A new source-to-sink synthesis of the Middle Triassic Helsby Sandstone Formation (Sherwood Sandstone Group) river system of the British Isles

Abbreviated title: A new synthesis of Mid-Triassic rivers in Britain

Xiang Yan, Gary J. Hampson and Alexander C. Whittaker*

Department of Earth Science and Engineering, Imperial College London, London SW7 2AZ, UK

***Correspondence: Xiang.yan19@imperial.ac.uk**

XY: https://orcid.org/0009-0001-5167-3008

GJH: https://orcid.org/0000-0003-2047-8469

ACW: https://orcid.org/0000-0002-8781-7771

Abstract

Sediment grain size and mineralogy change in sediment routing systems from source to sink. A better understanding of sediment routing allows improved predictions to be made of the bulk grain-size and mineralogy of sandstone fairways. We present a new appraisal of sediment routing in the Triassic Helsby Sandstone Formation (Sherwood Sandstone Group) and lowermost Mercia Mudstone Group of the British Isles, which constitute a key play for geological sequestration of CO2. These strata were deposited and supplied by a major, north-flowing river system, which is traced from its source region in north France to beyond the Irish Sea. We construct a new, integrated litho- and chronostratigraphic model to correlate key units across the British Isles. We then present sediment isopachs and volumes for this chronostratigraphic interval, and resolve palaeogeographic discrepancies using published sedimentological datasets, supplemented by a new synthesis of bulk sandstone mineralogy. Finally, we present a unified, updated sediment routing map for the Helsby Sandstone Formation. Substantial north-south differences in bulk sandstone mineralogy indicate that that sediment input from tributaries modified the composition of the Helsby Sandstone Formation along the course of the sediment routing system.

Introduction

Sediment transport via rivers is a key surface process that transfers mass from sediment sources to sediment sinks. Source-to-sink systems can be divided into segments: areas of uplift and erosion where sediment is generated, areas of sediment bypass and transient storage, and subsiding depocentres (e.g. Somme et al., 2009; Romans and Graham, 2013; Helland-Hansen et al., 2016). The size, shape and distribution of sediment routing systems are controlled by their geomorphology (e.g. Somme et al., 2009; Helland-Hansen et al., 2016; Markwick, 2019), which is seldom completely preserved over deep time (Romans and Graham, 2013; Helland-Hansen et al., 2016). Consequently, reconstructing palaeogeography is essential for constraining source-to-sink sediment routing in the geological record (e.g. Markwick, 2019; Wrobel-Daveau et al., 2022). Understanding source-to-sink sediment routing is in turn a crucial tool to evaluate landscape responses to climate change and tectonics, as well as for predictive resource exploration (Wrobel-Daveau et al., 2022; Castelltort et al., 2023).

Source-to-sink sediment routing is commonly constrained by several methods, and involves the integration of lithostratigraphy, chronostratigraphy, and palaeogeography, the latter constrained by methods including quantitative provenance analysis, sedimentology and palaeocurrents (e.g. Morton and Hallsworth, 1993; Hampson et al., 2014; Helland-Hansen et al., 2016; Michael and Zuhlke, 2022; Castellort et al., 2023). Synthesising these data can produce a defined stratigraphy and age model, sediment volumes, and a defined map of sediment source areas and sinks.

The Triassic Sherwood Sandstone Group (SSG; **table 1**) of the British Isles represents a regionally important, predominantly fluvial sediment routing system, dated c. 249-240 Ma (**fig. 1a,** Hounslow and McIntosh, 2003; Hounslow and Gallois, 2023). The SSG was deposited at low latitudes of ca. 20° N during the early breakup of Pangea (**fig. 1b**), and in the aftermath of the Permo-Triassic extinction (Radley and Coram, 2016; Newell, 2017a; b). Much of the SSG is interpreted to have been laid down by major, north-flowing river systems that originated from Variscan highlands, now situated in northern France (**fig. 1c,** e.g. Wills, 1956; Burley, 1987; Tyrrell et al., 2012; Morton et al., 2016; Newell, 2017a; Burgess et al., 2025). The SSG has served as a key target for hydrocarbon exploration and production (e.g. Cowan, 1993; McKie et al., 1997, Floodpage et al., 2001; Medici et al., 2019a; Scorgie et al., 2021), for geothermal energy production (Downing et al., 1983; Knox et al., 1984), and is a major groundwater aquifer (Plant et al., 1999; Newell and Smith, 2009; Medici et al., 2019b). More recently, the SSG has also become a key target for geological sequestration of CO_2 (e.g. Holliday et al., 1991; Newell and Shariatipour, 2016; Scorgie et al., 2021; Chedburn et al., 2022; English et al., 2024; Gibson-Poole et al., 2025; Head et al., 2025). During the mid-Triassic, the SSG transitioned into the Mercia Mudstone Group (MMG), which forms the sealfor the SSG reservoir (**fig. 1a**, e.g. McKie et al., 1997; Scorgie et al., 2021; Chedburn et al., 2022; English et al., 2024; Hounslow and Gallois, 2023).

The most recent holistic palaeogeography for this time interval, published more than 30 years ago (**fig. 1c,** Warrington and Ivimey-Cook, 1992), describes a major northward-directed sediment routing system originating from the remnant Variscan highlands of north France, flowing through a series of linked extensional basins in the British Isles, into the East Irish Sea Basin (EISB). This follows the older palaeogeographic interpretations from Wills (1970), Audley-Charles, (1970b), and Burley (1987). However, unlike previous interpretations, there is no mention or depiction of lateral sediment inputs, and sediment routing in the Wessex Basin and beyond the EISB remains unclear. Furthermore, the SSG-MMG transition is poorly understood. Finally, the palaeogeographic extent of the catchments which sourced the fluvial systems of the SSG remain poorly constrained, as is their relation to the wider palaeogeography of northwest Europe.

Integration of data and research that has become available since the publication of Warrington and Ivimey-Cook (1992) could help to address these knowledge gaps. For instance, subsequent regional studies on the British Triassic system have collected and synthesised existing information to build basin-scale depositional models (e.g. Hamblin et al., 1992; Jackson et al., 1995; Plant et al., 1999; Dunford et al., 2001; Newell, 2017b; 2023; Marsh et al., 2022) while quantitative provenance analysis (Tyrrell et al., 2012; Morton et al., 2013; 2016) has provided higher resolution constraints on sediment source areas and sediment routing within the SSG. At the same time, better characterisation of the pre-Triassic basement allows inferences to be made about source area composition (e.g. Baptiste, 2016; Butler, 2018). Emerging chronostratigraphy has allowed the improved correlation of coeval units both across the British Isles (Mange et al., 1999; 2007; Hounslow and McIntosh, 2003; Hounslow et al., 2017; Houslow and Gallois, 2023), and to the wider European Triassic system (Bourquin et al., 2011, McKie, 2017). Lastly, an improved understanding of the early Triassic climate (Péron et al., 2005; Ravidà et al., 2021) and tectonics (Newell, 2017a) have offered further insights into controls on sediment generation.

Consequently, the last 30 years of research has resulted in a situation in which the SSG and MMG of the British Isles is locally well-characterised in many aspects, yet is poorly resolved on the scale of the sediment routing system. The aim of this paper is to produce a comprehensive, up-to-date and quantitative reconstruction of this source-to-sink system, harmonised with the palaeogeography of northwest Europe. To this end, we develop a unified lithostratigraphic and chronostratigraphic synthesis of key units in the SSG and MMG, focussing on a well-defined chronostratigraphic interval consisting of the upper SSG and lower MMG in which the sediment routing system is well constrained. We present new maps of the sediment fairway using standardised nomenclature compiled from previous palaeogeographic studies. Using these products as a framework, we present the first quantitative estimates of the volume and distribution of fluvial and aeolian deposits within the fairway. We then derive isopach maps and volumes for units of interest, and we synthesise downsystem trends in sediment composition and provenance to characterise source-to-sink sediment routing, as well as the composition and extent of source areas. Finally, we use these data to evaluate the size and position of sediment inputs into the sediment routing system.

Geological framework

The British Triassic system begins during the lower Triassic with the SSG (Hounslow and McIntosh, 2003), and passes into the MMG during the mid-Triassic (**fig. 1a**, Hounslow and Gallois, 2023). Deposition occurred in a series of linked, N-S trending extensional basins throughout the British Isles, spanning the area between the English Channel and the Irish Sea (Warrington and Ivimey-Cook, 1992). Deposition occurred under an arid and semiarid climate, which is widely evidenced by sedimentology and palaeontology (e.g. Brookfield, 2008; Evans et al., 2011; McKie, 2014; Newell, 2017a; b; Coram et al., 2019).

The standardised lithostratigraphy of the SSG, defined by the British Geological Survey (BGS, Ambrose et al., 2014), divides the group into three formations based on a succession typified in the Cheshire Basin. These three standardised formations are the conglomeratic and sandy fluvial Chester Formation (CHF), the mixed fluvial-aeolian Wilmslow Sandstone Formation (WSF) and the fluvial-aeolian Helsby Sandstone Formation (HSF) (**fig. 2**; Ambrose et al., 2014; Newell, 2017a). Deposition of the HSF in the Wessex Basin and Worcester Graben was partially contemporaneous with the deposition of the lowermost MMG in the Cheshire Basin and EISB (**fig. 1a, c**). The stratigraphy of the MMG is similarly standardised (Howard et al., 2008), and is represented by the Tarporley Siltstone Formation (TSF) and the Sidmouth Mudstone Formation (SMF) (**fig. 2;** e.g. Warrington et al., 1970b; Wilson, 1990; 1993; Newell, 2017a).

The BGS standardised stratigraphy supersedes older stratigraphic terminology which differed between sedimentary basins (**fig. 2**). Unit names for basin-scale stratigraphy are presented in **Figure 2,** and are based on the synthesis of Ambrose et al. (2014) and Howard et al. (2008). Although the older, basin-scale terminology is still widely used (e.g. Newell, 2017a; b; Scorgie et al., 2021; Marsh et al., 2022; Chedburn et al., 2022), the standardised BGS stratigraphy enables the SSG and MMG to be represented effectively on the source-to-sink scale, as it allows units to be robustly correlated between basins whilst avoiding any complex or redundant terminology.

The CHF (**fig. 1a**) was deposited during the lower Triassic by a regionally significant fluvial system sourced from the remnant Variscan mountains in north France (e.g. Tyrrell et al., 2012; Morton et al., 2013; 2016). This system flowed northwards into the East Irish Sea Basin, possibly reaching Northern Ireland (Franklin et al., 2020; Moscardini et al., 2025). Deposition during the CHF occurred in a highly dynamic, but consistently hyperthermal semiarid climate during the aftermath of the Permo-Triassic extinction (Sun et al., 2012), resulting in its unusually coarse grain size (Radley and Coram, 2016; Newell, 2017a).

The overlying WSF is conformable over the CHF **(figs. 1a, 2)**, and is interpreted to represent a period of dominantly aeolian activity caused by accelerated extensional faulting, resulting in the disconnection of basins and dissection of the SSG fairway (Newell, 2017a). The boundary between the WSF and the overlying HSF is largely unconformable (**fig. 2**), representing a period of tectonic uplift traditionally attributed to the Europe-wide Hardegsen tectonic event (Evans et al., 1993; Mange et al., 1999; 2007; Bourquin et al., 2011).

The HSF (**fig. 1a**) represents a second, mid-Triassic interval of fluvial activity (Newell, 2017a; b). The HSF was deposited in a more stable, albeit still semiarid climate (Newell, 2017a) coinciding with a biotic recovery (Benton and Spencer, 2002; Coram et al., 2019). The mid-Triassic then saw a gradual, diachronous aridification, with the river systems of the HSF retreating southwards. Fluvial-aeolian deposition was replaced by the playa lakes and marine evaporites of the MMG, initially in the EISB (**fig. 1a**, e.g. Greenwood and Habesch, 1991; Jackson et al., 1995; Plant et al., 1999; McKie, 2017) until fluvial activity finally ceased in the Wessex Basin, and the HSF was replaced by the MMG (Newell, 2017b; Hounslow and Gallois, 2023).

Deposition of the CHF and HSF has previously been attributed to the 'Budleighensis' River (sensu Wills, 1956; 1970; 1976). This was interpreted to be a regionally significant river system sourced from the Variscan massifs of northern France (Tyrrell et al., 2012; Morton et al., 2013; 2016) which flowed into EISB towards Ireland (e.g. Dunford et al., 2001; Franklin et al., 2020; Moscardini et al., 2025). The drainage scale of this fluvial system, approximately 1000km, would be comparable to the modern Ebro River in Spain (Helland-Hansen et al., 2016). Substantial changes in sediment mineralogy occur between the Wessex Basin and the East Irish Sea Basin (**fig. 1c,** Burley, 1987; Plant et al., 1999; Morton et al., 2013), and it remains unclear how important the northern France source area was for the sediment routing system, relative to other potential sediment inputs. In the CHF, it has been proposed that variations in clast concentration suggest substantial sediment inputs occurring downstream of the northern France source area (Burgess et al., 2025).

In the context of northwest Europe, the northern France source area is known as the Gallic Massif (sensu Sass et al., 2023), a major upland region encompassing the modern-day Variscan-Cadomian-aged Armorican Massif, the French Massif Central and the buried basement surrounding them under the Paris Basin and English Channel. The north-flowing 'Budleighensis' system shared a Gallic Massif source area with two other substantial fluvial systems: an east-flowing system which deposited the Buntsandstein in France and Germany (the 'Alemania' river, *sensu* Ravidà et al., 2021), and a southeast-directed system which deposited the Buntsandstein in Iberia (e.g. Sanchez Martínez et al., 2012; Bourquin et al., 2011; McKie, 2017).

The SSG exists in tectonostratigraphic continuity with underlying Permian aeolian sandstones and playa lake mudstones, which represent the first significant basin fill after the extensional collapse of the Variscan Orogeny (e.g. Hamblin et al., 1992; Jackson et al., 1995; Newell, 2017a), as well as the overlying MMG (e.g. Howard et al., 2008; Hounslow et al., 2017; McKie, 2017). The post-depositional history of the SSG is variable between basins, however the unit has generally undergone 2-4 km of burial across the UK (e.g. Carter et al., 1995; Mikkelsen and Floodpage, 1997; Bray et al., 1998; Carter et al., 2001; Pharaoh et al., 2018). The northern section of the SSG fairway, particularly in northwest England and offshore in the Irish Sea, has additionally seen substantial exhumation and erosion during the Cenozoic, bringing the SSG to outcrop (e.g. Mikkelsen and Floodpage, 1997; Pharaoh et al., 2018).

Overall, four uncertainties remain in characterising the SSG of the British Isles, which this study addresses. First, the chronostratigraphy of the SSG and lower MMG is not rigorously integrated with the existing lithostratigraphy across the British Isles. Secondly, its sediment fairway and depositional volumetrics have not been mapped out or quantified. Third, variations in bulk sandstone mineralogy must be appraised down the sediment fairway. Finally, sediment routing, and source areas must be reappraised using updated, published data. We seek to address these research needs in this study.

Methods

A synthesis of the lithostratigraphy of the HSF, TSF and lower SMF was completed to correlate units between sedimentary basins in the British Isles. Chronostratigraphy was synthesised using the magnetostratigraphically constrained section of the HSF in the Wessex Basin (Hounslow and McIntosh, 2003; Hounslow and Gallois, 2023), and an equivalent section in the EISB (Hounslow and McIntosh, 2003; Mange et al., 1999), which was then correlated to the global Triassic timescale (Ogg et al., 2020). These sections are then supplemented by published palynology, and the correlation of lithostratigraphic units and boundaries across the HSF, TSF and lower SMF. From this lithostratigraphic and chronostratigraphic model, a single, time-equivalent interval could then be defined across the British Isles as a basis for further spatial, volumetric and palaeogeographic analysis. This studied interval spans 5 Myr, from 246.5 Ma to 241.5 Ma, as detailed later.

To map the fairway of this chronostratigraphically defined interval, a geological database was compiled from published outcrop sections and borehole logs, and borehole records held by the BGS Onshore Single Borehole Index, the Bureau de Recherches Géologiques et Minières, the UK Onshore Geophysical Library, and the North Sea Transition Authority National Data Repository (n = 393). For data points where stratigraphic units were completely preserved and not truncated by erosion, unit thicknesses and dominant lithologies were recorded. Boreholes were also recorded where the defined stratigraphic interval was not deposited, delimiting the edge of the fairway (**fig. 3)**. In areas where data points were too dense to manually parse or where sources offered contradictory interpretations, published interpretations were prioritised. In the absence of any existing interpretations, original interpretations were made using wireline logs and lithological data. The sediment fairway was then mapped from these data. Where data were sparse or absent, or where the SSG was absent due to post-depositional erosion, the fairway was mapped based on existing geological constraints and palaeogeographic interpretations.

The resulting sediment fairway map was then integrated with nomenclature for sedimentary basins, palaeohighs and major structural features from existing palaeogeographic reconstructions (e.g. Wills, 1956; 1970, Audrey-Charles, 1970b; Burley, 1987; Warrington and Ivimey-Cook, 1992; Bourquin et al., 2011; Newell, 2017a) to create a full palaeogeographic framework for the middle Triassic of the British Isles. Our reconstruction addresses major unknowns in fairway extent and reconciles inconsistencies between previous interpretations.

Where the sediment fairway was sufficiently constrained by thickness data (**fig. 3**), stratigraphic thicknesses were combined with a series of points where deposition is inferred to be absent (n = 32), representing nondeposition around Triassic massifs from the previously developed palaeogeographic framework. These points were collectively interpolated with a regional fault map based on BGS data (DiGRock250k, 2008; 2013) and Newell (2017b) to produce isopach maps for each studied lithostratigraphic unit. From these isopach maps, resulting sedimentary rock volumes were then computed for each basin, and were converted to solid rock volumes by removing pore space, a parameter well-constrained by previous studies. For the HSF, we used porosity estimates compiled by Medici et al. (2019a) for the EISB, Cheshire, Midlands and Worcester basins **(table 2)**. Porosity for the Wessex Basin is estimated at 18% (**table 2,** Bowman et al., 1993; Newell and Shariatipour, 2016). The same value of porosity is assigned to both aeolian and fluvial deposits in the HSF in each basin. For the MMG, mean values of 14.9% for the TSF and 17.8% for the SMF (Parkes et al., 2021) were applied for all basins. The Preesall and Northwich Halites are assumed to have zero porosity.

Fluvial and aeolian HSF volumes were estimated from literature-derived basin-scale sedimentological trends. Previous basin-scale estimates of the proportion of fluvial deposits were calculated by Medici et al. (2019a), but were limited to outcrop observations and are therefore biased to basin margins. Furthermore, as their method of calculation is not explicit, it is challenging to verify these estimates. We provide new estimates for the proportion of fluvial deposits based on basin-scale sedimentological trends derived from published outcrop, borehole and seismic data. Three depositional environments are recognised: fluvial, aeolian, and fluvial-aeolian. For each basin, these depositional environments are used to calculate the proportion of two deposit types: fluvial and aeolian. Fluvial depositional environments are considered to have a fluvial deposit content of 100%. Aeolian depositional environments are considered to have an aeolian deposit content of 100%. Fluvio-aeolian environments, where fluvial and aeolian strata coexist in close succession, are inferred to contain 50% fluvial deposits, and 50% aeolian deposits: the most probable, representative value. These derived proportions are then used to calculate the overall basin-scale volume of fluvial and aeolian deposits.

Petrographic data for bulk sandstone mineralogy in the HSF were compiled from 7 sources across 16 localities in the sediment fairway, resulting in 320 data points. These data cover both borehole and outcrop localities, and represent either fluvial or aeolian facies (Ali, 1982; Knox et al., 1984; Burley, 1987; Chisholm et al., 1988; Svendsen and Hartley, 2001; Meadows, 2004; Scorgie et al., 2021; De Sainz Simpson, 2022, see **supplementary material 2 for full dataset**). Owing to historical differences in point counting technique (e.g. Garzanti, 2019; Augustsson, 2021), these data cannot be compared as a single group but must be divided by method: Indiana and Gazzi-Dickinson, based on their classification of rock fragments (**see supplementary material 4 for more detail**). For each point counting method, data were grouped by basin, and then separated by aeolian and fluvial deposits to characterise the bulk mineralogical variability of sandstones within the sediment fairway. Sediment mineralogy within the HSF has also been studied in the context of quantitative provenance analysis (e.g. Plant et al., 1999; Tyrrell et al., 2012; Morton et al., 2013; 2016). These studies are equally important in constraining sediment routing and source areas, and are discussed separately in the basin-by-basin synthesis of sediment routing (see below).

Although the bulk mineralogy of the lower MMG has also been studied in its sand fraction (Scorgie et al., 2021; De Sainz Simpson et al., 2022) and silt-clay fraction (Jeans, 2006; Armitage et al., 2013; Jones et al., 2025), interpreting sediment routing in the MMG is problematic. There are no sediment provenance studies to support compositional data, and understanding of depositional environments in the MMG in the Cheshire Basin and EISB remains limited. For the purposes of this study, we hence focus on sediment mineralogy in the HSF. A first-order synthesis of diagenesis was then compiled to assess its impact on detrital mineralogy. This was then generalised throughout the fairway by using a compilation of burial histories for each basin. From this, the detrital mineralogy of the HSF in each basin could be characterised, and fairway-scale trends in bulk sandstone mineralogy in the HSF could be assessed.

Basin-level sedimentological data were then synthesised to reconstruct fairway sediment routing. Firstly, published, basin-scale studies characterising the HSF and lower MMG were collated. For each basin, previously documented palaeocurrents, sedimentological trends and quantitative provenance analysis results were catalogued. These datasets were further complemented by the new synthesis of bulk sandstone mineralogy, as well as the compilation of predominant lithologies from borehole logs (**fig. 3**). For each basin, a map of dominant lithofacies could then be created by plotting sedimentological trends and borehole lithological data within the previously established fairway limits. Sediment routing directions were determined from representative palaeocurrent indicators, basin-scale sedimentological trends and quantitative provenance analysis. Sediment inputs into the system were inferred using quantitative provenance analysis and our synthesis of bulk sandstone mineralogy. Where present, the degree of fluvial-aeolian interaction was also inferred from the synthesis of bulk sandstone mineralogy. Basin-level sediment routing was then linked together to provide a harmonised record of sediment routing within the whole fairway.

Using the previously developed palaeogeographic and sediment routing framework, emergent uplands across northwest Europe were then lithologically and, where possible, topographically characterised. Sediment routing for the HSF was then integrated with existing constraints on sediment routing in northeastern Iberia and northwest Europe to produce a regionally consistent map of sediment sourcing. By constraining the extent and coverage of non-preserved drainage in the source areas of the HSF, the source-to-sink system could be fully characterised.

Stratigraphy

Revised terminology

Table 1 lists commonly abbreviated stratigraphic and geographic terms. The ‘Budleighensis River’ (sensu Wills, 1956) was conceived as the main, north-flowing river which brought the distinctive quartzite clasts of the CHF from a southern Variscan source area into the Midlands. Since then, the term ‘Budleighensis’ has expanded to encompass all fluvial activity occurring within the CHF and HSF (e.g. Plant et al., 1999; Tyrrell et al., 2012; Radley and Coram, 2016; Newell, 2017a; Franklin et al., 2020; Burgess et al., 2025). This is problematic, as the CHF and the HSF represent temporally and sedimentologically distinct river systems (e.g. Hounslow and McIntosh, 2003; Morton et al., 2013; Newell, 2017a). Further, multiple tributaries and bifurcations have been interpreted for these river systems (e.g. Smith and Edwards, 1991; Morton et al., 2016; Burgess et al., 2024; Gibson-Poole et al., 2025). Nomenclature which is more spatially generic but temporally rigorous is necessary to represent these source-to-sink systems. We henceforth refer to this system as a whole as the ‘Sherwood River System’, with the ‘Sherwood-1 River System’ referring to the rivers of the CHF, and the ‘Sherwood-2 River System’ referring to the rivers of the HSF.

We adopt the term Mid-Triassic Unconformity (*sensu* Newell, 2017a) for the early Anisian unconformity below the HSF (**fig. 4**). Its former name, the Hardegsen Unconformity (e.g. Ambrose et al., 2014), is misleading, as although likely caused by the same regional tectonic event, the Franco-German Hardegsen Unconformity is distinctly older than its British equivalent (Hounslow and McIntosh, 2003). The new terminology avoids any implied time equivalency between the two.

Lithostratigraphy

Our lithostratigraphic synthesis **(fig. 4)** builds on the standardised nomenclature in Howard et al. (2008) and Ambrose et al. (2014). The stratigraphy in **Figure 4** is arranged by depocentre from south to north, i.e. down the depositional system. Basin-scale lithostratigraphic divisions are depicted to aid correlation, and to illustrate the spatio-temporal evolution of the SSG and MMG. Although the correlations of Howard et al. (2008) and Ambrose et al. (2014) terminate in the EISB and Solway Basin respectively, the SSG and lower MMG can be correlated further (e.g. Jackson et al., 1997; Mange et al., 1999; 2007; Simms, 2009) and we integrate these areas into our stratigraphic framework.

On the largest scale, the SSG is divided into four formations in accordance with Ambrose et al. (2014): the Hopwas Breccia Formation, the CHF, WSF, and HSF. The lower MMG, in accordance with Howard et al. (2008), is divided into the TSF and the SMF (**fig. 4**). The SSG overlies various Permo-Triassic units that represent the initial, post-Variscan basin fill.

The HSF represents the second period of fluvial activity within the SSG. In the western Wessex Basin, the HSF is divided into four well-characterised members at outcrop (**fig. 4**, Newell, 2017b). The HSF lies over a prominent ventifact horizon developed at the top of the CHF: a manifestation of the Mid-Triassic Unconformity (Hounslow and McIntosh, 2003). In the Central Wessex Basin, no formal lithostratigraphic divisions exist, though in the Wytch Farm oilfield, the HSF has previously been split into five units separated by widespread floodplain-playa deposits (McKie et al., 1997). In the Southampton 1 borehole, the HSF is divided into two members by lithology (Thomas and Holliday, 1982) and heavy mineral composition (**fig. 4,** Morton et al., 2016).

In the Worcester Graben, the HSF is divided into three members by lithology (**fig. 4**, Old et al., 1991; Barclay et al., 1997; Sumbler et al., 2000). The HSF here passes gradationally upwards and northwards into the TSF, which in turn grades into the SMF. The HSF remains undivided in the Knowle, Needlewood, Hinkley and Stafford Basins of the Midlands, and similarly grades into the TSF and then the SMF (**fig. 4**).

The HSF is absent from the East Midlands Shelf. Instead, a ventifact horizon, marking the Mid-Triassic Unconformity, lies on top of the CHF (Burley, 1987; Newell, 2023). This is in turn overlain by the MMG, which has a well-defined stratigraphy in this area (Howard et al., 2008). It is suggested that tectonic activity associated with the Mid-Triassic Unconformity uplifted the Pennine-Charnwood Ridge, preventing the Sherwood-2 river system flowing northeast (Warrington and Ivimey-Cook, 1992; Ambrose et al., 2014; Newell, 2017a; Newell, 2023). The East Midlands Shelf became reconnected to the Hinkley Basin during the late Anisian, towards the top of the studied interval (Ambrose et al., 2014; Jones et al., 2025).

In the Cheshire Basin, the HSF is typically divided into the fluvio-aeolian Thurstaston Member, the fluvial Delamere Member and the fluvio-aeolian Frodsham Member (**fig. 4;** Ambrose et al., 2014). It is likely that these members represent large-scale, interdigitating facies associations (Thompson, 1970a; Burley, 1987; Plant et al., 1999). In the northwest Cheshire Basin (**fig. 3**), the lower boundary of the HSF may lie at the base of the Delamere Member, with the previously identified Thurstaston Member being part of the WSF instead (Earp and Taylor, 1986; Hough, 2002). The HSF grades into the TSF, which locally contains the aeolian Malpas Sandstone Member (**fig. 4**; e.g. Plant et al., 1999; Wilson, 1993; Jackson et al., 1995; Mikkelsen and Floodpage, 1997). The TSF then grades into the SMF (Plant et al., 1999). The Northwich Halite Member lies within the SMF and forms a lithologically uniform marker unit across the basin (**fig. 4,** e.g. Evans and Holloway, 2005; Evans et al., 2011).

In the EISB, the Mid-Triassic Unconformity disappears (Jackson et al., 1995), and the HSF and WSF appear conformable (**fig. 4**). No accepted division of the HSF exists on a basin scale. The HSF has been variously divided into two or three members (Jackson et al., 1997). In the Morecambe Gas Field **(fig. 3)**, the HSF is split into four members, following the tripartite stratigraphy of the HSF in the Cheshire Basin with the addition of the Waterstones Member (Bushell, 1986). However, any stratigraphic equivalency implied by the assignment of members is misleading, because these members represent large-scale, interdigitating facies associations, as previously noted for the HSF in the Cheshire Basin (Meadows and Beach, 1993b). The isochronous and widespread 'Century Playa' interval, (**fig. 4**; Thompson and Meadows, 1997; Meadows, 2006) is the only consistent, correlatable unit occurring within the HSF. The top of the HSF is sharp with the overlying MMG. The TSF is only present in the southeastern part of the EISB (Burley, 1987; Scorgie et al., 2021), and the SMF directly overlies the HSF elsewhere **(fig. 4)**. The stratigraphic nomenclature of the MMG differs between the offshore basin centre and onshore eastern basin margin, but strata in these locations are directly correlatable. For example, the Preesall, Mythrop and Rossall Halites are directly equivalent in both regions (**fig. 2, 4**). The Preesall Halite is also the lateral equivalent of the Northwich Halite of the Cheshire Basin (**fig. 4;** Jackson et al., 1995; Howard et al., 2008).

In the Peel, Kish Bank and Central Irish Sea Basins, the Ormskirk Sandstone Formation is equivalent to the HSF in the EISB (**fig. 4**, Mange et al., 1999; 2007; Floodpage et al., 2001; Merlin Energy Resources Consortium, 2020). The Leyland Formation and Preesall Halite of the MMG also correlate to their equivalents in the EISB (Chadwick et al., 2001; Merlin Energy Resources Consortium, 2020). In the Solway Basin, the HSF is undivided (**fig. 4**, Ambrose et al., 2014). The Silloth Halite is equivalent to the Preesall and Northwich Halites in the EISB and Cheshire Basin (Jackson et al., 1995; Floodpage et al., 2001; **fig. 4**).

In the Larne Basin of Northern Ireland, HSF-equivalent units are absent, and instead the siltstone-rich Lagavarra Formation is present above the Mid-Triassic Unconformity (**fig. 4**, e.g. Jackson et al., 1995; Simms, 2009). The Larne Halite of the SMF is likely correlative with the Preesall and Northwich Halites of the EISB and Cheshire Basin, respectively (Jackson et al., 1995).

Chronostratigraphy

The base of the HSF, i.e. the Mid-Triassic Unconformity and its correlative conformities (**fig. 4**), is magnetostratigraphically dated to the lower Anisian in both the Wessex Basin and the EISB (Hounslow and McIntosh, 2003). This boundary is thus an approximately isochronous surface, dated at c. 246.5 Ma (Ogg et al., 2020).

The top of the HSF, i.e. the SSG-MMG boundary, is widely documented to become progressively older to the north (**fig. 4**). At the Devon Coast section in the Wessex Basin, this boundary is magnetostratigraphically dated to the lower Ladinian (Hounslow and Gallois, 2023), at c. 239.6 Ma (Ogg et al., 2020). In the Worcester Graben, palynology puts the upper part of the HSF within the Anisian or possibly the lower Ladinian, with the SMF being Ladinian in age. (**fig. 4**; Barclay et al., 1997). In the Midlands, palynology suggests the lower SMF is Anisian in age (**fig. 4**; Bridge and Hough, 2002). In the East Irish Sea Basin, magnetostratigraphy suggests the top of the HSF is mid-Anisian in age (lower Pelonsian, Hounslow and McIntosh, 2003), at c. 244 Ma (Ogg et al., 2020, **fig. 4**). On the East Midlands Shelf, the HSF is absent, though palynology suggests the TSF is Anisian in age (Howard et al., 2008).

Within the MMG of the Cheshire and East Irish Sea Basins, the Northwich and Preesall Halites (**fig. 4**) are interpreted to record marine transgressions (Greenwood and Habesch, 1991; Thompson and Meadows, 1997) and their top provides an isochronous surface of upper Anisian age (Jackson et al., 1995; Evans et al., 2011; Chedburn et al., 2022). The Anisian-Ladinian boundary (c. 241.5 Ma, Ogg et al., 2020) is constrained by palynology and lies just above this marker unit, within the upper Byley Mudstones in the Cheshire Basin and within the lower Kirkham Mudstones in the EISB (**fig. 4,** Wilson and Evans, 1990; Plant et al., 1999).

The Silloth and Larne Halites in the Solway and Larne basins are thought to be correlative to the Preesall and Northwich Halites (Jackson et al., 1995), and therefore are of equivalent age (**fig. 4**).

From these chronostratigraphic constraints, a single, roughly time-equivalent interval, defined in duration by activity of the Sherwood-2 River System, can be projected along the sediment routing system: Interval S2. The base of S2 (**fig. 4**, c. 246.5 Ma, Ogg et al., 2020) is taken at the Mid-Triassic Unconformity between the Wessex Basin and Cheshire Basin, and its correlative conformity (the HSF-WSF boundary) in the EISB, Solway Basin, Kish Bank Basin, Peel Basin and Central Irish Sea Basin **(fig. 4)**. In Northern Ireland, the base of S2 is taken as the unconformity at the base of the TSF. The top of Interval S2 follows the Anisian-Ladinian boundary (c. 241.5 Ma, Ogg et al., 2020) as closely as possible, but is defined separately for each basin. In the Wessex Basin, the top S2 boundary follows the HSF-SMF boundary, which is lower Ladinian in age (Hounslow and Gallois, 2023), c. 239.6 Ma (Ogg et al., 2020). The true Anisian-Ladinian boundary is within the upper Otterton Ledge Member of the HSF in the western Wessex Basin (Hounslow and Gallois, 2023), however the absence of correlation elsewhere in the Wessex Basin prevents this boundary from being used **(fig. 4)**. In the Worcester Graben, the Midlands and the East Midlands Shelf, we use the TSF-SMF boundary as the top S2 boundary. This boundary is roughly of Anisian-Ladinian age in the Worcester Graben. Although the boundary becomes older in the Midlands and the East Midlands Shelf, the absence of more distinctive stratigraphic markers within the SMF means the top of the TSF remains the best option for correlation **(fig. 4)**. In the Cheshire Basin, EISB and further north, the top of S2 is taken at the top of the Northwich and Preesall Halite Members of the SMF and their stratigraphic equivalents, which are late Anisian in age **(fig. 4)**.

In summary, Interval S2 encompasses the HSF, the TSF, and the SMF up to and including the Preesall and Northwich Halites and their stratigraphic equivalents. Interval S2 has a duration of approximately 5 Ma, but this may be longer in the Wessex Basin (c. 6.9 Ma), and shorter in the Midlands Basins (**fig. 4**). This time-defined stratigraphic interval serves as an important framework for sediment fairway mapping across the British Isles, subsequent volumetric calculations, and the creation of a temporally-defined sediment routing synthesis.

Palaeogeography and fairway extent

The mapped fairway of Interval S2 encompasses an area between the Wessex Basin in the south and the Central Irish Sea, Kish Bank and Peel Basins in the north, (**fig. 5**). The fairway is surrounded by major upland areas, and smaller, mostly non-emergent structural highs which separate basins.

The southernmost depocentre is the Wessex Basin, bounded by the Central English Channel High to the south, the Start-Cotentin High to the southwest, and the Cranborne-Fordingbridge High and Mendip High in the north (**fig. 5,** Newell, 2017a; b). While the Wessex Basin was previously considered a basin produced largely by E-W trending normal faults (e.g. Buchanan, 1998; Butler, 1998; Hawkes et al., 1998; Underhill and Stonely, 1998; Miliorizos and Ruffell, 1998), recent evidence suggests that Triassic extension was largely controlled by an older set of N-S extensional faults, consistent with the Triassic stress regime and structural configuration of the Wessex Basin (Newell, 2017b).

North of the Mendip High, the Wessex Basin passes into the Worcester Graben **(fig. 5)**. Although a connection between the two basins is critical in allowing long-distance, northwards sediment routing (Tyrrell et al., 2012; Newell, 2017a), there has been no consensus on the connection's location through the Mendip High (Audley-Charles, 1970; Wills, 1970; Burley, 1987; Warrington and Ivimey-Cook, 1992; Newell, 2017a; Burgess et al., 2025). We identify the point of connection in the area around the Shrewton 1 and Devizes 1 wells (**fig. 3**), which penetrate c. 70m of sandstone-siltstone facies, lithostratigraphically equivalent to the HSF. This area, termed the Pewsey Trough (PT, **fig. 5**), had been a N-S oriented, possibly fault-controlled depocentre since the Permian (Pullan and Donato, 2022), and persisted as a deep, distinct depocentre in the late Triassic during MMG deposition (Newell, 2024).

The Worcester Graben is a structurally controlled depocentre controlled by the East Malvern Fault, the Inkberrow Fault and the Clopton-Clapton-Northleach Fault (**fig. 5,** Chadwick and Evans, 1995; Newell, 2017a), though the HSF also onlaps the pre-Permian basement to the west. There are four basins in the Midlands **(fig. 5)**, but they are grouped into a single 'Midlands Basins' province in our source-to-sink synthesis, owing to their connectivity and small size. The Midlands Basins are joined across the Market Drayton Horst to the Cheshire Basin. This is a half-graben basin primarily bounded by the Wem-Red Rock Fault in the southeast (**fig. 5**), and is separated from the EISB by the Llyn-Rossendale Ridge (Plant et al., 1999). The EISB contains numerous N-S faults which split the basin into sub-basins (**fig. 5**, Jackson et al., 1995). Beyond the EISB, there are a series of smaller, fault-controlled depocentres, including the Solway, Larne, Peel, Kish Bank, Kingscourt and Central Irish Sea basins.

Lying to the east of the Pennine High is the East Midlands Shelf, a structurally simple, east-dipping ramp which forms the western edge of the Southern Permian Basin (**fig. 5,** McKie, 2017; Newell, 2023). The HSF is absent on the East Midlands Shelf, which was likely never a depocentre for this unit. If the HSF had been deposited here, the strata would need to have been removed by erosion after the Mid-Triassic Unconformity, yet the resulting unconformity has never been found in any basin. In line with existing interpretations, the East Midlands Shelf was separated from the main fairway by an emergent Pennine-Charnwood high (**fig. 5**, Warrington and Ivimey-Cook, 1992; Ambrose et al., 2014; Newell, 2017a; Newell, 2023), and only became reconnected to the Midlands Basins towards the end of this time interval (Ambrose et al., 2014; Jones et al., 2025).

Substantial upland areas served as sediment sources during the Triassic (e.g. Mange et al.,1999; 2007; Meadows, 2006; Tyrrell et al., 2012; Morton et al., 2013; 2016; Burgess et al., 2024). These include the Gallic Massif to the south of the Wessex Basin (**fig. 5,** sensu

Sass et al., 2023). To the west, the fairway is bounded by the Cornubian, Welsh and Irish Massifs, and to the east, by the Pennine High and London-Brabant Massif (**fig. 5**). Smaller elevated regions are also present within the sedimentary fairway: the South Staffordshire Horst and Coventry Horst in the Midlands, and the Isle of Man Massif and the Ogham Platform in the EISB (**fig. 5**).

Uncertainties in fairway extent

The southwesterly extent of the HSF in the Wessex Basin is largely unknown due to limited offshore exploration. The southernmost wells which penetrate the HSF are 97/12-1 (Ainsworth and Riley, 2010) and 97/24-1A (**fig. 3**). The southern limit for the sediment fairway can be plausibly constrained to lie between the southernmost Permo-Triassic seabed outcrop (**fig. 5**) and the modern-day Channel Islands and north France, a recognised sediment source for the SSG (Morton et al., 2013). The fairway extent in the rest of the Wessex Basin and Worcester Graben is constrained by well data, with generally little post-depositional erosion (**fig. 5**).

North of the Worcester Graben, Interval S2 is only partially preserved following post-depositional erosion. Though existing palaeogeographic interpretations all agree that Triassic units had a greater distribution in the past, the interpreted extent to which they were formerly distributed varies (Wills, 1956; 1970; Audley-Charles, 1970; Warrington and Ivimey-Cook, 1992; Jackson et al., 1995; Dunford et al., 2001; Hounslow et al., 2006; Bourquin et al., 2011; McKie, 2017).

Multiple lines of evidence can be used to constrain the original depositional extent of Interval S2. The absence of basin margin deposits analogous to those in the Wessex Basin and Worcester Graben (e.g. Smith and Edwards, 1991; Barclay et al., 1997; Newell, 2017b), palaeocurrents directed across palaeohighs (e.g. Thompson et al., 1970b; Chisolm et al., 1988), outliers of SSG (Chisolm et al., 1988), and recycled Triassic detritus incorporated into younger deposits (Walsh et al., 1980; 2018) all indicate that the fairway extent used to be greater, and that the preserved distribution is primarily a reflection of where structurally-controlled basins were deepest (Chadwick and Evans, 1995). The most eroded area in the fairway encompasses the East Irish Sea, Peel, Kish Bank and Central Irish Sea Basins (**fig. 5**), which are interpreted to have formerly comprised a contiguous 'Greater Irish Sea Basin' (*sensu* Dunford et al., 2001; Meadows, 2006). However, we do not use this term as sediment routing west of the EISB remains poorly understood. The original sediment fairway can also be inferred from the extent of Permian sedimentation, which occurred under the same extensional tectonic regime as the SSG. In the northern parts of the fairway, Interval S2 is likely to have overstepped, or at the very least equalled the distribution of Permian strata in the same way it does in the Wessex Basin and Worcester Graben, where both Permian units and the SSG are fully preserved (Hamblin et al., 1992; Chadwick and Evans, 1995). Our interpreted depositional boundaries (**fig. 5**) are conservative estimates based on these lines of evidence.

Sediment isopachs

Isopach maps, created from compiled data constraints (**fig. 5**), reconstruct deposited sediment thicknesses for Interval S2. Data coverage is sufficient to fully resolve sediment thicknesses between the Wessex Basin and the EISB (**fig. 6a**), and partially resolve thicknesses in the Solway and Peel basins north of the Ramsay-Whitehaven Ridge **(fig. 6a)**. These maps accurately resolve the spatial and structural configuration of the sediment fairway for the first time. Deposition of all lithostratigraphic units occurs in deep, structurally-controlled basins, with strata thinning over inter-basin palaeohighs (**fig. 6**). The East Midlands Shelf **(fig. 5)** was excluded from this volumetric analysis. As previously established, this was not a fluvial depocentre for the HSF, and stratigraphic markers coeval to those defining Interval S2 are absent (**fig. 4**, Howard et al., 2008).

The HSF in the Wessex Basin is thickest towards the west, at 320 m. The HSF thins gradually towards the east, and towards the Gallic Massif in the south (**fig. 6b**). Notably, thickness variations in the HSF are gradual **(fig. 6b)**, and appear only to be controlled by the oblique-slip Quantocks-Coker-Cranborne Fault System, which bounds the Cranborne-Fordingbridge High (**fig. 5, 6b,** Newell, 2017b). This shows that major W-E-trending extensional faults, which were active later in the Mesozoic (e.g. Buchanan, 1998; Butler, 1998; Hawkes et al., 1998; Underhill and Stonely, 1998; Miliorizos and Ruffell, 1998) were inactive in the Triassic. In the Worcester Graben, the HSF thickens westwards towards the faulted basin margin, reaching a maximum of 400 m (**fig. 6b**), which represents the greatest depositional thickness in the fairway. In the Midlands, the maximum thickness of the HSF is approximately 220m in basin centres (**fig. 6b**). The HSF in the Cheshire Basin is thickest in the southeast, where thicknesses approach 210m (**fig. 6b**). Sediment thicknesses generally thin westwards towards the Llyn-Rossendale Ridge, and towards the southwestern basin margin. HSF thicknesses in the EISB are greatest at the basin centre, at 210m (**fig. 6b**), and decrease towards the basin margins.

The TSF is predominantly concentrated in the Cheshire Basin (**fig. 6c**), where thicknesses reach 200 m in the southeast. The TSF thins to the northwest towards the southeastern EISB. Here, thicknesses do not exceed 100m. To the south, the TSF is widely distributed but thin (<50 m) in the Midlands, East Midlands Shelf and the Worcester Graben, locally reaching 60 m thick in the hanging wall of the East Malvern Fault.

The lower SMF (below the Preesall and Northwich Halites) (**fig. 6d**) reaches up to 410 m thick in the northeastern Cheshire Basin, although it is generally 200-400 m thick elsewhere in the basin. In the EISB, the SMF gradually thickens towards the northwest part of the basin, where the unit reaches thicknesses of 900 m (**fig. 6d**). The SMF thins towards the Ramsay-Whitehaven Ridge, and the basin margin in the west.

The Northwich Halite in the Cheshire Basin reaches a maximum thickness of 230m (**fig. 6e**), and is thickest along a NW-SE axis through the centre of the basin, thinning out towards the basin margins. The Preesall Halite is 570m thick in the centre of the EISB (**fig. 6e**), and is thickest along a N-S axis at the basin centre. Both the extent and the thickness of the Preesall Halite is reduced over the Llyn-Rossendale Ridge, where thicknesses do not exceed 200m.

Sediment porosity and facies

The calculated proportion of aeolian and fluvial deposits reflects the distribution of sediment at the time of deposition, and provides insight into the distribution of aeolian and fluvial processes operating within the HSF fairway. It should be noted that this figure cannot directly represent the extent of fluvial-aeolian sediment reworking, nor the ultimate provenance of the sediments. These aspects require further sedimentological and petrographic data to discern, and are discussed below as part of the basin-by-basin synthesis of sediment routing.

For the HSF, the proportion of fluvial deposits in the EISB is 64%, and was estimated by averaging areas covered by mapped seismic facies (figs. 8 and 9 in Meadows and Beach, 1993b). The proportion of fluvial deposits in the Cheshire Basin is 71%, and was estimated from vertical facies successions from borehole logs (figs. 6 and 7 in Thompson et al., 1970a). In the Midlands and Worcester Graben, the composition of the HSF is assumed to be 100% fluvial, as no widespread aeolian facies have been documented in outcrop, core or wireline log data (Ambrose et al., 2014). In the Wessex basin, the first-order proportion of fluvial deposits is estimated at 90% and is consistent in both the western and central areas (McKie et al., 1997; Newell, 2017b).

Sediment volumes

Solid rock (porosity removed) sediment volume for Interval S2 is 15,600 km^3 (**fig. 7**, with further data in **Supplementary Material 3**). Of this volume, 5,590 km^3 (36%) is represented by the HSF of the SSG. The remaining 10,000 km³ (64%) is represented by the MMG. Within the MMG, 613 km³ is in the TSF, 6190 km³ in the lower SMF, and 3210 km³ in the Preesall and Northwich Halites; these lithostratigraphic units comprise 4%, 40% and 20% of the total sediment volume of Interval S2, respectively.

By volume, the EISB is the largest basin, with a total sediment volume of 9750 km³, representing 62% of the total volume of Interval S2 (**fig. 7**). However, the HSF only comprises 1820 km³ (19%) of the EISB's sediment volume, and only 1160 km³ (12%) is composed of HSF fluvial deposits. The Cheshire Basin is the second largest depocentre, with a total sediment volume of 2500 km³. The HSF comprises 533 km³ (21%) of the Cheshire basin's total volume, of which 379 km³ (15%) is fluvial deposits. The Wessex Basin is third largest depocentre, with a total sediment volume of 1870 km³. Interval S2 is only composed of the HSF here, with 1690 km³ of fluvial deposit volume. The Worcester Graben has a total sediment volume of 1090 km³. Sediment volumes here are dominated by the entirely fluvial HSF, at 1030 km³ (95%), with the remainder of this volume (54.5 km³, 5%) comprising the TSF. The Midlands Basins are collectively the smallest depocentre, with a total sediment volume of 386 km³. Again, this volume is dominated by the entirely fluvial HSF, at 335 km³ (87%), with 51.7 km³ (13%) being the TSF. Overall, the largest volume of HSF occurs in the Wessex Basin, followed by the EISB, the Worcester Graben, the Cheshire Basin, and then the Midlands basins (**fig. 7**).

When sediment volumes are integrated with the well-constrained chronostratigraphy in the EISB and Wessex Basin (**fig. 4**), solid rock sediment accumulation rates can be calculated. In the EISB, Interval S2 has a total duration of 5 Ma: 2.5 Ma for the HSF, and 2.5 Ma for the lower MMG (TSF, SMF and Preesall Halite). In the Wessex Basin, Interval S2 has a duration of 6.9 Ma. For the EISB, sediment accumulation rates increase fourfold from 726 km³/Myr in the HSF, to 3170 km³/Myr in the lower MMG. The overall accumulation rate across Interval S2 in the EISB is 1950 km³/Myr. In the Wessex Basin, the sediment accumulation rate within Interval S2 is 271 km³/Myr.

Errors and uncertainties in sediment volume

Uncertainties in the original fairway extent cause uncertainties in calculated sediment volumes. The greatest uncertainty in fairway extent occurs in the southwestern part of the Wessex Basin, where there are very few constraints on the thickness and distribution of the HSF (**fig. 3**). North of the Midlands (**fig. 6a**), uncertainties in fairway extent are caused by post-depositional erosion. This uncertainty is reduced by the fact that basin centres are fully preserved and well-constrained, with only the former basin margins, where Interval S2 was thinnest, being eroded. Furthermore, as the boundaries of the sediment fairway are drawn from conservative estimates (**fig. 5**), the resulting isopach maps and sediment volumes are also conservative estimates.

Uncertainties in defining lithostratigraphic boundaries are low, as for most units, lithologies and wireline log responses are distinct (e.g. Meadows, 2006; Ambrose et al., 2014 Newell, 2017a; Chedburn et al., 2022). More uncertainty occurs in areas where the TSF is gradational between the HSF and the SMF. However, the impact of this uncertainty at the fairway scale is small, as the TSF is the volumetrically smallest unit of Interval S2 (**fig. 7**).

Uncertainty in rock porosity is generally low in the SSG, as porosity is well-characterised from a large dataset compiled across the sediment fairway (**Table 2**, Bowman et al., 1993; Newell and Shariatipour, 2016; Medici et al., 2019a). Uncertainties in the MMG are higher, as far fewer measurements of porosity are available (Parkes et al., 2021). However, owing to the limited range of porosities in mudstones (<20%, AlNajdi and Worden, 2023), the impact of porosity on sediment volume is limited compared to the other uncertainties discussed.

The classification of fluvial and aeolian deposits in the HSF in the Cheshire Basin and EISB represents a further uncertainty. Though there is good spatial coverage of basin-scale sedimentology, criteria used to recognise aeolian, fluvial and fluvial-aeolian successions differ between these basins (Thompson, 1970a; Meadows and Beach, 1993b). Our calculated fluvial and aeolian deposit volumes, which are derived from these facies distributions, represent a first-order estimation of the facies distribution within the sediment fairway.

Bulk sandstone mineralogy in the HSF

Data for bulk sandstone mineralogy in the HSF is outlined in table 3, and are classified by study, point counting method and depocentre. Overall, there is a notable difference in bulk sandstone mineralogy between the Wessex Basin in the southern part of the sediment fairway, and the Midlands basins, Cheshire Basin and EISB to the north (**fig. 8a**). Although there is an absence of data in the Worcester Graben, sandstones are clearly more feldspathic in the southern part of the fairway than the north (**fig. 8b,** see **Supplementary Material 4** for full dataset).

By the Gazzi-Dickinson method of point counting, quartz and feldspar are the dominant mineralogical components in the HSF, though proportions change substantially between basins. In the Wessex Basin, bulk sandstone mineralogy appears similar in both the eastern and western basin, with quartz, feldspar and lithic contents of 50-70%, 20-50% and 0-20%, respectively (**fig. 8b**; Knox et al., 1984; Hartley and Svendsen, 2001). Although there is no quantified petrographic data for the central part of the Wessex Basin (**fig. 8a)**, its bulk mineralogy appears comparable to the eastern and western Wessex Basin (Rhys, 1982; Bath et al., 1987). To the north, the HSF appears to have a similar bulk mineralogy in both the Cheshire Basin and EISB, with a quartz content of 80-95%, a feldspar content of 0-15%, and a lithic content of 0-10% (**fig. 8b**, De Sainz Simpson, 2022). Furthermore, fluvial and aeolian sandstone facies in the Cheshire Basin and EISB appear to have a similar bulk mineralogy.

By the Indiana method of point counting, resultant proportions of quartz, feldspar and lithic fragments are more variable, though again, mineralogical proportions vary between basins. In the Wessex Basin, the HSF largely has a quartz content is of 40-70%, a feldspar content of 15-50%, and lithic content of 10-50% (**fig. 8a,** Burley et al., 1987). In the Cheshire Basin and EISB, bulk sandstone compositions are similar, with quartz, feldspar and lithic contents of 50-90%, 0-25%, and 5-40%, respectively (**fig. 8b;** Burley, 1987; Meadows, 2004; Scorgie et al., 2021). In the Cheshire Basin, there appears to be a difference in bulk mineralogy between fluvial and aeolian facies, with aeolian sandstones (n = 4) being more quartz-rich than fluvial sandstones (n = 58). In the EISB, fluvial and aeolian facies appear to have a similar bulk mineralogy.

Sediment mineralogical data appear consistent in the Midlands, despite the point counting method being unclassified. The quartz content of sandstones is 80-90%, the feldspar content is 5-15%, and the lithic content is 2-10% (**fig. 8b,** Ali, 1982; Chisholm et al., 1988).

Diagenesis and its impact on bulk sandstone mineralogy

Diagenetic alteration of unstable detrital grains also contributes to uncertainties in reconstructing original bulk sandstone mineralogy. Lithic fragments and feldspars are ubiquitously altered in the HSF across all basins, evidenced by grain dissolution textures, skeletal grains, and the presence of authigenic clays and feldspars (e.g. Ali and Turner, 1982; Burley, 1984; Knox et al., 1984; Bushell, 1986; Strong and Milodowski, 1987; Greenwood and Habesch, 1993; Plant et al., 1999; Scorgie et al., 2021). Grain dissolution porosity is measured at 7% in Devon in the western Wessex Basin, 8% in the Marchwood 1 borehole in the eastern Wessex Basin, and up to 7% in the EISB margin (Burley, 1984).

On the fairway scale, the maximum burial depth for the HSF can be used to approximate the maximum effects of diagenesis in each basin. Burial histories (**fig. 9**) are derived from apatite fission track analysis and vitrinite reflectance (Carter et al., 1995; Mikkelsen and Floodpage, 1997; Bray et al., 1998; Gent, 2006; Pharaoh et al., 2018). Selected wells are located away from basin margins, and so likely represent maximum burial depths for each basins. The burial depth for the HSF at the Wytch Farm oilfield in the Wessex Basin is

3.5 km (Bray et al., 1998). The SSG in the Midlands Basins reached a palaeotemperature of 75 ± 10 °C between 150 and 70 Ma (Carter et al., 1995). Assuming a geothermal gradient of 30 °C/km, this implies a burial depth of 2.5 ± 0.3 km (**fig. 9b**). The HSF in the Knutsford 1 well in the Cheshire Basin reached a burial depth of 2.9 km (**fig. 9b**, Mikkelsen and Floodpage, 1997), and for well 110/7b-6 in the EISB, 1.8 km (**fig. 9b,** Gent, 2006; Pharaoh et al., 2018). This implies the HSF across Great Britain reached comparable maximum burial depths (c. 3km), except in the EISB, which was buried to shallower depths (c. 2km). This in turn suggests that the maximum impact of diagenesis is relatively similar in all basins except for the ESIB, which may have experienced less extreme diagenetic alteration.

These figures indicate that HSF sandstones were originally more lithic- and feldspar-rich, with a modest amount (<10% total rock volume) of grains removed during burial diagenesis. Data points in **Figure 8b** cannot be translated uniformly to remove diagenetic effects, as burial depths and diagenetic histories differ for data collected at basin margins and palaeohighs, compared to deeper basin centres (Green et al., 1995; Bray et al., 1998; Scorgie et al., 2021). However, the variance of bulk sandstone detrital mineralogy both within basins and between basins **(fig. 8b)** is substantially greater than any compositional variations expected from diagenesis. This in turn indicates that spatial variations in sandstone composition are a primarily depositional signal, and so can be used to interpret sediment routing within the fairway.

Fairway sediment routing

Overall, our source-to-sink synthesis suggests Interval S2 was deposited by a single, continuous fluvial system, evidenced by consistently north and northwest-directed palaeocurrents and an overall decrease in grain size along the sediment fairway **(fig. 10a, b).** The connectivity of sediment routing is also strongly supported by our synthesis of quantitative provenance analysis (Plant et al., 1999; Tyrrell et al., 2012). Our synthesis also resolves the presence of secondary sediment inputs and fluvial-aeolian interactions, and provide insight into sediment routing beyond the EISB and across the transition between the SSG and MMG (i.e. the distal segments of the Sherwood-2 River System). A more detailed overview of sediment routing in the Wessex, Cheshire and East Irish Sea Basins, as well as the SSG-MMG transition, is presented in **Supplementary Material 5** to honour the breadth and depth of published information available.

Sediment routing within the HSF

In the Wessex Basin, quantitative provenance analysis indicates the Sherwood-2 River System operated as a series of at least three north-flowing tributaries (**fig. 10a,** Morton et al., 2016). The HSF is dominated by material with a Variscan-Cadomian provenance, sourced from the basement units of the Gallic Massif (Tyrrell et al., 2012; Morton et al., 2013; 2016). This is supplemented by material sourced from the granites of the Cornubian Massif (Smith and Edwards, 1991) and recycled Devonian sediment from the London-Brabant Massif (Morton et al., 2016). All tributaries likely coalesced south of the Pewsey Trough and flowed nothwards as a single trunk river into the Worcester Graben **(fig. 10a)**.

In the Worcester Graben, the main axis of sediment routing was to the north (**fig. 10a,** Old et al., 1991). Although the presence of extraformational clasts in the HSF suggest proximal sediment inputs (Barclay et al., 1997; Old et al., 1999), there are no contemporary studies of sediment provenance or petrography in the Worcester Graben, and the details of sediment routing here are largely unknown.

In the Midlands Basins, recorded palaeocurrent azimuths suggest the primary axis of sediment routing was northwards (**fig. 10a,** Old et al., 1987; 1991, Chisolm et al., 1988). Multiple sediment inputs from the Welsh and London-Brabant Massifs are proposed by Audley-Charles (1970), based on observed clast compositions in the HSF (**fig. 10a**). The pronounced difference in HSF bulk sandstone composition between the Wessex Basin and the Midlands basins (**fig. 8b**) suggests that substantial dilution of Variscan-derived material by sediments from other source areas had already occurred before the Sherwood-2 River System reached the Midlands Basins (Plant et al., 1999; Morton et al., 2013). However, bulk sandstone mineralogical data for the Midlands Basins is limited (**fig. 8b**), and thus the mineralogical diversity of the HSF here may not be fully captured. The CHF in the Midlands appears to have a substantial lithic component (Indiana method, Burley, 1986) which could also be present in the HSF.

During much of Interval S2, an emergent Pennine-Charnwood Ridge disconnected the Sherwood-2 River System from the East Midlands Shelf. Accordingly, the East Midlands Shelf was devoid of large-scale fluvial activity, and was instead a low-energy coastal plain where the MMG was deposited (Jones et al., 2025). Reconnection between the Midlands and the East Midlands Shelf occurred during the latter stages of Interval S2 during deposition of the TSF **(fig. 10b)**.

In the Cheshire Basin, palaeocurrents suggest the main axis of fluvial transport was towards the northwest (**fig. 10a,** Thompson, 1970b; Plant et al., 1999; Mountney and Thompson, 2002; De Sainz Simpson, 2022; Cosgrove et al., 2025). This was accompanied by an input of fluvial sediment from the Welsh Massif (Plant et al., 1999) (**fig. 8b**). A further, well-documented component of aeolian activity is associated with the fluvial system. Palaeowinds originated from the east, and aeolian sediments were sourced from the Pennine High (**fig. 10a**, Thompson, 1970b; Rees and Wilson, 1998; Mountney and Thompson, 2002; De Sainz Simpson, 2022; Cosgrove et al., 2025). The proportion of fluvial and aeolian deposits is highly variable both spatially and temporally (e.g. Burley, 1987; Cosgrove et al., 2025), and their distribution likely had underlying climate and subsidence controls, which in turn controlled sediment flux, accommodation generation, and water table level (Newell, 2017a; Cosgrove et al., 2025). In spite of this variability, a throughgoing, northwest-flowing fluvial system was maintained, as widespread, perennial fluvial activity occurred downsystem in the EISB (Meadows and Beach, 1993a; b; Meadows, 2006).

In the EISB, the Sherwood-2 River System entered the basin in the south, and then turned west (Cowan, 1993; Herries and Cowan, 1997; Plant et al., 1999; Dunford et al., 2001; Meadows, 2006; Marsh et al., 2022). Here, Mange et al. (1999, 2007) also identified a sediment input from the Welsh Massif **(fig. 10a)**, though this signal may have propagated from the Cheshire Basin. There was also an aeolian sediment source from the Pennine High to the east (**fig. 10a,** Meadows and Beach, 1993a; Jones and Ambrose, 1994; Meadows, 2006; Scorgie et al., 2021; Marsh et al., 2022). There was likely considerable aeolian reworking of fluvial sediments in the EISB prior to deposition: monocrystalline feldspars within both fluvial and aeolian facies have a provenance signal suggesting a Gallic Massif source (Tyrrell et al., 2012). There is no systematic variation in mineralogy between facies (**fig. 8b**) suggesting that these feldspars were also well-mixed in the basin. The provenance of the lithic fragments, which are composed primarily of quartz and feldspar and are also present in the Cheshire Basin (**fig. 8b**), is currently unknown. More marginal localities of the EISB are 100% aeolian (Jones and Ambrose, 1994; Medici et al., 2019a), whereas major fluvial activity is maintained in the basin centre, with aeolian facies only comprising 5-10% of the rock volume in the Morecambe gas field (Cowan, 1993). In more detail, spatial partitioning of fluvial and aeolian deposits in the basin may have followed structurally controlled highs and lows (Meadows and Beach, 1993b).

After the EISB, the Sherwood-2 River System flowed further west to the Kish Bank, Peel, and Central Irish Sea basins. These basins formerly formed a contiguous depocentre with the EISB (**fig. 10a,** Dunford et al., 2001; Meadows, 2006; Marsh et al., 2022). The sedimentology of the HSF in these basins is poorly characterised relative to the rest of the HSF fairway, a problem exacerbated by the severe degree of post-Triassic erosion in the area. All basins contain a mix of fluvial and aeolian sandstone facies (Newman, 1991; Naylor et al., 1993; Dunford et al., 2001; Floodpage et al., 2001).

During the early stages of Interval S2, the Irish Sea area was unlikely to have been the ultimate terminus of the Sherwood-2 River System, as there is no indication of an endorheic terminal splay system here (e.g. McKie, 2011; 2014, Gibson-Poole et al., 2025). Topographic barriers, and an absence of fluvial facies within strata equivalent to Interval S2 indicate the Sherwood-2 River System did not flow north towards the Solway and North Channel basins (**fig. 10a,** Marsh et al., 2022) or south into the Celtic Sea Trough (**fig. 10a**, Dunford et al., 2001). It is most likely that the Sherwood-2 River System therefore flowed west via the Kingscourt Basin, possibly draining externally towards the shallow marine Porcupine Basin, west of Ireland (Croker and Shannon, 1987).

Sediment routing across the SSG-MMG transition

The onset of MMG deposition is diachronous (**fig. 4**), and coincides with the regional Muschelkalk marine transgression and a climatic aridification (Greenwood and Habesch, 1991; Thompson and Meadows, 1997; McKie, 2014; Newell, 2017a). Within the lower MMG, marine flooding was brief, shallow, but regular, and is well-evidenced through isotope geochemistry, sedimentology and palaeontology (e.g. Greenwood and Habesch, 1991; Old et al., 1991; Thompson and Meadows, 1997; Barclay et al., 1997; Evans, 2011; Warrington and Pollard, 2021). These transgressions likely originated from the marine domain west of Ireland (Croker and Shannon, 1987) and combined with aridification, caused a southwards backstepping of fluvial activity and an ingress of halite lake and playa facies initially into the EISB, and then into the Cheshire Basin, Midlands basins and Worcester Graben by the end of the Anisian (**fig. 4, 10b**).

In the EISB, there is a sharp transition from the aeolian and sabkha deposits of the HSF into the playa lake deposits of the SMF (**fig. 4**, Thompson and Meadows, 1997; Meadows, 2006). In the Cheshire Basin, the aeolian-dominated upper HSF transitions into the playa margin deposits of the TSF (**fig. 4; 6c;** Mikkelsen and Floodpage, 1989; Burley, 1987; Scorgie et al., 2021; De Sainz Simpson, 2022). In the Midlands Basins and Worcester Graben, the fluvial deposits of the HSF transition into fluvial, playa margin and marginal marine deposits of the TSF (e.g. Warrington, 1970a; b; Charsley, 1982; Old et al., 1991; Barclay et al., 1997; Warrington and Pollard, 2021; Jones et al., 2025), although these latter successions are thin and impersistent (**fig. 6c**). The Worcester Graben represents the southern limit of marginal marine deposits in the TSF (**fig. 4**). In the Wessex Basin, the uppermost HSF is composed of ephemeral lacustrine and sandflat deposits in the basin centre (McKie et al., 1997), and is fluvial in the west (Newell, 2017b). Both areas then transition into the arid playa lake mudstones of the SMF **(fig. 4)**. Although sand-grade sedimentation ceased during the deposition of the MMG, the dominance of terrestrial and shallow subaqueous depositional environments in this unit (Arthurton 1980; Wilson, 1993) imply sediment fluxes remained sufficient to fill basins. The EISB was filled despite the previously calculated fourfold increase in sediment accumulation rate across the SSG-MMG boundary. A general increase in accommodation generation through time, due to varying tectonic subsidence rate (Newell, 2017a), may have contributed to the southwards retreat of sand-grade deposition (e.g. Paola and Martin, 2012; Reynolds, 2024). Further insight into the role of active faulting in controlling stratigraphic architecture is only possible with decompaction and better chronostratigraphic constraints.

During the later stages of Interval S2, the assemblage of evaporitic playa lake, playa margin, and intercalated fluvial-aeolian deposits in the SMF, TSF and HSF (**fig. 4**) corresponds well to a terminal splay depositional model (e.g. Lang et al., 2004; McKie, 2011, 2014). Incoming fluvial systems were dispersed at the playa margin. Fluvial activity became increasingly ephemeral and unconfined, and declined rapidly towards the basin centre playa lake (**fig. 10b**). The SSG-MMG transition therefore represents the southward retreat of the Sherwood-2 River System. The absence of fluvial facies in the upper HSF and TSF in the EISB and Cheshire Basin may be due to preservational bias, as inactive fluvial deposits were rapidly reworked and incorporated into playa margin and aeolian deposits (Lang et al., 2004; McKie, 2011).

In the EISB and Cheshire Basin, the large volumes of SMF observed **(figs. 4, 6d, e)** were deposited in ephemeral lacustrine and dry mudflat settings (Arthurton, 1980; Wilson, 1990; 1993). The provenance of the MMG has not been directly addressed in this part of the British Isles. Ephemeral lacustrine sediments were likely sourced from distal flash floods, of which the Sherwood-2 River System would have been a contributor. Dry mudflat deposits require fine sediments with an aeolian source. In modern arid settings, fine sediments are highly mobile, and can be transported for hundreds of kilometres by dust storms (Jefferson et al., 1990; Brookfield, 2008; McKie, 2011; Mao et al., 2021; Marx et al., 2022). While the nature of lacustrine-aeolian reworking, as well as preservational biases within playa settings, require further study (McKie, 2011), it is probable that not all the mudstone within the SMF has an origin from the Sherwood-2 River System. West-blowing Triassic palaeowinds may have served to rework sediment both into, within and out of these basins (**fig. 10b**).

Source areas and regional correlation of the Sherwood-2 River System

Palaeo-lithological domains

Upland areas of pre-Triassic bedrock represent the ultimate source of sediment for the Sherwood-2 River System (**fig. 11**). The pre-Triassic surface of northwestern Europe is lithologically diverse, and encompasses an area from the core of the Variscan Orogeny in the south (Baptiste, 2016; Martínez Catalán et al., 2021) to the Palaeozoic sedimentary cover of cratonic Avalonia in the north (Butler, 2018).

Although the distribution of basement lithologies during the Triassic is not known, key Variscan basement units had already been exhumed and were supplying sediment to the British Isles by the end of the Carboniferous (c. 300 Ma, Hallsworth et al., 2000; Jones et al., 2011; Morton et al., 2021; 2024). The pre-Triassic geology of northwest Europe can be categorised by large-scale tectonic domains, each with a differing geological history resulting in a distinct metamorphic, igneous and sedimentary succession. Domains have been characterised using outcropping lithologies, and in places where the pre-Triassic surface is buried under more recent sedimentary cover, using boreholes and geophysical methods (Baptiste, 2016; Butler, 2018). Where possible, we focus on the distribution of granitoids and gneisses, which provide provenance-sensitive feldspars, zircons and other heavy minerals to their respective fluvial catchments (Paul et al., 2008; Sanchez Martínez et al., 2012; Tyrrell et al., 2012; Morton et al., 2013; 2016; Augustsson et al., 2018; Sass et al., 2023). Additional constraints on sediment routing, including inferences made from known constraints on palaeotopography, can be found in **Supplementary Material 5.**

Internal Variscan metamorphic units

The internal Variscan metamorphic units comprise a complex sequence of tectonic domains which form the core of the Variscan Orogen in northwest Europe. The Mid-Variscan Allochthon forms much of the basement in central France (**fig. 11**). Variscan-aged granitoids, gneisses and migmatites are found throughout this unit, and are presently the most common group of rocks (Baptiste, 2016; Catalán et al., 2021). The North and Central Armorican tectonic domains to the north are primarily composed of metasediments and, respectively, Cadomian-aged granitoids and gneisses and Varican granites (**fig. 11,** Baptiste, 2016). The northernmost tectonic domain is the Léon-Normannian-Saxothuringian Domain, which lies mostly at subcrop and under the English Channel in the study area, and is poorly characterised (Shail and Leveridge, 2006). However, in north Brittany, this domain contains Variscan granitoids (Catalán et al., 2021). In the east, this domain also contains Cadomian granitoids or gneisses, and the Variscan Barfleur Granite (Baptiste, 2016; Donato et al., 2023).

The Gallic Massif is entirely composed of internal Variscan metamorphic units. (**fig. 10a, 11**). In the Wessex Basin, the delivery of Variscan-aged material to the HSF (Morton et al., 2016) necessitates a sediment source in the Central Armorican Zone and Mid-Variscan

Allochthon, where the closest Variscan granitoids are concentrated. This yields approximately 300 km of non-preserved drainage for the Sherwood-2 River System over the Gallic Massif (**fig. 11**). In the central and eastern Wessex Basin, observed Variscan ages (Morton et al., 2016) are likely derived from the Barfleur Granite in northern France, owing to its proximity to the sediment fairway **(fig. 11)**. In southern Brittany, the Biscay Rift likely directed fluvial systems south towards the Iberian Peninsula (**fig. 11**, Péron et al., 2005; Bourquin et al., 2011; Sanchez Martínez et al., 2012). The remaining part of the Gallic Massif is inferred to have supplied the Franco-German Buntsandstein **(fig. 11)**. This configuration allows for Cadomian and Variscan source signals to be supplied to this latter sediment routing system (Paul et al., 2008; Augustsson et al., 2018; Sass et al., 2023).

Dominantly sedimentary domains

Two basement tectonic domains are predominantly composed of sedimentary rocks: the Rhenohercynian Zone, which represents the Variscan fold-and-thrust belt, and Cratonic Avalonia, which has experienced mild to no Variscan deformation **(fig. 11)**. Both domains are both composed of synorogenic Variscan clastic sediments, as well as carbonates and clastics predating the Variscan Orogeny (e.g. Busby and Smith, 2001; Butler, 2018; Pharaoh, 2021). The Rhenohercynian Zone additionally contains Variscan granites of the Cornubian Batholith, with an associated contact metamorphic aureole (**fig. 11,** Searle et al., 2024). In the Triassic the Rhenohercynian Zone and Cratonic Avalonia would have had a more extensive cover of younger and stratigraphically higher Carboniferous rocks, since removed by erosion.

The catchment for the Sherwood-2 River System likely extended into the Cornubian Batholith in the Rhenohercynian Zone, around 30 km west of the Wessex Basin (**fig. 11**, Smith and Edwards, 1991; Morton et al., 2013). On the eastern side of the Wessex Basin, the London-Brabant Massif lies in both the Rhenohercynian Zone and Cratonic Avalonia, and has potential to provide a sizeable drainage area into the S2 fairway. However, the extent of the drainage which supplied recycled Devonian clastics from the London-Brabant Massif (Morton et al., 2016) is unclear owing to the abundant subcrop of this lithology beneath the Variscan unconformity (Butler et al., 2018). The Welsh Massif also has potential to supply a sizeable drainage area for the S2 fairway (**fig. 10a**), and HSF sandstones in the EISB appear to have been derived from North Wales (Mange et al., 1999), though the overall extent of this catchment remains unclear. The Pennine High separates the mudstone-dominated East Midlands Shelf from the sandstone-dominated EISB (**fig. 10a**), and was a well-documented sediment source for the latter (Meadows and Beach, 1993a; Meadows, 2006; Scorgie et al., 2021; Marsh et al., 2022). The Pennine High was likely small in extent and/or elevation, implied by the lack of fluvial activity on the East Midlands Shelf (Howard et al., 2009; Jones et al., 2025).

Sediment routing over the London-Brabant and Welsh massifs remains poorly known owing to the absence of geological and mineralogical constraints in the Midlands and Worcester Graben. By area, these massifs are the second and third largest uplands after the Gallic Massif (**fig. 11**). Regionally, precipitation was highest in the south of the fairway, driven by Tethyan monsoons passing over the Variscan mountains (Péron et al., 2005; McKie, 2014; 2017). Lastly, the erodibility of the Palaeozoic sediments which cover the London-Brabant and Welsh massifs may be several times greater than the metamorphic-granitic basement of the Gallic Massif (Syvitski and Milliman, 2007). These lines of evidence suggest that comparatively large sediment fluxes from these uplands may have entered the Sherwood-2 River System in the Worcester Graben or Midlands basins. This sediment was likely lithic-rich and felspar-poor, containing lithoclasts of metasediments, volcanic rocks, carbonates and chert, and reflecting the mineralogy of recycled Devonian and Carboniferous sandstones (Knox et al., 1984; Glover and Powell, 1995; Bridge et al., 1998; Jones et al., 2011). Although bulk sandstone mineralogy clearly changes between the Wessex Basin and the Midlands, lithic fragments of the aforementioned nature are not reported from the northern part of the fairway. Here, lithics are composed of quartz and feldspar by the Gazzi-Dickinson method, which classifies lithic fragments by their constituent mineral phases (**fig. 8b**). Hence, changes in bulk mineralogy **(fig. 8b)** may not only be a product of interactions between different source areas, but may also result from the breakdown of recycled lithic fragments and feldspar during sediment transport and diagenesis. However, the ability of these processes to alter sandstone mineralogy has been questioned (Frings, 2008; Garzanti, 2017), and requires quantitative investigation.

Discussion and Conclusions

Overall, the stratigraphic architecture of Interval S2 is controlled by an increase in aridity and a series of frequent, but brief marine transgressions during the latter part of the Anisian (e.g. Newell, 2017a; McKie, 2017). The Sherwood-2 River System was initially externally draining, but continued aridification meant that for the majority of Interval S2, the fluvial system largely ended in terminal splay systems, discharging into a network of playa lakes with intermittent marine influence. Semiarid fluvial and aeolian deposits of the HSF were gradually replaced by mudstone-dominated playa and halite lake facies of the MMG (**fig. 4, 10a, b**).

Within Interval S2, the EISB is the largest sediment sink within the mapped fairway, representing 62% of the total sediment volume deposited during this interval (**fig. 7**). Although sand-grade sedimentation ceased during the deposition of the MMG, sediment fluxes were sufficient to fill basins. As previously discussed, calculated sediment accumulation rates were temporally variable, and likely controlled by differential tectonic subsidence (Newell, 2017a), although a paucity of chronostratigraphic constraints within Interval S2 limits the spatio-temporal resolution of this control.

North-flowing palaeocurrents in the HSF (**fig. 10a**) and the widespread distribution of Variscan-Cadomian material throughout the sediment fairway (e.g. Mange et al., 1999; Plant et al., 1999; Tyrrell et al., 2012; Morton et al., 2016), suggest that the Sherwood-2 River

System was one, continuous river network. On the other hand, substantial changes in bulk sandstone mineralogy (**fig. 8b**) and differences in heavy mineral indices between basins (Plant et al., 1999; Morton et al., 2013) suggest sediment composition changes within the fairway. The HSF in the Wessex Basin is dominated by feldspathic sediments supplied from the Gallic Massif, which by area and elevation was the largest catchment feeding the Sherwood-2 River System (**fig. 11**). The bulk mineralogy of the HSF in the Wessex Basin contrasts with that of the Midlands basins, Cheshire Basin and EISB, where sediments are substantially more quartz-rich (**fig. 8b**). This implies sediment composition was substantially modified in the Worcester Graben or the Midlands basins (**fig. 8a**), likely through substantial tributary input. In the Cheshire Basin and the EISB, fluvial and aeolian inputs of sediment are well-documented, and these basins were domains for considerable fluvial-aeolian interactions. Aeolian processes may have continued to be a substantial conveyor of sediment during the deposition of the MMG, and served to both import and export sediment from the fairway.

Evidence for additional fluvial inputs into the Sherwood-2 can be further observed when the fluvial systems of the SSG are compared to modern analogues in the Kati Thanda–Lake Eyre Basin (Brookfield, 2008; McKie 2014; Morón et al., 2014; English et al. 2024). Under semiarid climates and with no secondary inputs, these modern river systems experience high water transmission losses of around 80% over approximately 200 km (Costelloe et al., 2000), and are mostly ephemeral. Despite a comparable climatic setting, the Sherwood-2 River System was perennial in both its proximal and distal reaches over a length scale of 500km (Meadows and Beach, 1993; McKie et al., 1997; Meadows, 2006). As such, secondary fluvial inputs may have been important in maintaining a consistently perennial system, consistent with the substantial sediment inputs into the Sherwood-2 north of the Wessex Basin expressed in bulk sandstone mineralogy. Similarly, the decline of these proximal sources of sand during the onset of aridification may have contributed to generate the SSG-MMG transition. This occurred in the northern part of the fairway despite a sustained semiarid climate in the Wessex Basin (Newell, 2017b), and a steady supply of fluvial sediment from the Gallic Massif recorded by the time-equivalent HSF (Morton et al., 2016).

In conclusion, through the creation of a new chrono- and lithostratigraphic framework, and an updated paleogeographic framework for the mid-Triassic of the British Isles, we resolve the spatial and temporal dynamics of the HSF, TSF and lower SMF, and construct a source-to-sink depositional model linking the three units. Our new synthesis of bulk sandstone mineralogy, supported by a synthesis of sediment routing and source area lithology shows that although the Sherwood-2 River System was a single fluvial system, mineralogical changes occur between the south and north parts of the sediment fairway, suggesting that there were likely multiple, substantial sediment inputs north of the Wessex Basin. These tributaries likely drained from the London-Brabant and Welsh Massifs into the Midlands basins and Worcester Graben. The temporal evolution of the Sherwood-2 river system was dominated by a southwards retreat of fluvial deposits of the HSF, which were replaced by playa-lacustrine deposition of the TSF and SMF. This change is typically attributed to a regional increase in aridity. However, our results show a greater than fourfold increase in sediment accumulation rate in the EISB, the largest depocentre in the sediment fairway. As such, differential tectonic subsidence was likely a previously unrecognised control on stratigraphic architecture during this time interval.

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Author contributions

XY: Conceptualization (lead), Data curation (lead), Formal analysis (lead), Investigation (lead), Methodology (lead), Visualization (lead), Writing – original draft (lead), Writing – review and editing (equal); **GJH:** Funding acquisition (lead), Methodology (supporting), Supervision (equal), Visualization (supporting), Writing – review and editing (equal); **ACW:** Funding acquisition (supporting), Methodology (supporting), Supervision (equal), Visualization (supporting), Writing – review and editing (equal).

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data generated or analysed during this study are included in this published article (and its supplementary material files).

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