Lawrence, Preene, Lawrence and Buckley
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The Channel Tunnel Study Group – an Anglo French adventure in the Chalk

M Preene[*1] and *A Davey*[2]

[1] *Preene Groundwater Consulting Limited, Wakefield, UK*
[2] *Tilia Publishing UK, Sussex, UK*
[*] *Corresponding Author*

ABSTRACT The construction of the Channel Tunnel in the 1980s and 1990s owes a great deal to the work of the Channel Tunnel Study Group (CTSG) 30 years earlier. The CTSG was an eclectic Anglo-French group tasked to develop schemes for a fixed crossing. The two phases (1958–9 and 1964–5) of marine and land investigations contributed the significant majority of investigation boreholes available at the time of tunnel construction. Key contributions included packer permeability testing in the Chalk Marl (the preferred tunnelling horizon), and the development of a detailed biostratigraphy based on microfossils (specifically the ratio of planktonic to benthonic foraminifera) to correlate strata between boreholes. This stratigraphic framework was used in an updated form when the tunnel was constructed by Trans Manche Link three decades later.

1 INTRODUCTION

The Chalk is a geological stratum, dominated by relatively soft white limestones, present across large areas of England and north-west Europe (Lord, et al. 2002). But the Chalk is much more than that – its place on the south coast of England has been mythologized into the 'White cliffs of Dover' of Vera Lynn and World War II singalongs. The iconic cliffs represent the barrier between England and France that is formed by the Straits of Dover.

That barrier was permanently breached during the 1980s and 1990s by the construction of the Channel Tunnel. The tunnel is rightly recognised as one of the great engineering projects of modern times, and is an established part of travel between England and France. Its relatively untroubled design and construction seems, in hindsight, to make forming a 50 km long subaqueous tunnel through potentially treacherous wet chalk merely routine.

Of course, the construction of the Channel Tunnel was a huge undertaking, by a team of workers, managers, engineers and geologists, from the time the competing bids were first developed in the mid-1980s to the opening of the tunnel in 1994. However, it is not widely recognised that the success of the 1980s/1990s tunnelling under the Channel by Trans Manche Link (TML) owes a great deal to the work of the Channel Tunnel Study Group (CTSG) in the 1950s and 1960s. The CTSG was an eclectic Anglo-French group tasked by the British and French Governments to develop schemes for a fixed crossing, opting for a tunnel by 1960 (at that time both bored and immersed tube tunnel methods, and bridges, were also under consideration).

One of the CTSG's principal challenges was to carry out geological, hydrogeological and geotechnical characterisation along the proposed route, with limited equipment, in the deep waters of the Channel. Often, they had to develop their own methods of working, because they had to deliver marine investigations on a scale rarely before attempted.

This paper describes the work of the CTSG investigating the Chalk, including: the origins of the CTSG; the investigation and testing methods used; and the legacy of the work and the contribution to the better understanding of the Chalk in engineering and geology.

2 CHALK AS A TUNNELLING MATERIAL

The Chalk is a challenging medium for tunnelling. Sir Harold Harding said '*A wise tunnelling engineer should view Chalk with deep suspicion. It looks so safe when standing on 100 feet high cliffs or Chalk pits, but it can be deceptive and can vary widely and suddenly in its condition'* (Harding, 1981).

The Channel Tunnel was to be formed through the Lower Chalk. Planning could not build directly on previous experience of tunnelling in chalk because prior to modern investigations (beginning with the 1958–9 CTSG works) the Lower Chalk was virtually unknown in engineering terms (Mortimore and Pomerol 1996). Furthermore, the principal proposed tunnelling horizon, the Chalk Marl, was apparently so different in nature to the classic white chalks of the Upper and Middle Chalk that existing estimates of engineering and hydrogeological properties were of little value without validation by specific investigation and testing in the relevant horizons.

Chalk strata decrease in calcium carbonate content and have greater clay content with increasing stratigraphic depth. The lowermost zone of the Chalk (immediately above the Glauconitic Marl) is often considered as a distinct geological unit – the Chalk Marl. As a tunnelling medium, the Chalk Marl is typically less brittle and of lower permeability than the higher zones of the Chalk, and has many attractive characteristics for tunnelling, including low rates of groundwater inflow. Investigating the Chalk Marl was a key objective of the CTSG investigations.

3 THE CHANNEL TUNNEL STUDY GROUP

The scope of the CTSG was an engineering feasibility study that would be recognised by today's profession. But its origins and execution seem idiosyncratic compared to modern procurement and practice.

The CTSG story began in 1956, when an American lawyer, Frank P. Davidson, was crossing the English Channel by ferry with his wife, who apparently became quite seasick. Davidson was the son of the commissioner for water supply in New York, who had commissioned the world's longest bored tunnel to carry drinking water for 129 km from Delaware (constructed 1930–1945). The romantic notions of a tunnel or bridge across the English Channel, dating back at least to Napoleon, were not lost on him. With his two brothers, John and Alfred Davidson, he set about addressing the problem. They formed Technical Studies Inc. in March 1957, with the intention of gathering information about French and English laws, various means of finance, technical capabilities and engineering concepts.

By July 1957 they had mobilised three other companies, to form the Channel Tunnel Study Group (CTSG) its scope being stated in (CTSG, 1960) as '*to carry out joint studies of the conditions in which it would be possible to build and operate a submarine tunnel for rail and/or road traffic, connecting British territory with that of Continental Europe'* – the inclusion of a bridge option happened soon after in the process.

The group comprised: the Channel Tunnel Company Ltd; The Société Concessionaire du Chemin de Fer Sous-marin entre la France et l'Angleterre associated with the International Road Federation; the Compagnie Financière de Suez; as well as Technical Studies Inc. of New York. M. Rene Malcor, Ingenieur en Chef des Ponts et Chaussees, was appointed to direct the financial and technical studies, with H.J.B. (later Sir Harold) Harding on the British side coordinating matters.

This work continued from 1958 to 1971, The current paper focusses specifically on the 1958–9, and 1964–5 phases, specifically the ground investigations in chalk. The CTSG's approach was that the techniques and specialists chosen for the work should be those considered to be capable of getting the best results and this meant a good mix of innovation and unexpected practical pragmatism, as evidenced by the use of a mix of sea craft to carry out the deep-sea boring and the study of microfossils (foraminifera) to correlate key zones within the Chalk.

The first phase of work, the 1958–60 technical study (Bruckshaw et al. 1961) was wholly privately funded by the members of the CTSG, and was consequently a relatively low budget exercise. With many priorities involved it was hard to get funding for the site investigation work agreed and for much of the time their base was the bar of a Dover hotel, and later an abandoned railway carriage. The second phase (1964–5) was a much larger scale affair and, after some contractual tenacity, the finance for that survey came from the Governments and not from the CTSG.

4 MAKING THE STUDY A REALITY

The concept of a channel tunnel has been studied on scientific basis since the 19th century, and much information was available, if it could be found and collated. The CTSG methodically assembled the earlier data. There were two large steel-engraved charts, which showed the numbered position of each of many thousands of samples from the sea bed from the French survey of 1875–6. Bizarrely, the samples had been discovered in a French suburban railway waiting room.

There was material from 1866 when Sir John Hawkshaw and his assistant Henry Brunel (Isambard Kingdom's son) had carried out a borehole survey of the Channel. The 207 drop sample positions were located by sextant. The same drop sampling technique invented by Brunel was also used for supplementary information in 1958–9.

In 1882–3 two pilot tunnels of 7ft (2.13m) diameter had been driven on the English side using early Beaumont boring machines, to be stopped short by government cold feet. In 1958 the CTSG visited the earlier workings at Shakespeare Cliff, by then flooded, and viewed the tail of a crude Whitaker tunnelling machine from another test run in 1922.

On the French side, at Sangatte the 1882 pilot workings were opened, and pumped out. The shaft was found to contain scrapped machines and other debris, probably dumped by the German troops during World War II. Although it had been filled for 77 years with 70 m of water, once this was pumped out the tunnel was found to be quite water tight, which reassured some doubters about the nature of the Chalk before it was resealed. The opportunity was taken to allow most of the engineers and geologists of the CTSG (as well as some eminent experts) to inspect the workings (Figure 1).

Figure 1. CTSG visit to inspect drained Sangatte Workings, 1958 (courtesy of Amanda Davey).

A key challenge for the investigations was to be able to drill (and test) overwater boreholes in the busy shipping lanes and often rough seas of the Channel. Luckily, Harding had faced this problem before (Harding and Davey 2015).

In 1948 Harding had done deep-sea drilling off the coast of Syria, and there opted for self-propelled platforms, rather than tugs and pontoons, as being easier to manage in rough conditions. Two tank landing craft were used, upon which the boring rigs were welded, and were able to cope with the conditions effectively. Later, in 1950 Harding's firm bought two ships for similar work off Southsea, one of which (GW14) became involved in the 1964–5 Channel Tunnel investigations (Figure 2).

Grange and Muir Wood (1970) state that during the 1964–5 investigations the drilling rigs worked from staging cantilevered over the side of the vessel (Figure 2). An outer fixed casing was sealed some 6 m into the seabed (Figure 4). An inner drilling casing was then installed through the fixed casing. In the event of bad weather (a frequent occurrence at times, requiring the drilling vessel to return to harbour) the upper casing was buoyed, fitted with a top collar and lowered to within the fixed casing, to allow recovery when the vessel returned to complete the borehole.

Each intended borehole had to be notified to the Admiralty; Ministry of Transport; Trinity House; Lloyds; The Ministry of Agriculture, Fisheries and Food - and their French equivalents – in order that the Notices to Mariners could be issued.

The work of drilling and testing the boreholes in the Channel was undoubtedly challenging, and the work of George Wimpey & Co Ltd (borings at sea and on land) and Craelius Limited (land boring) should be acknowledged. A full list of contractors and consultants is given in Bruckshaw et al. (1961).

Figure 2. Drilling rig working from platform extended over side of drilling vessel GW14 during 1964–5 investigation (courtesy of Amanda Davey).

5 GEOTECHNICAL INVESTIGATIONS

5.1 *Scope of the investigations*

The CTSG works included two fieldwork programmes – a relatively modest array of boreholes in 1958–9, and a more extensive, better funded, investigation in 1962–5; further details are in Grange and Muir Wood (1970) and Muir Wood and Caste (1970). Table 1 shows that the number of boreholes in the 1958–9 and 1964–5 investigations are a significant proportion of the total boreholes drilled prior to start of construction by TML in the 1980s.

The range of investigation methods deployed by the CTSG was diverse (including geophysics, see Arthur et al. 1996). However, two key aspects of the Chalk that were targeted during the investigations were better defining the stratigraphy (to identify, *inter alia*, the Chalk Marl) and to obtain permeability (hydraulic conductivity) values at the level of the likely tunnel vertical alignment. These elements of the investigation will be discussed in the remainder of this paper.

Table 1: Summary of Channel Tunnel alignment investigation borehole quantities (based on Varley *et al.,* 1996)

Campaign	UK land	UK marine	French marine	French land
1958–59	3	5	3	1
1964–65	14	32	41	10
1972–74	8	9	7	-
1986–87 (Phase I)	19	3	9	15
1986–87 (Phase II)	-	5	2	-

The CTSG boreholes were of great use during the building of the Channel Tunnel, decades later. Unfortunately, some of these boreholes were close to the final tunnel alignment, and were a concern for the TML construction team as their precise location and the details of their backfilling was not known.

5.2 *Correlating stratigraphy of the Chalk Marl*

A key challenge for the CTSG investigations (and indeed for later TML studies) was to identify the stratigraphy of the target tunnelling horizon (the Chalk Marl) from core samples recovered from boreholes. Consistency of visual logging of lithology was difficult to achieve. In any event, descriptive frameworks for logging of chalk (for example the Mundford grades – Ward et al. 1968) were not well developed at the time.

A fundamental innovation and legacy of the CTSG was the development of a detailed biostratigraphy based on microfossils (Carter 1961, later developed as Carter and Hart 1977). The approach was so powerful that, in a refined form, it was used more than 25 years later in the 1980s/1990s TML investigations and tunnelling (Harris, et al. 1996).

The first application of micropalaeontological analysis to investigations for a channel tunnel was by Carter in 1958 to help characterise the large number of sea bed drop samples from 1958–9. Twenty one stratigraphical zones were defined, each identified by its contained foraminifera. Eight zones were in the Lower Chalk, with zones 8, 9 and 10 representing the Chalk Marl (Figure 3).

During the 1964–5 investigation the method was applied to samples taken at 1 m intervals in 32 boreholes. The samples were examined and the ratio of planktonic to benthonic foraminifera were recorded. This allowed depth profiles of planktonic/benthonic ratios to be developed for each borehole. In most cases these showed characteristic maxima and minima (representing biostratigraphic zones) that could be correlated from borehole to borehole, and in some cases from one side of the Channel to the other (which proved useful in checking consistency of logging from the English and French boreholes).

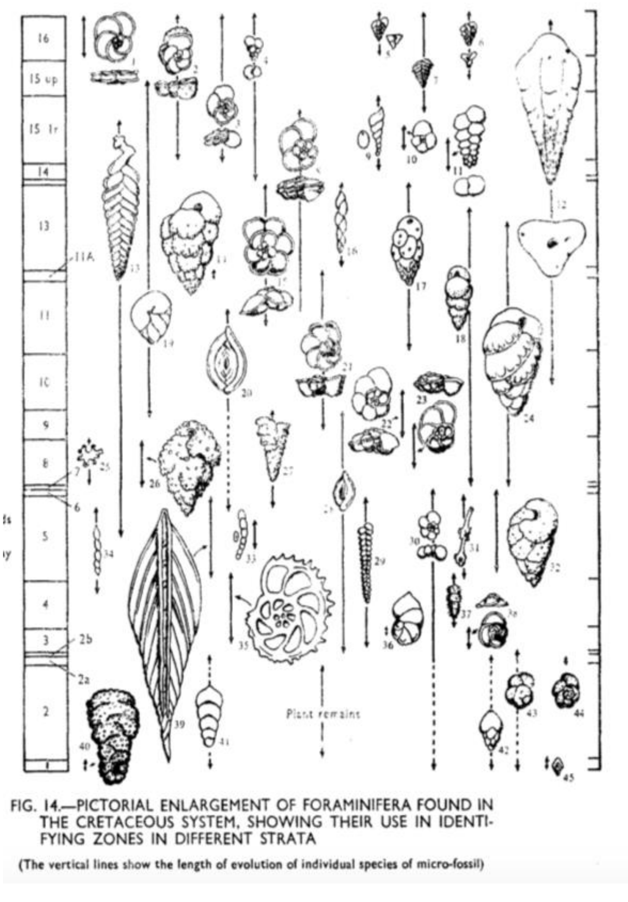

Figure 3. Biostratigraphical system used to identify stratigraphy of the Chalk (Carter, 1961, in Bruckshaw *et al*., 1961: reproduced with permission).

It is difficult to overstate how useful Carter's method was – given how hard it was to visually differentiate beds at the level of the tunnelling horizon. Harris, *et al*. (1996) states, from the perspective of TML's work in the 1980s and 1990s '*At the time* [Carter's] *work was undertaken it was technically very advanced and it certainly achieved its main aim of producing a detailed stratigraphic framework across the Channel.*' TML re-checked some of the original by Carter (on the Dover No.1 borehole) and proved its accuracy.

5.3 Permeability testing

A significant focus of in-situ testing during the 1964–5 studies was to make direct measurements of chalk permeability at the likely level of tunnelling. The major test programme was pumping-in tests in marine and land boreholes; the current paper focuses on the pumping-in tests.

The test method was the packer permeability test (where a test section within the borehole is isolated by expanding packers). By the 1960s the method was well established, having been developed from the Lugeon test, which dates from the 1930s. However, due to the tests being operated overwater from floating vessels or jack-up drilling platforms, there were specific challenges that required state of the art equipment.

Figure 4 shows a typical layout for a pumping in test carried out from a floating vessel.

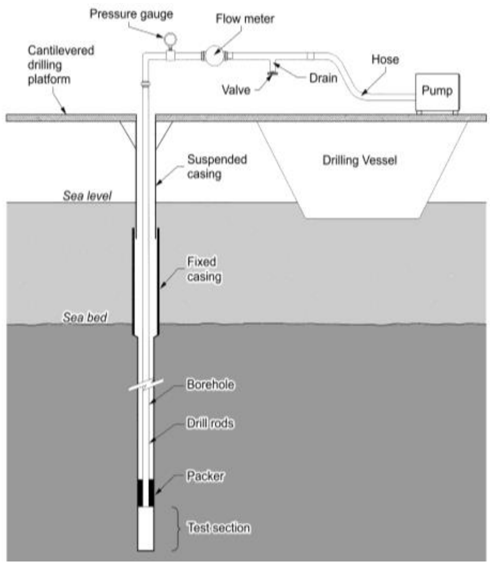

Figure 4. Typical layout for pumping-in test permeability test from drilling vessel (based on Muir Wood and Caste, 1970).

For the marine boreholes, the costs of the drilling vessels and jack up platforms meant that the time durations of the permeability tests was limited to about 3 hours. Furthermore, permeability testing at intermediate levels during drilling would have slowed down the drilling process, so all tests were carried out after boreholes were completed to total depth – boreholes were fitted with a fixed casing extending up from the sea bed (see Figure 4), which allowed a vessel to return and work on a borehole.

Permeability tests were generally carried out as single packer tests – where the test section is between the base of the packer and the bottom of the borehole – rather than double packer tests where the test section is between upper and lower packers. This was because the irregularities of the borehole periphery meant it was very difficult to simultaneously seal two packers sufficiently well to allow a valid test. Test analysis included plotting of pressure/flow rate curves for each test, to see how behavior changed during each phase of the tests. Muir Wood and Caste (1970) report that 73% of the tests gave permeability results that were assessed to be 'reliable'. The remaining 27% of the tests were split roughly half and half between tests where no useful information was obtained, and tests where the permeability values were considered 'doubtful'; reasons for poor tests include: leakage past the packer; sealing or scouring of fissures; possible over-stressing of the ground; or excessive loss of head.

Muir Wood and Caste (1970) highlight that the permeability tests may have had limited value. They conclude: '*It is nevertheless necessary to treat the results of pumping-in tests in highly fissured zones with a certain amount of reserve. The permeability derived from pumping-out tests, which reproduce more nearly the conditions affecting the* [inflow] *of water into a tunnel, suggest that local unsealing of fissures may cause* [permeability] *to increase by a factor of 3 or 4*.'

6 THE LEGACY OF THE CTSG

The CTSG investigations were the first modern investigations of the Chalk associated with a channel tunnel. The legacy of data and methods leads directly to the tunnel as constructed by TML decades later.

The 1958–9 and 1964–5 CTSG investigations contributed the significant majority of investigation boreholes available at the time of tunnel construction, and packer tests provided permeability data for the Chalk Marl tunnelling horizon. The biostratigraphic framework based on microfossils (specifically ratios of planktonic to benthonic foraminifera) improved understanding of the Chalk Marl and was used in an updated form during tunnel construction in the 1980s and 1990s.

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