithm assumes a smooth increase in velocity with depth, so does not consider step-changes in velocity, as might be expected at the top of unweathered (competent) Palaeozoic rocks. The resulting plots thus show the likely geometries but may be less accurate in terms of absolute depth.

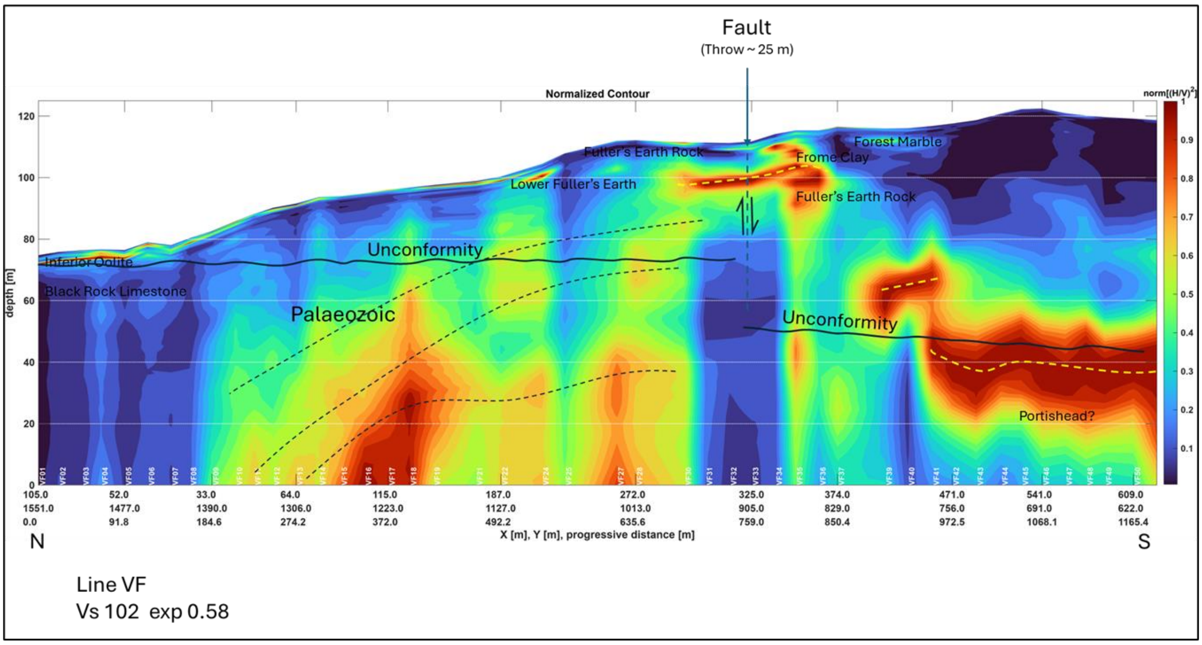

Figure 13. Example of the colour contour plot generated in HeeVee. The yellow, orange and red colours show zones of high acoustic impedance contrast.

4.4 INTERPRETATION

The colour contour plots of the passive seismic transects are presented in Appendix 4, along with maps showing the measurement locations. The measurement locations were recorded using hand-held GPS, so generally have a horizontal accuracy of approximately +/- 10 m. Elevation was extracted from a 2 m resolution DTM, so has greater accuracy. The data were processed using an assumed near-surface shear-wave velocity (Vs) of 102 m/s to 150 m/s, and an exponent value (exp. or α) of 0.50 to 0.58, depending on the location. The exponent value accounts for the rate of increase in Vs with depth, as calculated using the equation below:

$Vs_z = Vs * (1+z)^{\alpha}$

Where Vs_z = Shear wave velocity at depth z; α is the exponent value

The parameters were chosen after considering the data from MASW measurements, the mapped superficial and bedrock geology, borehole data that showed depth of superficial deposits, and typical values of Vs from literature. Also, pragmatic decisions had to made to consider lateral variations of geology along the transects.

High amplitude H/V peaks, shown by the transition to red and orange colours were interpreted variously as the base of superficial deposits and/or relatively weak rocks such as Frome Clay, Fuller's Earth; or the top of strong bedrock such as Portishead Formation ('Old Red Sandstone'). Where there is a gradational change in acoustic impedance, or where measurements were taken on outcrop of strong bedrock, no distinct H/V maximum is seen.

The peak acoustic impedance contrast highlights the parts of the section where there is the greatest difference in the acoustic signal and thus may indicate possible geological boundaries. These could include, variously: the base of superficial deposits; buried valleys; top of hard rock units; or base of topsoil. It may also be related to the depth of weathering. However, these are indications only and not the final geological interpretation which is based on wider considerations of the geology derived from geological mapping and other borehole data. Some lateral changes in acoustic impedance contrast may reflect differences in values due to poor instrument connection with the ground surface.

4.4.1 Line OP (Orchardleigh Park)

Line OP extends from Orchardleigh Park to the outskirts of Frome, and cuts across the northern limb of the Beacon Hill pericline, here largely concealed by the Jurassic cover (Figure 14). The transect passes across several east-west trending faults, especially around Spring Gardens.

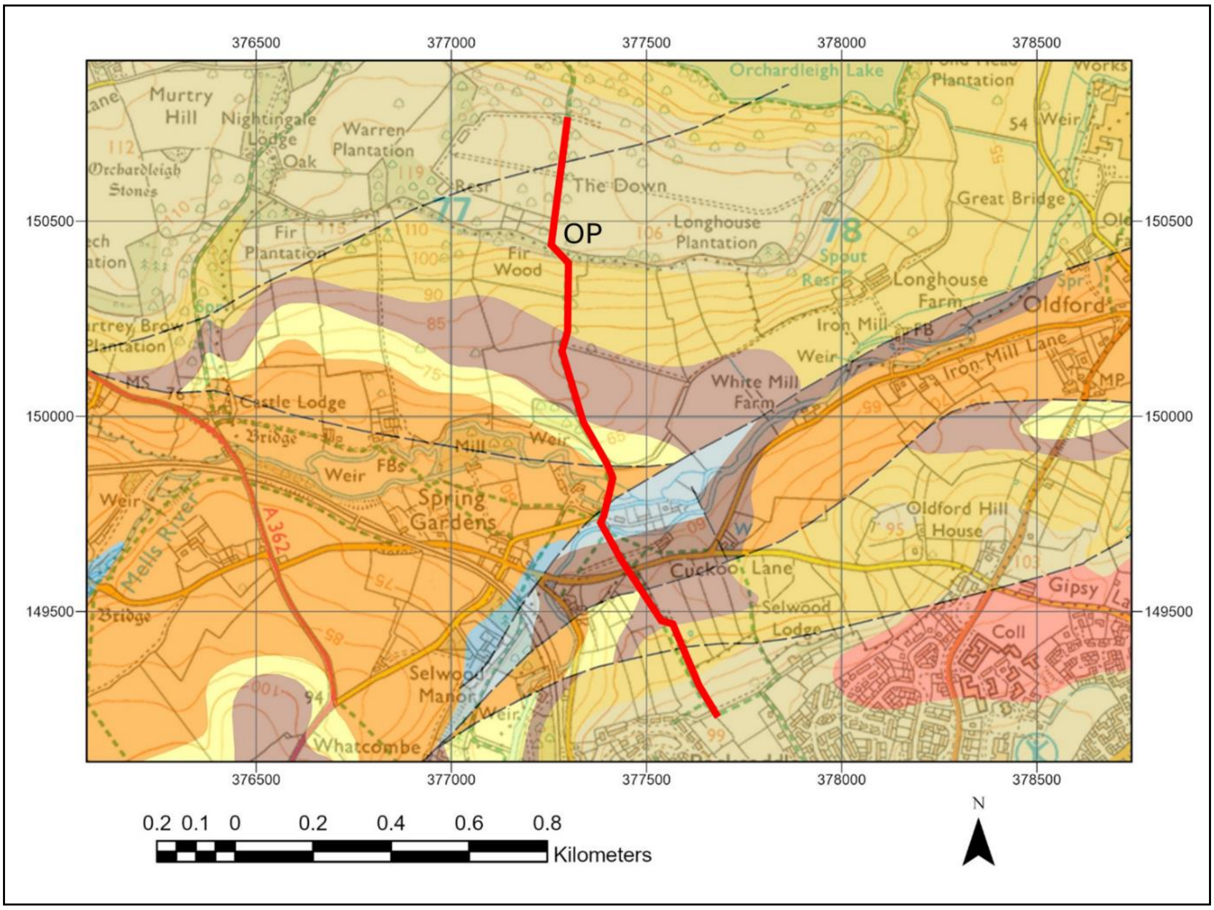

Figure 14. Location map for line OP (Orchardleigh Park). The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.

With such complex geology, the seismic data (Figure 15) can be hard to interpret, but several features stand out. The thin alluvial deposits beneath the valley floor show up quite clearly. Several possible faults can be identified on the seismic, which generally accord well with the mapped features. The faults shown on Figure 15 are the locations of the mapped faults. The southernmost fault, in the Frome Clay shows up as a region of high acoustic impedance contrast (orange-red), with a slight down to the south offset, a short distance north of the mapped location. The next fault to the north is again shown by a narrow vertical region of higher impedance a short distance north of the mapped fault. The dark blue vertical strip close to the valley floor is the outcrop of the Portishead Formation. This shows a very low acoustic impedance contrast due to the vertical homogeneity of the unit. The faults beneath the valley floor are harder to pick up due to the interference from the superficial deposits, but some lateral offsets and changes in acoustic impedance contrast can be identified which may equate to the mapped faults.

Two inclined trends of high acoustic impedance contrast can be identified to the north of the Frome valley. These may be the northward dipping contracts between the Fuller's Earth Rock-Lower Fuller's Earth, and the Frome Clay-Fuller's Earth Rock respectively. The base of the Forest Marble is marked by an increase in acoustic impedance contrast. A fault in the Forest Marble can be picked up by a vertical zone of high acoustic impedance contrast which accords well with the surface mapping. A similar southward dipping contrast between the Fuller's Earth Rock and the Frome Clay can be seen at the southern end of the transect, intersected by a fault. Some of the sharp lateral changes in acoustic impedance contrast (for example beneath the northerly Frome Clay outcrop) may reflect poor instrument connectivity with the ground rather than faults.

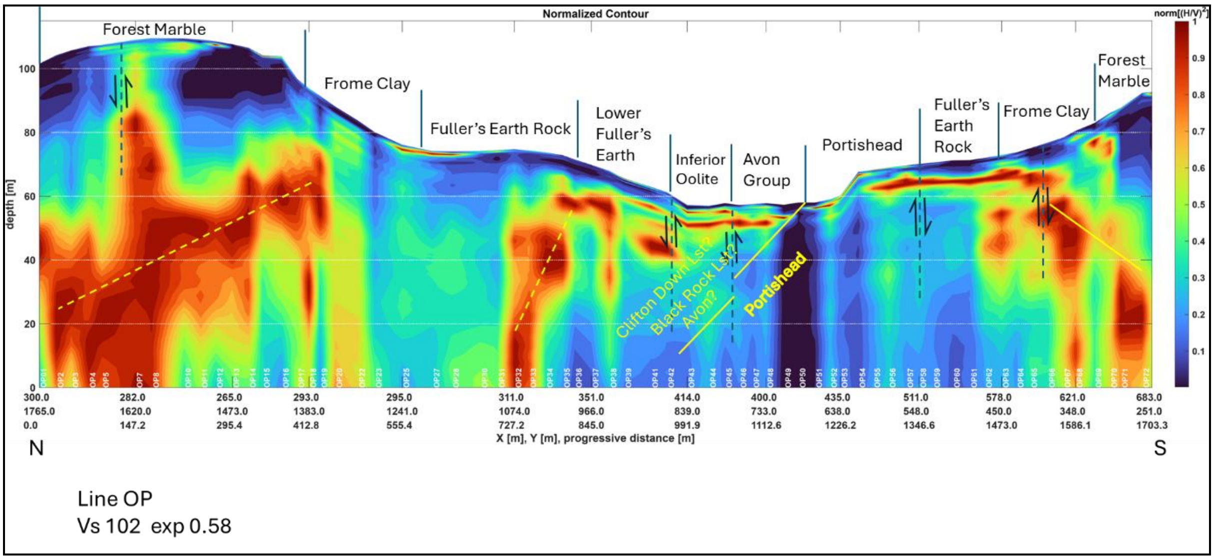

Figure 15. HV contour plot for line OP (Orchardleigh Park). Mapped surface geology is shown, and mapped faults with sense of throw (vertical black lines). Geological units described in yellow writing are inferred from geological mapping and borehole information. Yellow dashed lines are trends identified from the seismic data, and not necessarily geological features.

4.4.2 Line EM (East Mendip)

Line EM extends from the A362 on the northern outskirts of Frome to the Egford Brook valley at Vallis Farm (Figure 16). As with Line OP, this cuts across a fault juxtaposing the Fuller's Earth against the Frome Clay & Forest Marble. This fault is clearly visible in the seismic data (Figure 17) as an offset in the southern dipping acoustic impedance contrast, which may be the unconformity between the Jurassic and the underlying Palaeozoic rocks. It matches the surface location of the fault very well. The reflector is at very shallow depth at the northwestern end of the transect, indicating a very thin cover of the Inferior Oolite here, which is borne out by the exposures in the Egford Brook valley. At the southernmost end of the transect, a zone of higher acoustic impedance contrast may reflect the boundary between the Frome Clay and the Fuller's Earth Rock.

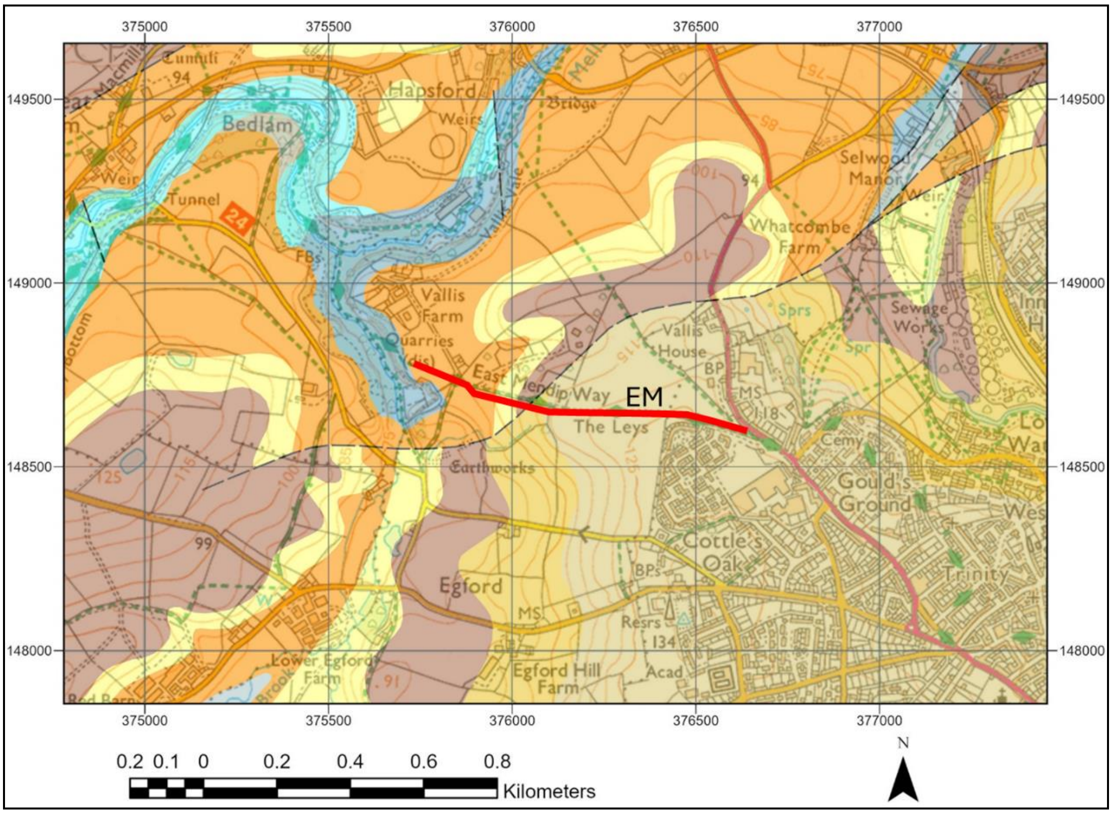

Figure 16. Location map for line EM (East Mendip). The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.

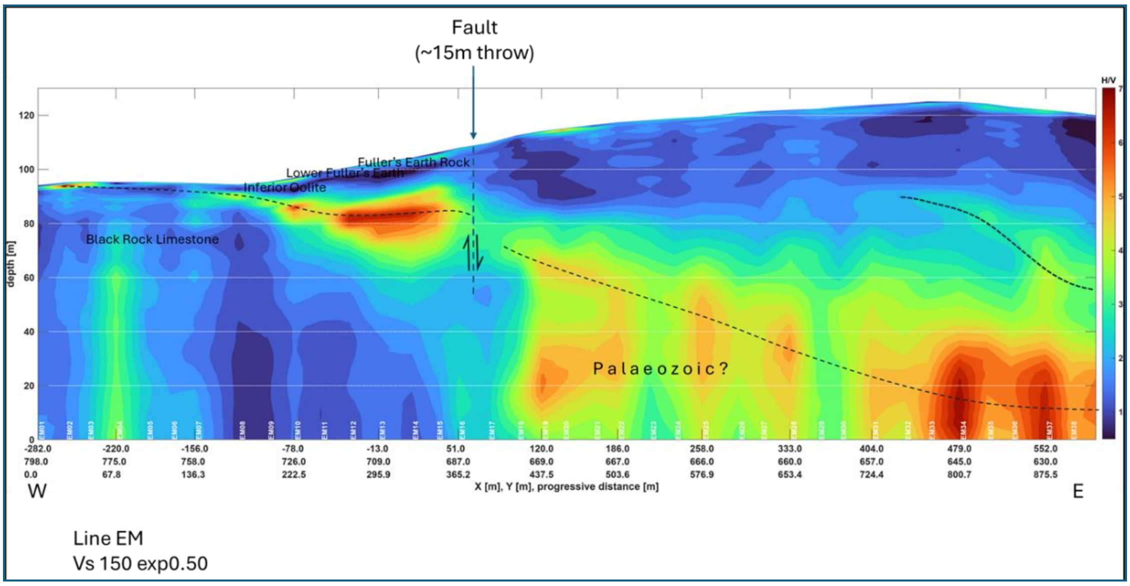

Figure 17. HV contour plot for line EM (East Mendip). Surface and sub-surface geology is shown, and a mapped fault shown as a vertical dashed line, with sense of throw indicated. Other dashed lines highlight H/V peaks, inferred to be the interface of stronger rock underlying relatively weak rock.

4.4.3 Line VF (Vallis Farm)

Line VF extends from the A362 on the northern outskirts of Frome to Hapsford (Figure 18). This also cuts across the fault juxtaposing the Fuller's Earth against the Frome Clay & Forest Marble. A zone of faulting is identified in the seismic section (Figure 19) at points VF31-VF34 on the transect, close to the location of the mapped fault, with a second offset slightly further south at VF40-VF41. This appears to show the main fault has split into two or more faults, down throwing to the south, as it passes over the ridge between the Egford Brook valley and the Frome valley. Although not a huge shift, this secondary fault may account for the small springs on the east side of the ridge. The shallow unconformity is picked up well above the uniform upper part of the Black Rock Limestone Subgroup (strike section) at the Hapsford end of the transect, and at the southern end where there is a strong contrast with the underlying Palaeozoic strata, probably the Portishead Formation, but is less clear in the middle section, probably due to the reduced contrast between the dipping, more shaley parts of the lower Black Rock Limestone Subgroup.

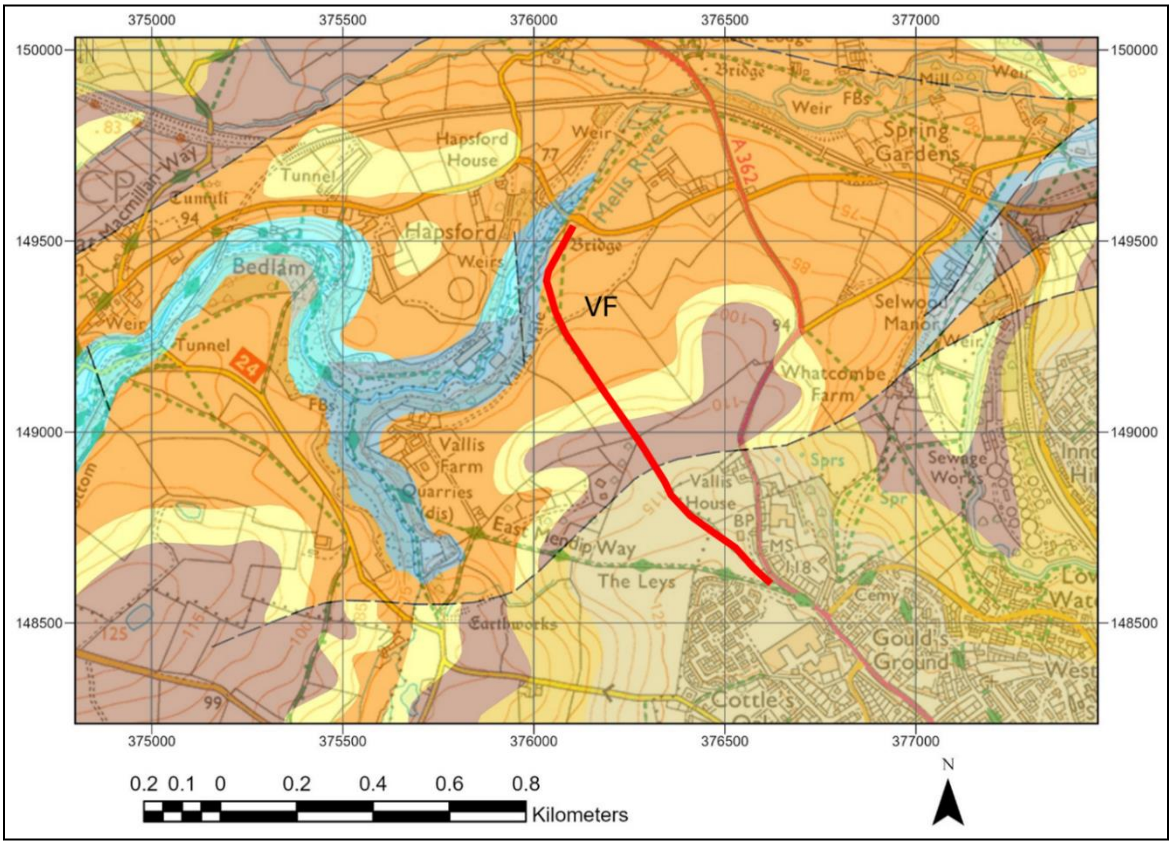

Figure 18. Location map for line VF (Vallis Farm). The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.

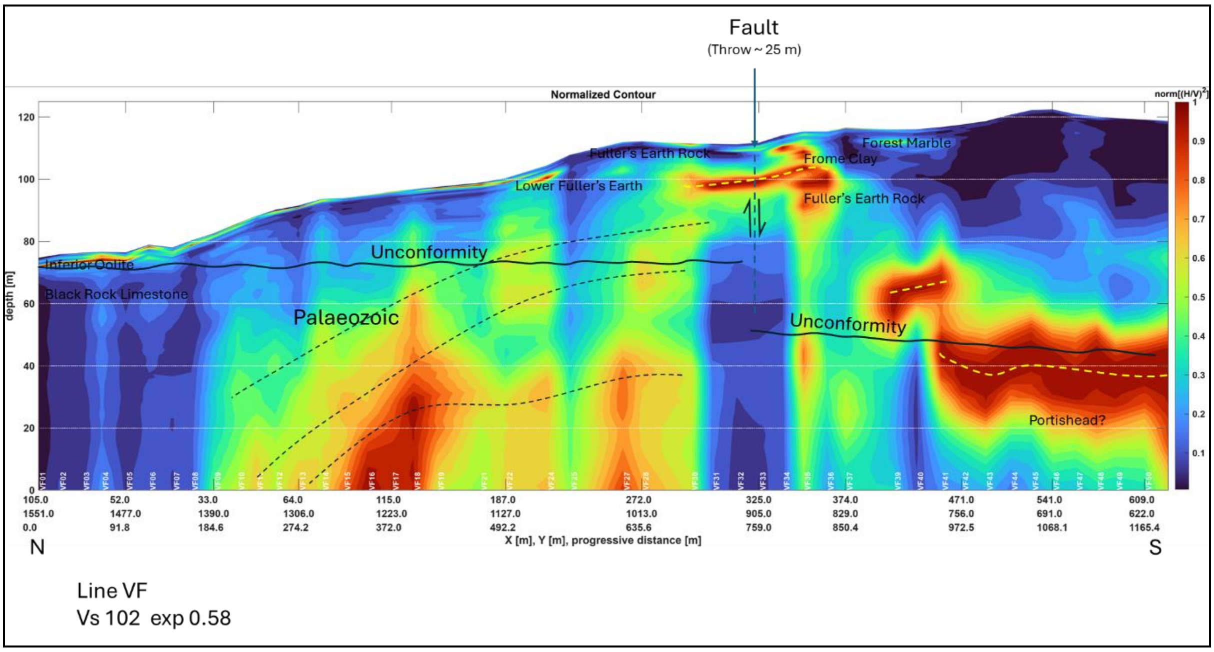

Figure 19. HV contour plot for line VF (Vallis Farm). Surface and sub-surface geology is shown, and a mapped fault shown as a vertical dashed line, with sense of throw indicated. Other dashed lines (both black and yellow) highlight H/V peaks, inferred to be the interface of stronger rock underlying relatively weak rock.

4.4.4 Line GE (Great Elm)

Line GE extends across the interfluve between the Egford Brook valley and the Mells River valley along the footpath roughly parallel with Elm Lane (Figure 20). The seismic data clearly shows a thin zone of high acoustic impedance contrast at shallow depth which is interpreted to be the unconformity at base of the Inferior Oolite. There appears to be little obvious structure in the underlying Carboniferous limestones which suggests they are relatively uniform with no major faulting.

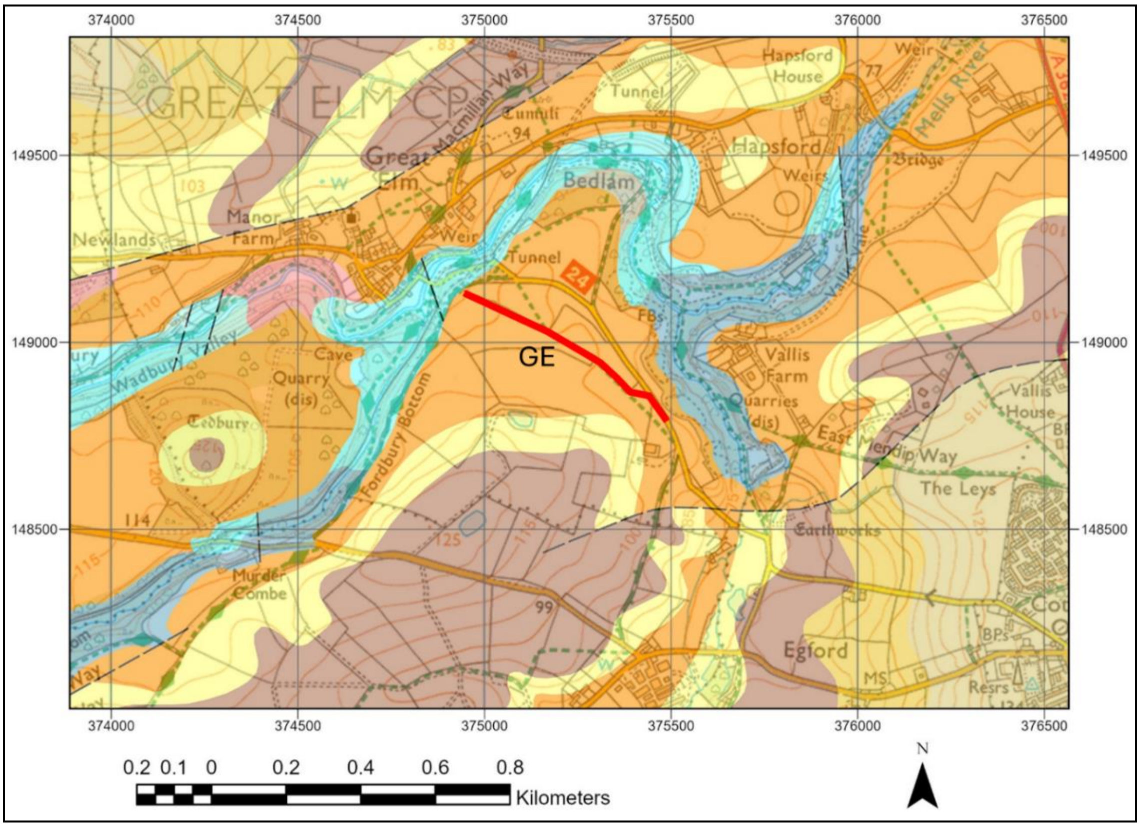

Figure 20. Location map for line GE (Great Elm). The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.

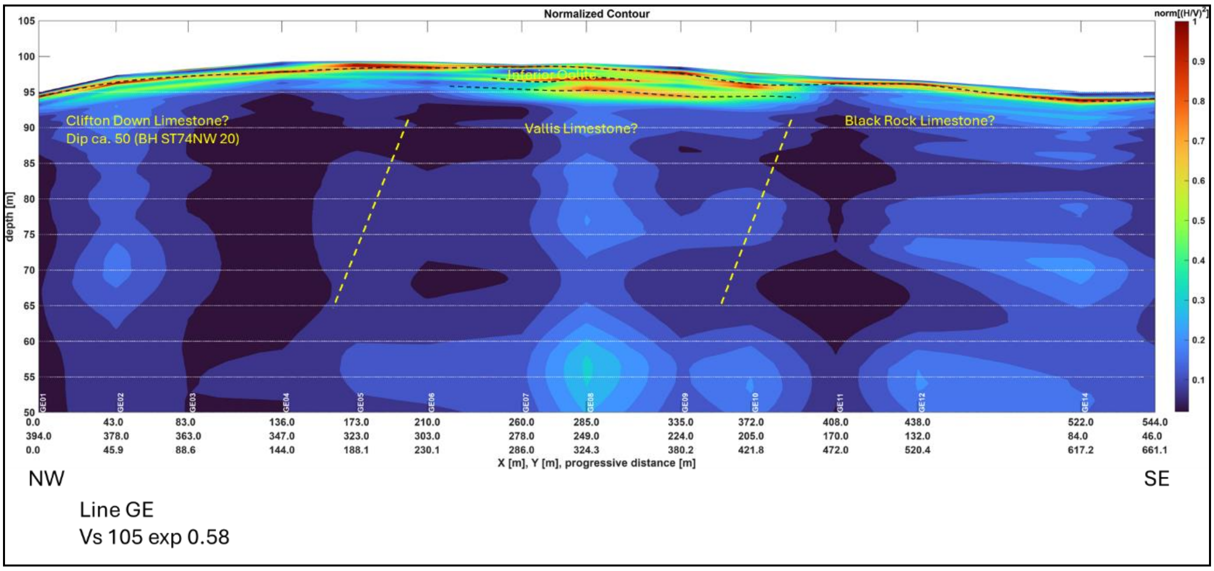

Figure 21. HV contour plot for line GE (Great Elm). Inferior Oolite is mapped at surface but is presumed to be very thin due to underlying rocks outcropping in the adjacent valley. Sub-cropping Clifton Down Limestone, Vallis Limestone and Black Rock Limestone (marked in yellow) have been extrapolated from the nearby mapped geology.

5 Model Datasets

The following section describes the main datasets used to inform the BGS 3D geological model of the Eastern Mendips. The available data in the region is relatively sparse and inconsistently distributed (Figure 22). Key datasets used to model the surfaces detailed in section 2 include:

- BGS geological maps (Figure 2)
    - BGS 1:50 000 scale bedrock geology map linework and structural measurements
- Digital Terrain Model
    - OS Open 50 DTM
- BGS borehole records (Figure 22)
    - 36 BGS boreholes (see Appendix 2/Table 3)
- Deep seismic records (Figure 22)
    - Three legacy 2D surveys and subsurface interpretations acquired by GECO UK for Carless Exploration in 1982,1985 and 1986 as part of three hydrocarbon exploration campaigns in Somerset and Avon.

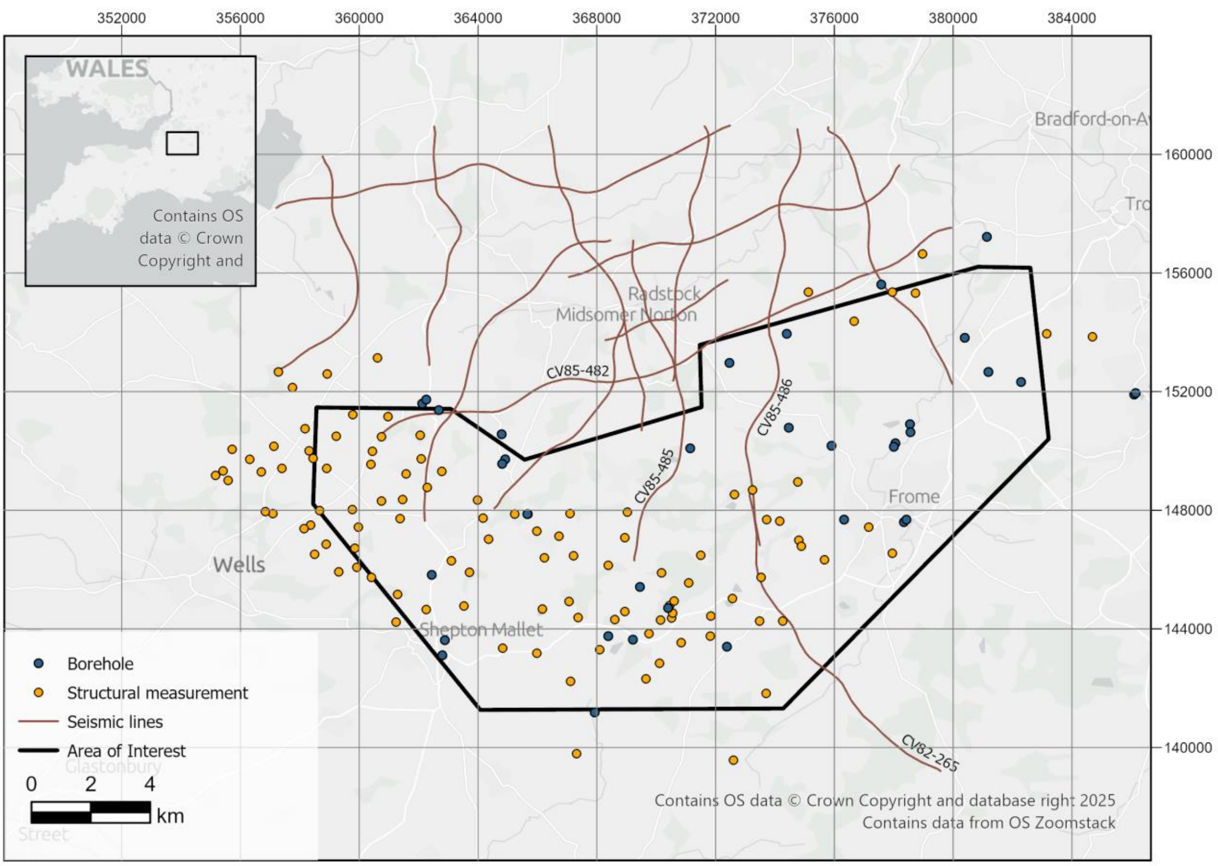

Figure 22. Location of borehole, seismic and structural measurements considered in the 3D geological model. Structural measurements refer to dip and strike measurements from published geological maps. Contains information provided by the North Sea Transition Authority and/or other

5.1 GEOLOGICAL LINEWORK

Geological linework for the bedrock units in the study area was extracted from BGS Geology 1:50,000 map data. The extracted data was subsampled to fit the resolution of the DTM in order to minimise noise along the outcrop boundaries.

5.2 DIGITAL TERRAIN MODEL

Topographic data used in the model is the OS Terrain® 50 with a horizontal resolution of 50 m. This was subsampled by the 3D modelling software.

5.3 BOREHOLE DATA

A review of borehole records in the BGS *Single Onshore Borehole Index* (SOBI) in the model area was carried out and those that held sufficient geological information were selected as input to the model. This review yielded a total of 36 usable boreholes (Figure 22) which were digitally coded and entered into BGS databases to build the 3D geological model. All selected boreholes penetrated at least 35 m and up to about 560 m of strata. The median drill depth is at 114.5 m. The respective horizons within the boreholes were marked according to their attribution to the BGS Lexicon.

It should be noted that many of these boreholes were logged in imperial units, so the depth values were converted to metric and rounded to the nearest metre; handwritten borehole logs could be difficult to read and often used mining terms which were unique to the local area, these were interpreted and converted into modern rock types found in the BGS Rock Classification Scheme. The stratigraphical markers present in each borehole, and used in the construction of the model, can be seen in the Appendix (Table 3).

The boreholes only penetrated down as far as the Variscan Unconformity (VU), So the Carboniferous and older strata do not have any boreholes determining their depth. This creates significant uncertainty in the Palaeozoic strata. Many boreholes in steeply dipping or vertical strata do not provide much stratigraphical information as they are often confined to a singe stratigraphical unit.

5.4 DEEP SEISMIC RECORDS

Three legacy 2D seismic surveys were acquired by GECO UK for Carless Exploration in 1982,1985 and 1986 as part of three hydrocarbon exploration campaigns in Somerset and Avon. Post-stack time migration (PSTM) original seismic processing after acquisition for each survey has been utilised in this study. In total, fourteen seismic lines were interpreted, with the majority located in the northern periphery of the project AOI. However, this region is partially covered with just six lines, most of them limited by the Mendip hills to the south (Figure 22). The southernmost line CV82-265 runs north-south immediately east of Whatley Quarry, where it intersects with line CV85-486 to have the only complete cross section through the AOI.

5.5 DATA NOT USED AS MODEL INPUT

Data gathered during both the field and passive seismic surveys (sections 3 & 4) provide additional information on sub-scale heterogeneity. As such, they are useful to estimate uncertainty of the current map data and provide further information on the nature of modelled lithological units. Due to the significant scale differences between the available data (e.g. Tromino® survey; 10s metres deep, cf. Figs. in section 4, and deep seismic surveys; 100-1000 metres deep), they were not used as input in the modelling process as they would have resulted in limited (if any) change to the modelled surfaces on the scale of the model.

6 Deep Seismic Interpretation

The subsurface stratigraphic and structural seismic interpretation of 2D seismic surveys was conducted using Petrel (v2023.5.0). Surfaces and faults were produced at three primary seismic levels: Top Old Red Sandstone Super Group, Top Avon and Pembroke Limestone groups and the Variscan Unconformity. For the integration with the 3D geological model, the resultant data was depth converted, using a velocity model derived from the intersection of the two-way-time horizon picking with borehole formation tops at each borehole location. Depth conversion was applied for the Top Pembroke Limestone Group and Variscan Unconformity; however, obtaining a depth surface for the Base Pembroke Limestone Group was not possible due to the lack of boreholes penetrating the full thickness of the group. Given the depth of the strata, this is a source of considerable uncertainty which has significant impacts on the 3D model. The resolution of the seismic data across the survey area is variable, ranging from moderate to poor. This inconsistency in data quality, specifically to the south, around the Mendip Hills, affects the clarity of subsurface features and poses challenges for detailed structural and stratigraphical interpretation. For that reason, this area of poor seismic resolution has been delineated for each mapped horizon.

6.1 SUBSURFACE STRUCTURAL STYLE

Early interpretation of seismic line CV85-482 by Ates & Keary (1993) suggest conformable stratigraphical units comprising Silurian volcanic rocks, Devonian sandstones, Carboniferous limestones and the Coal Measures, as well as Triassic and younger units. These form a continuous sequence without any major faults within a regional depression. This interpretation only considers a south-verging thrust system related to Mendip Hills formation shown in other lines of the survey. McCann *et al.* (2013) later interpreted the same seismic line, suggesting that the subsurface is affected by multiple extensional faults, defining a normal structural style. In this study, seismic interpretation was conducted on the Carless 2D seismic survey (which includes line CV85-482) that lies partly within the study area (Figure 22). Due to the identification of a series of thrusts and associated folding, the structural style along this line has been redefined in this study. The structural style is Variscan compressional deformation with thrust faulting, followed by tectonic extension in the Mesozoic, with subsequent basin inversion in the Miocene. This interpretation presents a different structural concept of the area, which better reconciles the subsurface structural framework with the surface configuration, represented by Variscan fold and thrust structures exposed through the Permian-Mesozoic cover (Williams and Chapman, 1986).

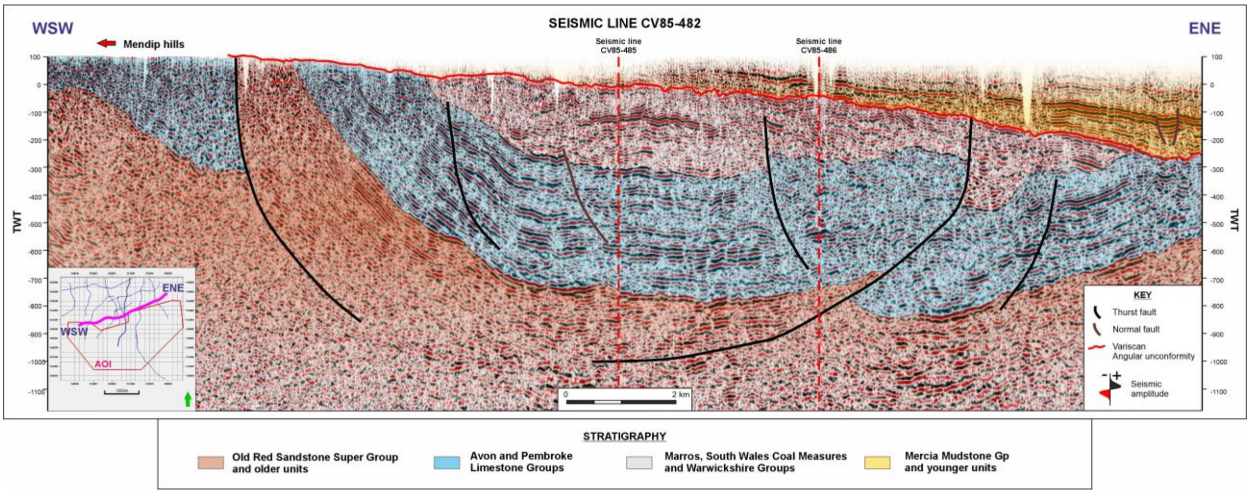

Figure 23. West southwest – east northeast seismic line CV85-482, in time domain, interpreted previously by Ates & Keary (1993) without any brittle deformation (faults), only by a regional flexural deformation, and by McCann *et al.* (2013) compartmentalised by normal faults. Re-interpretation of this seismic line exhibits the compressional structural style typical of the study area, defined by thrust faults and folds that affect Devonian and Carboniferous stratigraphical units, including the Carboniferous Avon and Pembroke Limestone Groups. The compressional deformation is buried by the Variscan Unconformity, truncating strata and thrusts and underlying Permo-Triassic strata with few extensional faults. Vertical dashed lines represent the intersections with seismic line CV85-485 and CV85-486. Contains information provided by the North Sea Transition Authority and/or other third parties.

6.2 STRUCTURAL CONTINUITY AND GEOTHERMAL IMPLICATIONS

A key aspect of this study is the structural continuity of the Pembroke Limestone Group, which serves as a geothermal reservoir for the hot springs in the region (e.g. Edmunds, 2014). North-south-oriented seismic lines, such as CV85-485, reveal compressional deformation characterised by thrust faults cross-cutting the Avon and Pembroke Limestone Groups along with associated folding (Figure 24). Williams and Chapman (1986) interpreted the structural configuration of the bedrock and extrapolated it downward into the subsurface. A north-south transect (Figure 7 in Williams and Chapman, 1986) shows that the geometry and vergence direction of the largest thrusts correspond to the identified in seismic interpretation of this work, particularly in line CV85-485 (Figure 24). The displacement of the thrust faults identified on seismic around the area of interest is not large enough to completely disconnect the faulted Carboniferous Limestone blocks. However, the connection of this line with another 2D survey further north, outside the current study area, towards the Bath urban area, suggests the presence of a thrust fault system with significant displacement that produces a structural discontinuity of the carbonate units and could potentially break the geothermal fluid flow pathway between Mendip and Bath.

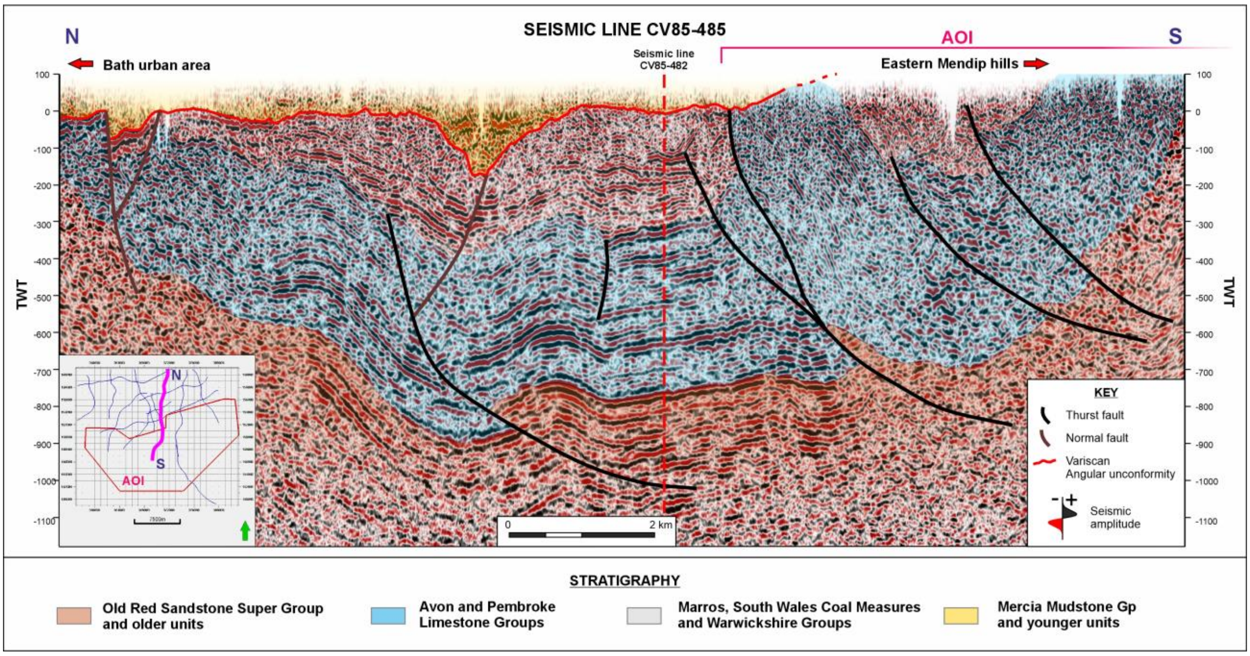

Figure 24. North-south seismic line CV85-485, in time domain, showing the dominant compressional configuration of the Devonian and Carboniferous stratigraphic units, especially in the Avon and Pembroke Limestone Groups, represented by thrust faults and associated folds, which are truncated by the Variscan Unconformity. Vertical dashed line represents the intersection with seismic line CV85-482. This line is an example of moderate seismic resolution displaying deformation related to thrusting and folding (central part of the section). Contains information provided by the North Sea Transition Authority and/or other third parties.

A composite seismic section CV85-486 – CV82-265 exhibits a compressional structural style represented by thrusting and folding (Figure 25), similar to the interpretation of parallel seismic line CV85-485 to the west. These lines are connected by line CV85-482, showing consistency with a 3D representation of the structural features and surfaces, necessary for the model. This section is the only one that covers the project area of interest, passing through the Mendip Hills close to Whatley Quarry. However, seismic resolution is poor around this area (central part of the section) but improves to the north and southeast (left- and right-hand side of the section), and toward a section where the Mercia Mudstone Group and younger units thicken. This composite section indicates a structural continuity of the Avon and Pembroke Limestone Groups. To the southeast of the Mendip Hills (right-hand side of the section), the Mesozoic strata overlie the Pembroke Limestone Group above the Variscan Unconformity. The unconformity indicates erosion of the Marros, South Wales Coal Measures and Warwickshire groups, present to the north of the Mendip Hills.

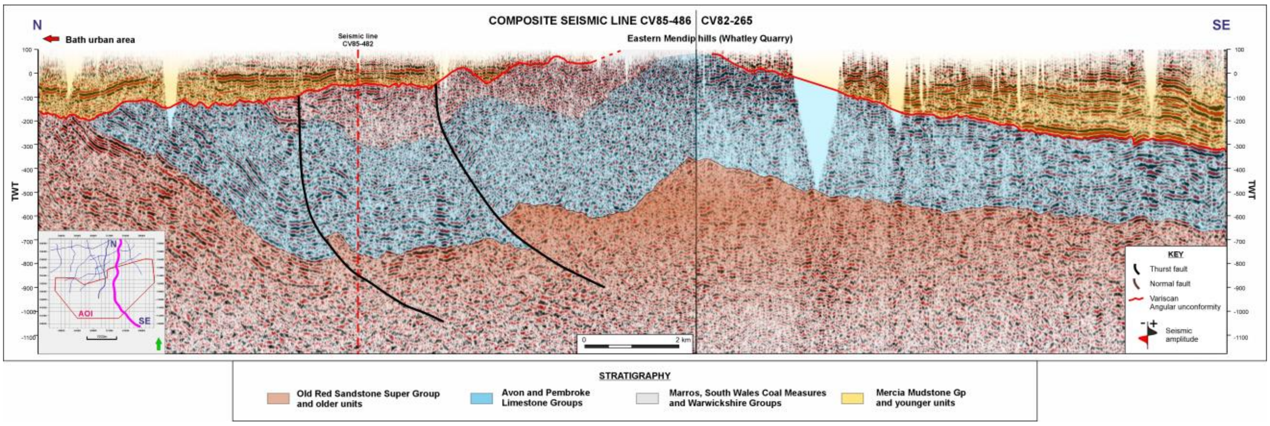

Figure 25. North-southeast composite seismic line CV85-486 and CV82-265, in time domain, passing around the Whatley Quarry, in the Eastern Mendip Hills. The compressional structural style of thrusts and folds of the area is consistent with the interpretation in seismic line CV85-485. The Variscan unconformity places the Mercia Mudstone Group and younger units directly over the Pembroke Limestone Group, where the Marros, South Wales Coal Measures, and Warwickshire Groups are absent. Seismic resolution is generally moderate on both sides of the section; however, it noticeably becomes poor toward the central part of the section. Contains information provided by the North Sea Transition Authority and/or other third parties.

6.3 SEISMIC MAPS

The main seismic horizons (reflectors) identified as suitable for picking (interpretation) are the top of the Old Red Sandstone Supergroup, the top Pembroke Limestone Group and the Variscan Unconformity, all of which are more continuous and characterised by higher amplitude signals (i.e. easier to identify and map) across the Carless survey area. There is an uncertainty in assigning the mapped seismic horizons to the top of the stratigraphical units from well and outcrop data due to lack of check-shot or vertical seismic profile logs to establish a time-depth relationship between seismic and well data. However, the position of the Variscan unconformity has less uncertainty as it is the only major angular unconformity displayed in the seismic data and so correlates with the major unconformity identified in outcrops and wells.

6.3.1 Top Old Red Sandstone Supergroup

The Top Old Red Sandstone Supergroup is present in all the seismic lines, with exception of local areas to the northeast and toward the Mendip Hills. The seismic reflector followed as the top of this unit is a trough (negative amplitude of the wavelet), which is consistent with calcite mudstone and limestone layers of the Avon Group over the dominant sandstone beds of the Old Red Sandstone Super Group. The stratal termination associated to this horizon is underlying and overlying parallel beds, which suggest no major changes in the basin development through the Devonian and Carboniferous in this region. The main structural deformation across this surface is a group of thrust faults and folds that have been identified and interpolated through several seismic lines of the Carless survey. The orientation of these structures is aligned with the regional west-east orientation of the Mendip Hills anticline axes, and their planes are mostly verging to south, except for one verging to the northeast, localised to the southwest of the survey area.

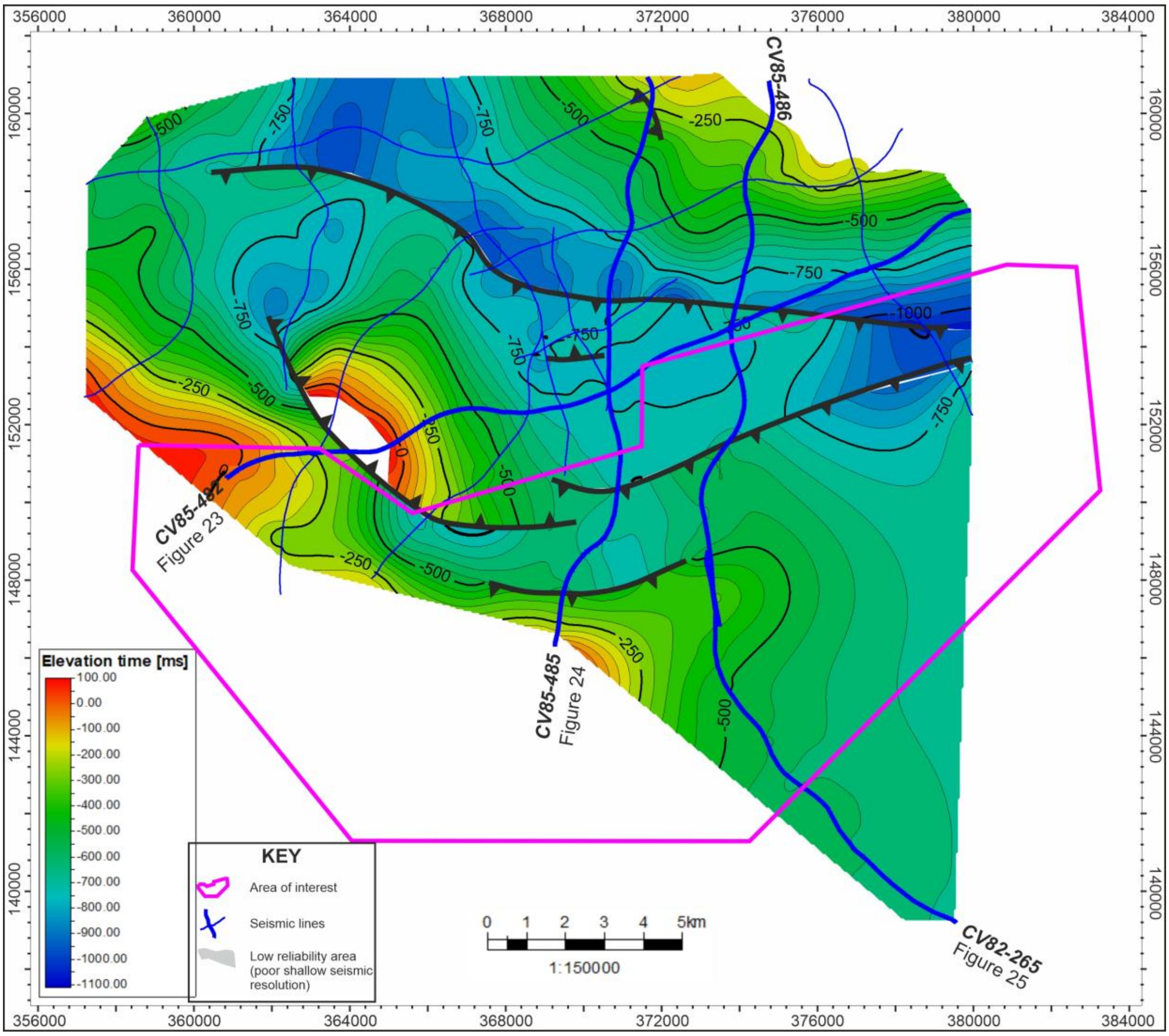

Figure 26 Surface seismic time map of the Top Old Red Sandstone Supergroup across the Carless survey. The map shows thrust faults (black jagged solid lines) that affect this horizon. These structures are aligned to the regional west-east orientation of the Mendip Hills anticline axes. Contains information provided by the North Sea Transition Authority and/or other third parties.

6.3.2 Top Pembroke Limestone Group

The Top Pembroke Limestone Group was mapped through most of the seismic lines, although this horizon was truncated by the Variscan Unconformity in some areas (Figure 27), as seen in the northeast and south (toward the Mendip Hills) of the survey area. The seismic horizon, representing the Top Pembroke Limestone Group, picked in the interpretation is also a peak (positive amplitude of the seismic wavelet), indicating that the limestone of this group is more compact than the overlying mudstone and sandstone of the Marros Group or younger units above, resulting in a downward acoustic impedance increase. The stratal terminations associated with this horizon are underlying parallel to sub-parallel strata and onlapping reflectors on top, which suggests a period of geodynamic changes of the basin (subsidence?). The same group of thrust faults and folds that have been identified and interpolated in the Top Old Red Sandstone Supergroup, can also be seen across this surface. These compressional structures, at this level, are also aligned to the general west-east anticline axes of the Mendip Hills, with a mostly south-facing fault plane vergence. This compressional deformation also affects the units between this horizon and the Variscan Unconformity, consistent with the Variscan orogeny.

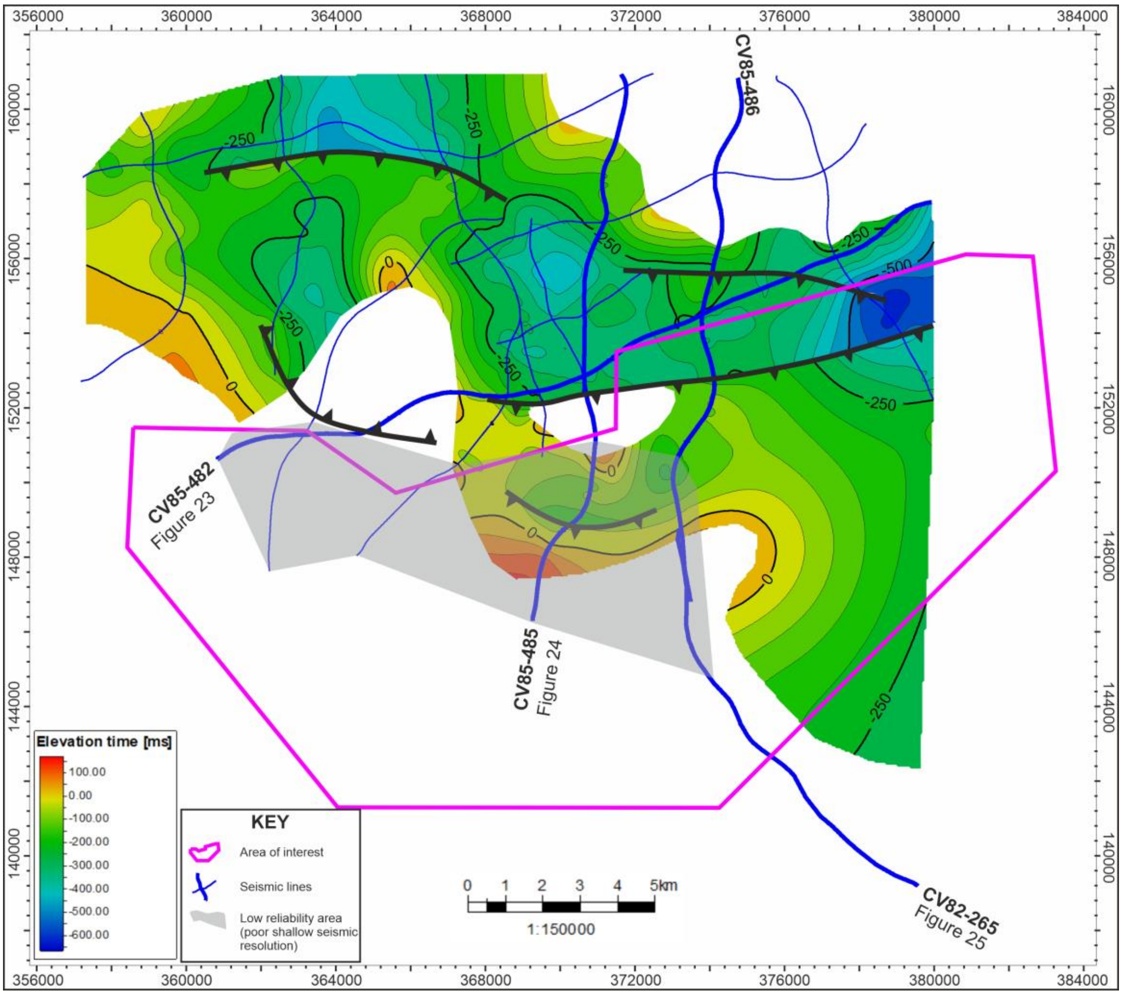

Figure 27 Surface seismic time map of the Top Pembroke Limestone Group across the Carless survey. The same structural configuration of thrusts and folds is shared with the horizon of the Top Old Red Sandstone Super Group. Contains information provided by the North Sea Transition Authority and/or other third parties.

6.3.3 Variscan Unconformity

The Variscan Unconformity is a seismic horizon (reflector) that was mapped over most of the seismic lines across the survey (Figure 28). However, as this horizon becomes shallower, it is more difficult to follow. The seismic reflector mapped as the unconformity is generally a peak (positive amplitude of the seismic wavelet), considering that the overlying strata is less compact than the underlying units that were affected by the overburden that was eroded. One of the main stratal terminations that represents this surface is the truncation of underlying seismic reflectors and discontinuities interpreted as faults. The configuration is consistent with a gap in the geological record led by erosion or non-deposition during the Variscan orogeny. Parallelism between this surface and the overlying reflectors with onlap in incised areas is another characteristic of the unconformity, which buried every compressional structure underneath. This is clearly visualised on Figure 28, where the contours are continuous. In addition, Figure 27 shows the deepest zones to the east of the survey area, which may be related to potential period of eastward tilting during the formation of the Wessex basin.

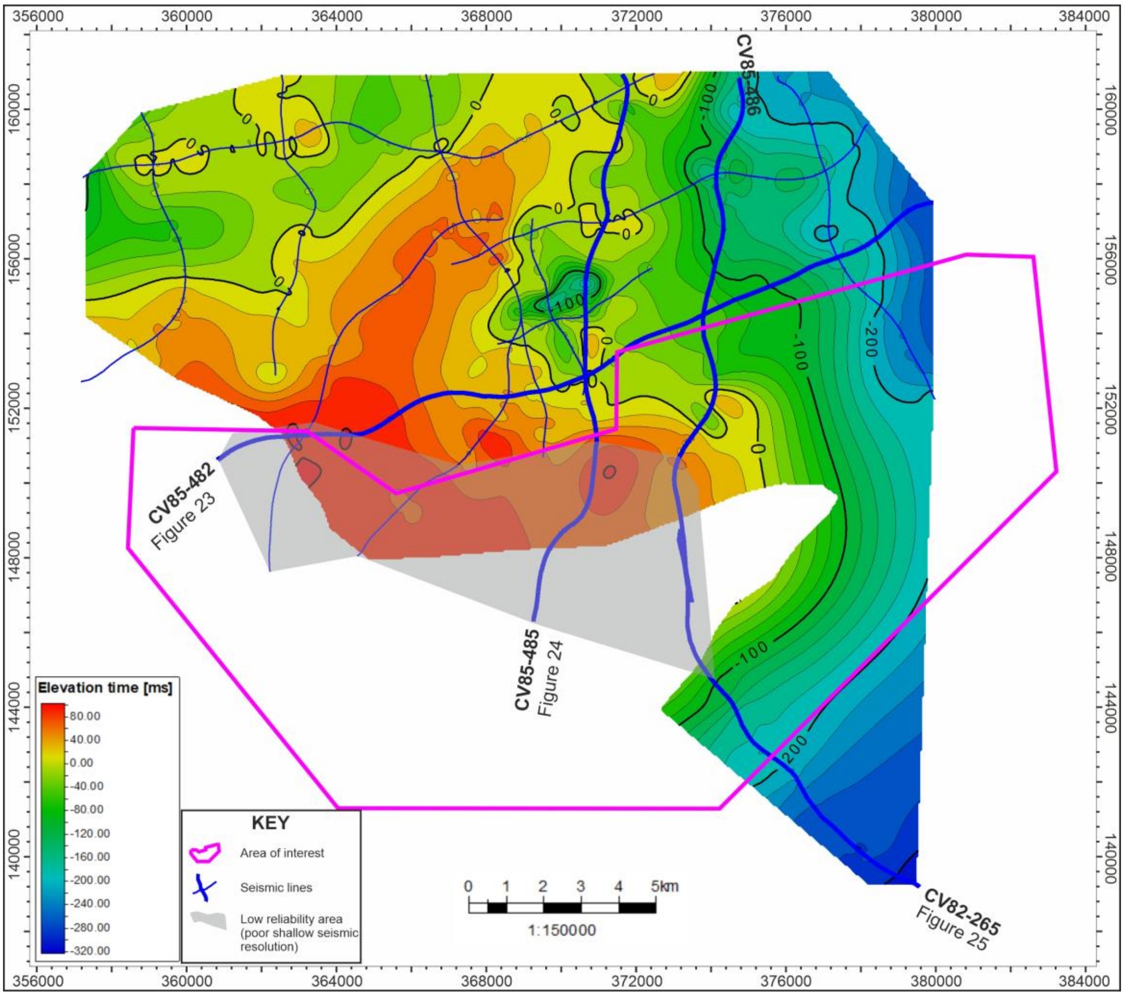

Figure 28 Surface seismic time map of the Variscan unconformity interpreted across the Carless survey. The map contours are continuous denoting a deepening to the east, and a raised area connected to the Mendip Hills. Contains information provided by the North Sea Transition Authority and/or other third parties.

7 Modelled Faults

Due to constraints of available data, the faults included in the model represent a simplified subset from faults mapped on BGS Geology 1:50 000 maps. The fault network was revised and simplified based on kinematic rules in the 3D modelling software. The simplification process was guided by the strata affected by the faults, with focus on NE-SW trending faults that displace units stratigraphically above the unconformity related to an extensional deformation phase. Because there is no information of dip or stratigraphic throw, all faults are assumed to be vertical for the modelling process.

Several thrust faults were identified from seismic data that displace the Top Pembroke Limestone Group (see section 5). The bulk of these surfaces lie outside the study volume which is why they were not included in the model. Thrust faults identified from fieldwork were mapped on a sub-model scale and are unlikely to reasonably represent the overall structural complexity within the Pembroke Limestone Group (cf. Figure 5). They will however influence groundwater flow at a local scale. Faults mapped from both seismic and field data were built as modelled objects and are provided as output along the modelled horizons.

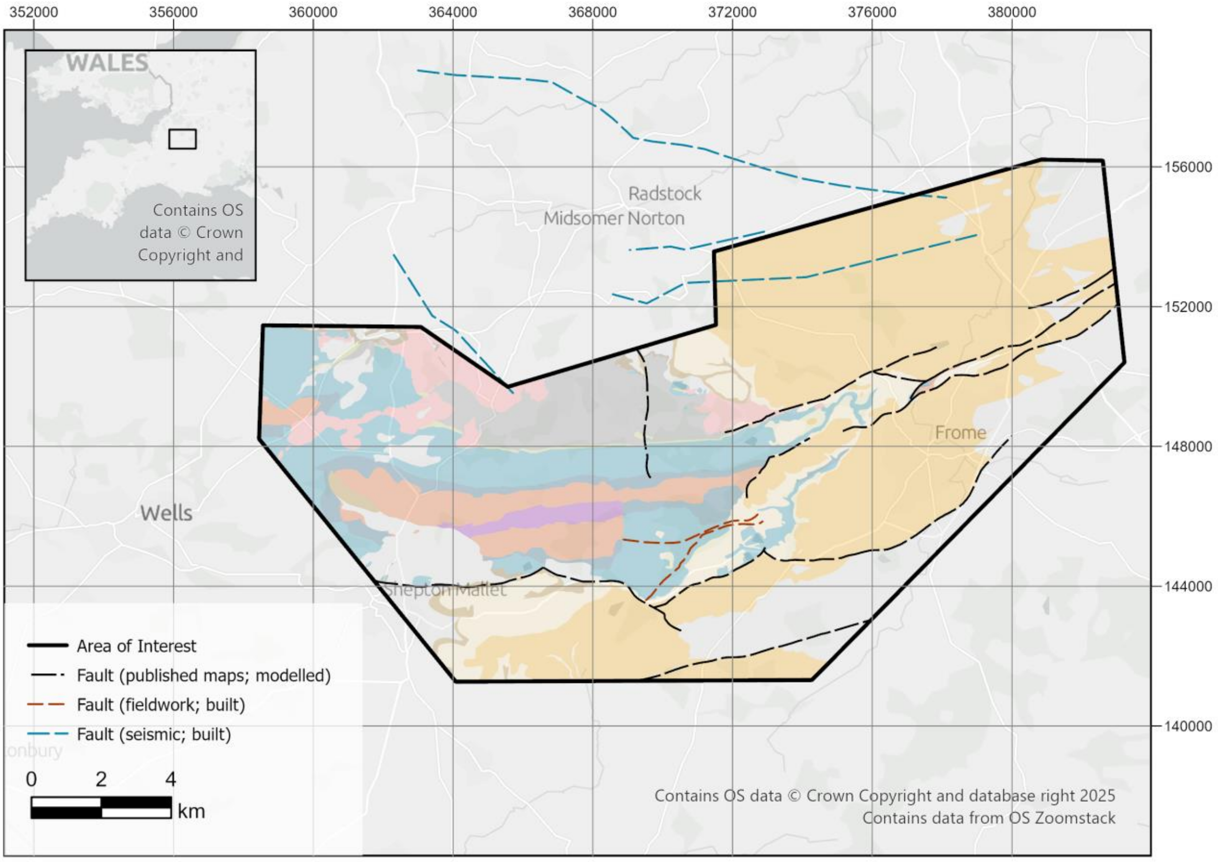

Figure 29. Selection of faults identified in the study area. Only major faults identified during fieldwork are shown. As outlined in the text, faults identified from seismic data and fieldwork shown on the map were built as surfaces but are not integrated into the model (i.e. are not affecting any surfaces). Faults from published maps shown on the map are fully integrated into the stratigraphically upper part of the model. Note that seismic faults are indicated as lines by their approximately highest part, all of which are below -100 m OD and reach up to depths of >1 km. Contains Ordnance Survey data © Crown copyright and database rights 2025. Contains data from OS Zoomstack. Contains BGS Geology 50k © UKRI 2025.

8 Data Processing and Model Workflow

The BGS 3D bedrock model for the Eastern Mendips area was constructed using Aspen SKUA™ (v14.2) using the Structure & Stratigraphy workflow. Due to the complexity of the geology and the variable spatial distribution of the control points, an implicit geological modelling method (e.g. Cowan et al., 2003) was used where all available input data are considered simultaneously to produce a continuous 3D scalar field from which geological horizons are then extracted. Geological rules were applied to ensure that stratigraphic relationships such as onlap and truncation at unconformities were honoured. The model extends down to -100 m OD.

The surfaces in Table 1 were constructed in a two-step process – each step focussing on the subset of strata on either side of the Variscan unconformity. The two sub-models were created using the available data detailed in section 5. The Palaeozoic strata comprising the tops of the (from old to young) Coalbrookdale Formation, Old Red Sandstone Supergroup, Avon Group and Pembroke Limestone Group are truncated by the Variscan unconformity and comprise the stratigraphically lower domain of the model. The stratigraphically upper domain consists of the tops of the (from old to young) Mercia Mudstone Group, Lias Group, Inferior Oolite Group and Frome Clay Formation that onlap onto the deformed Palaeozoic strata. Due to the stratigraphically limited information contained within them, boreholes only provided input to construct the upper domain of the model. The modelled surfaces mentioned above were extracted from their respective sub-model and together form the final model output.

9 Model Accuracy and Limitations

9.1 GENERAL MODELLING LIMITATIONS

- Geological interpretations are made according to the prevailing understanding of the geology at the time. The quality of such interpretations may be affected by the availability of new data, by subsequent advances in geological knowledge, improved methods of interpretation, improved databases and modelling software, and better access to sampling locations. Therefore, geological modelling is an empirical approach.

- It is important to note that this 3D geological model represents an individual interpretation of the data available; other interpretations may be valid. The full complexity of the geology may not be represented by the model due to the spatial distribution of the data at the time of model construction and other limitations including those set out elsewhere in this report.

- Best endeavours (detailed quality checking procedures) are employed to minimise data entry errors but given the diversity and volume of data used, it is anticipated that occasional erroneous entries will still be present (e.g. boreholes locations, elevations etc.) Any raw data considered when building geological models may have been transcribed from analogue to digital format. Such processes are subjected to quality control to ensure reliability; however undetected errors may exist. Borehole locations are obtained from borehole records or site plans.

- Digital elevation models (DEMs) are sourced externally by BGS and are used to cap geological models. DEMs may have been processed to remove surface features including vegetation and buildings. However, some surface features or artefacts may remain, particularly those associated with hillside forests. The digital terrain model may be sub-sampled to reduce its resolution and file size; therefore, some topographical detail may be lost.

- Geological units of any formal rank may be modelled. Lithostratigraphical (sedimentary/metasedimentary) units are typically modelled at Group, Formation or Member level, but Supergroup, Subgroup or Bed may be used.

- The geological map linework in the model files may be modified during the modelling process to remove detail or modify the interpretation where new data is available. Hence, in some cases, faults or geological units that are shown in the BGS approved digital geological map data (BGS Geology) may not appear in the geological model or vice versa. Modelled units may be coloured differently to the equivalent units in the published geological maps.

- Borehole start heights are obtained from the original records, Ordnance Survey mapping or a digital terrain model. Where borehole start heights look unreasonable, they are checked and amended, if necessary, in the index file. In some cases, the borehole start height may be different from the ground surface, if for example, the ground surface has been raised or lowered since the borehole was drilled, or if the borehole was not originally drilled at the ground surface.

- Borehole coding (including observations and interpretations) was captured in a corporate database before the commencement of modelling and any lithostratigraphic interpretations may have been re-interpreted in the context of other evidence during cross-section drawing and modelling, resulting in a mismatch between BGS databases and modelled interpretations.

9.2 MODEL SPECIFIC LIMITATIONS

- The model was constructed using relatively sparse data (cf. section 5) resulting in several horizons being only poorly constraint - particularly at greater depths. Therefore, the model is subject to significant uncertainties, especially where below 100 m below sea level.

- The Tromino® survey and field data were not used in the model because they are below model resolution. However, they do provide information about the sub-model heterogeneity.

- Seismic data in the AOI has little borehole control so the depth conversion has a high error and may have a vertical error in the 10's or 100's of meters depending on the depth and attitude of the geological unit.

- Due to the constraints in data availability, the modelled faults are a selection of mapped faults and assumed to be vertical. The modelled fault network can only represent a simplification of the regional structural complexity, which is very likely underestimating the number of fractures within the geological units. Furthermore, due to missing constraints at depth, faults are only modelled (i.e. affecting units) in the Mesozoic strata, however, seismic data indicates a higher complexity than was possible to model at lower depths.

- Geological input data such as maps and cross-sections are based on partly relatively old (+100 yrs) surveys and may therefore include interpretations that are potentially derived from outdated geological concepts, which may not be accurate.

10 Hydrogeological Significance

Groundwater flow in the East Mendip area is largely through karstic conduits within the lower Carboniferous Pembroke Limestone Group. There have been a number of studies investigating the karst hydrogeology of this region, notably water tracing work by Dr Willie Stanton and the University of Bristol (Figure 30; Barrington and Stanton, 1977; Atkinson, 1977; Atkinson et al., 1977; Stanton, 1982, Edwards et al., 1991; Newton, 2019).

Many small surface streams flowing off the Silurian and Devonian rocks on Beacon Hill sink underground along the boundary of the Avon Group ('Lower Limestone Shales') with the Black Rock

Limestone Subgroup tracer tests indicate that this water resurges at a series of springs along the flanks of the Mendips, notably the Ashwick Grove, St Dunstan's Well and the Finger valley springs on the north side of the Beacon Hill pericline, and the Seven Springs and Holwell Risings on the south side of the pericline. Some of the sinks on the north side of the pericline around Halecombe have been traced east to the Mells River Sink and on to the springs at Hapsford (Stanton, 1982).

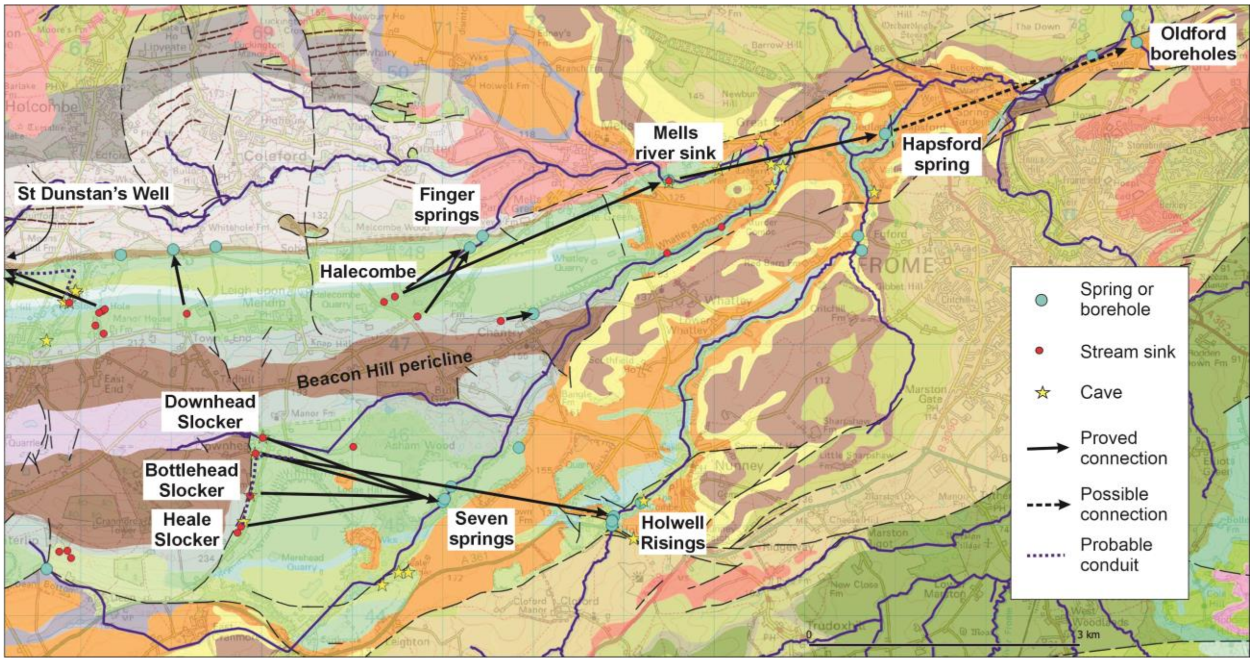

Figure 30 Proved groundwater links between stream sinks and springs from tracer test data (for example Barrington and Stanton, 1977). Geology is the published BGS 1:50,000 scale bedrock map. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.

Stanton (in Barrington and Stanton, 1977) suggested that the Oldford boreholes north of Frome is the only resurgence for all the water sinking along the north side of the pericline in dry summers when the rest of the springs are dry, but the stream sinks are still taking water. This suggests significant eastward groundwater flow in the Carboniferous limestones beneath the Mesozoic cover north of Frome, which then must transfer up into the overlying Inferior Oolite Goup limestone to reach the borehole. Evidence from caves in Cloford Quarry suggest that flow pathways in the Carboniferous limestones are able to transfer water up into the overlying Inferior Oolite Goup. Smith and Drew, (1972) describe a situation where a cave in the Carboniferous Pembroke Limestone Group passes up into the overlying Inferior Oolite Group limestone, ending in a series of small impassable conduits. This facilitates groundwater flow across the unconformity at the base of the Inferior Oolite Group.

Conduit development in karstic limestones is strongly influenced by lithology and geological structure. Strike dominated flow is favoured in steeply dipping limestones such as those on the north side of the Beacon Hill pericline, as bedding plane slip during folding creates asperities along the major bedding planes. These asperities create easy flow pathways along strike, explaining the eastward directed flow from the sinks around Halecombe and Mells to Hapsford and potentially to Oldford. Likewise, it is likely that karstic conduits from the sinks west of Torr Works quarry (for example, Bottlehead Slocker & Downhead Slocker) will be guided by key bedding planes ('inception horizons') and faults/fractures within the limestones.

The East Mendips 3D geological model provides the overarching architecture of the major lithological units in the east Mendips. It cannot be used to predict flow pathways through the limestones. These will be guided by sub-model scale heterogeneities such as smaller faults, fractures, bedding planes and other discontinuities. However, it does indicate where the Carboniferous limestones may be present in the subsurface, and where groundwater connectivity between recharge zones and springs may (or may not) be present, for example the boreholes at Oldford and the thermal springs at Bath.

11 Model Uncertainty

The geological complexity within the AOI and the lack of subsurface data means that there is more uncertainty in this model than in similar models in more flat lying strata. This is particularly true for any steeply dipping units as slight variations in the dip angle can affect the surface when it is projected into the subsurface.

It should be noted that the scale of the model and the thickness of the units modelled (to Group level as specified rather than individual formations) may limit the applicability of the model for site specific hydrogeological investigations. Please also note the limitations of the model and the data used to generate it (see section 9), in particular the lack of good quality deep borehole data and limited seismic data availability for the eastern Mendips. The lack of borehole control points, particularly for the Palaeozoic strata beneath the Triassic unconformity, limits what can be modelled and at what resolution. A detailed model at the formation scale will require significantly more data, particularly good quality borehole and seismic data (see section 12).

The modelling process also affects the horizontal accuracy (the geographical extent) of the modelled surfaces, as it simplifies the topography and the rockhead (base of the superficial deposits) surface. So, even though the 1:50 000 scale geological map linework (which shows where a horizon is known or expected to outcrop at rockhead) is used as an input to the model, the final modelled surfaces may show a significantly different outcrop pattern. Finally, fieldwork (section 3) highlighted a degree of geological complexity which is below the resolution of the model.

12 Recommendations for Future Work

As discussed above, the accuracy of the model is limited by a lack of data in key regions, in particular our understanding of the geology at depth beneath the North Somerset coalfield.

- To reduce the model uncertainty, we recommend deep >500 m boreholes to be drilled near to the seismic profile lines to the north of the current model.
- Shoot modern vibraseismic associated with the boreholes, optimised to key areas of interest and tuned to depth required.
- Build several different models at scales that capture the complexity in the geology.
- Conduct additional passive seismic surveys in the area north of Frome combined with new borehole data (or better down-hole imagery and geophysical logs) to provide more information on the Carboniferous limestones beneath the Jurassic strata.

The recommendation mentioned above would significantly reduce the uncertainty of the model. Without this there is a limit to how far the model is able to answer more specific questions about the subsurface.

13 Model Outputs

All modelled surfaces are delivered as ASCII grids (.asc) which are suitable for importing into common GIS software such as ArcGIS Pro. In addition, TSurf (.ts) files are provided for all modelled surfaces and larger faults identified during field surveys (see section 7).

Surfaces trimmed to -100 m OD

ASCII Grid	TSurf
top_avo_100mbsl.asc	Top_AVO_100mbsl.ts
top_cbrd_100mbsl.asc	Top_CBRD_100mbsl.ts
top_frc_100mbsl.asc	Top_FRC_100mbsl.ts
top_ino_100mbsl.asc	Top_INO_100mbsl.ts
top_li_100mbsl.asc	Top_LI_100mbsl.ts
top_mmg_100mbsl.asc	Top_MMG_100mbsl.ts
top_ors_100mbsl.asc	Top_ORS_100mbsl.ts
top_pemb_100mbsl.asc	Top_PEMB_100mbsl.ts
top_vu_100mbsl.asc	Top_VU_100mbsl.ts

Surfaces to full modelled depth (note uncertainty increases below -100 m OD)

ASCII Grid	TSurf
top_avo_fulldepth.asc	Top_AVO_FullDepth.ts
top_cbrd_fulldepth.asc	Top_CBRD_FullDepth.ts
top_frc_fulldepth.asc	Top_FRC_FullDepth.ts
top_ino_fulldepth.asc	Top_INO_FullDepth.ts
top_li_fulldepth.asc	Top_LI_FullDepth.ts
top_mmg_fulldepth.asc	Top_MMG_FullDepth.ts
top_ors_fulldepth.asc	Top_ORS_FullDepth.ts
top_pemb_fulldepth.asc	Top_PEMB_FullDepth.ts
top_vu_fulldepth.asc	Top_VU_FullDepth.ts

Vertical faults

- VerticalFaultNetwork.ts

Thrust faults

- Seismic_Thrust1.ts
- Seismic_Thrust2.ts
- Seismic_Thrust3.ts
- Seismic_Thrust4.ts

- Surface_Thrust1.ts
- Surface_Thrust2.ts

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Appendix 1

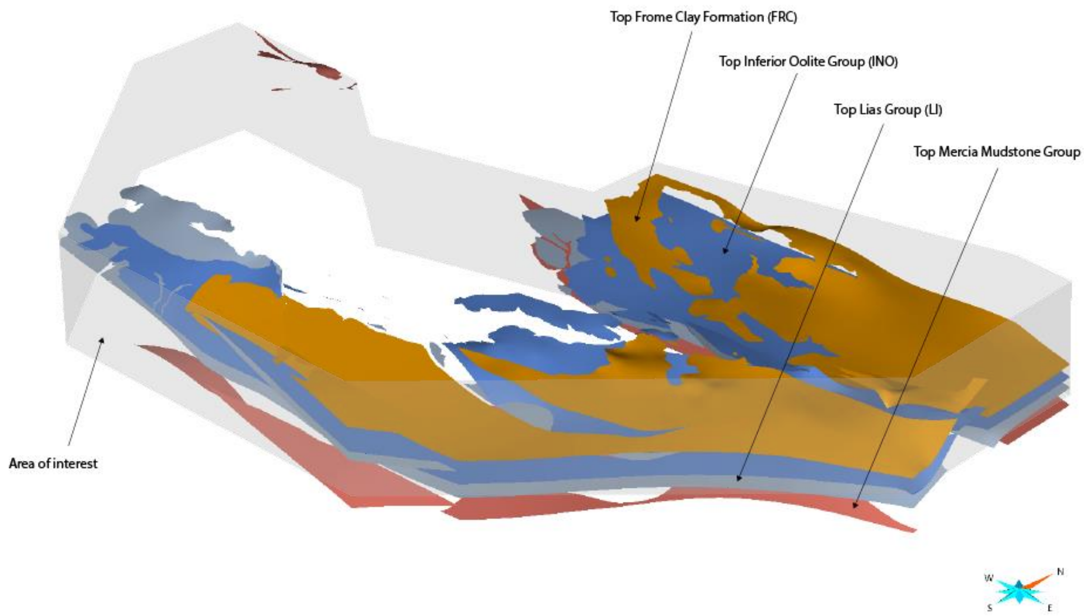


Figure 31. Screenshot of modelled Mesozoic surfaces in Aspen SKUA^{TM} shown with a 10x vertical exaggeration. Depth cutoff is 1000 mbsl.

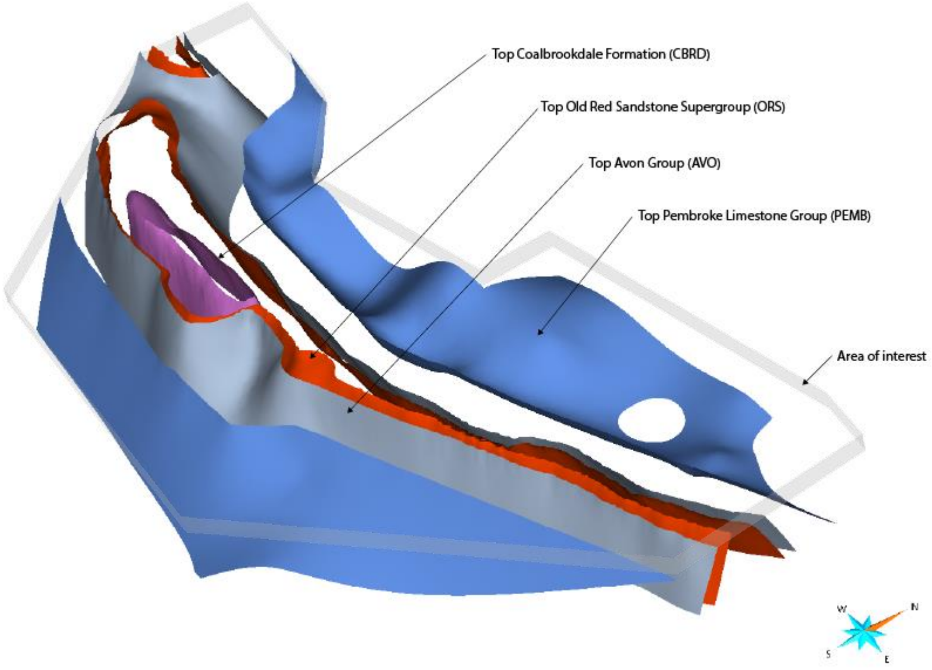
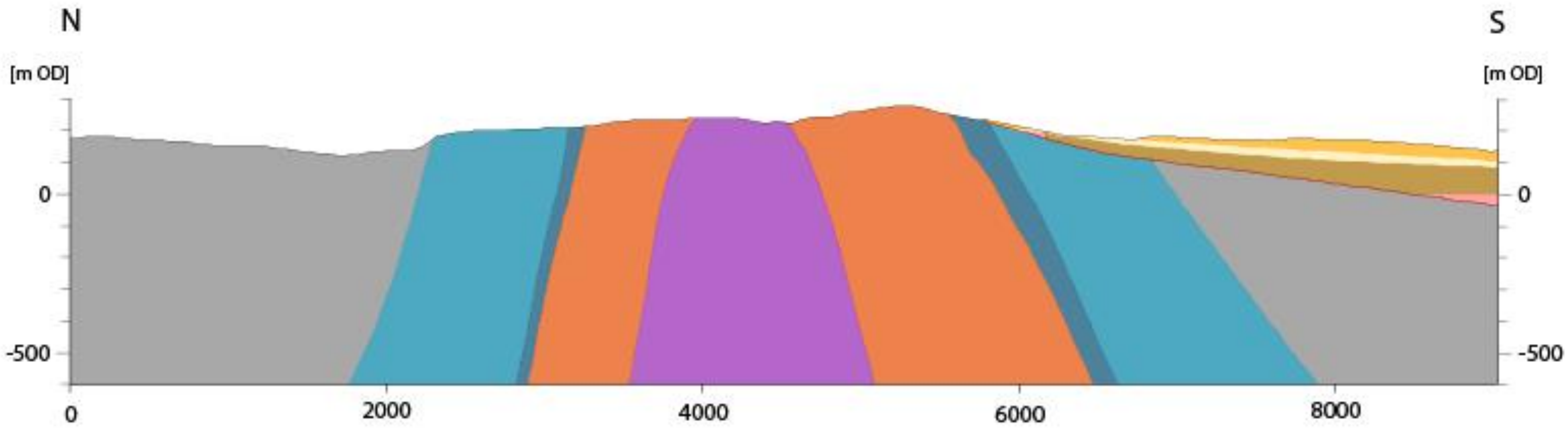


Figure 32. Screenshot of modelled Palaeozoic surfaces in Aspen SKUA shown with a 2x vertical exaggeration. Depth cutoff is 1000 mbsl

Section A



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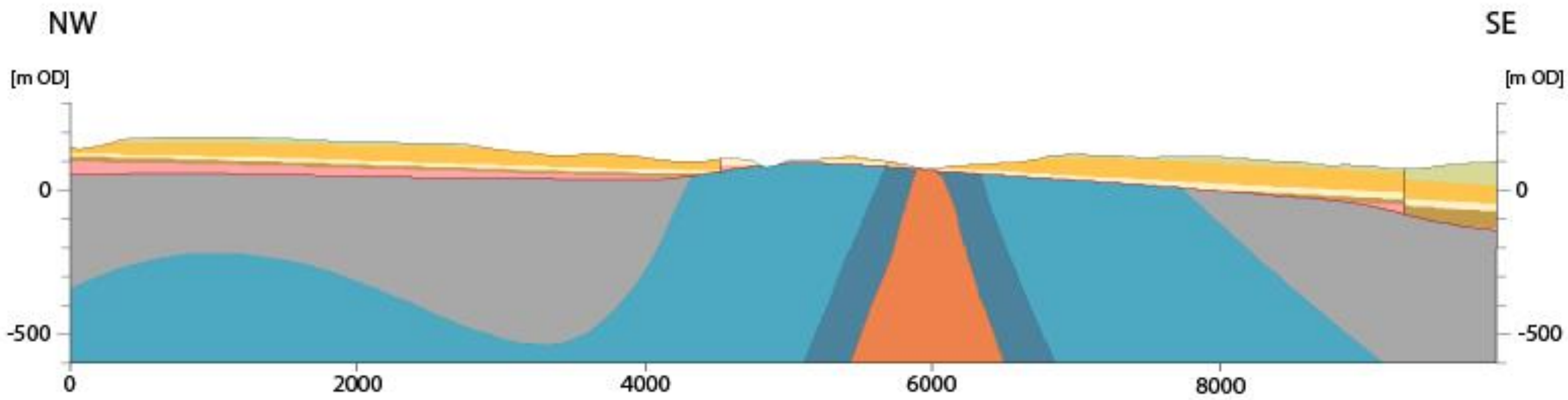
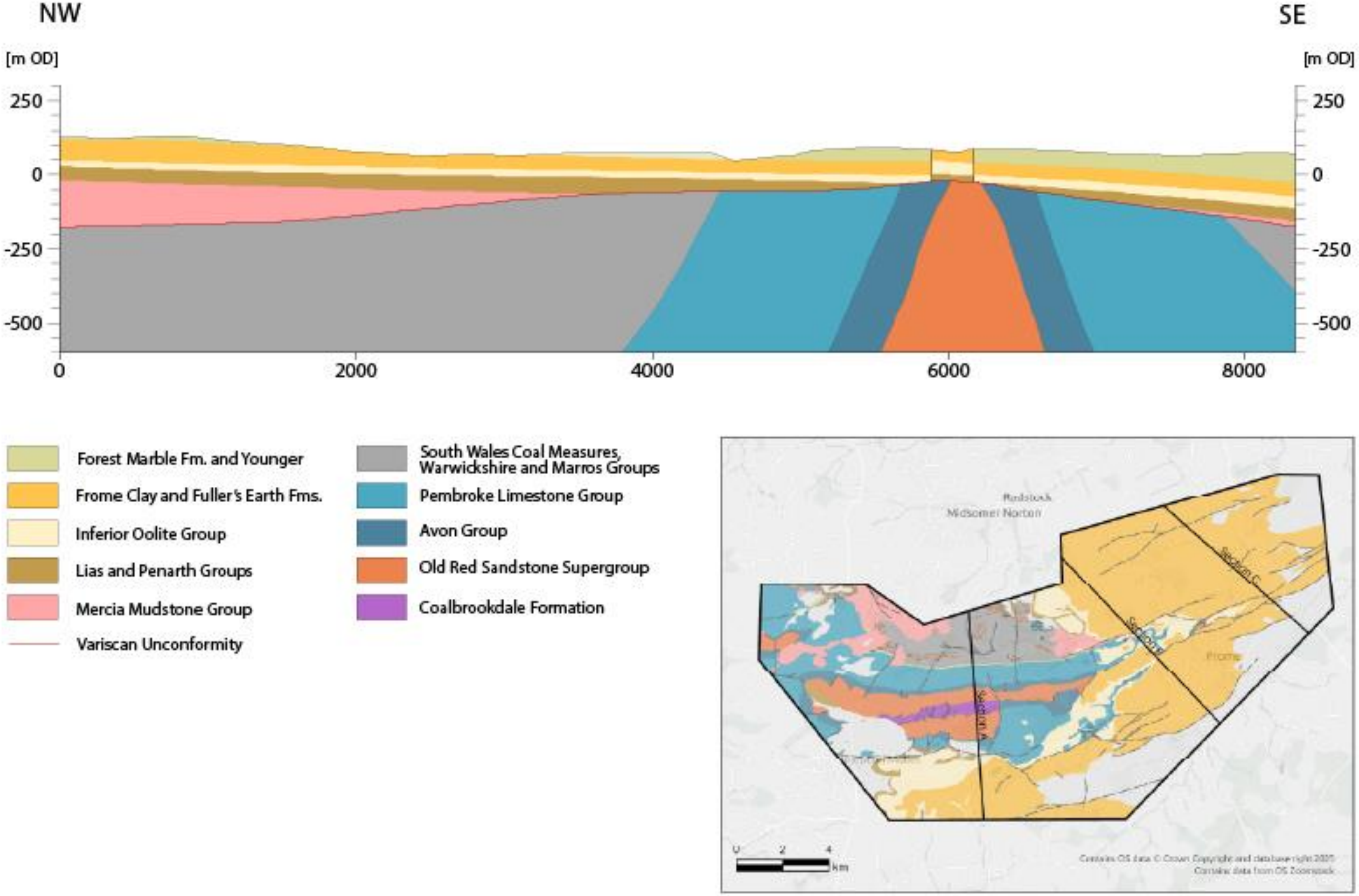


Section C


NW
SE
[m OD]
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250
0
-250
-500
0
2000
4000
6000
8000
Forest Marble Fm. and Younger
Frome Clay and Fuller's Earth Fms.
Inferior Oolite Group
Lias and Penarth Groups
Mercia Mudstone Group
Variscan Unconformity
South Wales Coal Measures, Warwickshire and Marros Groups
Pembroke Limestone Group
Avon Group
Old Red Sandstone Supergroup
Coalbrookdale Formation
Radstock
Midsomer Norton
Section C
Frome
km

Figure 33. Selected cross-sections through the 3D geological model. See inset map for cross section location. Contains Ordnance Survey data © Crown copyright and database rights 2025. Contains data from OS Zoomstack. Contains BGS Geology 50k © UKRI 2025.

Appendix 2

Table 3. Boreholes used in the model.

BGS ID	SOBI ID	BNG Easting	BNG Northing	Drilled Depth [m]	Stratigraphic Horizon	Depth [m]
390267	ST64NW1	364920	149710	28.65	Unconformity	28.65
390268	ST64NW2	364820	149570	21.95	Unconformity	21.95
390299	ST64SE6	367930	141180	22.47	Top Inferior Oolite Group	9.91
390299	ST64SE6	367930	141180	22.47	Top Lias Group	22.47
390342	ST64SW22	362890	143620	19.96	Unconformity	19.96
390481	ST65SW4	362250	151740	79.00	Unconformity	79.00
390482	ST65SW5	362120	151590	72.48	Top Mercia Mudstone Group	6.61
390482	ST65SW5	362120	151590	72.48	Unconformity	72.48
390483	ST65SW6	364790	150570	46.33	Unconformity	46.33
390484	ST65SW7	362680	151370	94.00	Unconformity	94.00
392412	ST74NE31	378340	147600	100.28	Top Fuller's Earth (NOT MODELLED)	20.73
392412	ST74NE31	378340	147600	100.28	Top Inferior Oolite Group	78.64
392412	ST74NE31	378340	147600	100.28	Top Lias Group	100.28
392422	ST74NE41	378420	147690	106.68	Top Inferior Oolite Group	83.52
392422	ST74NE41	378420	147690	106.68	Top Lias Group	106.68
392539	ST74SW8	372390	143400	122.00	Top Frome Clay Formation	36.00
392539	ST74SW8	372390	143400	122.00	Top Fuller's Earth (NOT MODELLED)	95.00
392539	ST74SW8	372390	143400	122.00	Top Inferior Oolite Group	108.50
392539	ST74SW8	372390	143400	122.00	Top Lias Group	122.00
392542	ST74SW11	370400	144700	3.30	Unconformity	3.30
392555	ST75NE11	377580	155610	117.80	Top Fuller's Earth (NOT MODELLED)	55.17
392555	ST75NE11	377580	155610	117.80	Top Lias Group	117.80
392616	ST75SE2	378050	150260	40.49	Top Inferior Oolite Group	10.26
392616	ST75SE2	378050	150260	40.49	Top Lias Group	29.26
392616	ST75SE2	378050	150260	40.49	Unconformity	40.49
392617	ST75SE3	378000	150140	30.66	Top Inferior Oolite Group	5.59
392617	ST75SE3	378000	150140	30.66	Top Lias Group	23.62
392617	ST75SE3	378000	150140	30.66	Unconformity	30.66
392619	ST75SE5	378540	150910	46.53	Top Inferior Oolite Group	30.43
392619	ST75SE5	378540	150910	46.53	Top Lias Group	46.53
392620	ST75SE6	378560	150630	70.51	Top Inferior Oolite Group	25.10
392620	ST75SE6	378560	150630	70.51	Top Lias Group	43.13
392620	ST75SE6	378560	150630	70.51	Unconformity	70.51
392621	ST75SE7	375910	150170	85.34	Top Lias Group	48.77
392621	ST75SE7	375910	150170	85.34	Top Mercia Mudstone Group	85.34
392637	ST75SW1	372470	152960	102.41	Top Inferior Oolite Group	26.52

392637	ST75SW1	372470	152960	102.41	Top Lias Group	38.40
392637	ST75SW1	372470	152960	102.41	Top Mercia Mudstone Group	60.05
392637	ST75SW1	372470	152960	102.41	Unconformity	102.41
392642	ST75SW6	371140	150090	8.47	Top Lias Group	3.35
392642	ST75SW6	371140	150090	8.47	Unconformity	8.47
392643	ST75SW7	374460	150790	88.15	Top Inferior Oolite Group	46.63
392643	ST75SW7	374460	150790	88.15	Top Lias Group	63.09
392643	ST75SW7	374460	150790	88.15	Top Penarth Group (NOT MODELLED)	84.40
392643	ST75SW7	374460	150790	88.15	Top Mercia Mudstone Group	88.15
392652	ST75SW16	374390	153950	94.55	Top Frome Clay Formation	33.88
392652	ST75SW16	374390	153950	94.55	Top Inferior Oolite Group	81.04
392652	ST75SW16	374390	153950	94.55	Top Lias Group	94.55
395668	ST85NW4	381130	157220	86.56	Top Lias Group	86.56
395703	ST85SE1	386150	151950	465.12	Top Inferior Oolite Group	302.82
395703	ST85SE1	386150	151950	465.12	Top Lias Group	341.99
395703	ST85SE1	386150	151950	465.12	Top Penarth Group (NOT MODELLED)	395.25
395703	ST85SE1	386150	151950	465.12	Top Mercia Mudstone Group	408.58
395703	ST85SE1	386150	151950	465.12	Unconformity	465.12
395726	ST85SE24	386100	151900	465.12	Top Inferior Oolite Group	302.82
395726	ST85SE24	386100	151900	465.12	Top Lias Group	341.99
395726	ST85SE24	386100	151900	465.12	Top Penarth Group (NOT MODELLED)	395.25
395726	ST85SE24	386100	151900	465.12	Top Mercia Mudstone Group	408.58
395726	ST85SE24	386100	151900	465.12	Unconformity	465.12
395773	ST85SW1	382290	152320	112.60	Top Frome Clay Formation	40.88
395773	ST85SW1	382290	152320	112.60	Top Inferior Oolite Group	94.79
395773	ST85SW1	382290	152320	112.60	Top Lias Group	112.60

Appendix 3

Table 4 provides the location and elevation of each data point along the four passive seismic transects in OSGB coordinates.

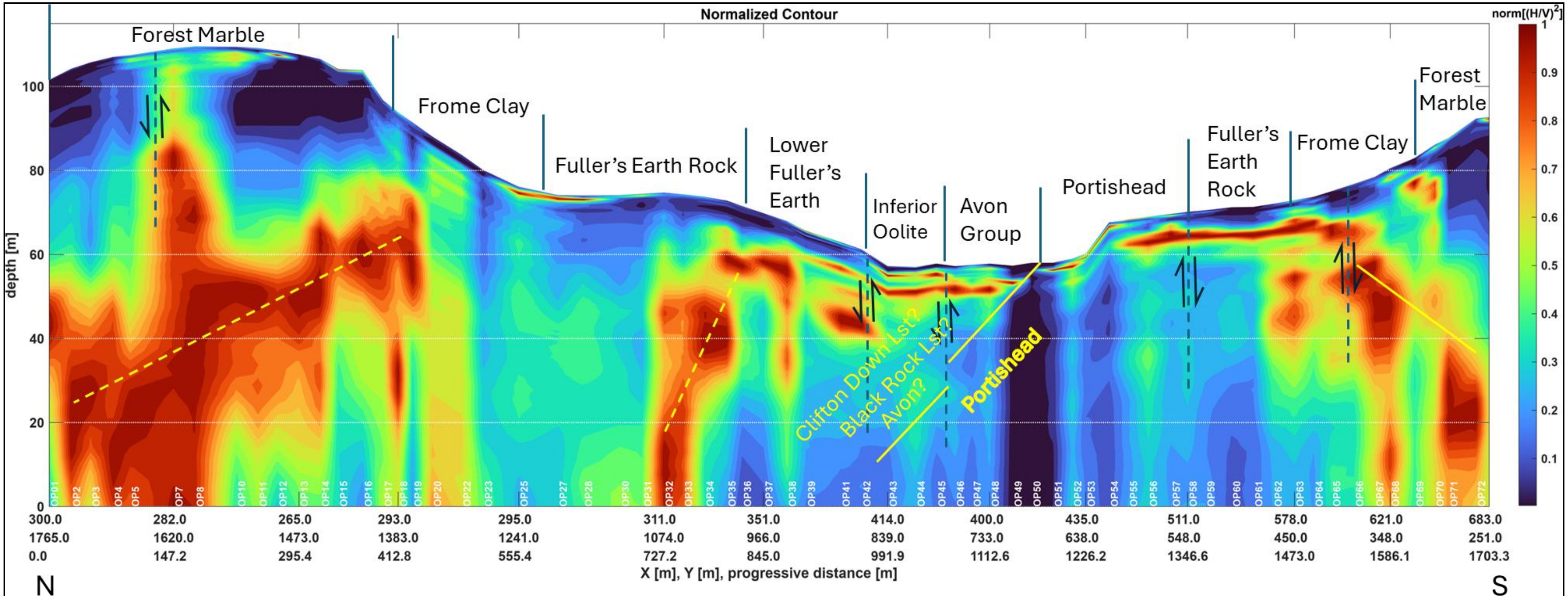
STN ID	East	North	Elev	STN ID	East	North	Elev
EM01	375718	148798	95.8	GE01	374941	149144	96.4
EM02	375740	148788	96.9	GE02	374984	149128	98.8
EM03	375755	148777	97.1	GE03	375024	149113	99.7
EM04	375780	148775	97.0	GE04	375077	149097	100.7
EM05	375805	148767	97.0	GE05	375114	149073	100.8
EM06	375823	148756	96.8	GE06	375151	149053	100.7
EM07	375844	148758	96.6	GE07	375201	149028	100.3
EM08	375875	148736	96.1	GE08	375226	148999	100.5
EM09	375899	148729	97.0	GE09	375276	148974	100.0
EM10	375922	148726	98.6	GE10	375313	148955	99.2
EM11	375941	148713	100.7	GE11	375349	148920	98.5
EM12	375963	148701	102.5	GE12	375379	148882	98.1
EM13	375987	148709	104.4	GE13	375428	148868	96.2
EM14	376011	148693	106.0	GE14	375463	148834	96.5
EM15	376032	148690	107.8	GE15	375485	148796	96.5
EM16	376051	148687	109.6				
EM17	376074	148675	111.4				
EM18	376099	148672	114.3				
EM19	376120	148669	115.8				
EM20	376138	148668	116.8				
EM21	376165	148668	118.1				
EM22	376186	148667	119.1				
EM23	376213	148660	119.9				
EM24	376234	148664	120.6				
EM25	376258	148666	121.1				
EM26	376288	148657	122.6				
EM27	376307	148659	123.2				
EM28	376333	148660	123.7				
EM29	376357	148660	124.1				
EM30	376376	148659	124.9				
EM31	376404	148657	125.6				
EM32	376432	148655	126.2				
EM33	376452	148649	126.8				
EM34	376479	148645	126.7				
EM35	376502	148639	126.0				
EM36	376522	148633	124.8				
EM37	376552	148630	123.7				
EM38	376572	148623	123.0				
EM39	376593	148615	121.7				

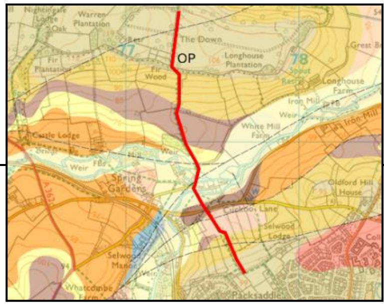
STN ID	East	North	Elev	STN ID	East	North	Elev
OP01	377300	150765	103.0	VF01	376105	149551	76.2
OP02	377303	150739	105.7	VF02	376093	149533	77.3
OP03	377297	150717	107.2	VF03	376075	149516	77.8
OP04	377292	150691	108.5	VF04	376066	149498	78.1
OP05	377290	150671	108.9	VF05	376052	149477	77.9
OP06	377288	150646	110.0	VF06	376044	149454	80.4
OP07	377282	150620	110.5	VF07	376032	149432	79.5
OP08	377279	150595	111.0	VF08	376027	149413	81.7
OP09	377281	150569	111.1	VF09	376033	149390	84.1
OP10	377277	150546	110.9	VF10	376040	149366	87.3
OP11	377272	150521	110.6	VF11	376048	149348	89.6
OP12	377269	150498	110.0	VF12	376055	149329	91.6
OP13	377265	150473	109.1	VF13	376064	149306	93.0
OP14	377258	150449	108.0	VF14	376074	149284	95.1
OP15	377268	150430	105.6	VF15	376085	149264	95.4
OP16	377296	150422	105.3	VF16	376100	149243	96.3
OP17	377287	150400	98.2	VF17	376115	149223	97.5
OP18	377293	150383	95.3	VF18	376128	149204	98.2
OP19	377293	150366	92.9	VF19	376143	149184	99.0
OP20	377294	150343	89.6	VF20	376158	149164	99.6
OP21	377296	150328	87.8	VF21	376169	149147	100.3
OP22	377294	150308	85.2	VF22	376187	149127	101.8
OP23	377290	150283	81.6	VF23	376202	149110	103.2
OP24	377296	150263	79.2	VF24	376213	149092	105.9
OP25	377295	150241	77.6	VF25	376228	149073	109.3
OP26	377296	150214	75.7	VF26	376242	149052	112.0
OP27	377285	150196	75.6	VF27	376256	149025	113.4
OP28	377286	150166	75.5	VF28	376272	149013	113.6
OP29	377290	150147	75.5	VF29	376278	148985	113.2
OP30	377298	150124	75.6	VF30	376289	148964	112.9
OP31	377302	150098	75.9	VF31	376301	148945	112.8
OP32	377311	150074	76.2	VF32	376307	148920	112.7
OP33	377316	150052	75.8	VF33	376325	148905	113.2
OP34	377325	150028	75.2	VF34	376340	148885	115.6
OP35	377339	150006	74.3	VF35	376349	148865	116.8
OP36	377338	149988	73.0	VF36	376360	148843	116.8
OP37	377351	149966	71.3	VF37	376374	148829	118.0
OP38	377368	149944	69.4	VF38	376397	148812	117.5
OP39	377380	149925	67.1	VF39	376414	148798	117.4
OP40	377385	149908	65.9	VF40	376435	148786	117.5
OP41	377407	149894	64.4	VF41	376457	148772	118.2
OP42	377411	149870	62.7	VF42	376471	148756	119.0
OP43	377414	149839	58.7	VF43	376491	148740	120.1
OP44	377412	149806	58.5	VF44	376510	148722	122.2
OP45	377407	149782	59.3	VF45	376525	148706	123.7
OP46	377394	149764	58.7	VF46	376541	148691	123.9
OP47	377384	149747	59.0	VF47	376559	148674	122.4
OP48	377400	149733	59.3	VF48	376573	148657	121.6

STN ID	East	North	Elev	STN ID	East	North	Elev
OP49	377402	149706	58.8	VF49	376589	148645	121.1
OP50	377406	149684	59.5	VF50	376609	148622	120.6
OP51	377410	149659	59.5	VF51	376629	148607	120.2
OP52	377419	149638	60.5				
OP53	377435	149638	61.7				
OP54	377458	149623	69.1				
OP55	377475	149608	69.8				
OP56	377489	149589	70.5				
OP57	377503	149566	71.1				
OP58	377511	149548	71.6				
OP59	377522	149530	72.0				
OP60	377538	149504	72.7				
OP61	377563	149496	72.8				
OP62	377572	149475	73.5				
OP63	377578	149450	74.4				
OP64	377592	149432	75.2				
OP65	377600	149413	76.5				
OP66	377603	149386	78.3				
OP67	377616	149366	79.9				
OP68	377621	149348	82.0				
OP69	377631	149321	84.4				
OP70	377649	149305	87.6				
OP71	377657	149291	89.2				
OP72	377672	149262	93.8				
OP73	377683	149251	94.2				

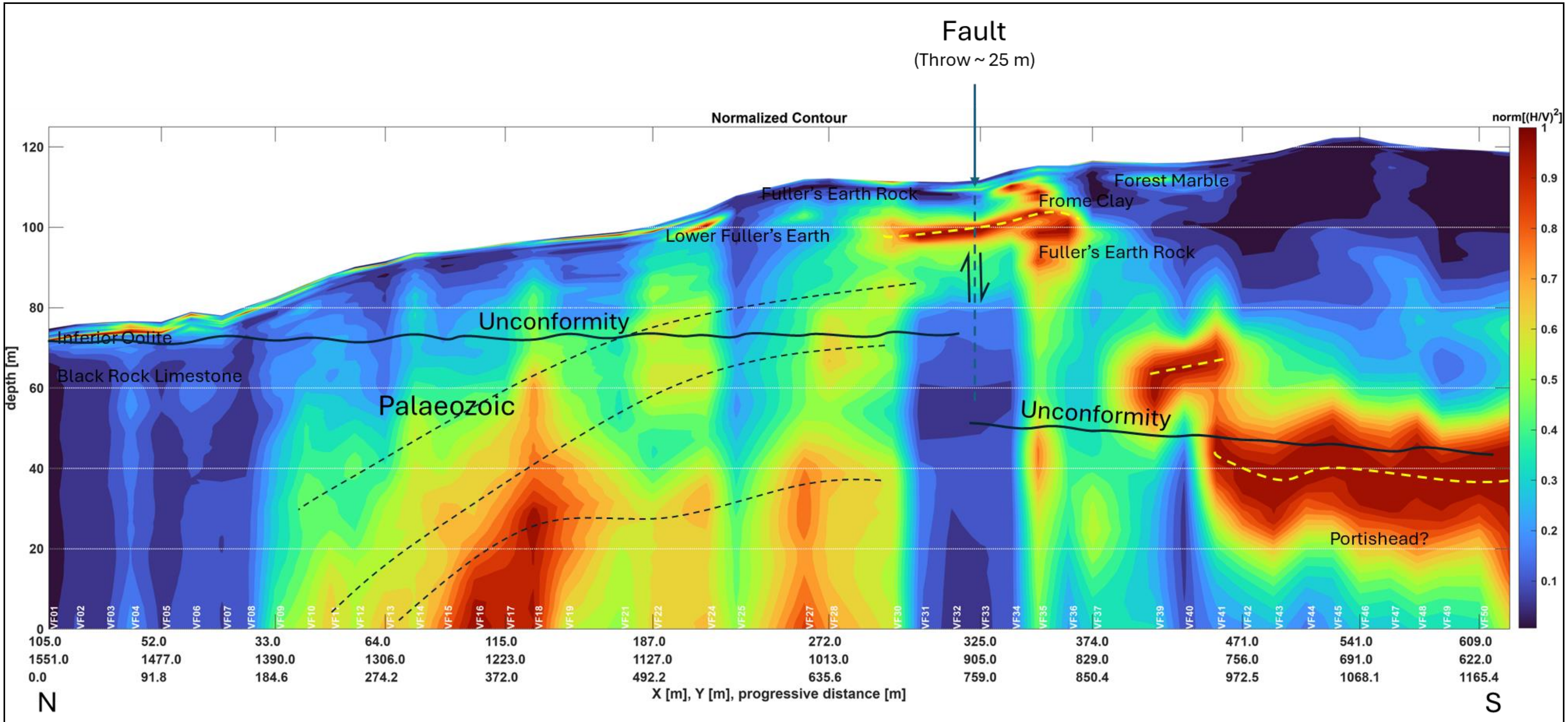
Appendix 4

Enlarged figures from the passive seismic sections.

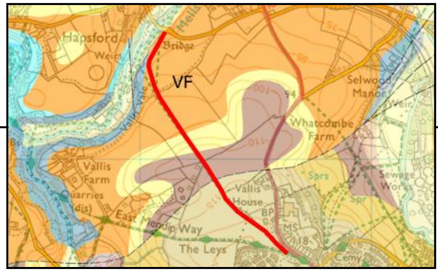




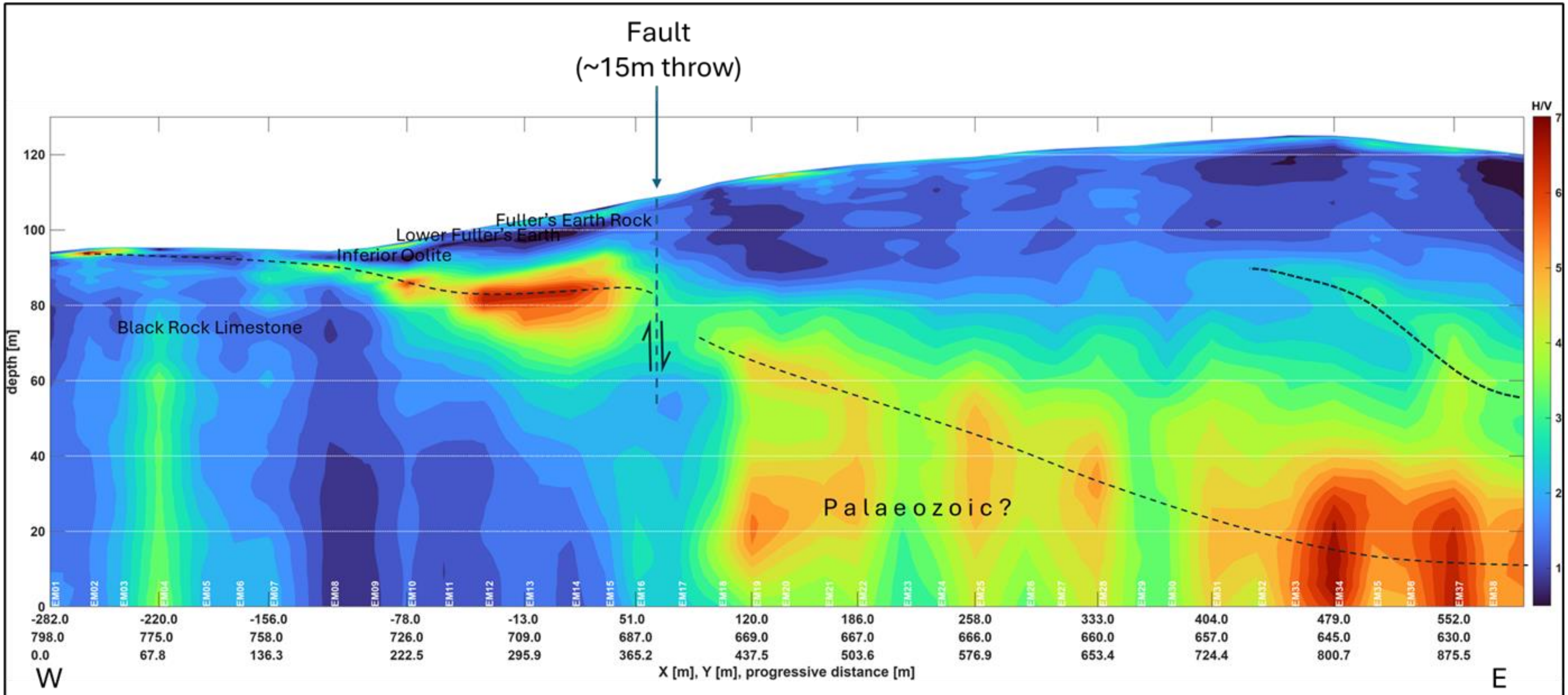
Location map and HV contour plot for line OP (Orchardleigh Park). Mapped surface geology is shown, and mapped faults with sense of throw (vertical black lines). Geological units described in yellow writing are inferred from geological mapping and borehole information. The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.



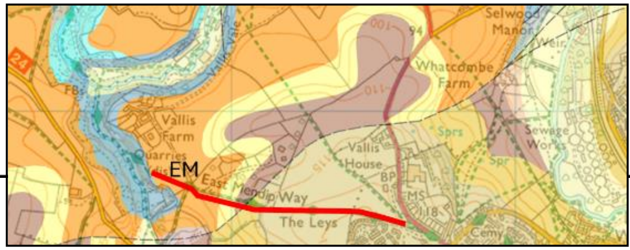
Line VF
Vs 102 exp 0.58



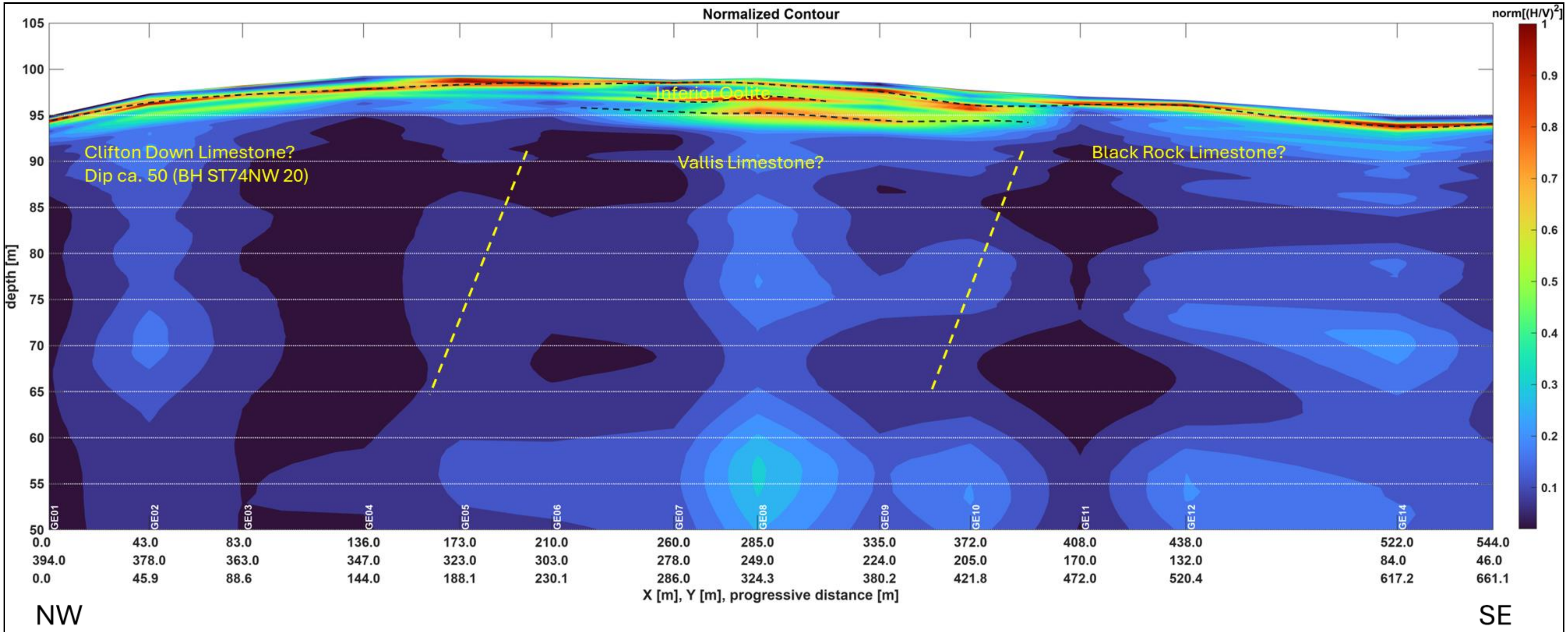
Location map and HV contour plot for line VF (Vallis Farm). Surface and sub-surface geology is shown, and a mapped fault shown as a vertical dashed line, with sense of throw indicated. Other dashed lines (both black and yellow) highlight H/V peaks, inferred to be the interface of stronger rock underlying relatively weak rock. The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.



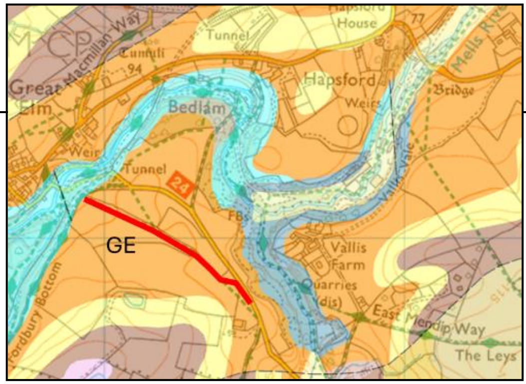
Line EM
Vs 150 exp0.50



Location map and HV contour plot for line EM (East Mendip). Surface and sub-surface geology is shown, and a mapped fault shown as a vertical dashed line, with sense of throw indicated. Other dashed lines highlight H/V peaks, inferred to be the interface of stronger rock underlying relatively weak rock. The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI 2025.



Line GE
Vs 105 exp 0.58



Location map and HV contour plot for line GE (Great Elm). Inferior Oolite is mapped at surface but is presumed to be very thin due to underlying rocks outcropping in the adjacent valley. Sub-cropping Clifton Down Limestone, Vallis Limestone and Black Rock Limestone (marked in yellow) have been extrapolated from the nearby mapped geology. The geology shown is that on the published 1:50 000 scale geological maps. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. OS AC0000824781. Contains BGS Geology 50k © UKRI