Session number 1– Oral presentation

New Insights into the Geology under London through the Analysis of 3D Models

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ABSTRACT

This paper will describe firstly the combined cognitive and geostatistical modelling methodology that was developed in order to produce a structural model of the Chalk under London and secondly how the resultant model has improved our understanding of how the London Basin evolved during the Cretaceous period.

A major difficultly in elucidating the structure of the Chalk in the London Basin is that the Chalk is largely unexposed. By using a combined cognitive and geostatistical approach, the resultant 3D model for the London Basin was more consistent with current geological observations and understanding. In essence, the methodology proposed here decreased the disparity between the digital geological model and the geological reality.

Previously, the geological structure of the London Basin was thought to be 'relatively' simple, being dominated by a broad north-east trending syncline. However, 3D modelling suggests that, in detail, the London Basin is a far more complex structure, being a collection of at least 5 fault-bounded basins. The model also indicates that the structural style of the basin changes moving north to south. This corresponds to the boundary between two structural provinces observed within the basement strata in the region (London Platform, part of the Midlands Microcraton in the north and the Variscan fold-thrust belt in the south).

INTRODUCTION

Since 3D geological modelling became an economic and technical reality in the late 1980s (Rosenbaum and Turner 2003), there has been a remarkable growth in computer modelling applications able to proffer 3D modelling solutions (Gibbs, 1993; Perrin et al., 2005; Sobisch, 2000). It is now possible not only to view and manipulate 3D models on a standard desk top computer but also to integrate disparate digital datasets (De Donatis et al., 2008; Kessler et al., 2008). This has enabled 3D geological models to become a standard geological tool (Rosenbaum and Turner, 2003; Xue et al., 2004).

One of the key developments within the UK has been the increased availability of digital geological data. This increased accessibility of digital data has resulted in 3D models moving from the conceptual model of Fookes (1997) towards the 'real' geological model of Culshaw (2005).

The production of detailed 3D geological models for London is providing new insights into the geological evolution of the London Basin. In this paper we will discuss the development of these models and how they are being used to better understand and communicate the subsurface geology of London.

GEOGRAPHICAL AND GEOLOGICAL CONTEXT

The model of the Chalk encompasses an area within the catchment of the River Thames (Fig.1). Geologically, the London Basin is a broad, gentle syncline, whose axis can be traced from Chertsey through to Chelmford (Fig.1). The London Basin formed in the Oligocene to mid-Miocene times during the main Alpine compressional event (Ellison et al., 2004). Formations in this region range from Cretaceous (144 to 65 Ma) to Quaternary (2 Ma to present day) in age. The Cretaceous Chalk is present at subcrop throughout the London basin and comes to the surface along the southern margin (the North Downs) and along the northwest margin Chiltern Hills) and is locally at or close to the surface e.g. along the Greenwich and Purfleet anticlines in East London.

The Cretaceous Chalk is typically a fine grained white limestone. It has a total thickness of between 175 and 200 m and generally thins from west to east. Overlying the Chalk is the Palaeogene deposits of the Thanet Sand Formation, the Lambeth Group, and the Thames Group, which consist of the Harwich and London Clay Formations. Quaternary deposits are encountered throughout the London Basin. These include evidence of ancient river systems and the development of the present-day River Thames valley.

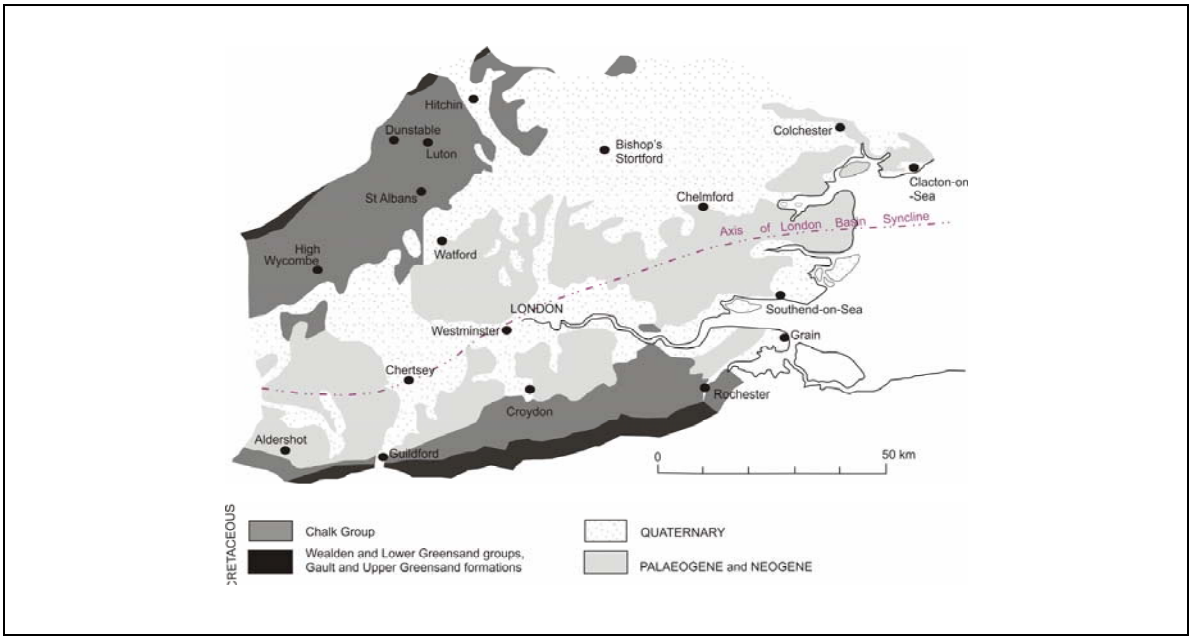

Figure 1 - *Geological sketch map of the project area. Adapted from Sumbler (1996)*

GEOLOGICAL MODELLING

Modelling was carried out to ascertain not only the distribution of the six Chalk Formations found within the London Basin but also the Chalk's structure (Fig 2). One of the major difficulties in ascertaining the structure of the Chalk within the London Basin is that the Chalk is largely unexposed, either covered by superficial deposits (drift) or obscured from view due to urban development. Therefore the project had to rely to a large extent on the interpretation of archival subsurface data.

Although few faults are indicated on the current published geological maps, there is a growing body of data, particularly from recent deeper engineering projects such as the Channel Tunnel Rail link (CTRL), CROSSRAIL and the Docklands light railway, that suggests that faults are far more numerous.

A methodology was needed to enable the modeller to pick out areas of possible faulting and to achieve a geologically reasonable solution even in areas where the data were sparse or uncertain (Lemon and Jones, 2003; Kaufmann and Martin, 2008). Therefore a methodology was developed that combined a cognitive and geostatistical approach using the combined functionality of GSI3D (version 2.5) and GoCad (version 2.1.3).

The GSI3D modelling methodology (Sobisch, 2000) was used as it allows the modeller to model the distribution and geometry of geological units by using a knowledge driven approach (Wycisk et al., 2009). This functionality provides the modeller with the ability to connect areas where there is either only partial data coverage or where the geometry of the geological units is poorly understood. The London Chalk Model was constructed by correlating outcrop data with boreholes that were linked together in a network of intersecting cross-sections.

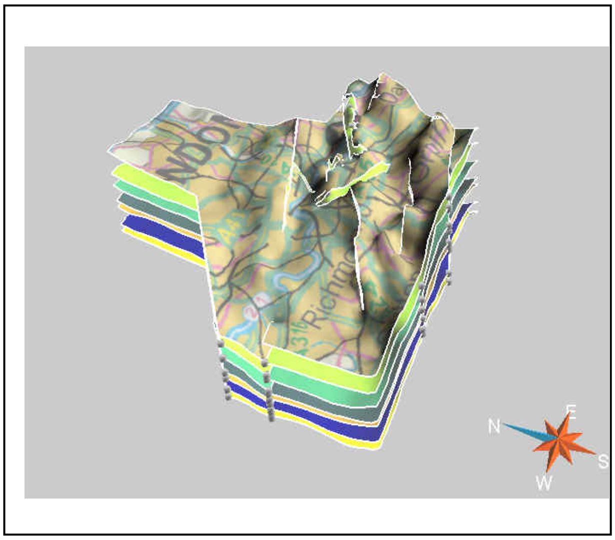

Figure 2 - 3D model of the 6 Chalk Formations under London (coloured yellow, blue and green in diagram). *OS data ©Crown Copyright. All rights reserved. BGS 100017897 / 2009*.

In order to determine the presence or absence of faulting within the Chalk of the London Basin, a set of criteria was devised. These included the following:

Dip of units: where the dip is greater than 5 degrees, then the Chalk strata were considered to be faulted.

Where boreholes show a change in depth of a unit progressively across a section, then the strata were considered to be folded.
Where boreholes show a sharp change in depth, then the strata are considered to be faulted.
Shape and style of folding: where folds are monoclinal with steep limbs dipping greater than 5 degrees, then the limb was considered to be faulted. Monoclinal folds were considered to be likely candidates for faulting.
Geological information on faults gathered from maps, memoirs and papers was digitised and used to aid decision making.
Linear zones of displacement were interpreted as faults, rather than regarding them as the consequence of folding. This preference is justified by: the general style of the linear zones; by their association with truncated and offset landforms; and by displacements determined from borehole data during the modelling process.

Once these steps were completed, the data was exported into a geostatistical modelling package; in this case GoCad. Using scripts within GoCad, triangulated surfaces were generated for each formation and fault plane. The surfaces were constructed using a discrete smooth interpolation (DSI) algorithm (Mallett, 1997). This algorithm produces a geometry which is smooth, but also takes account of a set of constraints, in this case the borehole and cross-section data (Galera et al., 2003). A series of steps were then followed which removed cross-over errors between the surfaces. Once these stages were completed, the resultant model could be visualised and assessed (Fig 2).

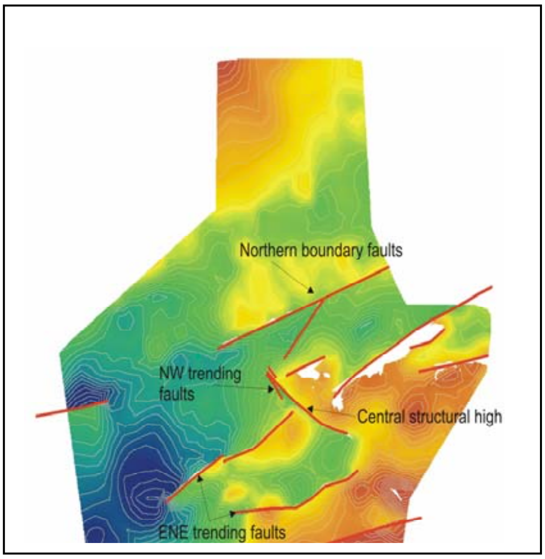

Figure 3 - Structure contour plot of the top of the Chalk, showing major fault groups and location of structural high (red- high, blue-low).

THE STRUCTURE OF THE CHALK UNDER LONDON AS DERIVED FROM THE 3D MODEL

The 3D geological model of the Chalk under London indicates that, in detail, the London Basin is a much more complex structure than previously thought, being a collection of at least 5 fault-bounded sub-basins (Fig. 3).The model also suggests that the project area can be split into two sections or regions, which have behaved differently during the evolution of the basin. This split can be related to the two structural provinces observed within the basement strata in the region (Ellison et al., 2004): the northern portion being underlain by the London Platform (part of the Midlands Microcraton) and the southern portion by a zone of transition between the London Platform and the Variscan fold-thrust belt (Fig. 4).

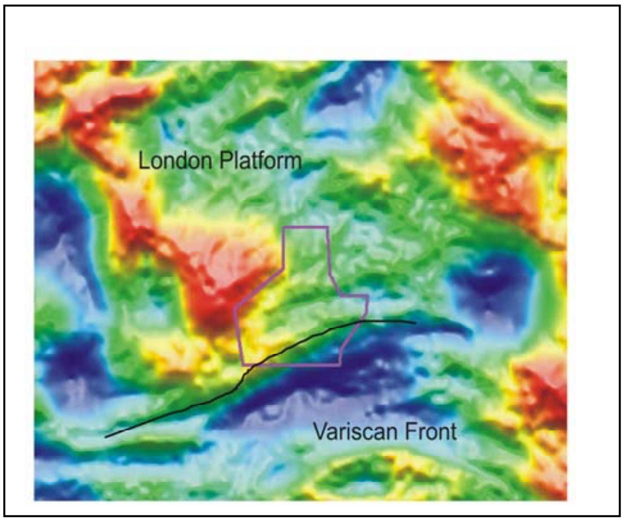

Figure 4 - Colour-shaded bouguer gravity relief map (red–high, blue–low) showing the location of the boundary between the two structural provinces (black line) dissecting the project area (outlined in purple).

This change in basement material across the Basin has determined, to a large extent, the type and intensity of geological features found in each region. For example, folding within the project area can be divided into two groups: the first group found south of the London Basin Axis (Fig.1) and coincidently South of the River Thames, consists of east-north-east trending periclinal folds, including the Greenwich and Streatham anticlines. These features are generally high amplitude and short wavelength folds, many of which are asymmetric, usually with steeper north-facing limbs. The second group is confined to the northern part of the project area and these are in the main low amplitude, long wavelength folds.

Faulting is predominantly confined to the south-eastern portion of the project area; its distribution within the London Basin again appears to have been controlled by the properties of the basement which underlies it. The faults, broadly speaking, can be divided into 3 groups (Fig. 3): ENE-trending faults, which downthrow to the north (the majority of faulting within the south-eastern sector); ENE-trending faults, which downthrow to the south (northern boundary faults); and northwest trending faults, which downthrow to the west (located between Lambeth and Catford). Displacements range between 10 to 50 m. The modelled Chalk surfaces also suggest the presence of a central structural high near Deptford, located between the Streatham and Greenwich faults. The central structural high is bound to the west by the NW-trending faults and to the north by an ENE-trending fault near Bermondsey.

CONCLUSION

To conclude, the 3D geological model of the Chalk under London represents a significant advance in the understanding of the evolution of the London Basin. The application of innovative procedures and software for the assessment of disparate spatial data has resulted in an improved understanding of the development of the London Basin.

ACKNOWLEDGEMENTS

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