OR/17/042 Conceptual geological model

From Earthwise

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Driver 1: primary and secondary bedrock properties

A range of discontinuities occurs with the SSG, which reflect primary genesis and post-depositional secondary structures formed during burial and subsequent exhumation (Table 4.1). Discontinuities are a characteristic of the Sherwood Sandstone Group, and are seen in the Ince Marshes region at both outcrop and in borehole core. Bedding, including laminations and partings, are common within the SSG and reflect subtle variations in depositional flow regime and sediment supply. Fractures including faults (i.e. fractures with a measureable displacement) are common throughout the SSG and could form in relation to a variety of primary (e.g. syn-depositional dewatering) to secondary (e.g. soft-sediment deformation, dewatering, consolidation, lithification, unloading and seismicity) contexts. Fractures can be exploited by weathering and groundwater which can enhance the depth of weathering profile, groundwater mobility and chemistry. The occurrence of primary or secondary discontinuities such as fractures within the SSG is ‘virtually certain’.

Table 4.1 Features that may be present beneath the Cheshire Energy Research Field Site and give rise to unpredictable sub-surface behaviour.

Feature	Description	Geometry	Impact	Likelihood of Occurrence
DRIVER 1: Primary and Secondary Bedrock Properties				
Bedrock discontinuities	Primary laminations and partings; fractures; fault zones.	Primary laminations and partings parallel to sub-parallel to bedding; fractures and faults may be of variable geometry.	Discontinuities may provide enhanced pathways into the bedrock volume for weathering processes.	Virtually certain
DRIVER 2: Subaerial exposure and weathering				
Long-term weathering	Weathered or partly-weathered bedrock strata. Strata may be de-structured and de-cemented. Potential occurrence of buried palaeosol horizons including iron-pan and calcrete.	Discontinuous and variable saprolite thickness. Generally likely to be up to 10 metres thick but locally may be thicker.	Unconsolidated or poorly-consolidated bedrock; can lead to complex geotechnical and hydrogeological properties and difficulties in the discrimination of bedrock and superficial deposits.	Virtually Certain
DRIVER 3: Glaciation				

Buried valleys	Buried channels incised into substrate that have little or no surface expression in the modern landscape. Saprolite is commonly absent in buried valleys.	Variable scale. Typically tens of metres deep and hundreds of metres wide (sometimes >km).	Enhanced hydraulic conductivity between the surface and shallow sub-subsurface, depending on properties of fill.	About as likely as not
Till sheets	A laterally-extensive sheet of glacial till.	Variable thickness but commonly several metres thick. May be discontinuous if subsequently eroded.	Can provide relative barriers to groundwater mobility; alternatively, may be sand-prone and fractured and allow communication between surface and subsurface.	Very likely
Lenses within till sheets	Discrete lenses of sand and gravel, sand or silt and clay.	Discontinuous, variable thickness.	Enhanced or reduced hydraulic conductivity between the surface and shallow sub-subsurface.	About as likely as not
Till fractures	Small-scale often ‘closed’ fractures (e.g. faults or joints).	Sub-horizontal and/or sub-vertical geometry; variable lateral and vertical continuity.	Enhanced hydraulic conductivity between the surface and shallow sub-subsurface.	Virtually Certain (if till present)
Basal decollement surface	Sharp structural detachment at the base of a till sheet.	Undulating but generally sub-horizontal geometry.	Large-scale sub-horizontal shear planes can be prone to failure.	About as likely as not
Large-scale folding and thrusting	Large-scale fold and thrust complexes that result in the structural re-ordering of the pre-existing stratigraphy.	Variable geometry depending on boundary conditions during formation. Deformation likely to occur over thicknesses of up to several tens of metres.	Large-scale shear planes that can be prone to failure; increased hydraulic conductivity.	About as likely as not
Glacitectonic rafts	Rafts of translocated substrate (e.g. bedrock) transported down-ice and deposited out-of-sequence.	Variable scale but may be over 10 metres thick.	Large-scale shear planes that can be prone to failure; increased hydraulic conductivity.	About as likely as not
Hydrofractures	Meso-scale fracture systems that can deform bedrock and superficial strata. Fractures can be ‘closed’ or infilled (i.e. ‘open’) by stratified sediment.	Sub-horizontal to sub-vertical in geometry often several metres length.	Enhanced hydraulic conductivity between the surface and shallow sub-subsurface.	About as likely as not

Heterogeneous sediments	Stratified sorted meltwater sediments including clays, silts, sands and gravels.	Often highly-variable with complex geometric relationship and variable contacts (e.g. sharp, intercalated or gradational).	Enhanced hydraulic conductivity between the surface and shallow sub-subsurface.	Very likely
Groundwater flushing beneath permafrost	Increased hydraulic head builds up the proglacial permafrost, with the potential to drive meltwater hundreds of metres into bedrock, flushing porewaters.	May influence bedrock porewaters up to hundreds of metres laterally and vertically from the glacier snout.	Porewater flushing with meltwater.	About as likely as not
DRIVER 4: Post-glacial				
Post-glacial isostatic rebound	Increased seismicity, fault reactivation and fracturing.		Enhanced hydraulic conductivity between the surface and shallow sub-subsurface.	About as likely as not
Sea-level change	Saline groundwater incursion.		Aquifer contamination; hydraulic conductivity between shallow sub-surface and sea bed.	Very likely
Aeolian sequences	Coversands with thin peat layers which can give rise to compressible ground.	Thin, metre-scale.	Generally free-draining with local low permeability (peat) strata; peat may be liable to compression when loaded.	About as likely as not

Driver 2: subaerial exposure and weathering

Cenozoic weathering

The bedrock geology beneath the study area is likely to have been subaerially exposed for several millions of years during the Cenozoic — possibly for much of the Neogene extending back in time to the Palaeogene. This restriction on ‘accommodation space’ limited where sediments could be deposited and critically their preservation. Palaeogene deposits occur discontinuously across southern East Anglia, the Thames Valley and southern England (Gale *et al*., 2006[1]). Collectively, these support global records (Figure 3.3; Zachos *et al*., 2001[2], 2008[3]) in demonstrating that so-called ‘greenhouse climates’ dominated and were generally much warmer and wetter than during later parts of the Cenozoic with several pronounced climatic optima (Westerhold et al., 2009[4]) and cooling events (Hooker *et al*., 2004[5]). Limited geological evidence exists for the Neogene within the UK. Heavily-degraded Miocene deposits crop-out within the Peak District and reveal a transition from sub-tropical, seasonally wet conifer-dominated forest to sub-tropical mixed forest (Pound and Riding, 2016[6]). Pliocene-age deposits occur principally in southern East Anglia and whilst deposited against a backdrop of progressive global cooling are still considered to reflect climates that were probably warmer than the present day (Haywood *et al*., 2000[7]; Johnson et al., 2000[8]; Williams et al., 2009[9]). Collectively, the prevailing tropical to temperate climatic conditions that prevailed during the Palaeogene and Neogene would have led to enhanced rates of chemical (e.g. saline water incursion, groundwater dissolution, soil development) and biological (e.g. root penetration, organisms) weathering (Huggett, 2011[10]).

During the Quaternary, the prevailing climate changed significantly with a progressive intensification of the global climate signal and development of regular cold ('glacial stages') and warm ('interglacial stages') climatic cycles. Within the Early Pleistocene (c.2.58–1.2 Ma), major climate changes occurred with moderate frequency (approximately every 41 000 years) but their magnitude and influence on geological systems was relatively modest (Rose, 2010[11]). Thus, whilst chemical and biological weathering was still active they were by no means the dominant geological agents. A globally-recognised interval, referred to as the Mid-Pleistocene Transition (1.2–0.6 Ma), records the amplification of glacial-interglacial cyclicity and switch to high-magnitude and low-frequency (approximately every 100 000 years) climatic oscillations. These acted to drive regular switches between extreme climatic regimes even in mid-latitude regions like Britain. During the optima of several interglacial events for example, palaeontological evidence demonstrate the presence of Mediterranean-style climates (i.e. high seasonal soil-moisture deficit) within Southern and Central Britain (Candy *et al*., 2010[12]; Schreve and Candy, 2010[13]). Geological evidence for temperate climate weathering includes the development of a range of soil types and chemical precipitates such as iron-pan and calcrete (Weil *et al*., 2016[14]). By contrast, colder climates within Britain have supported the repeated development of permafrost (ground that occurs beneath the 0°c isotherm for over 2 years) and periglacial processes (Boardman, 2011[15]; Busby *et al*., 2015[16]). Simple conductive air-ground heat exchange modelling has demonstrated that permafrost thicknesses during the past 130 ka have within major cold stages exceeded over 100 metres depth (Busby *et al*., 2015[16]). The combined effect of these warm- and cold-climate processes has, over the past one million years, led to dramatic increases in the mechanical (e.g. freeze-thaw, frost action), chemical (e.g. salt water incursion, groundwater dissolution, soil development) and biological weathering (e.g. root penetration, organisms) of materials exposed at or near to the surface (Rose, 2010[11]).

Because of its lithological and textural properties, with poorly-cemented porous and permeable units, bedding discontinuities, fractures and faults, the SSG is highly-susceptible to **chemical** and **biological weathering** associated with glacial and post-glacial processes and weathering (Yates, 1992[17]). Indeed, a study by Mottershead *et al*. (2003)[18] highlights the role of chemical and biological weathering and specifically the influence of marine salt crystallisation on weathering rates. Their study concluded, for example, that the presence of marine salts resulted in the acceleration of weathering rates by a factor of 1.59 (Mottershead *et al*., 2003[18]). Thus, saline water incursion into the SSG during successive global marine high-stands throughout the Cenozoic would have likely-resulted in enhanced salt weathering rates (Trenhaile and Mercan, 1984[19]; Williams and Robinson, 2001[20]). Weathering under longer-term cold climates is likely to include carbonate dissolution (greater at lower temperatures), salt weathering and frost weathering (mechanical weathering).

Frost weathering is another significant weathering process that may affect the SSG (Walder and Hallet, 1986[21]; Matsuoka, 1990[22]; Matsuoka and Murton, 2008[23]). Ice formed by the freezing of water within the void (pore) space between rock and sediment particles is called *pore ice*. The pressure exerted by the expansion in volume that occurs during the conversion of water to ice can cause a rock to mechanically fail. The growth of pore ice and susceptibility of a rock or sediment to failure will depend on: (1) the maintenance of an elevated water-table; (2) the void (pore) space within a rock or sediment and ease with which water can enter the pore space (related to permeability); (3) a greater ice volume to pore-space ratio. Due to its porosity, the SSG would be highly-susceptible to the growth of pore ice. Mechanical weathering of a rock or sediment can also occur by the growth of ice (called *segregated ice*) within isolated layers or lenses. The formation of ice by this mechanism requires strong capillary forces (the molecular force that exists between confined rock or sediment particles) to be active and these are typically greater in finer-grained rocks and sediments with lower void space. Increased capillarity enable elevated levels of cryosuction to build-up (Taber, 1929[24]) which acts to pull additional water into the zone of freezing forming segregated ice that grows in the direction with which heat is being most rapidly conducted away (i.e. towards the ground surface) (Williams and Smith, 1989[25]). Finer-grained horizons within the SSG are likely to be frost-susceptible with the growth of *segregated ice* causing mechanical breakdown of the parent material.

The wide range of weathering mechanisms that operated during the Cenozoic, combined with the properties of the SSG, make it susceptible to specific forms of weathering (Table 4.1). Strata that have been exposed at or near to the land-surface for prolonged periods of geological time, and/or strata that have been inundated by saline groundwater are particularly susceptible to weathering. Rock strata that have undergone varying degrees of *in situ* weathering in their ultimate conversion to soil are referred to as saprolites.

Saprolites developed on the SSG may comprise partly or completely de-structured sandstone (sand) or gravel where the cement that bonds individual sand particles has weakened or been removed. Restricted areas of ‘weathered bedrock’ derived from the Sherwood Sandstone Group, up to a maximum of 20 m thick, have been identified by Burke *et al*., (2016)[26] within the Cheshire Energy Research Field Site. Localised re-sedimentation of the saprolite may also have occurred in response to more recent fluvial activity or downslope movement. The thickness and extent of this material in the study area is difficult to determine due to the paucity of data. However, in a recent study based on the SSG in the East Midlands, Tye *et al*. (2011)[27] found that the depth of weathering reached a maximum of 40 metres. Weathering rates were greatest where faulting allowed meteoric waters to penetrate downwards to greater depths within the bedrock. Therefore, saprolite of discontinuous distribution and variable thickness (perhaps up to 40 metres) is ‘virtually certain’ beneath much of the study area.

Driver 3: glaciation

The Cheshire Basin has been glaciated on at least two occasions during the Quaternary. The last glaciation, corresponding to the Late Devensian, resulted in the region being overridden by ice from two sources. Firstly, Welsh ice originating from Snowdonia and the Arenig Mountains of north Wales (Thomas, 1985[28]; Jansson and Glasser, 2005[29]). Secondly, Irish Sea/Lake District ice that extended southwards through the Irish Sea Basin with an eastern offshoot directed across Lancashire into Cheshire, Staffordshire and the West Midlands (Boulton and Worsley, 1965[30]; Thomas, 1985[28]; Thomas, 1989[31]; Parkes *et al*., 2009[32]; Chiverrell *et al*., 2016[33]). Welsh ice was restricted to the western side of the modern River Dee with the study area overridden by Irish Sea ice (Howard *et al*., 2007[34]).

Buried valleys (meltwater erosion)

A striking feature within the northern part of the Cheshire Basin is the highly irregular rockhead surface with several deeply-incised buried valleys ranging up to tens of metres deep recognisable (Figure 4.1). Several buried valleys have been identified beneath modern rivers including the Dee and Mersey (Reade, 1873[35], 1885[36]; Boswell, 1925[37], 1937[38]; Jones, 1937[39]; Gresswell, 1964[40]; Howell, 1973[41]; Crofts, 1999[42]; Burke *et al*., 2016[26]) and elsewhere in Cheshire (Owen, 1947[43]; Worsley *et al*., 1983[44]).

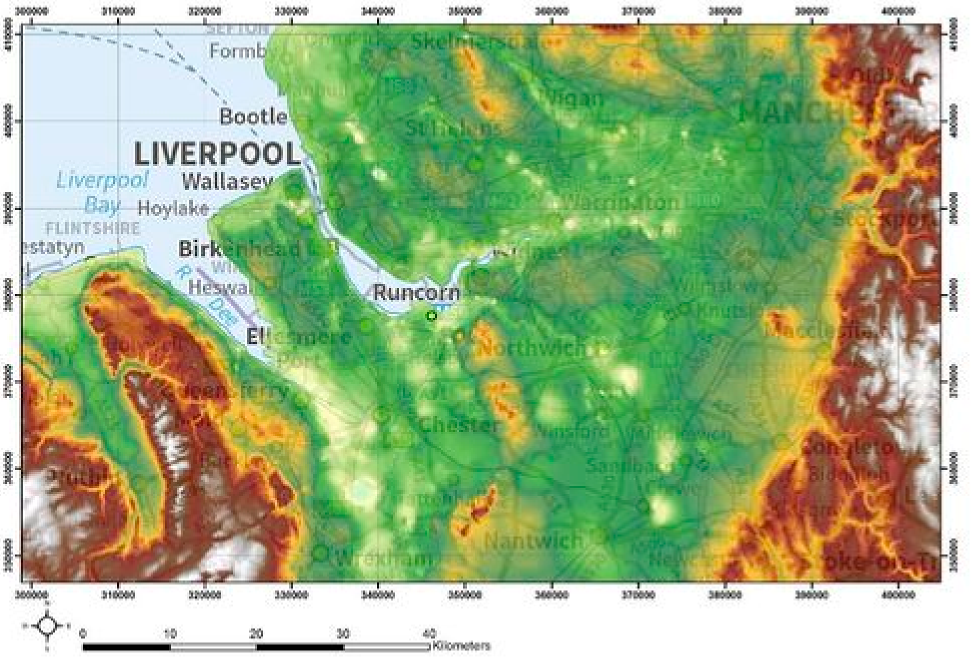

Figure 4.1 A rockhead (geological) relief model for the northern Cheshire Basin including the study area (green dot). Pale yellow and pale green areas of shading correspond to areas of lowest rockhead relief and, where connected, the location of major buried valleys. Includes Ordnance Survey data © Crown copyright and database rights [2017] Ordnance Survey [100021290 EUL].

The consensus within the literature is that these buried valleys were produced by glacial over-deepening (subglacial erosion) and/or subglacial meltwater incision (Gresswell, 1964[40]; Howell, 1973[41]). Buried valleys produced by subglacial meltwater incision are commonly called tunnel valleys (or tunnel channels in North America) and occur widely around former glacier margins (Ó Cofaigh, 1996[45]; Piotrowski, 1997[46]; Dürst Stucki *et al*., 2010[47]; Kehew *et al*., 2012[48]). Incision of tunnel valleys occurs under immense hydraulic gradients with flow regimes constrained by channel morphology and the thickness of overlying ice. A common characteristic of tunnel valleys is that their bases (referred to as the thalweg) are often undulating with significant normal and reverse changes in gradient developed along their long-profile. Infills to buried valleys tend to be highly-chaotic encompassing intercalated beds of till, glaciolacustrine (silt and clay) and glaciofluvial (sand and gravel) sediment that typically give-rise to chaotic and unpredictable hydrogeological behaviour.

The rockhead surface model provides a valuable insight into the nature of the rockhead surface beneath the study area. However, it only provides a generalisation of the rockhead surface with local variation also influenced by relative borehole density. The model shows a radial arrangement of buried valleys fanning outwards from the Liverpool-Skelmersdale area southwards and eastwards beneath the Cheshire/north Shropshire lowlands (Figure 4.1). The radial pattern conforms to the geometry of the hydraulic gradient that would generate perpendicular to the margins of a piedmont-style glacier lobe that fanned outwards across the Cheshire lowlands towards the west, south and east. This style of glacier geometry has previously been inferred for the Late Devensian ice lobe based upon the mapped distribution morainic landforms around the region (Boulton and Worsley, 1965[30]; Yates, 1967[49]; Thomas, 1989[31]).

Whilst a glacial origin for several of the larger buried channels is logical, some channels may have existed in the landscape prior to the Late Devensian glaciation and originally be of fluvial origin. For example, Worsley *et al*. (1983)[44] describes a buried channel that contains preglacial organic sediments overlain by glacial till and meltwater sediments. Of particular relevance to the study area is the existence of a major buried channel beneath the modern River Mersey (Figure 4.2). Small, broadly north-south trending offshoots of this buried valley occur to the west and east of Thornton-le-Moors. However, the resolution of the rockhead model mean that the true geometry of these buried valleys remains poorly constrained. Therefore, the presence of a buried valley beneath the Cheshire Energy Research Field Site is 'about as likely as not' (Table 2.1). Local perturbations in the rockhead surface up to 47 m below OD, some likely associated with buried channels, have been identified to the east of the village of Elton, beneath Ince Marshes and are described by Burke *et al.* (2016)[26].

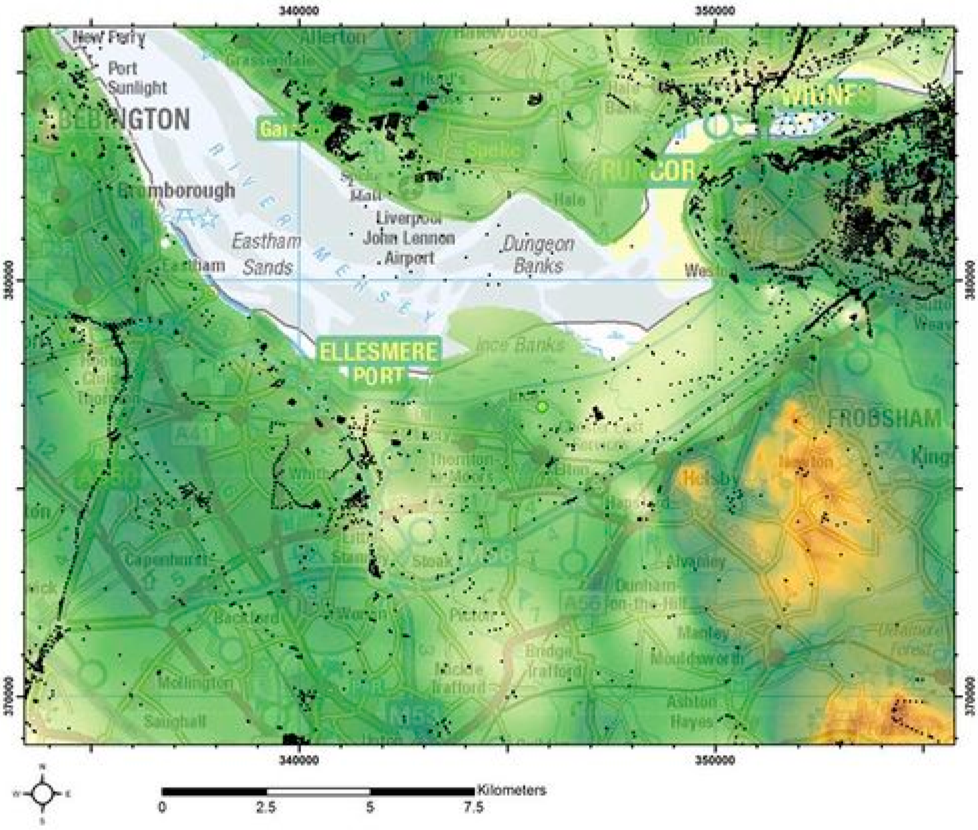

Figure 4.2 Rockhead (geological) surface model adjacent to the Cheshire Energy Research Field Site (green dot) showing a major buried valley (pale yellow to pale green) to the west extending northwards to Ellesmere Port joining an assumed valley that extends beneath the Mersey Estuary. Borehole locations are indicated by small black dots. Includes Ordnance Survey data © Crown copyright and database rights [2017] Ordnance Survey [100021290 EUL].

Tills (internal fractures)

Two lithologically-similar sheets of Irish Sea-derived till have been recognised adjacent to the Mersey (Thomas, 1989[31]) (Figure 4.3). They comprise over-consolidated, variably stony (matrix- to clast-supported), red-brown diamicton containing a mixture of locally-derived SSG and MMG material, and far-travelled clast lithologies derived from the Lake District and southwest Scotland (Wedd *et al.*, 1923[50]). Exposures of the Irish Sea Till in Cheshire are limited but several sections have been described and reported at Thurstaston on the Wirral Peninsula (Slater, 1929[51]; Brenchley, 1968[52]; Glasser *et al.*, 2001[53]). Till sheets directly overlie one another or bedrock, or are locally underlain and separated by a variably-thick sequence of glacilacustrine silts and clays and glacifluvial sands and gravels (Brenchley, 1968[52]; Worsley *et al.*, 1983[44]; Earp and Taylor, 1986[54]; Crofts, 1999[42]). Either or both till sheets are 'very likely' to be present beneath the study site and may locally attain thicknesses in excess of 20 metres (Crofts, 1999[42]).

Figure 4.3 A coastal section through Irish Sea-derived till from Anglesey, north Wales.

Although there are no known exposures of till in the study area, most subglacial tills contain horizontal and vertical fractures produced by compressional stresses (e.g. reverse or thrust faults), or extensional stresses including unloading (e.g. joints, normal faults) (Figure 4.4; Williams and Farvolden, 1967[55]; Derbyshire and Jones, 1980[56]; Eyles and Sladen, 1981[57]; Evans *et al*., 2006[58]). Their presence — assuming a till sheet(s) is present beneath the site is ‘virtually certain’ (Table 4.1). Equally, tills often contain discrete lenses (discontinuous) of sand, sand and gravel, or clay and silt and their occurrence within till — if present beneath the search site, is ‘about as likely as not’ (Table 4.1).

Figure 4.4 An example of a heavily-fractured till, east Yorkshire, showing vertical and horizontal joint sets.

Glacitectonic structures (folds and thrusts)

The process of glaciation is widely treated as a sedimentary process. However, the action of glaciers overriding and interacting with a pre-existing landscape is actually a tectonic process and akin in many respects (but not all) to continental-scale processes that occur with mountain belts and shear zones (Pedersen, 2012[59]; Lee *et al*., 2017[60]). The action of glaciers overriding and pushing into a pre-existing landscape can cause the widespread deformation of existing materials. Deformation can take place in a spatial continuum from subglacial (beneath the ice), ice-marginal (beneath or adjacent to the ice margin) or proglacial (in front of the glacier) (Benn and Evans, 2010[61]).

The base of major till sheets are commonly marked by a structural zone exhibiting glacitectonised substrate materials and bounded by variably-extensive sub-horizontal decollement surfaces (Banham, 1977[62]; Berthelsen, 1978[63]; Boulton and Hindmarsh, 1987[64]; Hart, 1995[65]; Evans *et al*., 2006[58]; Aber and Ber, 2007[66]; Lee and Phillips, 2013[67]). The thickness of these shear zones (encompassing glacitectonised substrate and till) can vary from metre-scale to tens-of-metre scale depending on substrate rheology (controlled by substrate lithology, porewater availability and temperature), and the degree of ice-bed traction (Boulton and Hindmarsh, 1987[64]; Boulton, 1996[68]; Murray, 1997[69]; Evans *et al*., 2006[58]; Kjær *et al*., 2006[70]; Lee and Phillips, 2013[67]; Phillips *et al*., 2013[71]). Their presence beneath the study site is 'likely' (Table 4.1). However, distinguishing between till and glacitectonised bedrock may prove problematic. This is because the appearance of both the till and glacitectonised bedrock may be similar and detailed laboratory analyses (e.g. strength, lithology, palynology) may be required to delineate them.

Terminal moraines are produced by the 'bulldozing' and pushing of ice-marginal and proglacial materials at the snout of a glacier and their geometry often mirrors the form and dynamics of the glacier margin (Boulton, 1986[72]; Krüger, 1993[73]; Aber *et al*., 1995[74]; Harris *et al*., 1997[75]; Bennett, 2001[76]). The construction of terminal moraines leads to the development of fold and thrust complexes similar (albeit much smaller) to those that form in continental-scale foreland fold-thrust zones within orogenic belts (Croot, 1987[77]; Aber and Ber, 2007[66]). The formation of a variety of fold and fault styles can alter the geometry and relative ordering of the main stratigraphic units bringing different units into juxtaposition (Figure 4.5; Slater, 1931[78]; van der Wateren, 1985[79]; Hart, 1990[80]; Aber, 1993[81]; Harris *et al*., 1997[75]; Phillips *et al*., 2007[82]; Roberts *et al*., 2007[83]; Phillips *et al*., 2008[84]; Thomas and Chiverrell, 2011[85]; Lee *et al*., 2013[67]). The likely occurrence of these features beneath the study site is 'about as likely as not' (Table 4.1). Commonly associated with this style of glacitectonism are the development of glacitectonic rafts. These are dislocated slabs or bedrock or cohesive sediment that have been detached along rheological discontinuities, transported by thrusting and deposited out-of-sequence down-ice (Ruszczynska-Szenajch, 1987[86]; Aber and Ber, 2007[66]; Burke *et al*., 2009[87]; Vaughan-Hirsch *et al*., 2013[88]). The geometry of glacitectonic rafts can vary markedly from metre-scale to tens and even hundreds of metres.

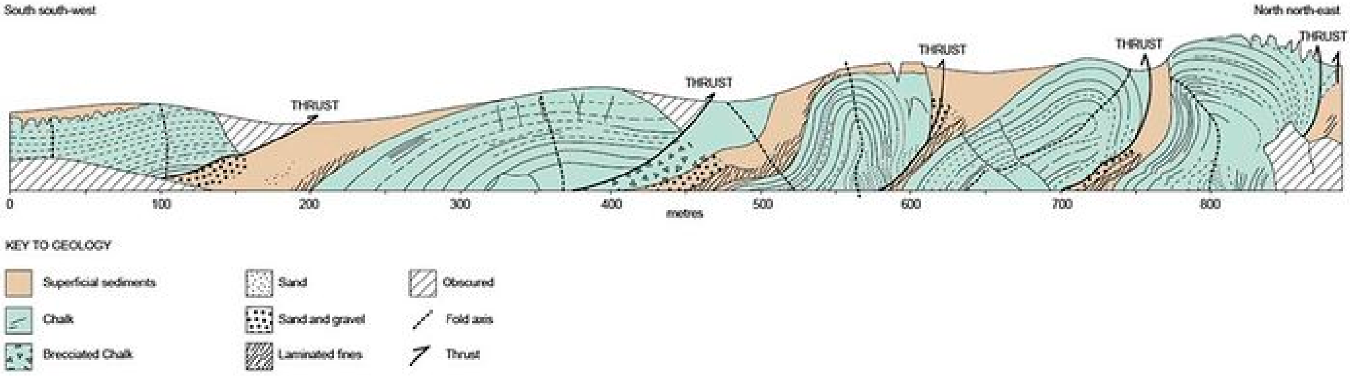

Figure 4.5 Structural interpretation of deformed bedrock and superficial sequences at Møens

Klint, Denmark (from Lee and Phillips, 2013[67]).

Within the Cheshire Basin (CB), a tripartite glacigenic sequence comprising two tills and intervening outwash deposits has been described (Worsley, 1991; Crofts *et al.*, 2005). They were laid-down in association with a lobe of wet-based Irish Sea Ice that extended across the Cheshire/Shropshire lowlands reaching as far south and west as the West Midlands. Evidence from both modern glacial environments and the geological record suggests that key controls on ice-bed interactions and in-turn glacier behaviour is meltwater availability (Eyles, 2006[89]; Bell, 2008[90]). Within the CB, given the lateral continuity of the major till facies, it suggests that ice-bed traction was largely limited with a meltwater-enhanced substrate zone effectively decoupling the glacier from its bed. This would have limited the transmission of strain into the substrate. Reducing and/or varying the availability of meltwater within the substrate typically has the effect of enhancing ice-bed traction enabling the transmission of strain into the glacier bed (Lee *et al.*, 2017[60]). This dramatically increases the potential for larger-scale deformation of the substrate including the development of glacitectonic folds, faults and bedrock rafts. Therefore, during collapse of the Irish Sea Ice and progressive northwards retreat of the ice margin across the CB, temporal and spatial variations in substrate water availability may have led to enhanced ice-bed traction and in-turn substrate deformation by glacitectonic processes. This effect of often amplified where the substrate is dominated by permeable lithologies (e.g. SSG) which act as meltwater sinks and/or where seasonal freezing of the glacier snout to its bed occurs (e.g. Hiemstra *et al.*, 2007[91]; Lee *et al.*, 2013, 2017[67]).

Evidence for these glacitectonic processes occurring in the CB is indicated by the development of terminal moraine complexes (Boulton and Worsley, 1965[30]; Thomas, 1989[31]; Price *et al.*, 2007[92]; Parkes *et al.*, 2009[32]; Clark *et al.*, 2012[93]; Crofts *et al.*, 2012[94]). To date, no glacitectonic rafts have been identified within the Cheshire Basin. However, the style of deglaciation coupled with the prevailing climatic conditions and hydrogeological properties of the SSG make it particularly susceptible to the development of these structures. The likely occurrence of these features beneath the study site is ‘about as likely as not’ (Table 4.1).

Hydrofracture systems

Another important feature recognised within glacial sequences and associated bedrock units are hydrofracture systems. These can develop within a range of different glacial systems where substrate water availability is high or seasonally variable (van der Meer *et al.*, 1999[95]; Phillips, 2006[96]; Roberts *et al.*, 2009[97]; Phillips *et al.*, 2013[71]; Lee *et al.*, 2015[98]). Hydrofractures are generated by the catastrophic failure of material in response to the release of over-pressurised porewater. Hydrofractures can exhibit a range of different geometries that are unique to the boundary conditions at the time of fracturing. Typically, a single hydrofracture is millimetre to tens of centimetres wide, and metres to tens of metres in length; complex hydrofracture networks can develop within the bedrock succession (e.g., Cowsill *et al.*, 2016[99]). If a hydrofracture has been reactivated then it can contain a stratified sediment fill when can prevent the fracture from re-sealing enabling further hydrofracturing and draining of the substrate (Phillips, 2006[96]). Hydrofractures have been widely reported from the Sherwood Sandstone Group (Hough *et al.*, 2006[100]) and more locally at Runcorn (Weathall *et al.*, 2001[101]) and near Preston (Cowsill *et al.*, 2016[102]). The elevated and variable meltwater availability that controlled the dynamics of the Irish Sea Ice lobe offer suitable conditions for their development. The likely occurrence of these features beneath the study site is ‘very likely’ (Table 4.1).

Driver 4: post-glacial

Post-glacial isostatic rebound

Since the last glaciation, rates of isostatic adjustment due to unloading of glacier ice from the crust in the UK are well documented (Shennan *et al*., 2006[103]). Isostatic adjustment can lead to an increase in seismicity, fault reactivation and crustal fracturing where strain stored within the crust is released as the vertical load is removed (Firth and Stewart, 2000[104]; Stewart *et al*., 2000[105]). The Cheshire Basin lies within an area of positive isostatic adjustment (uplift) and is therefore prone to rebound-related seismicity and fracturing (Shennan and Horton, 2002[106]). The likely occurrence of fractures relating to isostatic rebound are 'about as likely as not'.

Sea-level change

Following the retreat and melting of the glaciers at the end of the Late Devensian glaciation global sea-levels rose drowning previously exposed (and glaciated) areas of continental shelf and basinal areas including the Irish Sea. Immediately following deglaciation, a new drainage system became established including the River Mersey with a major period of sedimentation and stabilisation during the early Holocene (c.9,600–8,000 yrs BP) (Tooley, 1974[107]; Macklin *et al*., 2010[108]; Roberts *et al*., 2011[109]). Continued sea-level rise during the Holocene is likely to have resulted in the transition from terrestrial (fluvial?) to estuarine (proximal) and finally estuarine (distal) as continued sedimentation led to emergence of the coastal plain. Regional sea-level rise around the Mersey Estuary is 'very likely' to have led to saline groundwater incursion into the SSG depending on the hydraulic connectivity between the bedrock, overlying superficial deposits and seabed.

Additional geological features that may occur beneath the Cheshire Energy Research Field Site are aeolian sediments and inter-stratified peat horizons. Aeolian activity adjacent to the Irish Sea Basin was widespread following the end of the last glaciation because of the high-availability of suitable sediment (pre-existing glacifluvial deposits) and the prevailing climatic conditions (Wilson *et al*., 1981[110]). Extensive sand dune systems are present in coastal areas of Cheshire and Lancashire (Gresswell, 1937[111]; Pye and Neal, 1994[112]), North Wales and Anglesey (Greenly, 1919[113]; Ranwell, 1959[114]; Bailey and Bristow, 2004[115]) and an aeolian coversand (the Shirley Hill Sand Formation) has also been recognised in parts of the region (Wilson *et al*., 1981[110]; Howard *et al*., 2007[34]). Commonly associated with coversand and dune systems are thin discontinuous horizons or beds of peat. These typically form as thin immature soils or peat development within localised poorly-drained inter-dune areas. The presence of aeolian deposits of variable thickness beneath the study area, including sand (coversand) or loess (silt), is 'about as likely as not'. Accumulations of peat have also been identified offshore of the Wirral (Innes et al., 1990[116]; Kenna, 1986[117]) and some of these may be contemporaneous with peat units identified by Burke et al. (2016) within coastal deposits. Peats can acts as local aquitards and give rise to compressible ground conditions when loaded. Their presence within coastal deposits is 'very likely'.

Conceptual geological model of the study area

Based upon the narrative outlined above it is possible to predict the natural superficial geology beneath the Cheshire Energy Research Field Site area and this is shown below in a schematic cross-section (Figure 4.6). Many of the features identified in this conceptual model have been described at the Cheshire Energy Research Field Site by Burke *et al*. (2016)[26].

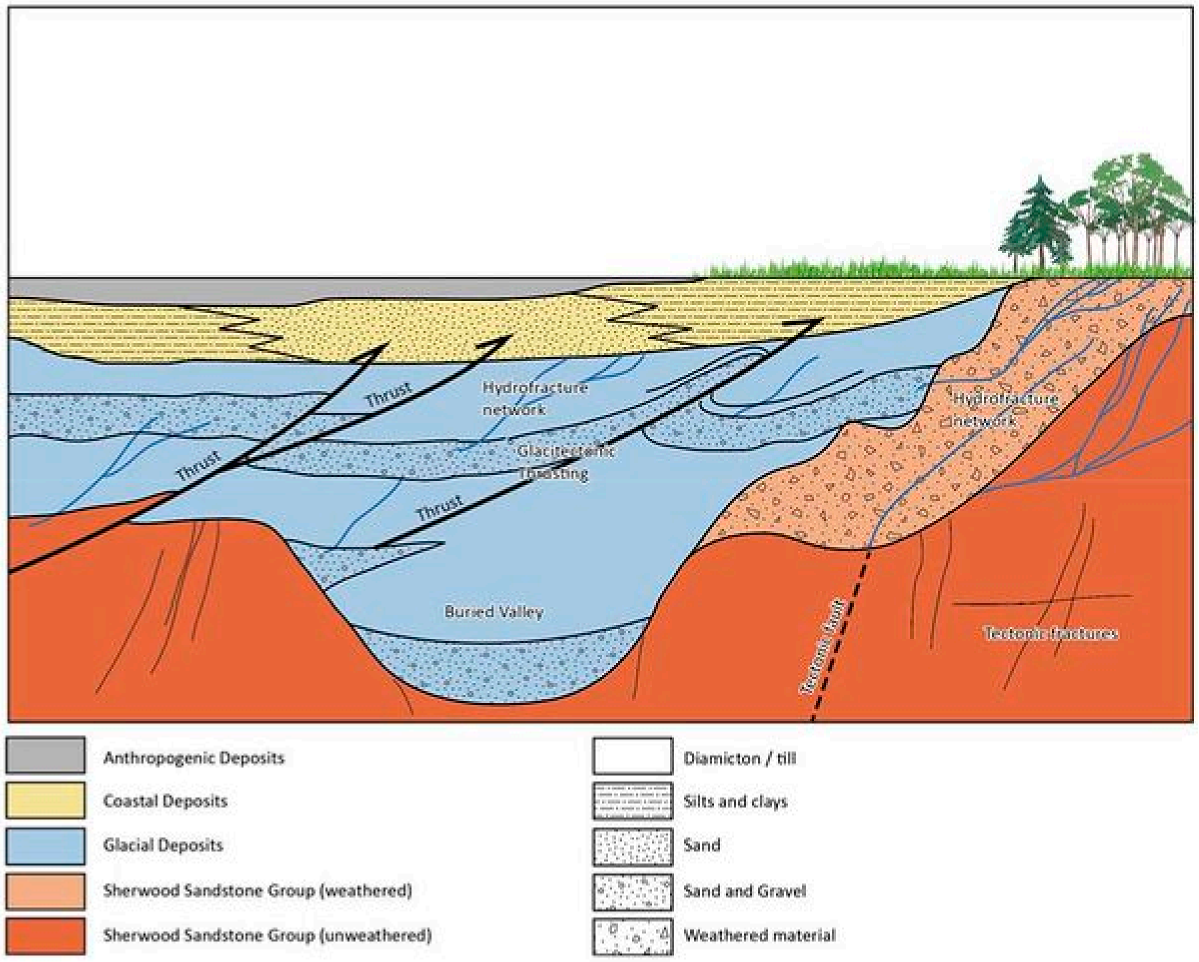

Figure 4.6 A schematic model (not to scale) showing the predicted natural superficial geology beneath the search area. The ground surface slopes from south to north.

In summary, based upon the application of the conceptual geological model methodology, the following features may need to be considered in any sub-surface ground investigations.

- Unweathered bedrock (Sherwood Sandstone Group) will be largely buried by natural superficial deposits beneath much of the search area. Bedrock is predicted to be mantled by a weathered zone of variable thickness and extent. Bedrock and weathered bedrock may be deformed by hydrofractures and by glacitectonic thrusting.
- The rockhead surface is predicted to be irregular reflecting both weathering of the bedrock and the possible presence of buried channels produced by meltwater incision.
- A glacial succession of variable thickness is predicted to be present beneath the much of the search site. It drapes the bedrock (or weathered bedrock) infilling buried channels that may be present and comprising a highly-variable succession of till, laminated silt and clay, sand and sand and gravel.
- The glacial sequence is predicted to be heterogeneous composed largely of till with localised discontinuous bodies of sand and laminated silt and clay. Till units are predicted to be deformed by vertical and horizontal joints, large-scale thrusts and/or folding and possibly by hydrofractures.

Holocene-age coastal deposits are predicted to overlie and, in places (e.g. tidal channels), truncate the glacial succession. These deposits are predicted to be heterogeneous and highly-complex comprising beds of peat, sand, silt and clay and gravel.

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- This page was last modified on 3 December 2019, at 14:30.