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The Geology of England – critical examples of Earth History – an overview

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ABSTRACT

Over the past one billion years, England has experienced a remarkable geological journey. At times it has formed part of ancient volcanic island arcs, mountain ranges and arid deserts; lain beneath deep oceans, shallow tropical seas, extensive coal swamps and vast ice sheets; been inhabited by the earliest complex life forms, dinosaurs, and finally, witnessed the evolution of humans to a level where they now utilise and change the natural environment to meet their societal and economic needs. Evidence of this journey is recorded in the landscape and the rocks and sediments beneath our feet, and this article provides an overview of these events and the themed contributions to this Special Issue of *Proceedings of the Geologists' Association*, which focuses on 'The Geology of England – critical examples of Earth History'. Rather than being a stratigraphic account of English geology, this paper and the Special Issue attempts to place the Geology of England within the broader context of key 'shifts' and 'tipping points' that have occurred during Earth History.

1. Introduction

England, together with the wider British Isles, is blessed with huge diversity of geology, reflected by the variety of natural landscapes and abundant geological resources that have underpinned economic growth during and since the Industrial Revolution. Industrialisation provided a practical impetus for better understanding the nature and pattern of the geological record, reflected by the publication in 1815 of the first geological map of Britain by William Smith (Winchester, 2001), and in 1835 by the founding of a national geological survey. Since the publication of Smith's map, our understanding of English geology has evolved in-parallel with major paradigm shifts (e.g. evolution, continental drift, plate tectonics, 'Ice Ages') in geological theory (Brenchley and Rawson, 2018). Now, through the Information Revolution disparate observations are increasingly being compiled to reveal new perspectives and insights into Earth-system processes.

Rather than attempting a stratigraphic review of the geological record of England, this Special Issue attempts to explore how the Geology of England provides examples for understanding regional geological successions within the context of much broader 'shifts' or 'tipping points' in Earth History. These key events produce a wide spectrum of geological responses, driving changes in earth surface processes, palaeogeography and palaeoenvironment. 'Process' and 'context' are two important themes that unify the articles in this Special Issue, allowing geological products (e.g. rock and sediment type, structure, geometry etc) and properties to be linked to large-scale causal mechanisms, and providing holistic understanding of regional geological successions. It also contributes to a better conceptual understanding of sub-surface geological heterogeneity; a broader appreciation of our geological heritage, and a greater knowledge of how geology (e.g. resources, hazards) influences society and our economy.

2. The geological history of England: a global context

The events described in this Special Issue represent key phases through the one billion year geological history of England. Here we provide a broader perspective of that history to function as a framework within which the associated events and processes can be understood. It is a remarkable fact that such a small region as England and the wider British Isles preserves material from virtually every part of the geological column. Global plate tectonic reconstructions (http://www.scotese.com/) show that for much of its geological history, England was located close to rifted basin margins, and at other times phases of mountain building created new lines of structural weakness to accommodate the products of the next depositional cycle. This imparts a particular structural

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complexity, facilitating the possibility of local extensional tectonics and deposition even during phases of broad regional compression and uplift.

In the following sections of this overview paper we outline five key phases within the geological evolution of England: (1) Neoproterozoic to Early Paleozoic: England's foundations and the emergence of complex life; (2) Late Paleozoic to Early Mesozoic: colliding continents; (3) Mesozoic rifting and epicontinental seas; (4) Cenozoic: exhumation and the transition to 'icehouse' climates; (5) Humans and Geology. Each phase is associated with significant 'shifts' or 'tipping points' in geological environments and processes which are described and linked to contributions (bold) in this Special Issue.

2.1. Neoproterozoic to Early Paleozoic: England's foundations and the emergence of complex life

The story of England's geological evolution can be traced back to the Neoproterozoic (1.0 Ga–541 Ma). Rocks of this age form a complex collage of different structural blocks including recycled continental crust, oceanic crust and oceanic island arcs which collectively form England's basement geology (Pharaoh et al., 1995, 1996; Pharaoh, 1999; Pharaoh, 2018; Beamish et al., 2016).

During the Neoproterozoic, England probably formed part of the Amazonian margin of the Gondwana supercontinent that was located at high southern latitudes and extended across the South Polar Region (Fig. 1, Late Neoproterozoic). In the Late Neoproterozoic (Ediacaran; 635–541 Ma) the first signs of complex life began to appear in the oceans, revealed as fossilised remains in rocks exposed at Charnwood Forest in the English Midlands (Fig. 1(i)). Although first discovered in Newfoundland in 1868 by Alexander Murray, and later in Namibia (Gürich, 1933) and the Ediacara Hills in South Australia (Sprigg, 1947), the significance of these fossil discoveries was initially dismissed because of the assumption that they must represent Cambrian successions. It was only the discovery of the fossil *Charnia* at Charnwood Forest in Leicestershire, in rocks of undoubted Precambrian age, that the potential importance of the earlier discoveries was realised (Ford, 1958). For many years since that initial discovery the rocks of Charnwood Forest appeared to offer little insight into the nature of Late Neoproterozoic life, with just a few additional records of *Charnia* to add to the fossil inventory (Ford, 1980, 1999; Boynton and Ford, 1995; Antcliffe and Brasier, 2008). In recent years however, all this has changed, with the discovery of a much wider range of complex life forms in these rocks (Wilby et al., 2011, 2015; Howe et al., 2012; Kenchington et al., 2018). As Kenchington et al. (2018) reveal in their overview in this Special Issue, the Charnwood biota is not only historically significant for establishing the antiquity of these life forms, but new discoveries provide an updated context for understanding its evolution and diversity. This new work demonstrates that there are several dozen horizons within the succession where fossil remains occur, rather than just the few surfaces previously known (Kenchington et al., 2018). These have revealed new details of fossil morphology, and shed new light on the relationship with related and partly coeval biotas known from Newfoundland (Canada). Fossil diversity and density is much greater than previously thought at Charnwood, and there are new species that are not known in the Newfoundland biota and which may be strongly controlled by local environmental setting (Kenchington et al., 2018).

Rifting of the Gondwana continental margin during the Cambrian or Ordovician gave birth to the micro-continent of Avalonia, with England corresponding to the eastern part of this region (Pharaoh et al., 1995, 1996; Pharaoh, 1999; Beamish et al., 2016). For much of the Ordovician and Silurian, a partly emergent Avalonia drifted towards mid-southern hemisphere latitudes. Avalonia was flanked by deep basins to the north-west (Iapetus Ocean), east (Tornquist Sea) and south-east (Rheic Ocean), and intermittently fringed by volcanic island arcs as the micro-continent began to collide and amalgamate with other crustal fragments (Smith and Thomas, 2015). By the mid-Silurian the Iapetus Ocean had closed and Avalonia was located around 30°S and had become accreted onto the southern margin of the Laurussia continental mass (Woodcock and Soper, 2006; Torsvik and Cocks, 2017). Evidence for this highly complex part of England's geological history is revealed by the geology of the Anglo-Brabant Massif (A-BM) situated beneath central and south-east England (Pharaoh et al., 1993), reviewed in this Special Issue by Pharaoh (2018). Early Paleozoic rocks that form the A-BM reveal a tripartite sequence that can be correlated with coeval sequences in Wales, Newfoundland and the northern Appalachians. These rocks demonstrate a south-west to north-east facies transition from shallow marine platform to deeper basinal sediments, and bear witness to voluminous igneous and volcanic activity associated with Ordovician subduction (Pharaoh, 2018). Subsequent deformation by latest Silurian and Early Devonian tectonic events defined the A-BM as a distinct structural entity, which continued to exert influence on the development of accommodation space and patterns of sedimentation through the remaining Paleozoic and Mesozoic history of England (Pharaoh, 2018).

2.2. Late Paleozoic to Early Mesozoic: colliding continents

During the Devonian, England experienced a warm to hot semi-arid climate on the subtropical southern fringe of Laurussia (Hillier and Williams, 2006; Kendall, 2017; Fig. 1 mid-Devonian), dominated by terrestrial environments. The evolution of rooted land plants caused atmospheric CO_2 concentrations to decline, promoting relative landscape stabilisation (Kendall, 2017) and increased rates of chemical weathering (Baars, 2017) and soil development (Kendall, 2017). Variable patterns of syn- to post-orogenic terrestrial sedimentation to the north of the A-BM (Kendall, 2017) contrast with areas to the south where largely persistent marine and marginal marine conditions occurred (Torsvik and Cocks, 2017). The varied successions are revealed in structurally complex basins across south-west England (Leveridge and Hartley, 2006; Leveridge and Shail, 2011a,b; Leveridge, 2011; Whittaker and Leveridge, 2011) that bordered a tropical oceanic corridor (Rheic Ocean) separating Laurussia and Gondwana (Torsvik and Cocks, 2017; Fig. 1). A protracted (Devonian – Carboniferous) series of terrane and larger continental collisions along this oceanic margin are responsible for the Variscan Orogeny (Torsvik and Cocks, 2017).

In the early Carboniferous, back-arc extension associated with the Variscan subduction zone, caused rifting along pre-existing lines of structural weakness (Guion et al., 2000; Stone et al., 2010). This particularly affected areas north of the A-BM and shaped the typical block-and-basin structural fabric which was progressively infilled by early Carboniferous marine limestones and late Carboniferous (Westphalian – Stephanian) delta plains (Guion et al., 2000; Waters and Davies, 2006; Stone et al., 2010; Fig. 1 Late Carboniferous). Occupying a broad equatorial swathe, these deltas were colonised by the iconic giant ferns, horsetails and club mosses of the coal swamp 'forests', the source of 'Coal Measures' deposits (Fielding, 1984; Waters et al., 1996; Waters and Davies, 2006).

The ecosystem diversity of the coal swamps, focussing particularly on the exceptionally well-preserved plant fossils from the Pennine Basin, is explored in this volume by Cleal (2018). Many of the floras represent a rather narrow range of environments, typically close to rivers where their remains would easily be transported to sites favourable for preservation, whereas the main