

# OR/17/042 Context of study area

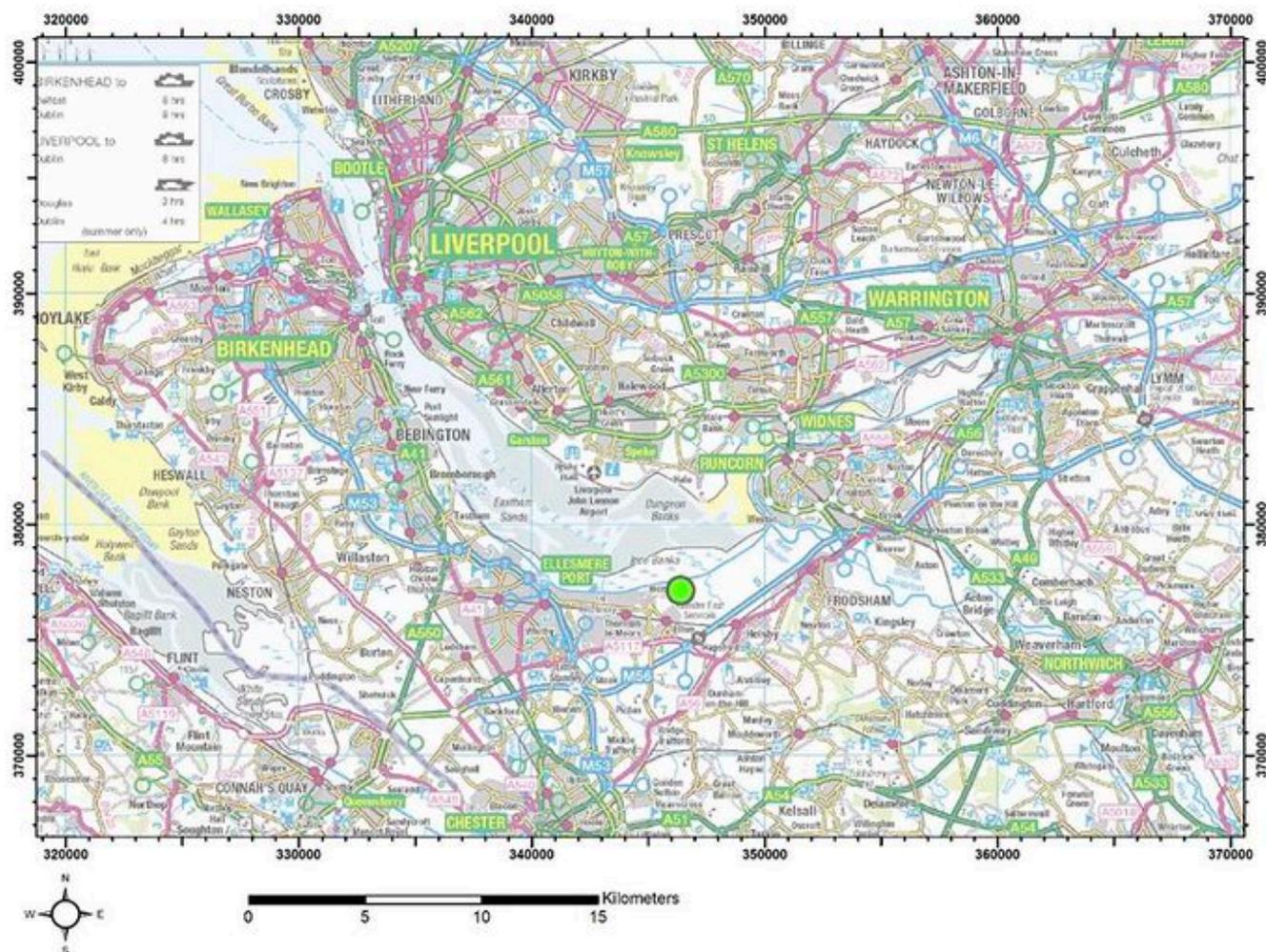
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Lee, J R, and Hough, E. 2017. A conceptual geological model for investigating shallow sub-surface geology, Cheshire energy research field site. *British Geological Survey Internal Report, OR/17/042*.

## Location of study area

The study site, approximately 0.5 km<sup>2</sup>, is the Cheshire Energy Research Field Site located between Stanlow and Ince Marshes, Cheshire. Situated adjacent to the Mersey Estuary, the Cheshire Energy Research Field Site is located east of Ellesmere Port and approximately 8.5 km to the northeast of Chester (Figure 3.1). It is bounded to the north by the Manchester Ship Canal that runs broadly east-west parallel to the shoreline of the Mersey Estuary, and to the south and west by the M56 and M53 motorways respectively. The area is low-lying, sloping gently northwards towards the Mersey Estuary and dissected by several drains and streams. The natural surface elevation around Ince Marshes lies between approximately 5–8 metres OD. However, coastal land-reclamation and flood protection measures constructed during the development of a nearby oil refinery and on-site industrial units mean that the current and/or localised elevation of the land-surface may be markedly higher.



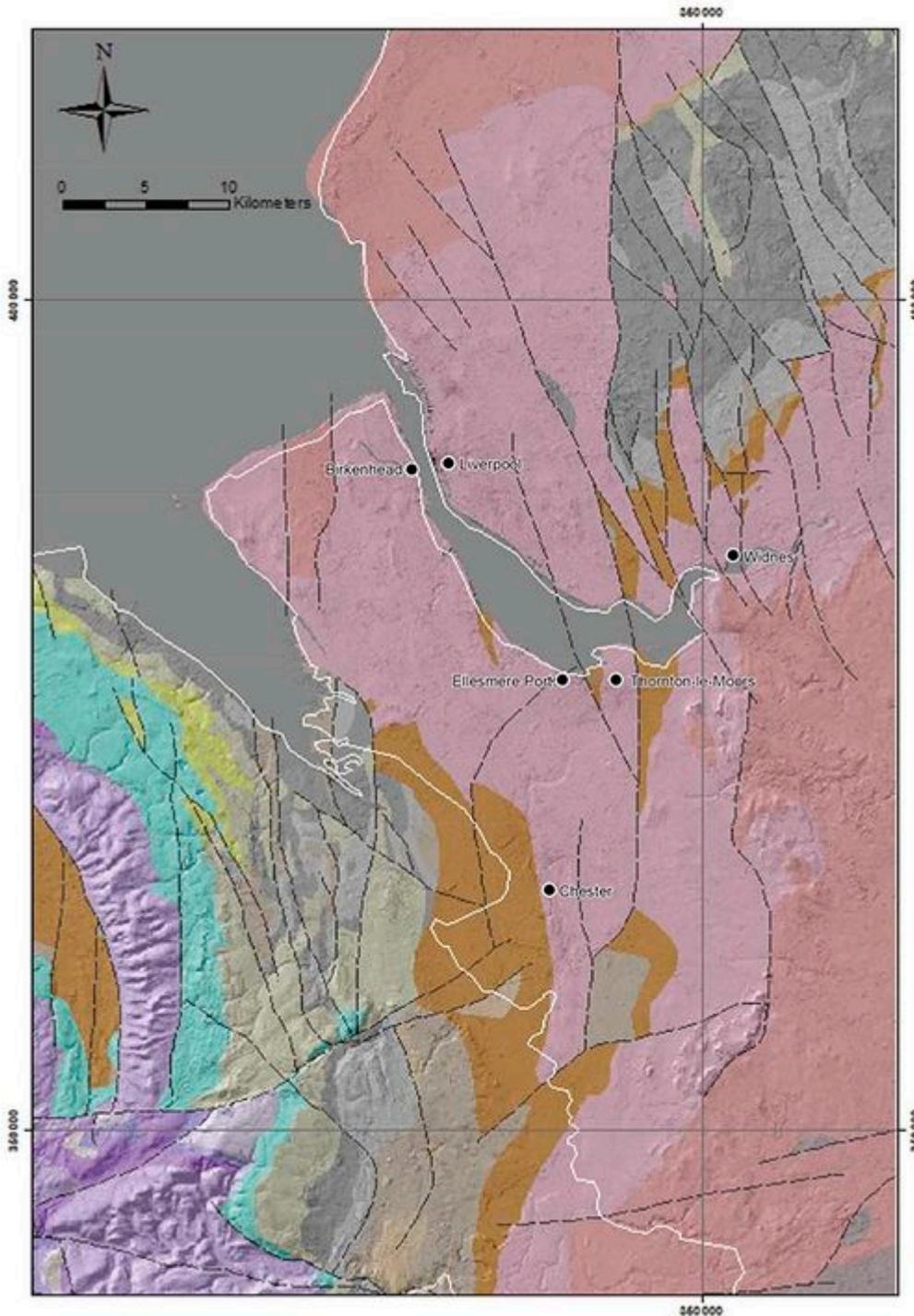
**Figure 3.1** Location of the Cheshire Energy Research Field Site (green dot) adjacent to the River

## Geological overview: drivers of landscape evolution

Within this section of the report, a regional overview of the long-term geological history of the broader Cheshire region is given, focussing on the geological drivers and where appropriate, the known geological processes and geological products.

The area around Ince Marshes lies within a major area of Quaternary erosion and deposition, which itself, is superimposed upon a Late Palaeozoic to Mesozoic basin known as the Cheshire Basin. The basin extends from Manchester in the north to Shropshire in the south and is bound by several large broadly north-south striking extensional (normal) fault systems that separate the basin from adjacent strata (Carboniferous and older) to the west and east. Formation of the basin began in response to crustal extension during the Permian, which also affected other parts of the West Midlands and the neighbouring Irish Sea (Newell, 2017<sup>[41]</sup>). The occurrence of additional extensional faults within the Cheshire Basin (CB) also demonstrate that basin subsidence did not occur *en bloc* but discretely through differential movement of faulted basinal blocks — presumably exerting a significant influence locally on sedimentation during the Permian and Triassic.

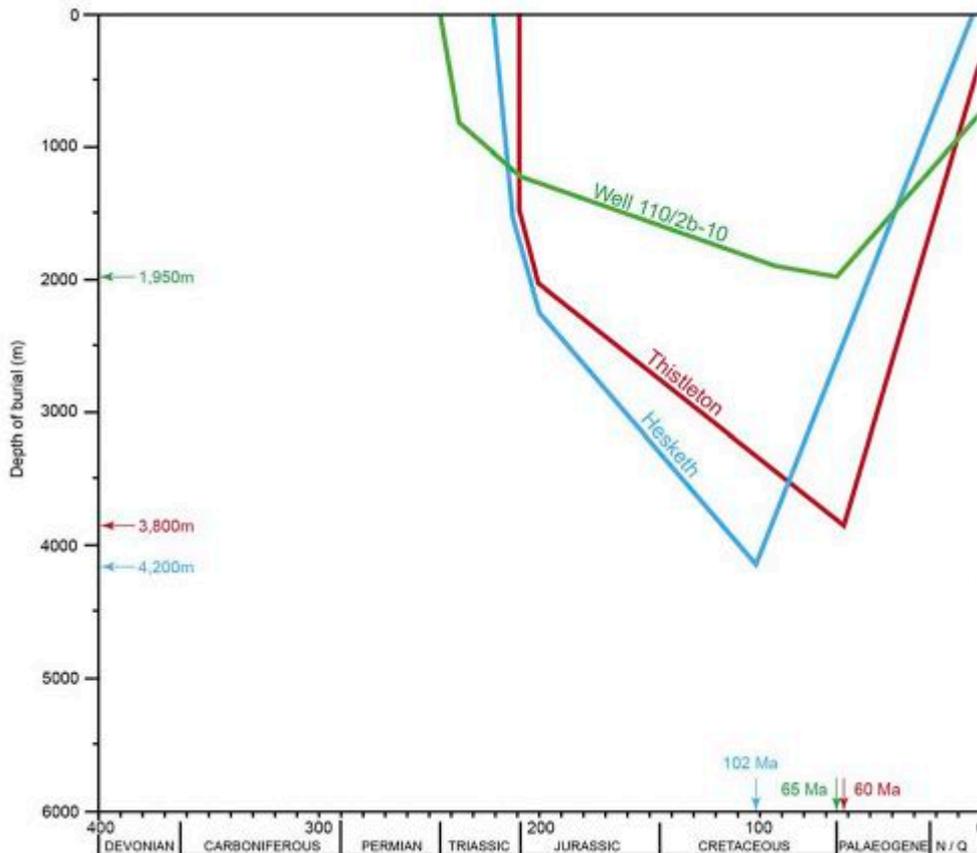
The geological infill of the Cheshire Basin comprises Triassic age sandstones (Sherwood Sandstone Group, SSG) and mudstones (Mercia Mudstone Group, MMG) (Figure 3.2; Ambrose *et al.*, 2014<sup>[2]</sup>). Beneath Ince Marshes, the bedrock geology is composed entirely of the SSG, a siliciclastic sandstone of Early to Mid-Triassic age (c.251–240 Ma) that dips gently (c.5°) to the south-east. Permo-Triassic rocks extend offshore into the East Irish Sea Basin (EISB) where up to 1,160 m of SSG is preserved (British Geological Survey, 2012<sup>[3]</sup>). Due to the paucity of age-diagnostic fossils, the SSG cannot be sub-divided biostratigraphically and in-turn chronostratigraphically. Instead, strata are classified lithostratigraphically with sub-division into lithofacies according to their primary (e.g. lithology and sedimentology) and secondary (e.g. colour and diagenesis) sedimentological properties. Examining and describing available bedrock exposures and borehole cores is therefore central to sub-division of the SSG. Two main lithofacies associations have to-date been recognised. Firstly, *fluvial facies* which correspond to the Chester, the upper part of the Wilmslow and parts of the Helsby formations and comprise single or multi-storey sand bodies comprising thick, upward-fining sets of sandstone with erosional-based, cross-bedded lower horizons. Where stratified, sandstone facies exhibit planar, low and high-angle cross-bedding, planar- and ripple-lamination indicating fluctuations in flow regime. Rip-up clasts are common within the lower parts of some sets and are composed of host (intraformational) or derived (extraformational) lithologies. Over-steepened bedding and water-escape structures are described in exposures at Runcorn (Mountney and Thompson, 2002<sup>[4]</sup>) and the Wirral (Benton *et al.*, 2002<sup>[5]</sup>). Similar sedimentary structures have been observed near Blackpool and are interpreted as the product of syn-depositional earthquakes (Wilson and Evans, 1990<sup>[6]</sup>). Alternatively, these types of structures could simply be the product of rapid syn-depositional loading of water-saturated strata (cf. Reineck & Singh, 1980<sup>[7]</sup>). Secondly, an *aeolian facies* (the predominant facies of the Wilmslow Formation, and developed in parts of the Helsby Formation), is described from equivalent units elsewhere in northwest England (e.g. Thompson, 1970<sup>[8]</sup>; Macchi, 1991<sup>[9]</sup>; Howard *et al.*, 2007<sup>[10]</sup>). This facies is composed of well-sorted sandstones with rounded medium- to coarse-grained frosted quartz-rich sand with well-developed ‘pinstripe’ cross-lamination and large-scale planar cross-bedding. The grain size distribution, maturity, grain frosting and sedimentary structures are characteristic of sedimentation as part of mobile sand dune fields.



**Figure 3.2** The bedrock geology of the Cheshire Basin (CB) showing the distribution of major bedrock units (Digital geological map data BGS © NERC; contains Ordnance Survey data © Crown Copyright and database rights 2017.) and faulting (dashed lines). Orange (Permian) and light pink (Triassic): Sherwood Sandstone Group; Dark pink (Triassic): Mercia Mudstone Group. NEXTMap Britain elevation data from Intermap Technologies.

A major regional unconformity exists between Triassic and Quaternary strata in the Cheshire Basin, extending north and westwards into the EISB (Jackson *et al.*, 1995<sup>[11]</sup>). Rocks of intervening age (Jurassic, Cretaceous and Palaeogene) occur to the southwest within parts of the Irish Sea Basin (Tappin *et al.*, 1994<sup>[12]</sup>) but are absent within the northern part of the Cheshire Basin and beneath Ince Marshes. Their removal from the majority of the Cheshire Basin reflects widespread Cretaceous and Cenozoic exhumation (uplift and erosion) that also occurred across much of the UK (Holford *et*

*al.*, 2005<sup>[13]</sup>; Williams *et al.*, 2005<sup>[14]</sup>). Apatite fission track analysis (AFTA) and vitrinite reflectance (VR) data demonstrate a polyphase exhumation history for the Irish Sea Basin with distinct exhumation phases occurring during the early Cretaceous (c.3 km), early Palaeogene (c.2 km) and late Palaeogene-Neogene (c.1 km) (Holford *et al.*, 2005<sup>[13]</sup>). No AFTA or VR data are currently available from the immediate study area. However, VR data have been published from three wells located in Lancashire (Hesketh and Thistleton) and the adjacent offshore area (110/2b-10) (Figure 3.3). Measurements suggest that the SSG was buried rapidly following deposition to depths of c.1,950 m (110/2b-10) and c.3,800–4,200 m (Hesketh and Thistleton). Exhumation was initiated in southern Lancashire during the Mid Cretaceous, migrating progressively northwards through the Late Cretaceous to Early Palaeogene (Andrews, 2013<sup>[15]</sup>). This implies that the onset of exhumation did not occur simultaneously across the EISB and it is possible that this is also the case with the neighbouring Cheshire Basin. Instead, it is likely that exhumation occurred sequentially as different structural elements became aligned to the contemporaneous tectonic stress regime. The primary Late Mesozoic and Cenozoic driver of exhumation was northwards-directed Alpine crustal compression caused by collision of the Eurasian, Iberian and African tectonic plates (Ziegler *et al.*, 1995<sup>[16]</sup>; Cloetingh *et al.*, 2005<sup>[17]</sup>). During the Palaeogene, widespread exhumation resulted in the inversion of several Mesozoic basins across the UK, such as the Sole Pit-Cleveland basin, the Wessex and Weald basin and EISB with evidence for compressive stresses identified along the North Atlantic Margin (Stoker *et al.*, 2005<sup>[18]</sup>). An additional temporary driver of exhumation during the Early Palaeogene was the migration (by continental drift) of western Britain and Ireland across the Iceland Mantle Plume (Jones *et al.*, 2002<sup>[19]</sup>). In places where crustal thickening occurred (a process called magmatic underplating) the crust was effectively anchored and stabilised; however, adjacent unanchored areas of crust became more buoyant and this resulted in rapid uplift and exhumation including areas bordering the Irish Sea Basin (Tiley *et al.*, 2004<sup>[20]</sup>; Williams *et al.*, 2005<sup>[14]</sup>; Westaway, 2009<sup>[21]</sup>). Interpretations suggest that parts of the Irish Sea Basin have undergone up to 6 km of exhumation since the beginning of the Cretaceous, about 140 Ma (Holford *et al.*, 2005<sup>[13]</sup>, 2009<sup>[22]</sup>). Evidence for this exhumation is considered to also include the general absence of younger Mesozoic cover rocks — including by inference the Cheshire Basin, across large parts of northern Britain (Huuse and Clausen, 2001<sup>[23]</sup>; Green *et al.*, 2012<sup>[24]</sup>).



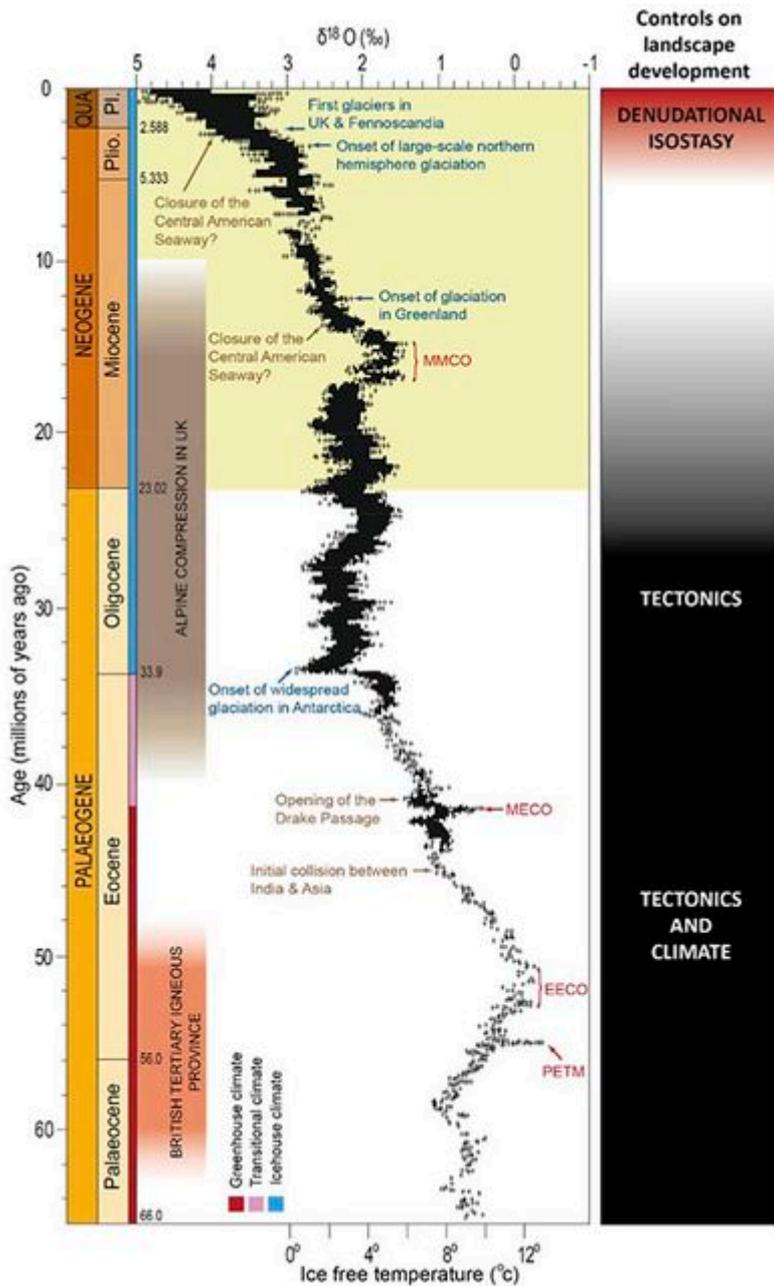
**Figure 3.3** The burial and exhumation history of the top of the Sherwood Sandstone Group based upon vitrinite reflectance (VR) data from three sites in NW England (DECC, 2013).

By the Late Miocene (c.11 Ma) the influence of the Alpine compression and the relative effect of magmatic underplating had either waned or ceased (in the case of the latter) as the UK migrated away from the Iceland Mantle Plume and the broader tectonic stress regime evolved (Figure 3.3). Instead, the primary driver of landscape evolution was climate-driven denudational isostasy (Westaway *et al.*, 2002<sup>[25]</sup>; Westaway, 2017<sup>[26]</sup>). Denudational isostasy is a process driven by the relative uplift of the crust in response to the reduction of an applied load due to surface erosion (Bishop, 2007<sup>[27]</sup>). In very general terms, the removal (erosion) of 1 km of crustal load is accompanied by approximately 0.85 km of crustal rebound (Bishop, 2007<sup>[27]</sup>).

Throughout the Plio-Pleistocene, the global climate signal underwent a progressive intensification resulting in the strengthening of the glacial-interglacial climate signal. This drove changes in the distribution of solar insolation (heat) across the planet's surface, enhanced seasonality and the sequential establishment of regular cold-warm climate cycles over 21 ka (Pliocene), 41 ka (from c.2.6 Ma) and finally 100 ka (from c.1 Ma) time-scales. These climatic cycles, have amplified the dynamics of earth surface processes (e.g. weathering rates, vegetation cover and sediment availability) and the behaviour of geological systems (e.g. rivers, slopes, glaciers etc). Put simply, the landscape of the UK has become more dynamic over the past two and a half million years with progressively increased rates of weathering, erosion and sediment mobility (in response to denudational isostasy).

Throughout the Miocene-Pleistocene time-interval (23 Ma to 0.012 Ma), much of the EISB and most likely the Cheshire Basin were probably emergent. Major regional depositional centres include the Celtic Deep and St George's Channel troughs within the Irish Sea Basin, which accumulated between 100-200 metres of sediment (Tappin *et al.*, 1994<sup>[12]</sup>; Jackson *et al.*, 1995<sup>[11]</sup>; British Geological Survey, 2009<sup>[28]</sup>). Subaerial exposure of the SSG and MMG means that the bedrock of the

Cheshire Basin is likely to have been susceptible to modification by warm and cold-climate weathering and other landscape-forming processes. Cold climate periglacial and glacial processes are likely to have played a particularly significant role in modifying substrate properties during the past 2.6 million years. Weathering may have resulted in significant episodes of cement removal, fracture formation and natural hydraulic fracturing of the near- surface bedrock interval. Glaciers have been active agents in the British landscape periodically over the past 2.6 million years (Lee *et al.*, 2011<sup>[29]</sup>, 2012<sup>[30]</sup>; Thierens *et al.*, 2012<sup>[31]</sup>). The largest glaciation occurred approximately 0.45 Ma (the Anglian) with ice sheets extending southwards towards London (Perrin *et al.*, 1979<sup>[32]</sup>; Bowen *et al.*, 1986<sup>[33]</sup>) and through St George's Channel and the Celtic Deep troughs (Tappin *et al.*, 1994<sup>[12]</sup>). Although no direct evidence occurs for this glaciation within the Cheshire Basin, the occurrence of erratic clasts from Cheshire (SSG) in tills in the West Midlands, demonstrates that ice crossed the study area from the Irish Sea Basin (Rice, 1968<sup>[34]</sup>; Bridge and Hough, 2002<sup>[35]</sup>). Much of the modern topography of the Cheshire Basin corresponds to the Late Devensian glaciation (c.27-17 ka) when the area was inundated by Irish Sea, Welsh and Lake District ice forming part of the Last British-Irish Ice Sheet (Price *et al.*, 1963<sup>[36]</sup>; Thomas and Chiverrell, 2007; Clark *et al.*, 2012<sup>[37]</sup>) (Figure 3.4). Glaciation (and deglaciation) of the Cheshire Basin resulted in the deposition of a variable thickness (locally exceeding 25 metres) of glacial deposits including tills, glaciofluvial and glaciolacustrine sediments which can be observed as the surface geology in much of the modern landscape (Figure 3.5; Price *et al.*, 1963<sup>[36]</sup>; Worsley, 1967<sup>[38]</sup>; Johnson, 1968; Longworth, 1985<sup>[39]</sup>; Wilson and Evans, 1990<sup>[6]</sup>). Over much of the Cheshire Basin, these superficial deposits have largely (but not completely) buried the Triassic bedrock, with the latter likely to have been modified either by direct ice-bed traction and/or by glacial meltwater incision.

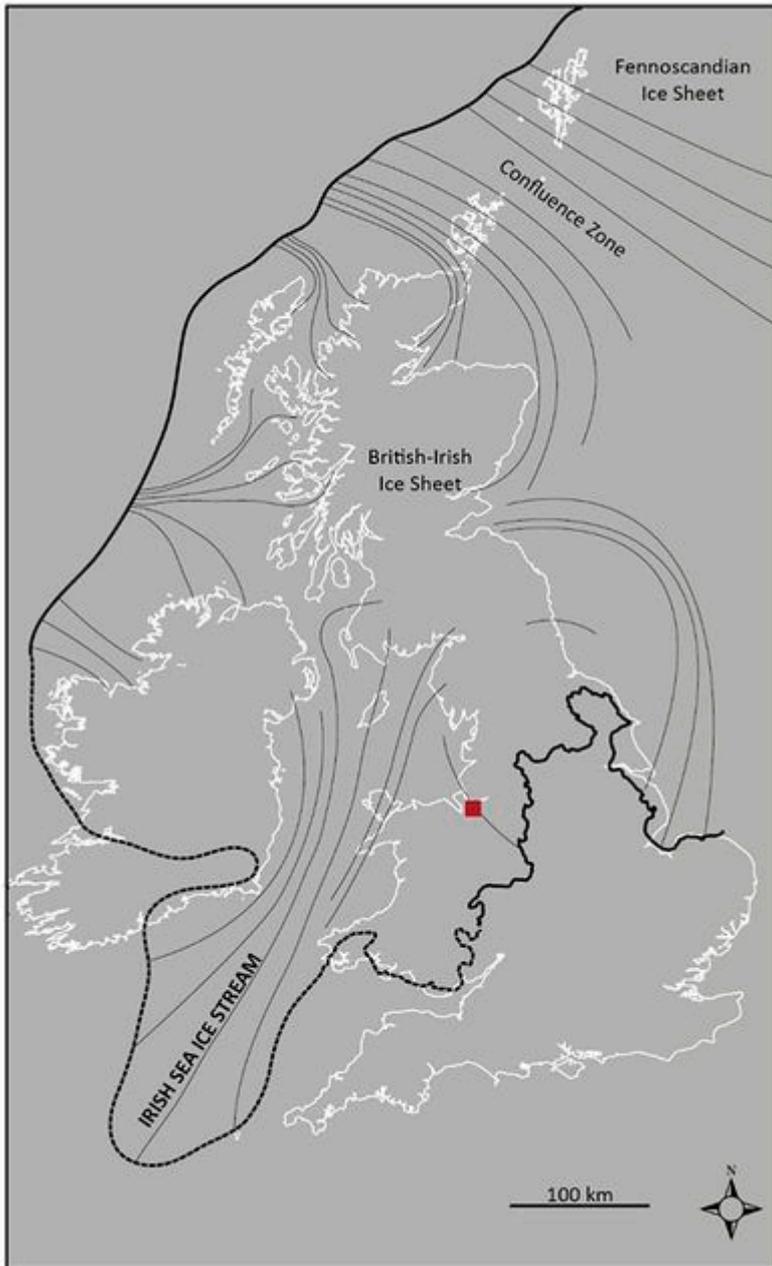


**Figure 3.4** Evolution of Cenozoic climate with specific references to major tectonic (brown) and climatic (blue/red) global events (Modified from Newell, 2014).

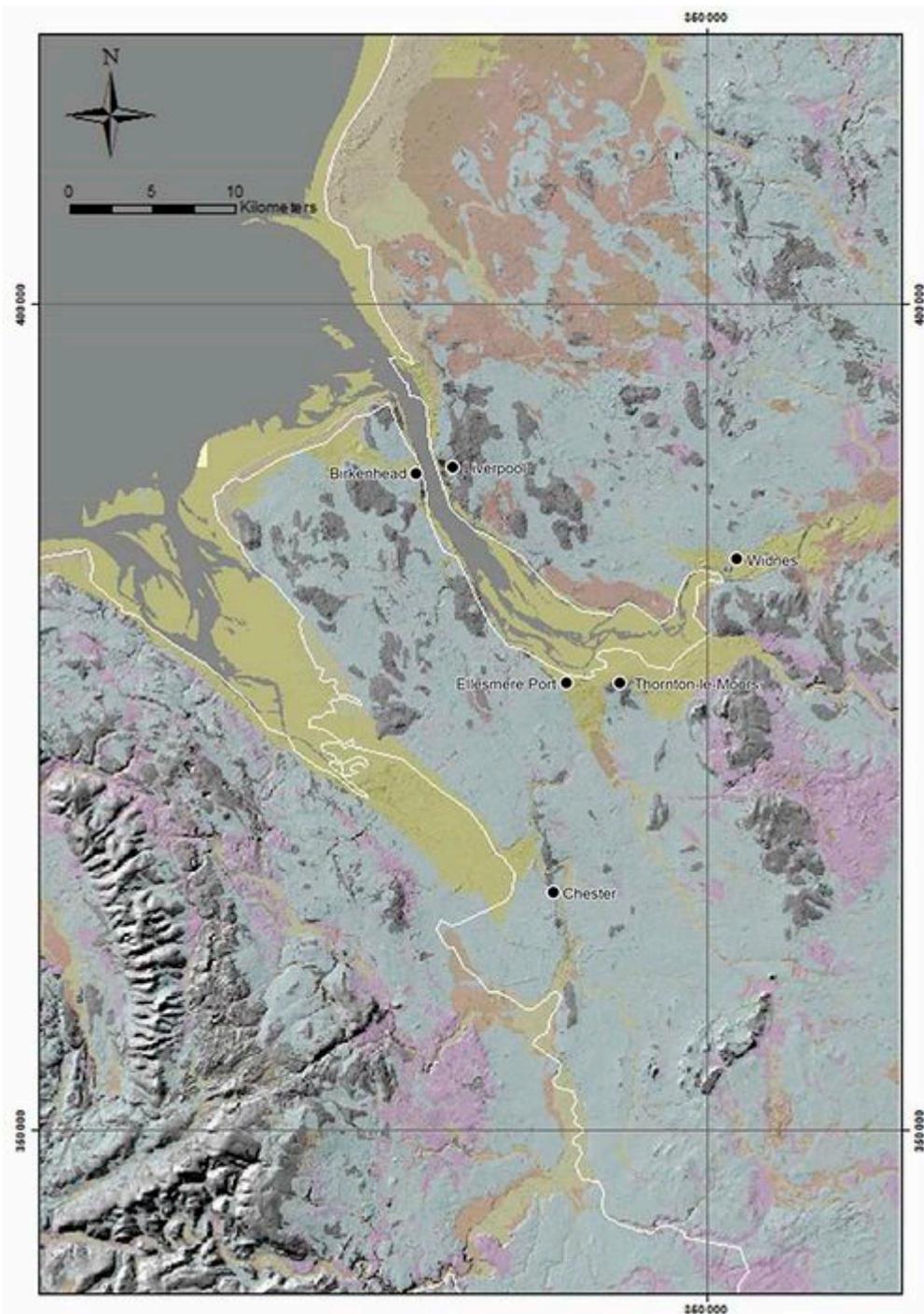
Oxygen isotope data from Zachos et al. (2008)<sup>[40]</sup>.

Abbreviations: PETM - Palaeocene-Eocene Thermal Maximum; EECO - Early Eocene Climatic Optima; MECO - Mid Eocene Climatic Optima; MMCO - Mid Miocene Climatic Optima.

Following deglaciation, post-glacial sea-level rise and the re-establishment of regional and local drainage systems led to the formation of the largely subdued topography that now dominates the Cheshire Basin. This landscape is incised by rivers including the Mersey and Dee, and near the Mersey Estuary forms a low-lying coastal plain comprising Holocene-age coastal deposits.



**Figure 3.5** The extent and dynamics of the Last British-Irish Ice Sheet during the Late Devensian glaciation (after Clark et al., 2012<sup>[37]</sup>). The thick solid and dotted line corresponds to the maximum known ice extent (non-synchronous). The Cheshire Energy Research Field Site is indicated by the red square.



**Figure 3.6** The superficial geology of the Cheshire Basin (CB) showing the distribution of major units (Digital geological map data BGS © NERC; contains Ordnance Survey data © Crown Copyright and database rights 2017). Blue: Late Devensian till; Pink: Late Devensian glaciofluvial deposits; Orange: river terrace deposits; Yellow: Holocene coastal deposits. NEXTMap Britain elevation data from Intermap Technologies.

## Summary

The Cheshire Basin and local study area possesses a long and complex geological history. A striking feature of its history being that rocks or sediments relating to the majority of its past 200 million years of evolution are absent having been removed by Late Mesozoic and Cenozoic exhumation. The following summary statements can be made about the post-Triassic history of the area:

- The Sherwood Sandstone Group is the youngest bedrock unit that occur beneath the Cheshire

Energy Research Field Site.

- Following deposition during the Triassic these rocks were initially rapidly buried to depths of several kilometres (c.2–4 km). These remaining rocks may therefore exhibit properties (e.g. diagenetic, structural) that reflect processes that occurred in the crust to these depths.
- Since the Late Cretaceous, these rocks have been progressively exhumed with younger cover rocks having been removed by erosion. These rocks may therefore exhibit properties (e.g. structural) that reflect the progressive removal of a vertical load.
- The SSG and MMG within the study area are likely to have been sub-aerially exposed for several million years — possibly extending back into the Palaeogene. The primary properties of the near-surface intervals of the SSG and MMG are likely to have been modified by sub-aerial weathering (both cold and warm climate weathering) and other surface near-surface processes.
- During the last two and a half million years, the Cheshire Basin and study area have been glaciated on at least two separate occasions. Glaciation may have altered the SSG and MMG by direct ice-bed traction and/or by meltwater erosion.
- During the last (Late Devensian) glaciation, the SSG and MMG were largely buried by a veneer of superficial deposits including till, glaciolacustrine and glaciofluvial deposits.
- Following deglaciation, the Cheshire Basin and study area have formed an area of low-lying relief dissected by rivers and lying adjacent to the Mersey Estuary.

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