Paleostress records in Cretaceous formations in NW Europe:

extensional and strike-slip events in relationships with Cretaceous-Tertiary inversion tectonics along crustal regional structures

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This paper presents a synthesis of paleostress studies carried out in NW Europe, principally on small tectonic features such as striated faults and joints in chalky Cretaceous rocks. Particular attention is focused on the relationship between paleostress and inversion of regional tectonic structures (Fig.1). In each region, detailed lithostratigraphic studies allowed stratigraphic location of the different fractures systems observed. Field investigations indicate that chalk is commonly affected by conjugate fault sets during sedimentation and diagenesis. Hence, each successive paleostress state is likely to have created new conjugate fault sets. For each paleostress state, newly-formed faults are much more abundant than inherited ones. For this reason, the direct inversion method INVDIR (Angelier, 1990) was considered applicable in this work. The age of the different tectonic events recorded in the Chalk formations in the NW European platform was deduced partly from the age of rock formations affected, and partly by relative dating of tectonic features.

Throughout the region studied, each area shows a similar paleostress history: an extensional regime

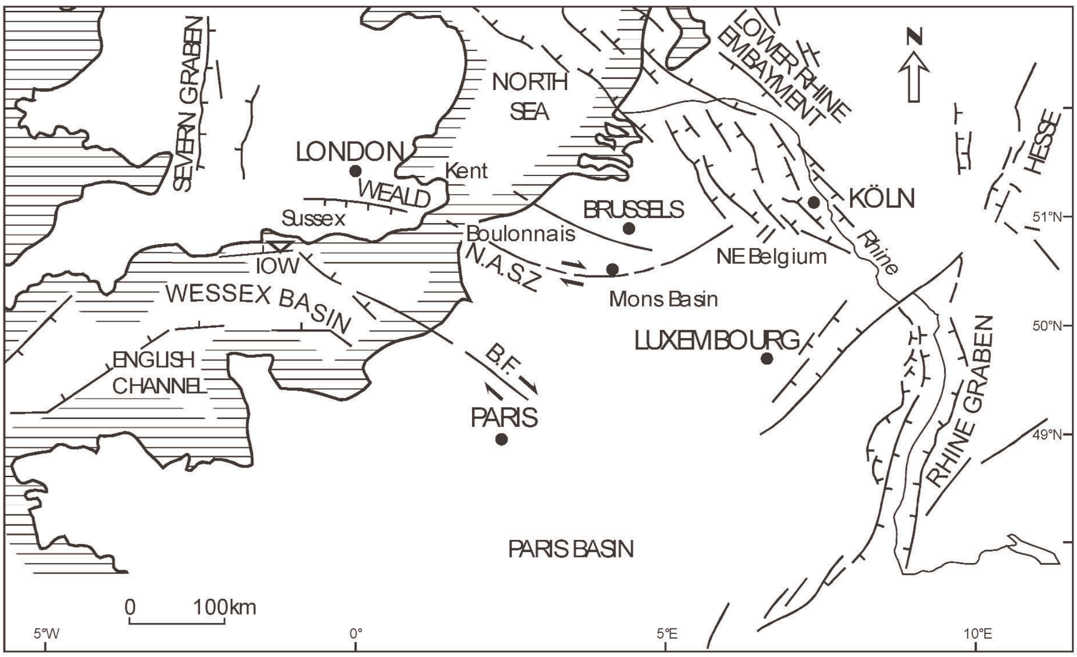

Fig. 1.- Tectonic framework of NW Europe (Belgium, north of France and U.K.) with the main crustal structures active in termes of brittle structures during the Meso-Cenozoic. NASZ : North Artois Shear Zone, B.F.: Bray Fault. The Cretaceous formations have been investigated in particular in the Isle of Wight (IOW), Sussex, Kent, Boulonnais, Mons Basin and NE of Belgium.

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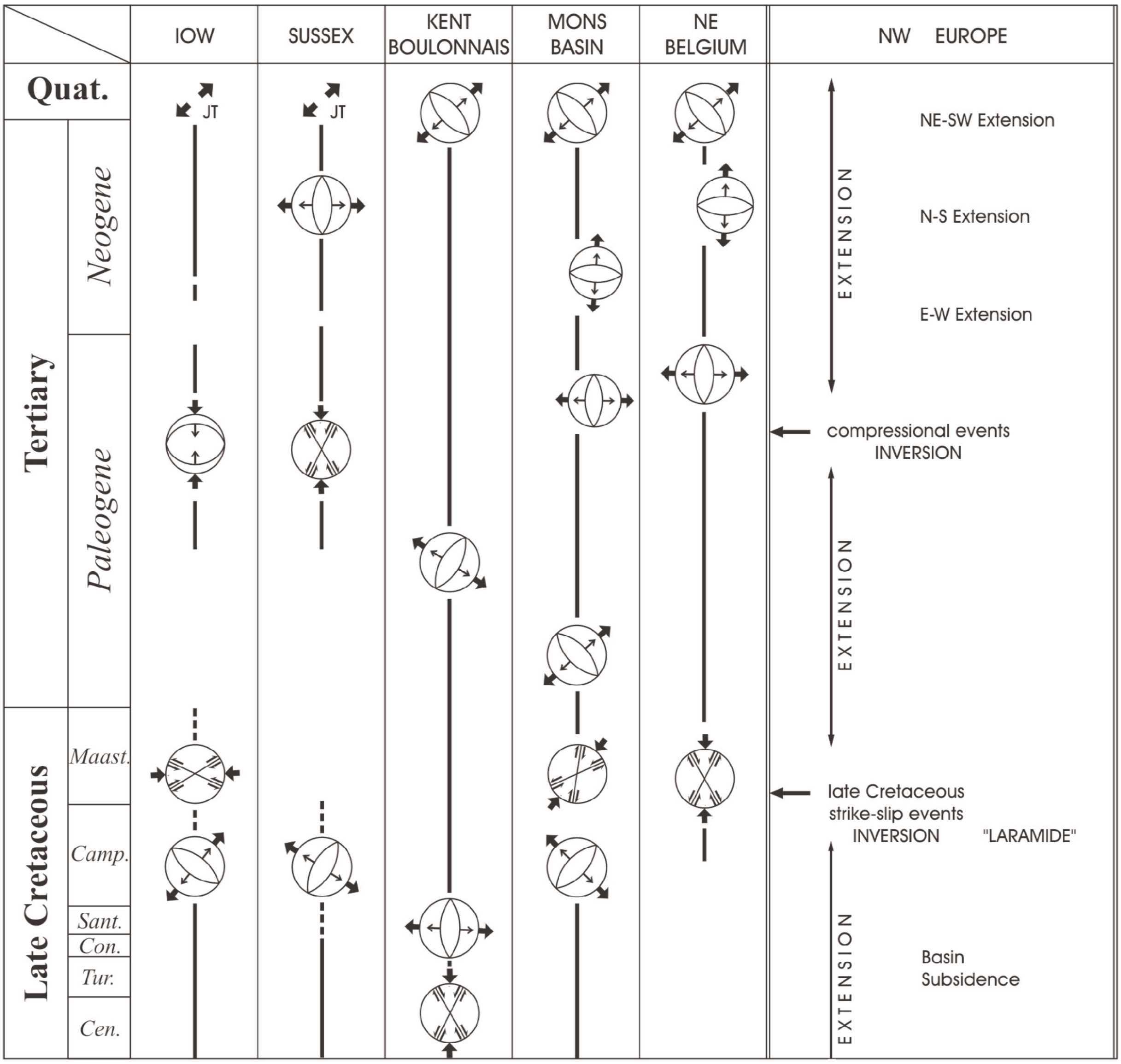

Fig. 2.- Palaeostress field evolution recorded in Cretaceous rocks observed in the six main studied areas. Synthetic approach integrating NW European inversion tectonics (from Vandycke, 2002).

punctually interrupted by strike-slip events generating inversions. One presents a synthetical approach of the paleostress evolution during and after the Cretaceous in the NW European platform (Fig. 2) Although extensional events during the Cretaceous did not occur simultaneously throughout the studied area, the present analysis suggests that the Cretaceous tectonics in this part of Europe was dominated by extensional tectonics (Fig. 2). These events may reflect a regional extension during the Cretaceous due to the displacement between the European plate and Greenland (Fig. 3) during the early part of the Late Cretaceous. Alternatively, because of the small throws and relative scarcity of the observed faults in the Upper Chalk (Wessex, Sussex and Kent), they may also represent a transitional stage between the end of the rift-related extensional tectonics of the Wessex Basin and the beginning of the thermal subsidence phase (Vandycke and Bergerat, 2001; Vandycke, 2002).

During the Cenozoic, an extensional regime was predominant in the eastern part of the studied domain. Three main extensional paleostress fields have been recognised. Tertiary NE-SW extension persisted since the Late Cretaceous. The corresponding NW-SE trending normal faults of the NE-SW extensional episode have been recognised in the whole study area. Inherited from the Late Hercynian tectonic framework, these NW features have been remobilised periodically until the present. Morphological studies (Colbeaux, 1974; Camelbeeck and Meghraoui, 1996) and analysis of brittle structures (Wazi, 1988; Wyns, 1977) have also hightlighted this recent tectonics, generally linking it to the Neogene-to-present rifting of the Lower Rhine Embayment. Also, neotectonic data from northwestern Europe (*in situ* stress measurements and earthquake mechanisms) show horizontal maximum stress (σ1 or σ2) trending NW-SE and horizontal minimum stress (σ2 or σ3) trending NE-SW (Camelbeeck, 1989; Paulissen *et al*., 1992). Except for σ1/σ2 stress permutations, these stress data suggest that NE-SW extension has endured since Cretaceous and remained constant from Neogene to Present.

The E-W and N-S extensions, reflected in normal faulting are not well developed in term of brittle structures in the study area. They are clearly post-Cretaceous in age. The N-S extensional regime might be related to the end of Wessex basin rifting in the eastern English Channel, in particular in the Boulonnais. In the Wessex basin, this N-S extension may be associated with strain release after the main compressional event. In the NE of Belgium, the extensional regimes are directly connected to the dynamics of the Lower Rhine Graben, active since the Oligocene (Paulissen *et al*., 1992). In the Isle of Wight, the inversion is marked by folding, but also by strike-slip faults developed prior to, during and after the flexure process, accompanied in the post-flexure stage by development of reverse faults (Vandycke and Bergerat, 2001). In the Sussex cliffs, a strike-slip system with N-S oriented σ1 is also identified and related to the same inversion dynamics (Vandycke, 2002). In different cases study, during Cenozoic, meso-faults and paleostresses are associated with inversion phases along well known regional structural axis, in particular in the Isle of wight and Sussex (Mortimore and Pomerol, 1997). The N-S late Eocene compression, well known over a large part of European platform (Bergerat 1985, 1987; Coulon, 1992) is paradoxically not evidenced in the Cretaceous formations in the North of France and in Belgium (Mons Basin and NE Belgium). Apparently, Cretaceous formations have not recorded this N-S compression in this part of the NW European platform. However, these compressions have affected the Ypresian (Eocene) clays in the northern part of Belgium and in the Miocene formations of Southern Belgium (Vandycke, 1992). One explanation can be that Chalk during the Cenozoic is quite well fractured by previous stress patterns and mechanically saturated in term of brittle structures.

Evolution of paleostress fields recorded by Cretaceous formations in NW Europe is mainly characterised by an extensional regime interrupted by strike-slip events related to inversion episodes. The stress field was not homogeneous during the Cretaceous. The Chalk formations well recorded the paleostress variations, resulting in development of numerous faults and joints. The Cretaceous was characterised by extensional events and strike-slip events. The post-Cretaceous period was

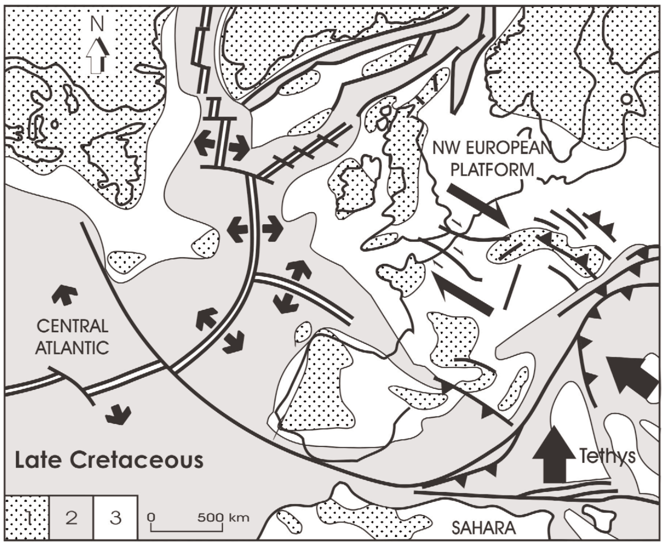

Fig. 3.- Late Cretaceous reconstructions of the Atlantic-Tethys domain (Vandycke, 2002 modified from Ziegler, 1989). The NW European platform is a dextral transpressional relay zone between the collisional Tethysian domain and the opening Central Atlantic. (Inset, 1: cratonic and orogenic highs, 2: oceanic basins, 3: continental to shallow marine sedimentary basins on continental crusts).

predominantly in extension, excepted during the Tertiary inversion in the Wessex basin. The post-Cretaceous extensional paleostress field events are recorded in the whole NW Europe.

Extensional periods are quite long and corresponding paleostresses are not synchronous. Compressional events related to inversion phases are accurately dated, to the end of the Late Cretaceous (Maastrichtian) and to Eocene-Oligocene boundary. This contrast is certainly due to stress transmission of the collision activity of the Tethys domain to the north European platform. Tectonic inversion in NW Europe is often associated with regional compressional tectonics due to Alpine collisional events (Ziegler, 1987, 1989). However this region is distant from the Alpine belt and is separated by regions of basin development stretching (Coward, 1991). The paleostress analyses revealed a more complex tectonic history with development of neoformated mesofaults along crustal reactivated regional structures. This observation leads to consider that inversion tectonics during the Cretaceous-Tertiary was active in a relay zone between Atlantic opening and Tethyan basin development (Fig. 3). In this case, Alpine collisional phases in the Tethysian domain can initiate the premary crustal movement and the deformation is transferred to the northern part of the European plate. Following Bergerat (1985, 1987), who detailed the repartition of the paleostresses related to the Africa-Eurasia collision at the periphery of the Alpine chain, this work complete this information in the northern European platform, in particular during the Cretaceous.

References

Angelier J. (1990) - Inversion of field data in fault tectonics to obtain the regional stress-III. A new rapid direct inversion method by analytical means. *Geophys. J. Internation.*, **103**, 363-376.

Bergerat F. (1985) - Déformations cassantes et champ de contraintes tertiaires dans la plate-forme européenne. Thèse d'Etat ès Sciences, University Pierre & Marie Curie, Paris VI, n° 85-07, 315 p.

Bergerat F. (1987) - Stress fields in the European platform at the time Africa-Eurasia collision. *Tectonics*, **6**, 99-132.

Camelbeeck T. (1989) - L'activité séismique actuelle (1985-1988) en Belgique. Comparaison avec les données de séismicité historique et instrumentale. Analyse séismotectonique. *Annales de la Société Géologique de Belgique*, **112**, 347-365.

Camelbeeck T., Meghraoui M. (1996) - Large earthquakes in northern Europe more likely than once thought. *Eos 77*, **42**, 405-409.

Colbeaux J.P. (1974) - Mise en évidence d'une zone de cisaillement Nord-Artois. *C. R. Acad. Sci. Paris*, **278**, 1159-1161.

Coulon M. (1992) - La distension oligocène dans le nord-est du Bassin de Paris (perturbation des directions d'extension et distribution des stylolites). *Bull. Soc. géol. Fr.*, **163**, 531-540.

Coward M.P. (1991) - Inversion tectonics in NW Europe. *Terra Abstracts*, **3**, 229.

Mortimore R., Pomerol B. (1997) - Upper Cretaceous tectonic phases and end Cretaceous inversion in the Chalk of the Anglo-Paris Basin. *Proceedings of the Geologists'Association*, **108**, 231-255.

Paulissen H., Dost B., van Eck T. (1992) - The April 13, 1992 earthquake of Roermond (NL); first interpretation of the NARS seismograms. *Geol. en Mijnbouw,* **71**, 91-98.

Vandycke S. (1992) - Tectonique cassante et paléo-contraintes dans les formations crétacées du Nord-Ouest européen. Implications géodynamiques. Ph.D. thesis, University of Paris VI, 92-02, 179 p.

Vandycke S. (2002) - Palaeostress records in Cretaceous formations in NW Europe : synsedimentary strike-slip and extensional tectonics events. Relationships with Cretaceous-Tertiary inversion tectonics. *Tectonophysics*, **357**, 1-4, 119-136.

Vandycke S., Bergerat F. (2001) - Brittle structures tectonic structures and paleostress analysis in the Isle of Wight, Wessex Basin, Southern U.K. *J. Structural Geol.,* **23**, 393-406.

Wazi N. (1988) - La fracturation de la falaise crayeuse de Criel-Plage (Pays de Caux) France. *Actes du Museum de Rouen*, **4**, 65-80.

Wyns R. (1977) - Tectonique récente dans l'Ouest du Bassin de Paris : méthodes d'étude et bilan des déformations plio-quaternaires. *Bull. Soc. géol. Fr.*, **7**, 12, 681-684.

Ziegler P.A. (1987) - Compressional intra-plate deformations in Alpine foreland. *Tectonophysics*, **137**, 420 p.

Ziegler P. (1989) - Geodynamic model for Alpine intra-plate compressional deformation in Western and Central Europe. *In* Cooper M.A. and Williams G.D. (editors). Inversion Tectonics, *Geological Society, London, Special Publications*, **44**, 63-85.