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How plate tectonics is recorded in chalk deposits along the eastern English Channel in Normandy (France) and Sussex (UK)

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ABSTRACT

Intra-plate stresses that occurred in the Anglo-Paris Basin and English Channel during Upper Cretaceous and Cenozoic times are a consequence of the convergence between Eurasia and Africa and the opening of the North Atlantic area. This geodynamic re-organisation is recorded on each side of the English Channel, with the emergence of regional structures such as the the Weald-Artois anticline and the reactivation of large-scale strike-slip faults. We analyse the Anglo-Paris Basin Chalk fracture system, on each side of the eastern English Channel, using a set of 1600 meso-scale fractures data collected on coastal chalk cliffs in Normandy (NW France) and Sussex (UK). Meso-scale fracture system is precisely dated using chalk lithostratigraphy correlations within the basin. Moreover, an inversion method is used on fault slip data to evidence a paleostress chronology in the Anglo-Paris Basin. Three main Upper Cretaceous extensive events, characterized by normal faults and jointing are recorded in Normandy and two Cenozoic compressive and extensive events with strike-slip and normal faults appear in Sussex. Paleostress records vary on each part of the eastern English Channel. The meso-scale fracture system is thus used to better define the type of relationship between meso-scale and large-scale brittle deformation in the Chalk during Meso-Cenozoic. A first NE-SW extension is recorded in Normandy in relation with local anticlines structures and related to the Lower Rhine graben opening. A second event is a WNW–ESE extension of local origin in relation with the subsidence axis of the Paris Basin. The third event is a NNE–SSW extension, well marked in Normandy and related to the activation of E–W normal faults in the western approaches of the English Channel. This event is also recorded in Sussex and reactivates locally older fractures in strike-slip. The Oligocene N–S compression/E–W extension related to the Pyrenean tectonics and the last E–W extension relative to the North Sea graben opening are well recorded in Sussex, but not in Normandy. Recent far-field stresses developed in the NW European platform are focused on deep crustal structures like the Artois hills and the Cotentin areas in France. These structures act as a stress barrier by protecting the Normandy Chalk from recent far-field stresses. On the contrary, recent far-field stresses are easily recorded by meso-scale brittle deformation on the folded Chalk in Sussex.

1. Introduction

Upper Cretaceous Chalk of the NW Europe provides an excellent record of brittle tectonics generated by far-field stresses of plate tectonics re-organisation during Meso-Cenozoic. As one of the intra-continental basins of NW Europe, the structural style of the Anglo-Paris Basin is strongly linked to the initial configuration of the basin, but also to the orientation of the basin axis relative to the direction of the greatest horizontal stress and the amount of strain and the lithological composition of its sedimentary infill (Ziegler, 1990). The aim of this study is to explore the precise relationships between meso-scale fracture data, large-scale tectonic lineaments and syn-sedimentary events in the Chalk of the Anglo-Paris Basin. The particularity of chalk deposits is to present a very high variety of lithofacies and syn-sedimentary events (e.g. hardground levels, dolomitisation…), that conducts to subsequent mechanical properties of the chalk at various scales (e.g. Lord et al., 2002; Mortimore et al., 2004a).

Previous studies have identified tectonic phases related to the so-called Subhercynian events (Mortimore et al., 1998; Ziegler, 1981, 1990) previously defined in the Subhercynian Cretaceous basins in the Harz foreland Germany (Stille, 1924); while other studies suggested a paleostress history for structures such as faults, deduced from microstructural analysis (e.g. Bergerat, 1987; Hibsch et al., 1995; Vandycke and Bergerat, 2001).

The eastern English Channel is an ENE–WSW trending basin crossing the north part of the Anglo-Paris Basin, extending along a NW–SE

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axis from the south of England to the east of France (Figs. 1, 2). During the Mesozoic time, the Anglo-Paris Basin development is related to the continental extension due to the North Atlantic history and to the basin inversion during Cenozoic compression (Ziegler, 1981).

Paleostresses have conducted to inversion along some large-scale North-West European ante-Mesozoic structures, as well as meso-scale brittle fracturing in the chalk cover. To give a more exact timing of the deformation in the Chalk located each part of the English Channel and the relationships between brittle deformation type at large-scale and at meso-scale, we choose to study in details two various regions of the Chalk basin. On the one hand, the Normandy coast located near the depot centre of the Chalk basin and characterized by a few large-scale tectonic structures. On the other hand, the East Sussex coast located in the border of the Chalk basin and affected by numerous large scale tectonic lineaments and folding.

We used a data set concentrated on the orientation and frequency of meso-scale fractures from the Chalk in the coastal cliffs of the eastern English Channel (Genter et al., 2004). A new paleostress analysis of Upper-Normandy meso-scale faults has been performed and combined with paleostress studies already undertaken in East Sussex (Vandycke, 2002) in order to establish both the tectonic phase timing and their chronology along the Eastern English Channel during Meso-Cenozoic.

Complementary studies have been carried out on chalk sedimentology and fracture type embedded within particular Chalk Formations throughout the entire basin. Chalk Formations were dated using the lithostratigraphy concept (Mortimore, 2011) and used to better constrain the age of the meso-scale fracturation.

The first objective of this paper is to present the results of about 1600 meso-scale fracture measurements recorded on the chalk cliffs of the eastern English Channel in Upper Normandy (France) and in East Sussex (UK). The aim of this paper is to better define the changes in stresses over time in the English Channel and associated areas.

Microstructural features (slickenslides) revealed on meso-scale fractures are used (1) to better define the tectonic behaviour of large-scale strike-slip and normal faults in the Chalk in relation with syn-sedimentary events recorded at regional scale, (2) to better constrain Meso-Cenozoic paleostress evolution in the Anglo-Paris Basin around the eastern English Channel.

2. Tectonic setting of the eastern English Channel

2.1. Ante-Mesozoic basement

The ante-Mesozoic basement of the English Channel is made of three main blocks, crossing the Channel from north east to south west. These units are (Fig. 1): the Brabant-Midland block, the Rheno-hercynian zone and the Cadomian block (Autran et al., 1994; Guillocheau et al., 2000; Stoneley, 1982). Each block is limited by two main tectonic lineaments, *i.e.* the North Variscan Front (VF) and the Bray Fault, which are considered to have had a great influence on the sedimentation and fracturing of the overlying Mesozoic chalk cover (e.g. Autran et al., 1994; Chadwick, 1986; Guillocheau et al., 2000; Héritier and Villemin, 1971; Mortimore and Pomerol, 1997; Shephard-Thorn et al., 1972). Both in Northern France and Southern England, tectonic lineaments associated with the Variscan Front are N110-120E oriented (Chadwick, 1986; Colbeaux et al., 1980; Lamarche et al., 1998; Shephard-Thorn et al., 1972). In NW France, the Bray Fault is oriented NW-SE (N130-140E) and is considered as a large pre-Mesozoic ductile dextral strike-slip fault, roughly parallel to the Variscan Front (Holder and Leveridge, 1986; Matte, 1986). The

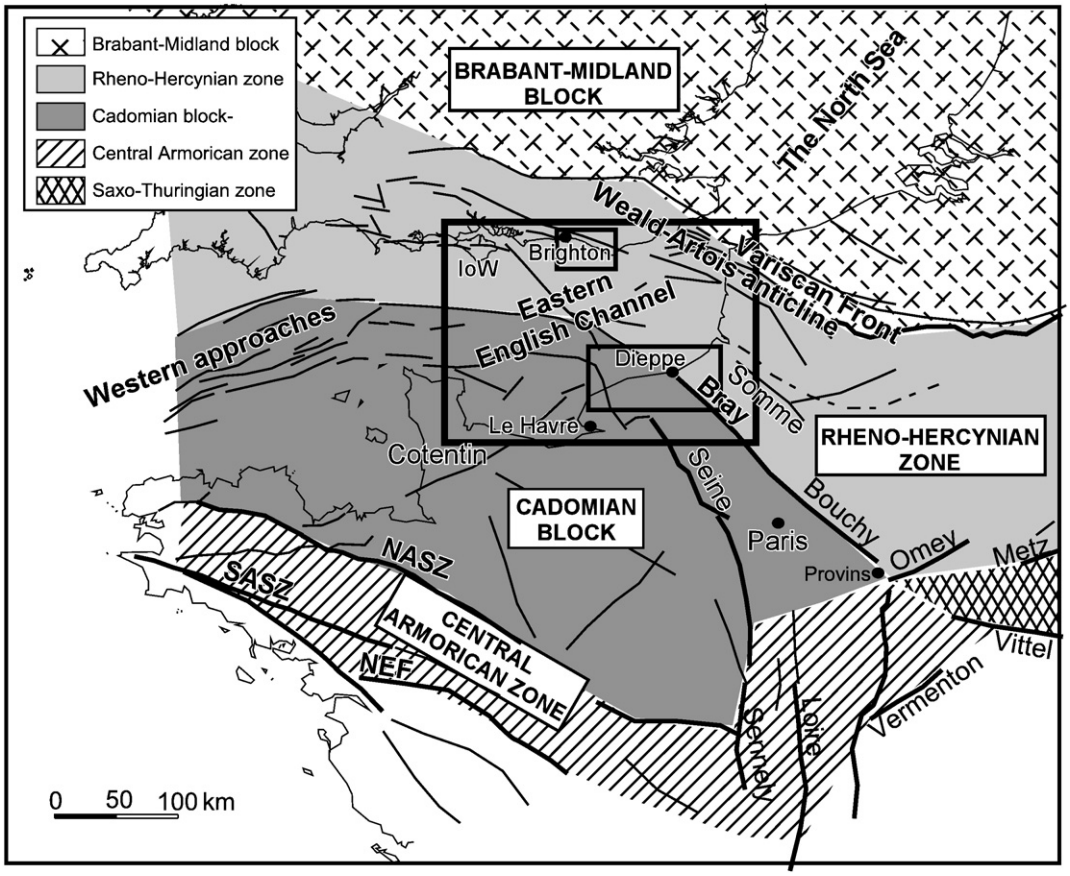

Fig. 1. The ante-Mesozoic basement in South England and North France. The main lineaments and blocks delimitations located in France are adapted from Autran et al. (1994) and Guillocheau et al. (2000). The English Channel and South England (Wessex Basin) are compiled from Stoneley (1982) and Lake and Karner (1987). NASZ: North Armorican Shear Zone; SASZ: South Armorican Shear Zone, NEF: Nort sur Erdre Fault. IoW: Isle of Wight. Fig. 2 location is indicated. The studied areas locations are also indicated (Figs. 5 and 8).