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The Cretaceous–Paleogene unconformity in England: Uplift and erosion related to the Iceland mantle plume

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ABSTRACT

During the late Cretaceous to early Paleogene, the present-day area of Britain and Ireland emerged from nearly total submergence by the chalk sea. What mechanism was responsible for this major marine regression? Combined studies of Paleogene depositional sequences offshore and coeval igneous rocks onshore, show that significant episodic uplift of northern Britain was at that time largely controlled by the early development of the Iceland mantle plume. How far south did this influence of the Iceland plume extend across England, and even beyond? We present new maps of the structure and denudation of the chalk surface in southern England. Some 500 m thickness of chalk was removed from the crest of a Chilterns–East Anglia dome before deposition of the earliest Paleogene sediments. Allowing for isostatic amplification by erosion, minimum uplift of the chalk surface above sea level was c.125 m. Early Paleogene crustal shortening of that chalk surface was by a factor of at most 1.01, contributing a maximum uplift of 25 m of the floor of the chalk sea. Compressional forces were not the main cause of the Cretaceous–Paleogene unconformity in southern England, as in the interpretation of this event as a distant reflection of the development of the Alps to the south. Postulated contemporary changes in global sea-level are also inadequate to account for the development of the unconformity in southern England. Here we suggest with some confidence that the main vertical surface movements involved in creating the unconformity were controlled by the Iceland mantle plume, as in northern Britain. We speculate that another hotspot, in Central France, may have influenced Paleogene sedimentation in the Paris Basin in a comparable fashion. We consider how to distinguish between our proposed mantle control of regional relative sea-level and global controls of Paleogene sea level.

1. Introduction

The unconformity between Cretaceous and Paleogene in the Hampshire and London basins is a major feature of the geological history of southern England, yet its main cause remains uncertain. Examination of this unconformity is of more than the local interest. In recent years there has been a revival of interest in the control exercised by mantle convection on vertical movements of Earth's surface.

A main line of these investigations of the surface effects of mantle convection (Nadin et al., 1995; White and Lovell, 1997) springs from Paleogene data released by the oil companies from exploration and production offshore Britain and Ireland. These studies form part of significant collaborative research between the oil industry, universities and national surveys that bears on the cause of episodic changes in regional relative sea-level in various geological settings.

Broadly, there are two main hypotheses for the cause of the Cretaceous–Paleogene unconformity in southern England, not mutually exclusive. Each hypothesis is linked to a major tectonic event nearby: one to the north and one to the south. The northern, hypothesis is uplift associated with the early Iceland plume. This contrasts sharply with the southern hypothesis of uplift resulting from compressional tectonics in the Alps. We here examine both local and regional evidence to see if it is possible to distinguish between these two controls.

We here test in this particular region of northwest Europe, at this particular time of the Mesozoic–Cenozoic boundary, the general proposal of Jones et al. (2012) that episodic behaviour of mantle convection causes marine transgression and regression on a range of timescales. That proposal of mantle control by Jones et al. includes analysis of the Paleogene uplift that established, for

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the first time in geological history, a recognisable outline of present-day Britain and Ireland.

A high-definition stratigraphical framework is required for a full test of this hypothesis of mantle control in relation to high-frequency changes in relative regional sea-level. With such a framework, one may distinguish episodic regional transgressions and regressions, as in the Paleogene (Plyusnina et al., 2016; Ruban et al., 2010, 2012) from periodic Milankovitch global changes in sea level, as in the Cretaceous (Gale et al., 2002, 2008). To the extent that this requirement of stratigraphical control is not met in northwest Europe, the conclusions we reach here concerning control of relative regional sea-level are tentative.

Within the episodic regional events that can be recognised, there is a distinction between:

(1) uplift caused by crustal shortening, associated with the classical tectonic activity of regional compression: recognised by evidence of dominantly horizontal movement.
(2) uplift associated with the convective system of the upper asthenosphere, including magmatic intrusion in the lower crust: recognised by evidence of dominantly vertical movement.

We present new data on the structure and age of the chalk in the Hampshire and London basins. We calculate the amount of uplift of the chalk, pre-Paleogene deposition, that may be ascribed to horizontal shortening.

These results, combined with regional data, lead us to conclude with some confidence that horizontal shortening was of minor significance in controlling the development of the Cretaceous–Paleogene unconformity in England. In contrast, we present evidence that vertical movements associated with the early Iceland mantle plume were a first-order control of the Paleogene uplift.

2. Offshore data and paleogeography

Wills (1951) produced the standard mid-century palaeogeographical atlas of Britain and Ireland. His work preceded both the discovery of plate tectonics in the 1960s and the release of oil-industry data from offshore in the 1970s. Wills' broad definition of paleogeography across the Mesozoic–Cenozoic boundary is nonetheless consistent with interpretations benefiting from those later developments (Hancock and Rawson, 1992; Murray, 1992). Wills shows the chalk sea covering much of Britain and Ireland in the late Cretaceous, withdrawing to form an early North Sea and English Channel by the Paleogene. 'North Atlantis' lies to the northwest, yet to "break up", in his words. Wills suggests that the disappearance of this land to the northwest may be associated the igneous activity in the region that is so much in evidence onshore in Scotland.

The first sets of palaeogeographical maps of Britain and Ireland that drew on both the new understanding of global tectonics, and on offshore data, were presented at the first North Sea conference in Bloomsbury in 1974 (Ziegler P.A., 1975; Ziegler W.H., 1975). At this meeting, oil-industry geologists shared with their academic colleagues the results of the first decade of exploration offshore. This openness with industry data enabled those training the next generation of petroleum geologists to incorporate the new findings rapidly in paleogeographical maps used in teaching (Lovell, 1977).

The new findings broadly confirmed earlier views on paleogeography. A recognisable outline of the future of Britain and Ireland emerged for the first time from the chalk sea in the Paleogene. The suspected widespread presence offshore of Late Cretaceous chalk was proven. What was new at the 1974 Bloomsbury conference was the evidence of the uplift of Scotland preserved in the Paleogene sandstones of the central and northern North Sea (Parker, 1975).

In addition, tuffs in the Paleogene sequence in the North Sea provided insights into the igneous activity to the west (Jaque and Thouvenin, 1975). Possible connections between the uplift of northern Britain and the development of the early Iceland plume (White, 1989) were investigated (Milton et al., 1990; Brodie and White, 1994, 1995; Nadin et al., 1995; Knox, 1996; White and Lovell, 1997). These studies establish the significance of Paleogene thermal uplift of northern Britain. Our interest here is to establish how far to the south the influence of the plume was felt.

According to Knox (1996), the influence of the plume can be seen in the Paleogene of southern England. Knox recognised several Paleogene depositional sequences in the London basin, which he correlated with Paleogene depositional sequences of the North Sea. This correlation is hard to prove fully, given the limitations of the onshore biostratigraphy, but Knox does propose a plausible connection between regional relative sea-level in southern England and the behaviour of the early Iceland plume.

The evidence from offshore bears strongly on our interpretation of the onshore data (Figs. 1 and 2). In Section 4 below we incorporate findings from offshore as we seek to understand the significance of the age and structure of the chalk surface beneath the Paleogene deposits of the Hampshire and London basins. In Section 5 we also use offshore data as we interpret the Paleogene depositional sequences that formed on that chalk surface. As background to those sections, we now review in Section 3 regional evidence for the tectonic significance of the early Iceland plume.

3. Uplift caused by the early Iceland plume

Following Jones et al. (2012), we here distinguish between (1) long-term regional uplift associated with the thermal swell of the Iceland plume, and (2) short- term local uplift associated with hot blobs in mantle convection travelling away from the axis of the plume. The regional uplift of the thermal swell lasted for some 30 million years (Jones et al., 2012); episodic uplifts on the flanks of the thermal swell had durations of the order of a million years (Shaw Champion et al., 2008; Hartley et al., 2011).

A further distinction may be made between transient uplift identified by Nadin et al. (1995) from the Paleogene of the North Sea, and the longer-term uplift of Scotland ascribed by Brodie and White (1994) to Paleogene magmatic underplating. White and Lovell (1997) appealed to pulsed magmatic underplating as the cause of episodic formation of Paleogene submarine fans in the North Sea. Maclennan and Lovell (2002) showed that both marine regression and transgression could be associated with the underplating process.

Underhill (2001), Smallwood and Gill (2002), Shaw Champion et al. (2008) and Hartley et al. (2011) quantify vertical Paleogene movements offshore Scotland. Subsidence following transient uplift is of such magnitude that underplating alone is not an adequate explanation for these events. Rudge et al. (2008) suggest that the primary mechanism for these episodic events is the passage of advected hot blobs in the upper asthenosphere. These hot blobs give rise to transient uplift of the order of hundreds of metres, up and down within a million or so years.

Lovell (2010) proposes that magmatic underplating is associated with the passage of these hot blobs only in some cases of transient uplift. Where there is significant associated igneous activity, as in the case of the episodic Paleogene uplifts of early Scotland, underplating may be recognised on geochemical evidence (Brodie and White, 1994). Surface uplift by magmatic