The Isle of Wedmore Relay Ramp: how fault evolution created King Alfred's historic landmark

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Abstract

Isle of Wedmore covers an area of ~ 19 km^2, rises up to ~ 65 m above the surrounding lowlands of the Somerset Levels, and was an island until the Middle Ages. The topography is interpreted as having been formed by a relay ramp between two right-stepping faults (the Weare Fault to the west and the Mudgley Fault to the east) which have tens of metres of downthrow to the south, and which are probably normal faults. The relay ramp has a dip of about 3° to the SW and is breached by the NW-striking Wedmore Fault, which has up to ~ 23 m downthrow to the NE. Several NE-trending faults occur in the relay ramp, which are interpreted as having formed when the relay ramp became a contractional step when the Weare and Mudgley faults underwent sinistral reactivation, or as N-S contraction occurred during the Cenozoic. Analogues for this behaviour are presented from the Liassic rocks on the coast between Lilstock and East Quantoxhead.

Keywords: Isle of Wedmore; faults; relay ramp; reactivation

1. Introduction

The Isle of Wedmore (51°13'39.74"N, 2°48'39.69"W; Figure 1) is a rhomb-shaped cuesta up to 72 m high above mean sea level, rising ~ 65 m above the surrounding Somerset Levels. The highest point is at Bagley Reservoir (51°12′36.83″N, 2°47′20.58″W). Note that heights here are given above mean sea level, using data for triangulation stations obtained from https://www.ordnancesurvey.co.uk/legacy/docs/gps/CompleteTrigArchive.zip (downloaded on 19th January 2023). The Isle of Wedmore covers an area of ~ 19 km^2, in the Sedgemoor district of Somerset, UK. The NE boundary is the escarpment (~ 8.5 km long) and the SW side is the lee slope (~ 7.2 km long). The northern (~ 2.9 km long) and southern (~ 6.6 km long) boundaries are the Weare and Mudgley faults, respectively.

Flint artefacts from the Isle of Wedmore indicate human presence from at least the Neolithic period onwards (Gathercole, 2003). Wooden trackways between the Isle of Wedmore and the Polden Hills, ~ 11 km to the south, dating from the first millennium BC. indicating settlements on these uplands (Coles, 1972). Evidence of Roman and Saxon farming has been recorded (Gathercole, 2003). Although the Romans began draining the Somerset Levels (Ripon et al., 2000), the main periods of drainage activity were from 1230 to 1330, from 1770 to 1830, and from 1939 onwards (Williams, 1963, 1970). The swampy, inaccessible Somerset Levels were therefore an ideal location for King Alfred the Great to hide from the invading Vikings. Gathercole (2003) states that "Wedmore" is thought to derive from the Saxon “Hunting Moor”, and suggests that there would have been a royal hunting lodge and a church (probably of minster status) by 878 AD. This was when the Treaty of Wedmore was ratified between King Alfred and the defeated Danes by the christening and confirmation of the Danish leader, Guthrum, at Wedmore (Asser, 893). We propose that the structural history of the area created the landmark that hosted one of the key moments in English history, when peace was established between the Anglo-Saxons and Vikings, and the Danelaw in eastern England was recognised.

The aims of this paper are to present a structural model for the Isle of Wedmore, including how the structure controls the topography, and to illustrate this model with analogues from the Liassic rocks of the Somerset coast, between Lilstock (51°12'9.10"N, 3°10'3.43"W) and East Quantoxhead (51°11'19.64"N, 3°14'52.09"W).

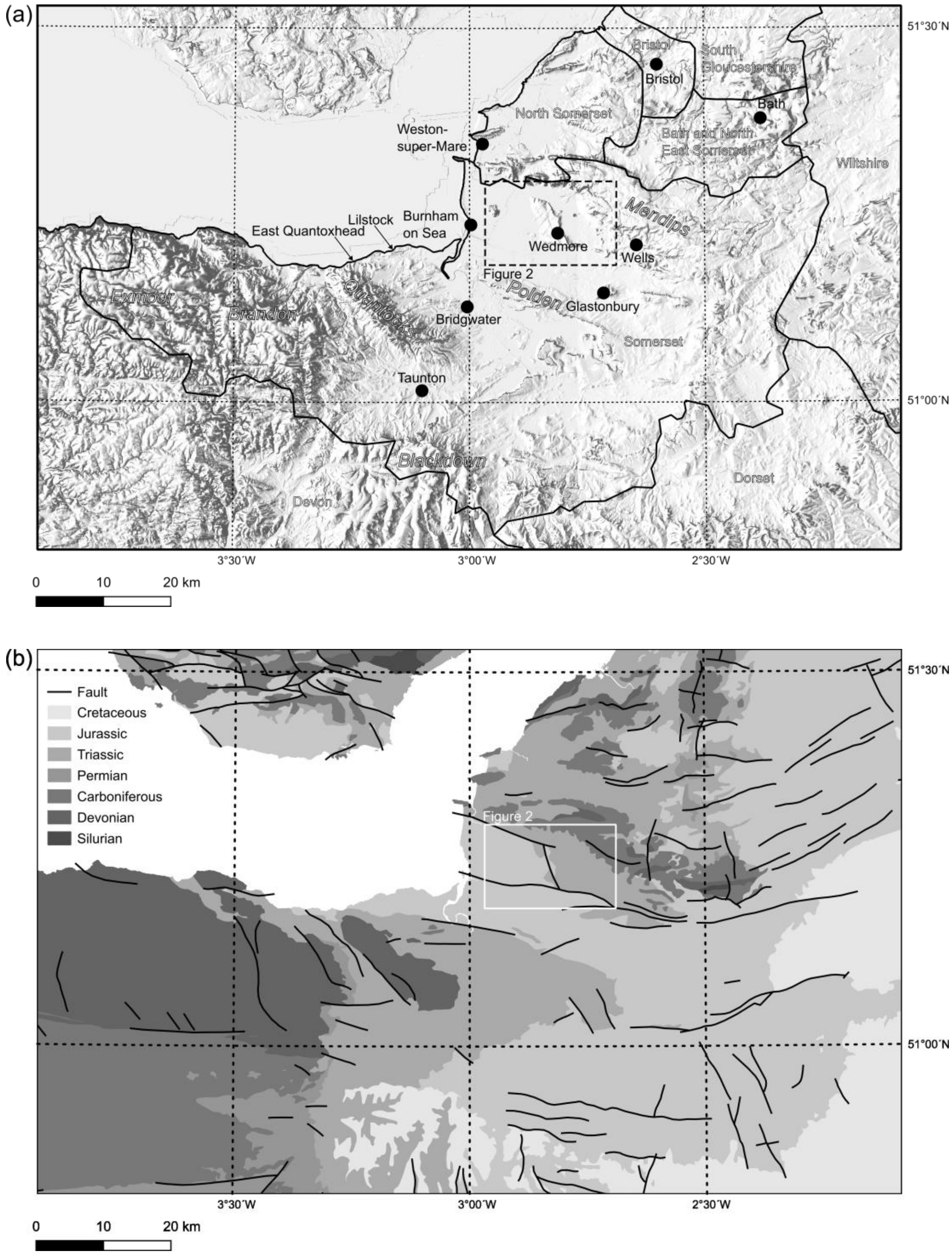

Figure 1. Maps of Somerset and surrounding areas. (a) Hillshade (from http://services.arcgisonline.com/ArcGIS/rest/services/Elevation/World_Hillshade/MapServer/tile/%7Bz%7D/%7By%7D/%7Bx%7D), to show the topography of the region. The map shows English county names (white) and boundaries (black lines), locations of several towns or cities (black letters), hill ranges (white italics), and the boundary of Figure 2. The locations of Lilstock and East Quantoxhead are also shown. (b) Geology of the region, showing rocks by geological period. The geology is from the British Geological Survey 1:625,000 scale map of the United Kingdom. Reproduced with the permission of the British Geological Survey ©NERC. All rights Reserved.

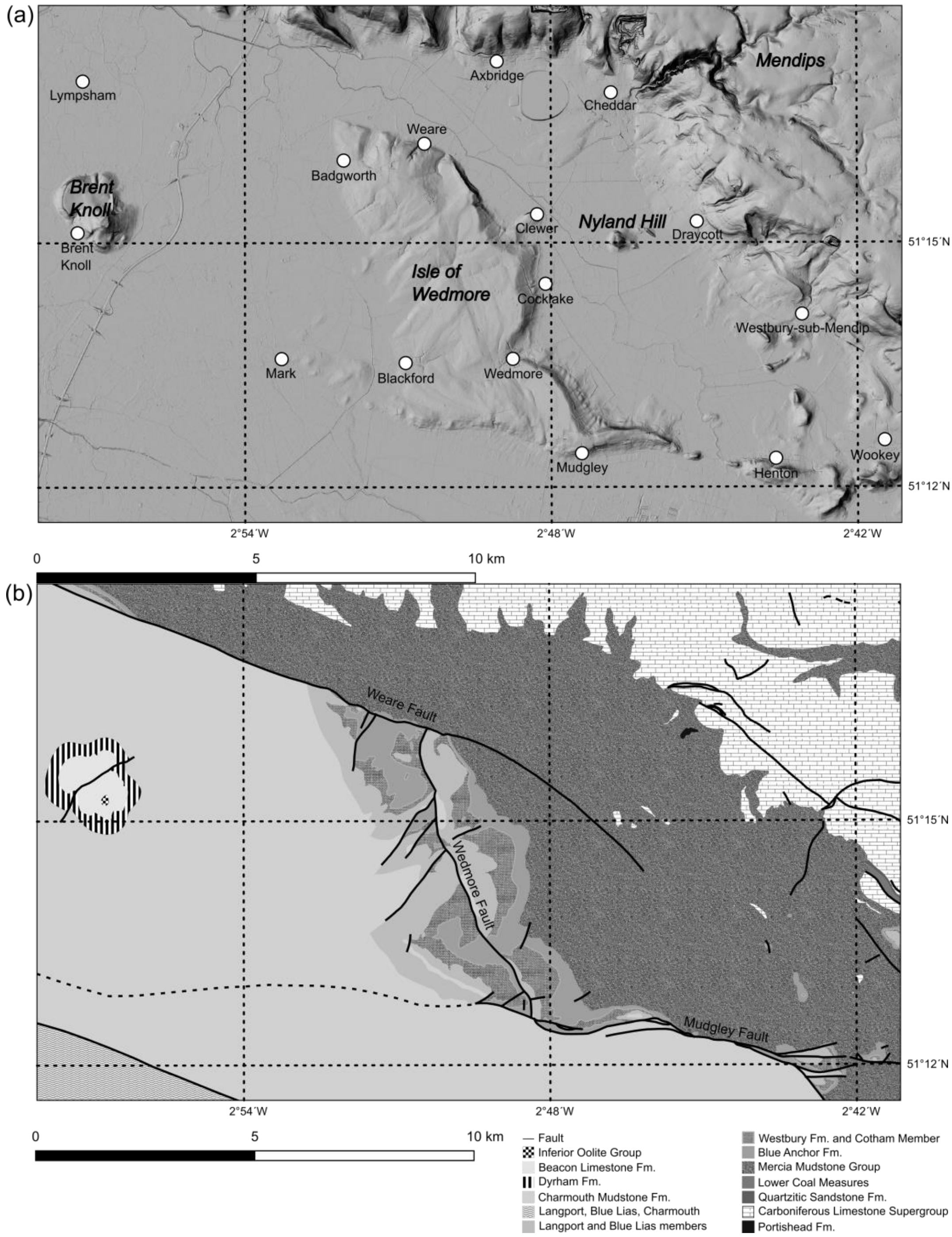

Figure 2. Maps showing the Isle of Wedmore (location shown in Figure 1). (a) Hillshade (from http://services.arcgisonline.com/ArcGIS/rest/services/Elevation/World_Hillshade/MapServer/tile/%7Bz%7D/%7By%7D/%7Bx%7D), to show the topography of the area, including the NE-facing scarp slope and SW-dipping lee slope of the Isle of Wedmore. The map shows the location of Wedmore, other villages and towns, and hill ranges. (b) Geological map, from the British Geological Survey 1:50,000 scale map of the area (Wells Sheet; Welch et al., 1963). Reproduced with the permission of the British Geological Survey ©NERC. All rights Reserved.

2. The geology and topography of Somerset

The geological history of Somerset can be summarised in terms of several tectonic and stratigraphic events:

1. The oldest rocks of the county are Silurian volcanics, exposed on the Mendip Hills (e.g., Green, 2008). The overlying Devonian and Carboniferous rocks were deposited on the southern edge of the Avalonian continent, to the north of the Rheic Ocean (e.g., Leveridge and Hartley, 2006). The Devonian Old Red Sandstone of northern Somerset (e.g., the Mendip Hills) were deposited in a fluvial environment (e.g., Barclay et al., 2015), while the Devonian rocks in the south-west of the county (Exmoor and Quantock hills) are dominated by sandstones and mudrocks that were deposited in both marine and non-marine environments (e.g., Webby, 1965). The Lower Carboniferous sequence (Carboniferous Limestone) represents a change to marine conditions, with deltaic siliciclastic rocks and coal dominating the Upper Carboniferous (e.g., Green, 1992). Carboniferous basins within the continent were mainly extensional in origin.
2. North-south contraction caused folding and thrusting during the late Carboniferous Variscan Orogeny, with kilometre-wavelength ~ E-W striking fold-thrust structures in the Exmoor and Quantock hills (e.g., Dineley, 1986), and in the Mendip Hills and further north (Williams and Chapman, 1986).
3. Post-Variscan exhumation occurred, with dominantly terrestrial siliciclastic rocks deposited during the Permo-Triassic (e.g., Talbot et al., 1994).
4. A marine transgression occurred at the end of the Triassic (e.g., Nordén et al., 2015), with shallow marine carbonate and clastic sedimentation occurring during the Jurassic and Cretaceous (e.g., Whittaker and Green, 1983). North-south extension during the Mesozoic created the Bristol Channel and Wessex basins, creating ~ E-W striking normal faults and probably reactivating some Variscan thrusts (Brooks et al., 1988). There is evidence for faulting during the Jurassic (Jenkyns and Senior, 1991). Van Hoorn (1987) suggests a phase of east-west dextral faulting in the South Celtic Sea and Bristol Channel Basin during the Late Jurassic to Early Cretaceous. Uplift, erosion and overall gentle tilting to the east in southern England are represented by mid-Cretaceous (e.g., Underhill and Stoneley, 1998) and end-Cretaceous (e.g., Gale and Lovell, 2018) unconformities.
5. North-south contraction occurred during the Cenozoic, involving reverse-reactivation of some Mesozoic ~ E-W striking normal faults (e.g., Glen et al., 2005). Strike-slip faults conjugate about ~ N-S were created (e.g., Peacock et al., 2016). Some of the larger-displacement ~ NW-SE striking dextral faults (hundreds of metres displacement or more) in SW England probably being reactivated Variscan structures (e.g., Miliorizos and Ruffell, 1998). This contractional event has been linked to the Alpine Orogeny (e.g., Blundell, 2002).
6. Uplift and erosion is probably related to Cenozoic north-south contraction. Kelly (2010) estimates 2 to 2.5 km of exhumation of the Mesozoic rocks of the Somerset coast based on apatite fission-track analysis and vitrinite reflectance data, and this is compatible with the thickness of the missing Jurassic and Cretaceous sequence. Neogene and Quaternary sediments, have, however, accumulated on the Somerset Levels, including extensive peat deposits (e.g., McMillan et al., 2011).

This geological history has created five distinct geological and topographic types of area in Somerset:

1. The Exmoor (maximum height = 519 m), Brendon (maximum height = 424 m) and Quantock (maximum height = 384 m) hills are dominantly Upper Palaeozoic rocks deformed during the Variscan Orogeny (e.g., Edmonds and Williams, 1985).
2. The Mendip Hills (maximum height = 325 m) show folded and thrusted Silurian, Devonian and Carboniferous rocks (e.g., Williams and Chapman, 1986), fringed by Permo-Triassic and Mesozoic rocks, and onlapping Upper Triassic to Lower Cretaceous rocks (e.g., Farrant et al., 2014). Similar Variscan structures occur to the north, including the area of the Lulsgate Plateau (maximum height = 202 m) and the hills around the Gordano Valley (maximum height = 136 m), and these Variscan structures can also be traced westwards to the coast, including at Brean Down (maximum height = 97 m) and Middle Hope (maximum height = 48 m).
3. Mesozoic rocks form the Blackdown Hills (maximum height = 315 m) in the south of Somerset, and also hills and escarpments in the east of the county, from Chard to Bath. Dundry (233 m high) is an outlier of Middle Jurassic rocks immediately south of Bristol. The Mesozoic rocks in the south and east of Somerset generally dip gently to the east, and transition eastwards into the Upper Cretaceous Chalk uplands of Salisbury Plain, in Wiltshire and Hampshire.
4. The Somerset Levels form a low lying (less than ~ 10 m above mean sea level) region covering ~ 650 km^2 (i.e., ~ 16% of the area of Somerset). The Levels generally comprise Quaternary tidal siliciclastic deposits covered by Recent peat (e.g., Kidson and Heyworth, 1976).
5. Hills of Triassic and Jurassic rocks occur in the Somerset Levels, including Glastonbury Tor (158 m high; Goudie, 2020), Brent Knoll (137 m high) and the Polden Hills (maximum height = 98 m). The Polden Hills, ~ 9 km to the south of the Isle of Wedmore, are fault-bound (~ WNW strike), with Donato (1988) suggesting the Polden Hills Fault is a down-to-the-north fault related to reactivation of an underlying Variscan thrust. There are also inliers of Carboniferous Limestone, such as Nyland Hill (76 m high). The Isle of Wedmore (Figure 2; maximum height = 72 m) appears to be structurally-controlled (Section 3).

3. The geology of the Isle of Wedmore

Several data types are available. Our attention was first drawn to the Isle of Wedmore as a relay ramp (Section 4) by seeing a digital elevation model (DEM), which illustrates the geometry of the ground surface (Figure 1). The exposure (*sensu* Woodward, 1929) quality in the area is low, being mostly limited to small, abandoned quarries. Detailed maps of the area are presented by the British Geological Survey (BGS), including the 1:63360 scale map of Welch et al. (1963). The data presented on the BGS Geology Viewer (https://geologyviewer.bgs.ac.uk/) appear to be based on the Welch et al. (1963) map. The BGS maps are the main source of data used in this paper, with important additional descriptions given in the BGS memoir for the Welch et al. (1963) map by Green and Welch (1965). A seismic line, CV82-263, is available (https://ukogl.org.uk/ukoglinteractive-map/, accessed 22nd January 2023). This is a 21.88 km long vibroseis N-S line shot in 1982 that extends down to 3 seconds two-way travel time. It passes through Mudgley, the eastern edge of Wedmore and through Clewer. Structures are, however, not obvious on this line.

The Isle of Wedmore shows outcrop (*sensu* Woodward, 1929) of Upper Triassic and Lower Jurassic rocks, the lithologies, ages and thicknesses of which are given by Welch et al. (1963) and the BGS Geology Viewer (summarised in Table 1). The outcrop pattern indicates an overall gentle dip of bedding to the south-west. Welch et al. (1963) show seven measurements of bedding, with dips of up to 8°, with dips towards the south-east, south and south-east. The area shows three named faults:

- The Weare Fault forms the northern boundary of the Isle of Wedmore. It strikes ~ WNW-ESE and has a down-to-the-south throw of 15.2 m to 30.4 m (Green and Welch, 1965). Welch et al. (1963) show a trace length of ~ 3 km, with the fault covered by Pleistocene and Recent alluvium eastwards and westwards. The BGS Geology Viewer, however, shows the Weare Fault continuing ~ 12 km ENE-wards to the coast between Brean and Brean Down, with the Mercia Mudstone Group in the north faulted against the Charmouth Mudstone Formation. The dip direction of the fault is not shown, but the Mesozoic development of the Bristol Channel Basin (e.g., Nemcok and Gayer, 1996) suggests it is a south-dipping normal fault.
- The Mudgley Fault forms the southern boundary of the Isle of Wedmore. It has a rather irregular, wavy trace, strikes overall a few degrees clockwise of east-west, and appears to splay near Henton (51°12'8.22"N, 2°43'43.83"W). It has a down-to-the-south throw of 61 m to 107 m (Green and Welch, 1965). Welch et al. (1963) show a trace length of at least 15 km, running off the western and southern edges of the map, including being extrapolated beneath Pleistocene and Recent alluvium in the west. Similarly, Farrant et al. (2018) extrapolate the Mudgley Fault to Burnham-on-Sea (51°14'14.60"N, 2°59'56.05"W), but acknowledge that this sector is poorly constrained. We suggest, however, that the Mudgley Fault dies out within ~ 5 km west of Wedmore, with displacement transferred onto the Weare Fault to the north and west, with the same geometry shown on the BGS Geology Viewer. This model is discussed in Section 4. Donato (1988, figure 7) shows the Mudgley Fault connecting eastwards into the Vale of Pewsey Fault. As with the Weare Fault, the dip direction of the Mudgley Fault is not shown by Welch et al. (1963), but the Mesozoic development of the Bristol Channel Basin suggests it is a south-dipping normal fault.
- The Wedmore Fault connects the Weare and Mudgley faults, having a trace length of ~ 7 km. It strikes NW-SE, with a down-to-the-ENE throw of ~ 7.6 m in the north and ~ 23 m in the south (Green and Welch, 1965). It is either a NE-dipping normal fault or a SW-dipping reverse fault.

Twelve smaller, unnamed faults are also shown on by Welch et al. (1963). These strike NNE-SSW to ENE-WSW, have mapped trace lengths of up to ~ 2.5 km, and show downthrows to either the NW or SE. Four are to the NE of the Wedmore Fault and eight are to the SW. Two of these faults abut the Weare Faults, two abut the Mudgley Fault and five abut the Wedmore Fault (Figure 2b).

Unit, as named by Welch et al. (1963)	**Maximum thickness in feet given by Welch et al. (1963)**	**Maximum thickness in metres**	**Stratigraphy from BGS**	**Lithologies from BGS**	**Age from BGS**
Lower Lias, grey marl	1200′	366 m	Charmouth Mudstone Formation	Mudstone	Jurassic, 199.3 and 182.7 m.y.
White and Blue Lias	100′	30 m	Langport Member and Blue Lias Formation	Interbedded mudstone and limestone	Triassic and Jurassic, 209.5 and 190.8 m.y.
Rhaetic	35′	11 m	Westbury Formation and Cotham Member	Interbedded mudstone and limestone	Triassic, 209.5 and 201.3 m.y.
Tea Green Marl	150′	46 m	Blue Anchor Formation	Limestone	Triassic, 228.4 and 201.3 m.y.
Keuper Marl	2000′	610 m	Mercia Mudstone Group	Mudstone and halite-stone	Triassic, 252.2 and 201.3 m.y.

Table 1. Stratigraphic data for the rocks outcropping on the Isle of Wedmore, based on the stratigraphic column presented by Welch et al. (1963). Stratigraphy from BGS (https://geologyviewer.bgs.ac.uk/, accessed 22nd January 2023).

Based on the rocks displaced, the faults must be syn- or post- late Triassic and early Jurassic, but it is possible they are reactivated Variscan faults (e.g., Brooks et al., 1988). The faults may be related to the Mesozoic extension that created the Bristol Channel and Wessex basins (e.g., Wall and Jenkyns, 2004), and it is also possible that they have undergone Cenozoic reverse or strike-slip reactivation (e.g., Lake and Karner, 1987).

4. The Isle of Wedmore as a relay ramp and analogues from the Somerset coast

We suggest that the Isle of Wedmore has been formed by a relay ramp between the Meare and Mudgley faults. A relay ramp (Figures 3 and 4) is a zone of kinematic interaction between two overlapping, sub-parallel normal faults, where strain is relayed from one fault to the other by rotation of bedding (Larsen, 1988; Peacock and Sanderson, 1991; 1994). Displacement is transferred between the Weare Fault, which dies out eastwards, onto the Mudgley Fault, which dies out westwards. The displacement is transferred both by the rotation of bedding, which dips a few degrees to the south or south-west in the Isle of Wedmore, and by the Wedmore Fault, which is a connecting fault (e.g., Peacock and Sanderson, 1994). The Wedmore Fault probably initiated as the relay ramp initiated between the Weare and Mudgley faults, during Mesozoic extension.

There are two features of the Isle of Wedmore that are not typical of relay ramps. Firstly, the Wedmore Fault has a downthrow to the NE, which is the opposite direction to the dip of bedding in the relay ramp. Secondly, the twelve ~ NE-SW striking faults mapped by Welch et al. (1963) do not seem to be compatible with the N-S extension implied by normal faulting on the Weare and Mudgley faults. We suggest, therefore, that the Weare and Mudgley faults have undergone a phase of strike-slip and/or reverse reactivation. Here, we present analogues from Somerset for such behaviour.

There is evidence for strike-slip reactivation of normal faults in exposures around Lilstock (51°12'7.77"N, 3°10'27.72"W; Peacock and Sanderson, 1999. Rotevatn and Peacock (2018) give a detailed description of an E-W striking normal fault zone in Liassic limestones and shales at Lilstock that has undergone sinistral reactivation, with right steps along the fault zone reactivated as contractional steps (Figure 4b). These contractions steps involve steepening of the bedding in the relay ramps and the development of NE-SW striking dextral faults. The NE-SW striking faults in the Isle of Wedmore relay ramp may be compatible with the dextral faults in the fault zone at Lilstock. It is possible that the Wedmore Fault is a reverse fault (dipping to the south-west) if the Isle of Wedmore relay ramp was reactivated as a contractional step. In this scenario, the Wedmore Fault initiated as a connecting fault during Mesozoic extension but was reactivated as a reverse fault during Cenozoic strike-slip. Note that Peacock and Sanderson (1995) describe relay ramps developed along strike-slip faults in Liassic limestones and shales at East Quantoxhead (51°11'30.46"N, 3°14'11.87"W), but the large throws on the Weare and Mudgley faults suggests they initiated as normal rather than strike-slip faults.

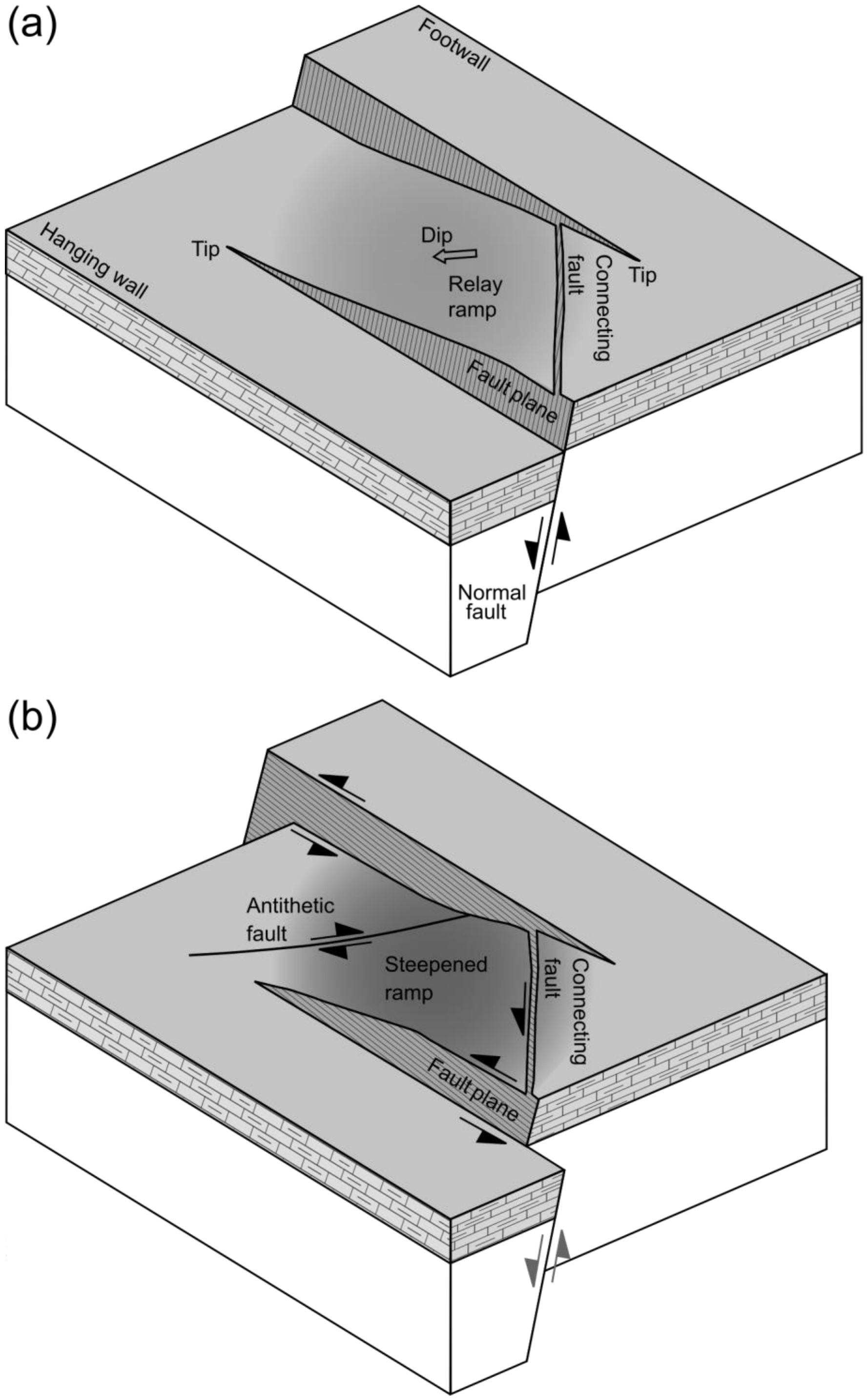

Figure 3. Schematic figure showing strike-slip reactivation of a normal fault system and how it affects a relay ramp, based on Rotevatn and Peacock (2018, figure 6). (a) Two overlapping normal fault segments that bound a relay ramp, with a connecting fault linking the two stepping faults. (b) Strike-slip reactivation of the normal fault segments shown in Figure 3(a) and how it affects the relay ramp. The relay ramp becomes a contractional step during reactivation, with steepening of the relay ramp and the development of new faults.

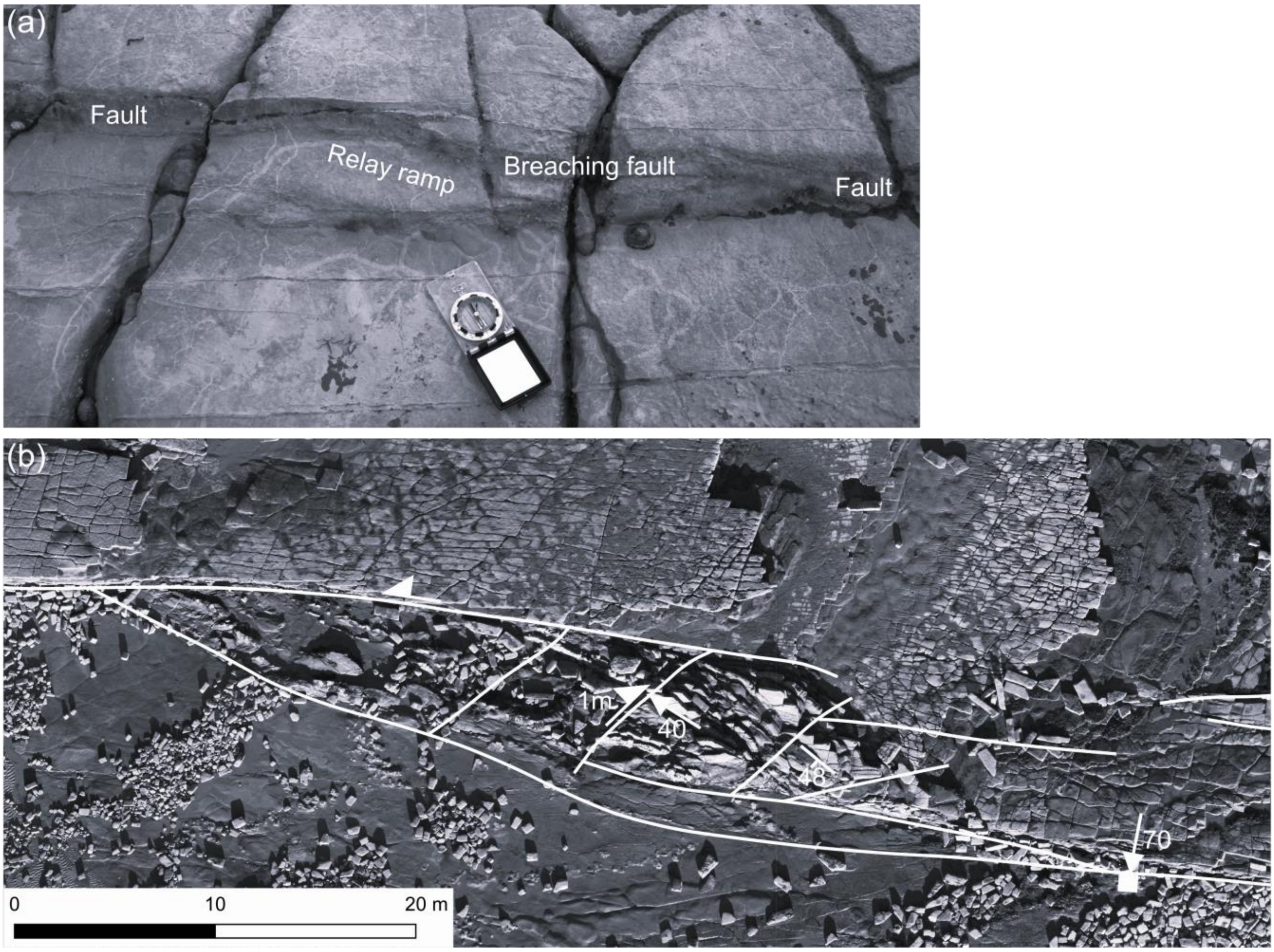

Figure 4. Examples of relay ramps from the Liassic rocks of the Somerset coast (see Figure 1a for locations). (a) A relay ramp between stepping normal faults at East Quantoxhead (51°11'25.67"N, 3°14'21.62"W). A breaching fault connects the right-stepping normal faults. (b) A relay ramp between right-stepping normal faults at Lilstock (51°12'7.81"N, 3°10'27.96"W) that have been reactivated as sinistral strike-slip faults (Rotevatn and Peacock, 2018). The relay ramp has been steepened to approximately 48° and several NE-SW striking antithetic (dextral) faults occur.

Cenozoic reverse reactivation of normal faults has been reported in the Bristol Channel and Wessex basins (e.g., Blundell, 2002; Glen et al., 2005), and this has caused reactivation of relay ramps. For example, Barton et al. (1998) show the effects of reverse reactivation on relay ramps in the Mere Fault Zone, ~ 35 km SE of Wedmore. The Mere Fault Zone strikes ENE-WSW for more than 20 km between Maperton (Somerset; 51° 2'3.93"N, 2°28'13.60"W) and West Knoyle (Wiltshire; 51° 5'17.48"N, 2°12'27.25"W), and is a braided zone of faults 1-2 km wide. Similarly, Kelly et al. (1999, figure 3) show a network of strike-slip faults, conjugate about ~ N-S developed in a step between reverse-reactivated normal faults in Liassic rocks at East Quantoxhead (51°11'28.72"N, 3°14'21.84"W). Note, however, that the fault described by Kelly et al. (1999) dip in opposite directions. Kelly et al. (1999) shows that normal fault in the Mesozoic rocks of the Somerset coast, between Blue Anchor (51°11'7.41"N, 3°23'7.43"W) and Lilstock (51°12'9.25"N, 3°10'2.48"W) show reverse-reactivation if they have throws of more than about 20 m, so it is plausible that the Weare and Mudgley faults have also undergone a phase of reverse reactivation.

We note that the throws on the Weare and Mudgley faults are likely to increase westwards and eastwards respectively, above those estimated by Green and Welch (1965), away from the relay ramp. It is also possibly that the present-day throws on these faults have been reduced by reverse-reactivation. We also note that the Meare and Mudgley faults are part of a longer system of Mesozoic normal faults in the region. For example, Farrant et al. (2018) recognise the “Bristol Channel-Weare-Brean Fault”, which they describe as an en echelon series of east-west trending faults that they have mapped over a distance of more than 188 km, mostly offshore in the Bristol Channel. Similarly, the Mudgley Fault probably connects to other faults in the east. Green and Welch (1965) describe the segmentation, bends and folding along the Mudgley Fault as far as Coxley (51°11'12.61"N, 2°40'53.20"W), but the fault zone is also shown on the British Geological Survey 1:50,000 scale map (BGS Sheet 296, Glastonbury) around North Wootton (51°10'23.07"N, 2°37'32.91"W) and Pilton (51° 9'57.13"N, 2°35'23.32"W), where it is called the North Wootton Fault Complex and the Pilton-Prestleigh Fault Complex by Bristow and Donovan (2015). It may link eastwards to the down-to-the-north, ENE-WSW striking Warminster Fault (Newell et al., 2018) in the vicinity of Chesterblade (51°10'4.08"N, 2°29'12.43"W; British Geological Survey 1:50,000 scale map, Sheet 297, Wincanton).

5. Conclusions

We present a model in which the Isle of Wedmore has formed as a relay ramp between the Weare and Mudgley faults, which have net down-to-the-south throws of up to ~ 100 m near Wedmore, and right-step ~ 5.3 km. These faults are probably south-dipping normal faults, developed during Mesozoic extension and basin development. The Upper Triassic and Lower Jurassic rocks in the relay ramp dip a few degrees to the south or south-west. The Weare and Mudgley faults are connected by the down-to-the-ENE Wedmore Fault, which has a throw of up to about 23 m. It is possible that the Weare and Mudgley faults have been reactivated, either as sinistral faults or as reverse faults during Cenozoic (“Alpine”) contraction. We interpret the smaller NE-SW striking faults mapped in the area as being sinistral faults developed within the reactivated relay ramp. Analogues for such geometries are presented from the Liassic rocks of the Somerset coast, between Lilstock and East Quantoxhead.

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