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REFEREED PAPER

# Specialist Maps Prepared by British Military Geologists for the D-Day Landings and Operations in Normandy, 1944

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*During the Second World War, British military geologists assisted planning for the Allied liberation of Normandy by generating specialist maps – supporting the greatest amphibious operation in world history. Maps of the landing beaches at a scale of 1:5000 indicated natural hazards to cross-beach vehicle mobility. Maps of northwest Europe at 1:1000 000 showed the varying suitability of ground for airfield construction, and larger scale maps guided the site selection and rapid construction of numerous temporary airfields. Hydrogeological maps were prepared as tracing overlays for topographical maps to guide enhancement of potable water supplies from new wells and boreholes – at a scale of 1:50 000 for coastal areas from the Cherbourg peninsula eastwards to Calais, and at 1:250 000 for most of northern France east into the Low Countries. A few 'soil' maps guided emplacement of depots for stores and vehicles, and at least two resource maps were prepared – to guide quarrying of material for road construction and sand for engineering work in general. Pioneering British military geological work on Normandy was extended for western coastal areas by large-scale American maps which included geological features for exit routes from the Omaha and Utah beaches. Bordering the eastern coast, at least two Canadian maps at 1:100 000 related geology to 'going' (cross-country trafficability). Printed in small numbers and great secrecy, few copies of any of these maps appear to have survived the war. The most extensive collection known is preserved in the Lapworth Museum of Geology, University of Birmingham. This is part of a unique personal archive, generated by Major F. W. Shotton when serving as Staff Officer (Geology) of the invasion force. It provides the basis for appraisal of broader specialist cartographic achievements contributing to Allied victory in Europe.*

## INTRODUCTION

Much has been written about the vast quantities of new maps that were produced for the British army during the Second World War – but not about maps generated by British military geologists. An authoritative book by Brigadier Archie Clough – the official history of the principal facts and features relating to British military maps and survey of this period – indexes only one entry concerning geological maps. Clough (1952, p. 102) notes that these 'were obtained from copies of foreign geological maps held by the Geological Survey [of Great Britain] in London from which the War Office prepared facsimile reproduced copies for Albania, Roumania, Yugoslavia, Hungary, the Central Balkans and the Middle Danube' and that 'Geological maps are of great value during the planning stage for an operation, when considering such things as water supply and suitability of terrain for airfield construction'. For Operation Overlord, the Allied landings in Normandy that began on D-Day, 6 June 1944, Clough makes no mention of geological maps, and only passing reference (Clough, 1952, p. 595) to 'Major W. B. R. King, RE ... for his geological advice ... [which was] very helpful when trying to correlate beach formations on either side of the English Channel' – this in a paragraph noting that experiments were made on beaches in England to help evaluate the likely properties of those of Normandy.

Peter Chasseaud (2001) has much more recently reviewed the wide range of mapping generated in preparation for the Normandy D-Day, with focus on the work of the Geographical Section of the General Staff (GSGS), significantly extending the range of map illustration provided by Swift and Sharpe (2000). Many aspects have also been covered in a D-Day 60th Anniversary commemorative issue of the *Journal of the Defence Surveyors' Association* (Anon., 2004), notably in brief articles by Chasseaud (2004) and Gray (2004). None of these publications, however, makes detailed reference to geology. In contrast, Rose and Pareyn (1995, 1996a, b, 1998, 2003)

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have described the role of a small number of British military geologists in planning and support for the invasion and subsequent operations in Normandy – but not specifically their role in generating specialist maps.

The purpose of this article is to illustrate and comment upon specialist maps prepared for Normandy by British military geologists – maps important for Allied operations but hitherto largely unknown, and few easily accessible to researchers in national map collections such as at the British Library, Bodleian Library, or the Imperial War Museum. These maps assisted planning of the greatest amphibious assault in world history, but seemingly represent one of the phases of mapping for which Clough (1952, p. vii) 'had some difficulty in finding any written records or reports ... owing to the overriding need for extreme security at the time, which reduced the information that could safely be recorded on paper to a minimum'. The account complements a recent article in The *Cartographic Journal* (Rose and Willig, 2004) which documented the role of German military geologists in preparation of specialist maps earlier in the war for a cross-Channel invasion – but in the opposite direction.

Published sources in books and journals are cited herein as references; maps, reports and other essentially archive documents by means of endnotes.

## BRITISH MILITARY GEOLOGISTS AND PLANNING FOR THE INVASION

Detailed planning for the Allied invasion began approximately a year before D-Day (Rose and Pareyn, 1995, 1996a, b, 1998, 2003). The planning staff at that time contained a geologist – Major (later Lieutenant Colonel) W. B. R. King OBE MC of the Royal Engineers (Figure 1), in civilian life Yates-Goldsmid Professor of Geology at University College in the University of London. 'Bill' King had considerable experience as a military geologist in both World Wars (Shotton, 1963a, b; Rose and Hughes, 1993a, b; Rose and Rosenbaum, 1993a, b; Rose, Häusler and Willig, 2000; Rose, 2004a, b), his work in 1915–18 as the first British military hydrogeologist providing much of the basis for subsequent Royal Engineer books on water supply (Anon., 1921) and applied geology (Anon., 1922). Ultimately, this experience led to his appointment in 1943 as the geological adviser – the SO2 [Staff Officer Grade 2] (Geology) – to the Chief Engineer of 21st Army Group (the invasion force), and effectively as the senior geologist in the British army as a whole.

The original plan, once Normandy rather than the Pas de Calais had been selected as an invasion site, was to land on the beaches of the Cotentin peninsula with the immediate objective of capturing the port of Cherbourg – deemed essential as a supply route. But air superiority and therefore a dozen temporary airfields to sustain it were also deemed essential, and it was King who pointed out that the region best suited for rapid construction of temporary airfields was not the Cotentin peninsula south of Cherbourg but the geologically very different Calvados plateau between Bayeux and Caen (Figure 2). According to 21st Army Group's Chief Engineer, Major General (later Sir) J. D. Inglis, King's appraisal of Normandy geology 'was, in fact, one of the main factors which led to the selection of the beaches eventually used' (Inglis, 1946, p. 177–178).

Figure 1. Professor W. B. R. King, as a Royal Engineer geologist officer, 1943. From Rose & Hughes (1993b), courtesy of the Institution of Royal Engineers, and his daughter Professor C. A. M. King

Although King was released from the army in October 1943 to take up appointment as Woodwardian Professor of Geology at the University of Cambridge, his role passed to a protégé, also a temporary officer in the Royal Engineers: Captain (later Major) F. W. Shotton (Rose and Rosenbaum, 1993b; Coope, 1994). 'Fred' Shotton, in civilian life at that time a lecturer in geology at Cambridge, had been called-up from the Army Officers Emergency Reserve to join King on military geology tasks in the United Kingdom in late 1940. In May 1941, however, he was sent to the Mediterranean region, to take responsibility under the Director of Works, Cairo, for all British military geological activities in North Africa and the Middle East. These dealt mainly with provision of groundwater supplies and technical direction of Royal Engineers well-drilling teams (Shotton, 1944, 1945, 1946).

Shotton was recalled to the UK in September 1943 to join a team (Figure 3) on the 21st Army Group planning staff led by the distinguished physicist and crystallographer J. D. Bernal, Professor of Physics at Birkbeck College in the University of London but seconded as Scientific Adviser to

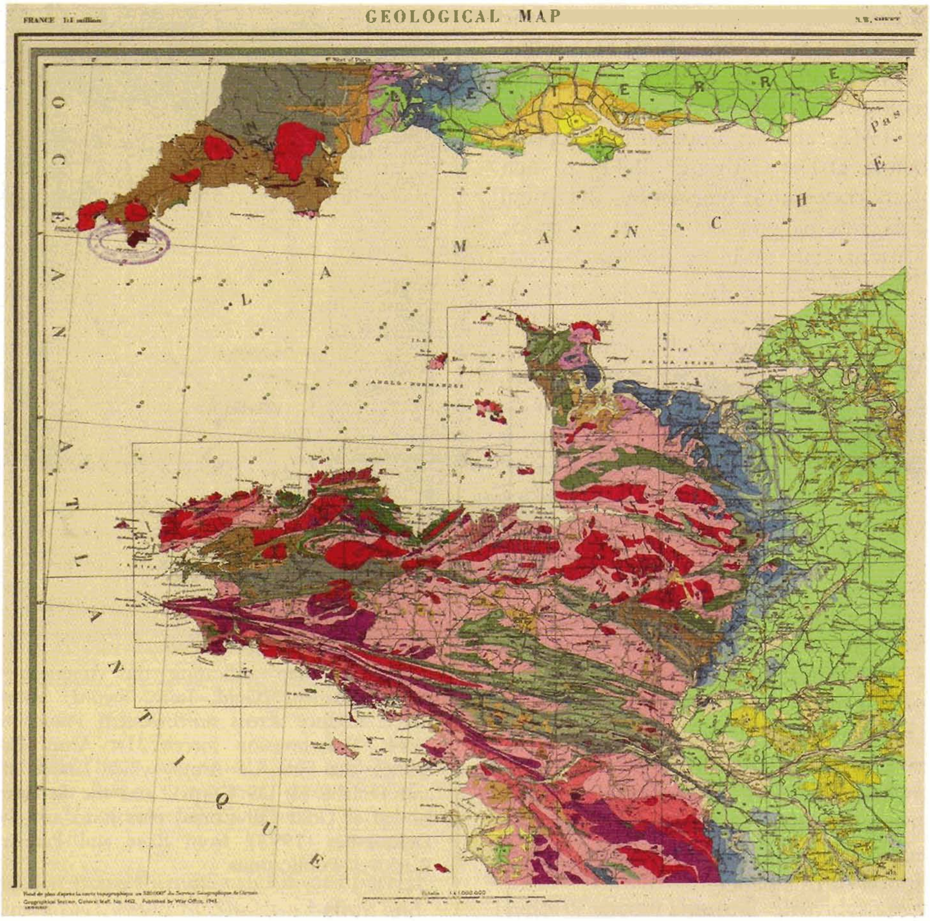


Figure 2. NW sheet of the 1:1000 000 geological map of France, published by the War Office in 1943; part of GSGS No. 4452, reprinted from the *Carte géologique de la France*, 3rd edition, of 1933. The legend (on the SW sheet only) shows that the rocks from the Cherbourg (Cotentin) peninsula westwards across Brittany are predominantly very old (Precambrian in age: coloured pink) and very strong (granites: coloured red), with a complex pattern of outcrop. These constitute the 'Armorican Massif' of contemporary geologists. In contrast, the rocks from the Calvados (Bayeux – Caen) region eastwards are much younger and weaker, largely Mid Jurassic limestones (blue) to Cretaceous chalks (green). Their simple pattern of outcrop, concentric about Paris to the east of the map area, reflects their position on the western margin of the 'Paris Basin'. Only the thickest deposits of more recent (Pleistocene) age can be shown on a map of this scale, notably those (coloured pale buff) flooring the major river valleys. From the Shotton Archive, courtesy of the Lapworth Museum

Figure 3. The planning staff at HQ 21st Army Group led by Professor J. D. Bernal which contained Major (later Professor) F. W. Shotton (standing, top left). Photograph from the Shotton Archive, courtesy of the Lapworth Museum

the Chief of Combined Operations. It has been known for some time that geologists' tasks associated with D-Day included library and photographic study of the cliffs of the proposed invasion areas; the provision of information on the foundations of enemy defences for their effective bombing; the preparation of water intelligence maps; information on sources of road metal, sand and gravel, and on the submarine geology of ports; and the detailed study of certain rivers with a view to assault crossings (Shotton, 1947). However, Shotton's definitive list of these tasks[1] (Table 1) has only recently been discovered, amongst his personal papers now preserved at the University of Birmingham.

The work of this team was complemented by that of the Inter-Service Topographical Department (ISTD), a geographical organization administered by the Admiralty whose primary role was to provide terrain intelligence by means of maps and reports. The unit was aware of the importance of geology by 1942. Its postwar review of military geological activities for northern France[2] acknowledged 'An excellent picture of the geological history and structure of France is to be found in the publications of the Naval Intelligence Division in the Geographical Handbook Series on France, Vol. 1, Physical Geography [Anon., 1942]'. However, geologists as such were not appointed to ISTD until October 1943, and an unpublished report[3] shows clearly that before D-Day, although ISTD as such was involved in projects concerning Normandy, the initial focus of its geologists was to prepare reports to guide planning of operations in Italy and the Far East. Non-geologists prepared Normandy maps (e.g. tactical maps at scale of 1:50 000 of the northeast coast of France and of Normandy showing communications, beaches and landing-places[4]) and other documents (e.g. an extensive mosaic panorama of coastal photographs to guide beach landings, as illustrated by Rioult *et al.* [1994], Rose and Pareyn [2003, figure 22]), but the growing Geological Section of ISTD began to contribute reports for northwest Europe only in March 1944, and then for Brittany rather than Normandy.

Some of the specialist maps generated by Fred Shotton and his associates to aid planning of the invasion (Figure 4) and subsequent operations during the Battle of Normandy formed part of his personal document collection. This accompanied him postwar first to the University of Sheffield on his appointment there as Sorby Professor of Geology in 1945, then to the University of Birmingham on his appointment as Lapworth Professor of Geology in 1949. The maps are now located within the 'Shotton Archive' in the Lapworth Museum of Geology at Birmingham, which forms the basis for much of this paper.

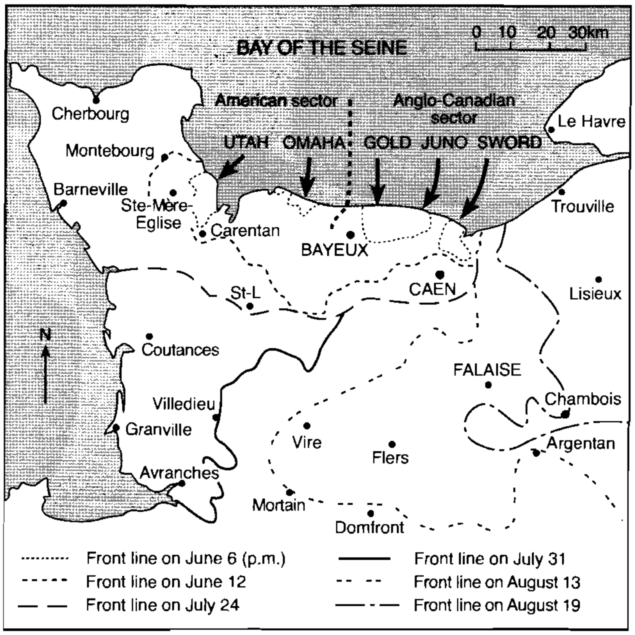


Figure 4. Map indicating the American (Utah, Omaha) and Anglo-Canadian (Gold, Juno, Sword) invasion beaches and the Allied advance across northwestern France through Normandy in 1944. The invasion force (21st Army Group) comprised two armies: the First US Army, which landed at Utah (7 US Corps) and Omaha (5 US Corps), and the Second British Army, which landed at Gold (30 Corps) plus Juno and Sword (1 Corps). After Desquesnes (1993); from Rose and Pareyn (1995), courtesy of Blackwell Publications

Table 1. 'Geological work with 21 Army Group. Including pre-D day planning and post-D day planning and operations done by SO [Staff Officer] Geology to CE [Chief Engineer] 21 Army Group (Lt./Col. King followed by Major Shotton) and from January 1945 also by DADW [Deputy Assistant Director, Works], Major Ponsford. Assistance from time to time from ISTD [Inter-Service Topographical Department].' (A typescript preserved in the Shotton Archive at the Lapworth Museum.[1])

**Pre-D-Day**

1. Detailed study of nature of invasion beaches.
2. Study of sand-bank changes on a British beach, as a guide to similar changes on the invasion beaches.
3. Selection of a British beach simulating the invasion bridge head.
4. Co-operation in vehicle trials and bombing results on the British counterpart beaches.
5. Detailed study of the Loire and Seine rivers, with a view to assault crossings.
6. Selection of an English river comparable to the Seine, and tests of amphibious vehicles on its banks.
7. Provision of information on the submarine geology of invasion ports.
8. Selection of parts of British coast for training commando parties in assault of French coast.
9. Preparation of water supply prospect maps for N.W. France (1:50,000 and 1:250,000 scale).
10. Study of the reaction of common French and Belgian road metals upon mine detectors.
11. Collaboration with M.E.W. [Military Engineers Works] on quarry resources, N.W. France.
12. Forecast of soil characteristics of projected airfield sites.
13. General co-operation with I.S.T.D. [Inter-Service Topographical Department] and T.I.S. [Theatre Intelligence Section] on terrain appreciation.
14. Advice on bomb weights and fusing.

**Post-D-Day**

1. Continuation of water prospect maps, Belgium, N.W. France and W. Germany.
2. Control of boring work RE [Royal Engineer] Boring Platoons.
3. Co-operation with C.R.E. [Commmander Royal Engineers] (Quarrying Groups) and S.H.A.E.F. [Supreme Headquarters Allied Expeditionary Force] on road stone resources.
4. Preparation of soil maps for D.C.E. [Deputy Chief Engineer] Airfields, and soil forecasts and developments for selected sites.
5. Preparation of soil maps (Holland and Germany) with particular reference to operational vehicle movement.
6. Collection of vehicle movement data (in co-operation with O.R.S.) to provide a check upon correctness of 'trafficability' forecasts.
7. Detailed study of the shores of S. Develand and Walcheren previous to the assault thereon.
8. Detailed study of the shores and approaches of the Fresian islands, preparatory to proposed assault.
9. Study of the River Rhine in detail, with a view to assault crossings and bridge building.
10. Selection of training area on River Meuse, with conditions as near as possible to those which would hold on the Rhine assault crossings.
11. Study of soil in relation to frost and thaw deterioration of roads.
12. Opinion, when required, on nature of foundations.

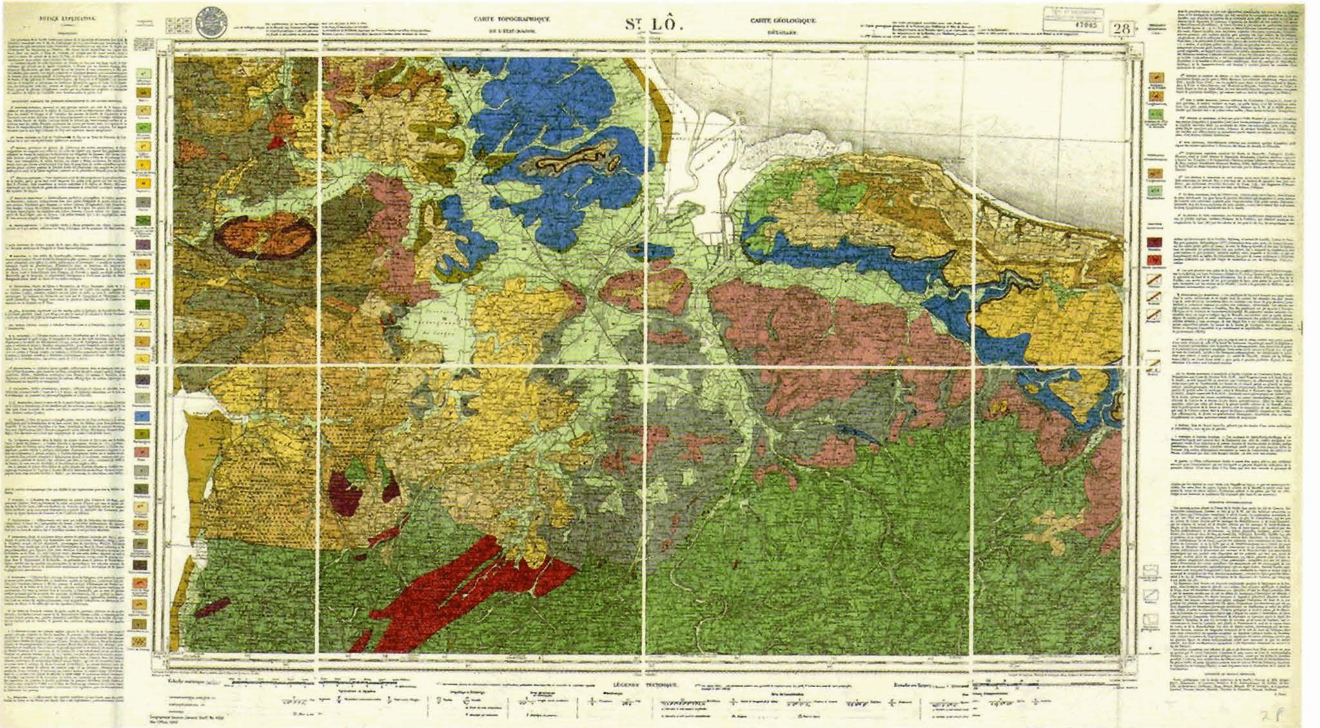


Figure 5. Sheet 28 St Lô of GSGS map series 4326, scale 1:80 000, published by the War Office, 1942: a facsimile reproduction of the *Carte géologique détaillée de la France*, first edition, sheet of 1891. The map reproduced was one that had been cut and mounted. Courtesy of the School of Geography, University of Birmingham

Preparation of specialist maps formed a significant part, if only a part, of the duties performed by Shotton before and after D-Day (Table 1) – particularly to indicate the nature of the invasion beaches, potential for airfield construction inland, and development of groundwater for potable water supplies. Such maps, if preserved within the multitude of reports relating to 'Operation Overlord' or to '21 Army Group' preserved in the National Archives (formerly the Public Record Office) at Kew, are not recognizable amongst the National Archive maps currently catalogued [e.g. by Beech (1998)], despite the guidance recently provided by Beech, Gill and Mitchell (2005).

## FRENCH GEOLOGICAL MAPS

France was the first country to found a national geological survey as such, based on earlier government awareness of the practical value of geology (Eyles, 1950). Fieldwork commenced in 1825, and was completed in 1835, although the resulting geological map of France was not published until 1840 (Brochant de Villiers, 1841). It was issued in six sheets, and at a scale of 1:500 000. Later, this was replaced by a revised map, at scale of 1:1000 000, whose third edition (published in 1933)[5] was the most recent version publicly available during the war. The US Army Corps of Engineers, in association with the US Geological Survey, used the map to help generate a terrain intelligence folio in 1943[6] and the British army reprinted the map in 1943 (as GSGS 4452), to aid Allied military planning. The Shotton Archive contains the four sheets (NE, NW, SE, SW) which together constitute the British map,[7] indicating that this was the version immediately accessible to Shotton himself. The NW sheet (Figure 2) provides coverage of Normandy and adjacent areas.

On 1 October 1868, a new geological survey, the *Service de la Carte géologique détaillée de la France*, was inaugurated (Eyles, 1950). This was to prepare maps on a more detailed scale than hitherto, and the scale soon selected was 1:80 000 – that of 24 sheets for northern France published and exhibited (at Paris) in 1855 (Ian Mumford, pers.com., 2005). The whole of France was divided into a grid, and the maps published (from 1873 onwards) as sheets similar in size to the 1 inch to 1 mile sheets published for the United Kingdom by the Geological Survey of Great Britain and Ireland. Sheet explanations and vertical and horizontal sections were also issued. A first edition, of 250 sheets, was completed in 1910.[8] A second edition followed, and work for a third edition was still incomplete in 1960 when the series was replaced by a new series at 1:50 000.

Between 1942 and 1944, copies of the 1:80 000 scale maps were reproduced by the British army for the northern third of France, plus Languedoc, Provence and most of Corsica. In total at least 113 maps were reprinted, 82 for northern France.[9] The invasion beach areas of Normandy were covered by sheets 28 (St Lô) (a second edition map dating from 1926, replacing a first edition of 1891) and 29 (Caen) (a second edition map of 1914, replacing a first edition map of 1889) of the original French maps. GSGS reprints of first edition maps for both areas, as for northern France generally, were made in 1942 (e.g. Figure 5). Additionally, a reprint of the second edition map for the Caen area (as for some other areas) was made in 1944 (Figure 6). Such maps, without further annotation, were

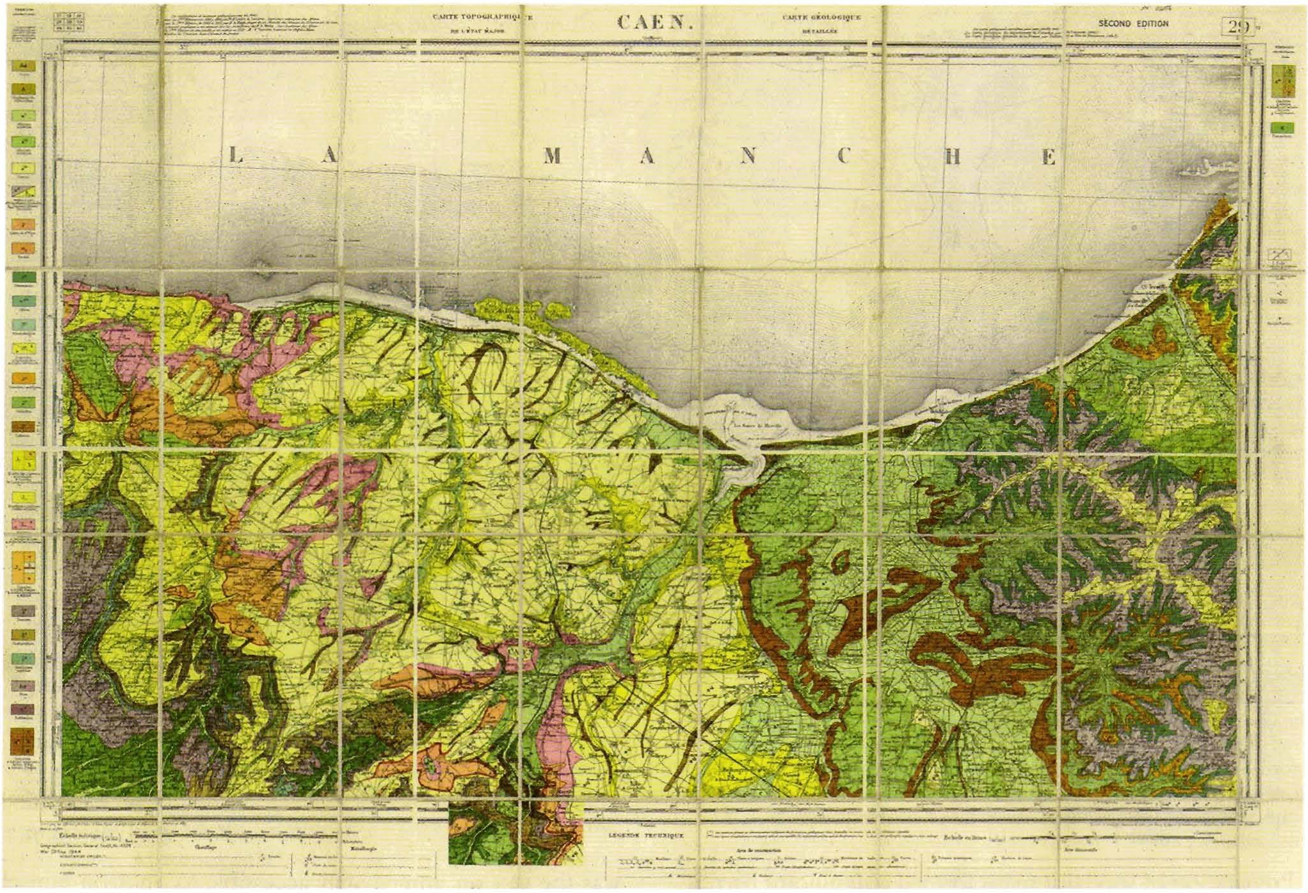


Figure 6. Sheet 29 Caen of GSGS map series 4326, scale 1:80 000, published by the War Office, 1944: a facsimile reproduction of the *Carte géologique détaillée de la France*, second edition, sheet of 1914. This particular copy has been re-cut, showing fold lines additional to those printed on the GSGS map. The yellow colouring which distinguishes most of the Calvados plateau between Caen westwards to Bayeux represents oolitic limestones of 'Bradfordian' (Mid Jurassic) age, pink colouring exposed in major river valleys the underlying, slightly older, 'Caen limestone'. Superficial deposits include a widespread cover of 'Limons' (= loess), coloured pale yellow, and alluvium (coloured green) in the major river valleys. Colouring as well as detail differs from that adopted in first edition maps, and explanatory notes were printed separately rather than marginally, on the face of the map (cf. Figure 5). Courtesy of the Geological Society of London

used by the Quarry Group Royal Engineers to guide deployment of the Quarrying Companies RE which generated the considerable quantities of aggregate required for repair and construction of roads, airfields, and hard standings for stores or vehicle depots in the Normandy region (Williams, 1950; Rose and Pareyn, 1995, 1996b, 1998, 2003).

## PRINTING OF HIGHLY CLASSIFIED SPECIALIST MAPS

Most of the specialist maps preserved in the Shotton Archive were initially (i.e. before D-Day) classified 'Bigot' (a special high level of security classification created specifically for documents associated with planning for the Normandy invasion) and 'Top Secret'. Copies were numbered individually, to facilitate strict control of use.

Data printed in the map margin typically indicate the number of copies printed, the month and year of printing, the Map Reproduction Section responsible for production, and the 'job number', e.g. 350/4/44/15M.R.S./167/94 (printed minutely at the bottom left corner of Figure 7). In this example, 350 copies were printed – most of the Shotton Archive maps show print runs of about 250 copies (sometimes in the format '2.5') – and printing took place during April 1944. Printing was by Map Reproduction Section number 15.

Three special Map Reproduction Sections – numbered 11, 13 and 14 – were created by the Director of Survey Royal Engineers under Home Forces (which later became 21st Army Group) in February 1943 (Clough, 1952, p. 39). No. 11 was soon transferred to War Office control for service in North Africa. Number 13 was, from its formation, employed on urgent, highly secret map production for the planning staffs, and it continued to be so employed until the end of the war, doing duty in turn for GHQ Home Forces, HQ 21st Army Group, Chief of Staff to the Supreme Allied Commander, and finally Supreme Headquarters Allied Expeditionary Force (SHAEF). With the formation of SHAEF in January 1944, the Survey organization in preparation for Operation Overlord included numbers 13, 14, 15 and 16 Map Reproduction Sections, all under HQ 21st Army Group (Clough, 1952, p. 41), and by the end of August Sections 14 and 15 had completed deployment to France. Map Reproduction Sections were fully-equipped, semi-mobile map printing units, each with a staff of about 80 all ranks, as described by Clough (1952) and Gray (2004).

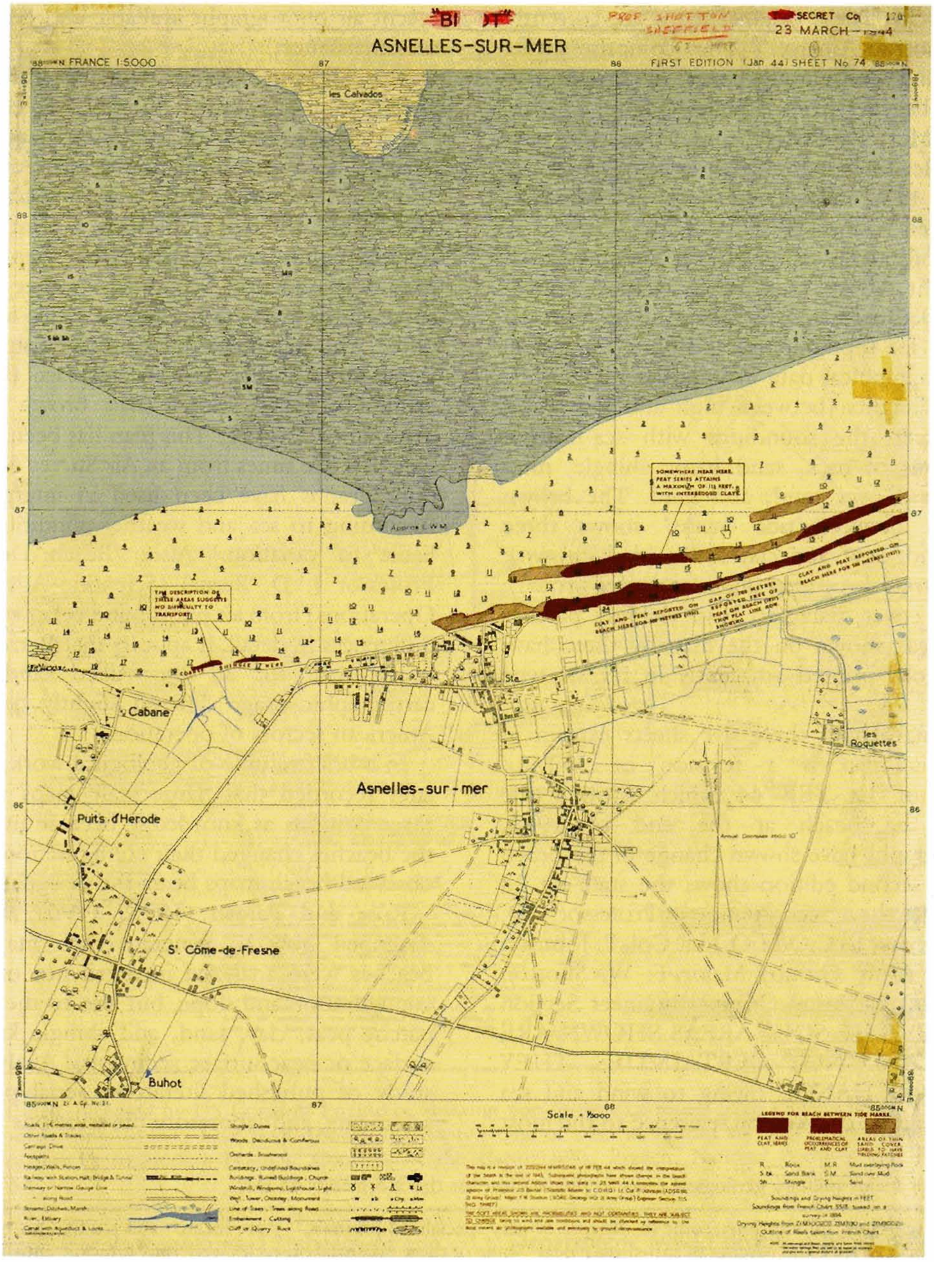


Figure 7. Sheet 74 Asnelles-sur-Mer of France 1:5000 series, 1st edition: January 1944, with overprint in brown dated 23 March 1944 showing interpretation of beach conditions. For explanation, see text. From the Shotton Archive, courtesy of the Lapworth Museum

**BEACH MAPS**

A definitive list of ISTD reports[10] shows that from early 1942 many were generated for coastal regions of France, but not specifically for Normandy. Sections of the Normandy coast and the beaches eventually used for invasion are amongst those later described (and illustrated by numerous 'holiday' photographs) in volume 2 of the Inter-Service Information Series report on France[11] but without geological detail or illustration by geotechnical maps. However, King (1951a, p. 137), in a postwar presidential address to Section C of the British Association for the Advancement of Science, noted that from 1943 planning for the Normandy invasion included 'preparation of large-scale maps of the beach indicating those parts which were unsuitable for the passage of assault vehicles', and that for this 'By far the greater part of the geological research was carried out by Professor Shotton who was then geologist at H. Q. 21st Army Group'.[12] Neither King nor Shotton was ever to describe or illustrate these maps.

The British Library possesses a file[13] which contains two coloured 1:5000 maps of Normandy beach areas prepared in October 1943: Ver-sur-Mer and Courseulles-sur-Mer. Marginal data printed on these maps state: 'Beach detail produced by Professor J. D. Bernal (Scientific Advisor to Combined Operations) from Air Photo and other sources'.

The file also contains full-size black/white photographic copies of five other maps, all of which (according to notes pencilled on the top margin) were returned to Professor Shotton when he was based immediately postwar at the

University of Sheffield. These original maps are currently preserved in the Shotton Archive.[14] They comprise sheets 74 to 78, providing continuous cover of the Anglo-Canadian invasion beaches from Asnelles (Figure 7) eastwards via Ver-sur-Mer, La Rivière, and Courseulles-sur-Mer to Bernières. Headings state this series to comprise the 'First Edition (Jan 44)', and all five sheets are dated 23 March and numbered 'Copy 170'.

Considerably more detail is given for natural beach features that might affect cross-beach vehicle movement than on the October maps, by overprinting in brown on the basic black (for topographic) and blue (for water) features. Black topographical data include soundings (offshore) and drying heights (between high and low water marks), both in feet, the soundings with sea-bottom information in terms of rock, sand bank, shingle, mud overlaying rock, sand over mud, and sand. The brown 'legend for beach between tide marks' shows three categories of ground: peat and clay series (dark brown); problematical occurrences of peat and clay (paler brown); areas of thin sand cover, liable to have yielding patches (palest brown). Areas shown on the map by these have additional descriptions printed adjacently in brown type (see Figure 7).

Marginal data on each of these five sheets explain in brown type: 'This map is a revision of 253/2/44.14M.R.S./146 of 1st FEB 44 which showed the interpretation of the beach at the end of 1943. Subsequent photographs have shown change in the beach character, and this second edition shows the state on 23 MAR 44. It embodies the agreed opinion of Professor J. D. Bernal (Scientific Adviser to C.O.H.Q.) Lt. Col. P. Johnson (A.D.S.R. HQ 21 Army Group) Major F. W. Shotton (SORE Geology HQ 21 Army Group) Engineer Section T.I.S. (HQ SHAEF). THE SOFT AREAS SHOWN ARE PROBABILITIES AND NOT CERTAINTIES. THEY ARE SUBJECT TO CHANGE owing to wind and sea conditions and should be checked by reference to the most recent air photographs available and eventually by ground reconnaissance.'

The Shotton Archive contains three similar maps[15] absent from the British Library file, covering beaches in the American sector of operations, each headed 'Plan of beach ... area with formation detail'. Although these maps also bear the caption 'First edition (Jan 44)', marginal data are slightly different, indicating a print run of 403 rather than 350, printing in March rather than April 1944, and by Map Reproduction Section 14 rather than 15, as three successive projects rather than a single task. Copy numbers differ. The statement referring to Shotton is missing from these three sheets, but in its place (beneath the scale) printed in black rather than brown type there is the explanation 'NOTE: This plan has been prepared on a base enlarged five times from an Air Survey Map. Large Scale air photographs have been used in interpretation of detail. According to sea and weather conditions, beach detail is liable to variation.' Also: 'Beach Detail produced by Professor J. D. Bernal (Scientific Advisor to Combined Operations) from air photos and other sources.' From these differences in detail, it appears that Bernal's team produced beach data for all the Allied landing beaches, but cartographic usage differed slightly between British and American sectors of operation.

In a brief résumé of geological work,[16] Shotton himself later recorded that 'large scale maps were produced (in three editions as knowledge became more precise, and as the beaches changed their configuration)', but none of the observed beach maps bears the designation 'third edition'.

Rose and Pareyn (1995, 1996a, 1998, 2003) have described how to generate such maps the Normandy beaches were analyzed in detail not only with regard to configuration and slope, but also to the distribution of the patchy peat, clay, sand, and shingle known to form the surface or near-surface sediments. Analyses were based on study of published literature, aerial photographs, beach sediments, and laboratory observations (Table 2).

Table 2. Categories of major military geological tasks in preparation for the Normandy D-Day

| |
|---|
| **Detailed literature searches**. Publications, some in obscure or very specialized journals,[17] were located and studied for information on the position of erratic blocks of rock and patches of sub-surface peat. Some of these potential obstacles were only intermittently exposed by storms and exceptional tidal conditions and so were not actually visible in the months immediately prior to the invasion. |
| **Aerial photographic interpretation**. Aerial photographs, some taken obliquely by aircraft flying along the beaches at altitudes as low as 50 feet (16 m), were used to provide information on natural as well as man-made obstacles. Shotton recounted after the war how patches of dark peat could be recognized after storm movement of the lighter-coloured sand; how the load-bearing properties of some beach areas could be estimated from the depth of wheel marks left by German carts transporting defence stores; and how he himself had been flown over the beaches to make observations at low altitude. |
| **Beach sample analysis**. Midget submarine X-craft operated by COPP (Combined Operations Beach Reconnaissance and Assault Pilotage Parties) carried specially trained volunteers close to the beaches (Rose and Pareyn, 2003). Their task was to swim ashore, and to covertly auger soft sediment and collect samples of 'stone' as well as to make observations on obstacles to cross-beach movement and exit. On return, beach samples were sent to the Geological Survey of Great Britain for analysis. Additionally, Glen (2004) has described from personal experience how Landing Craft Personnel (Large) – motor boats about 10 m long – were used for near-shore hydrographic surveys at night, and how on the night of 31 December 1943 Major Scott-Bowden and Sgt Ogden Smith of the Royal Engineers swam ashore from such craft to sample sand at Arromanches and measure the height of the wall at the back of the beach. |
| **Studies on UK beaches**. Shotton made detailed observations on several British beaches whose geology was deemed to be similar in particular respects to those of Normandy[18]. Notably, amongst trials of vehicles and equipment at Brancaster in Norfolk, the effects of peat as an obstacle to cross-beach mobility were assessed by landing large numbers of vehicles under different tidal conditions on different parts of the coast. |
| **Beach-process laboratory study**. Beach processes were studied in numerous laboratories – and particularly by R. A. Bagnold, who had served as a Royal Engineer officer in the First World War but had subsequently transferred to the Royal Signals, before retiring (as a Major) in 1935 to undertake research at Imperial College, London, on the physics of sand movement. He rejoined the army in the Second World War, founded the Long Range Desert Group in North Africa, and subsequently became Signal-Officer-in-Chief, Middle East. Bagnold, who became a Fellow of the Royal Society, was released from the army in 1944 (as a lieutenant colonel, honorary brigadier) to continue research, on the action of marine waves on the formation and erosion of beaches. |

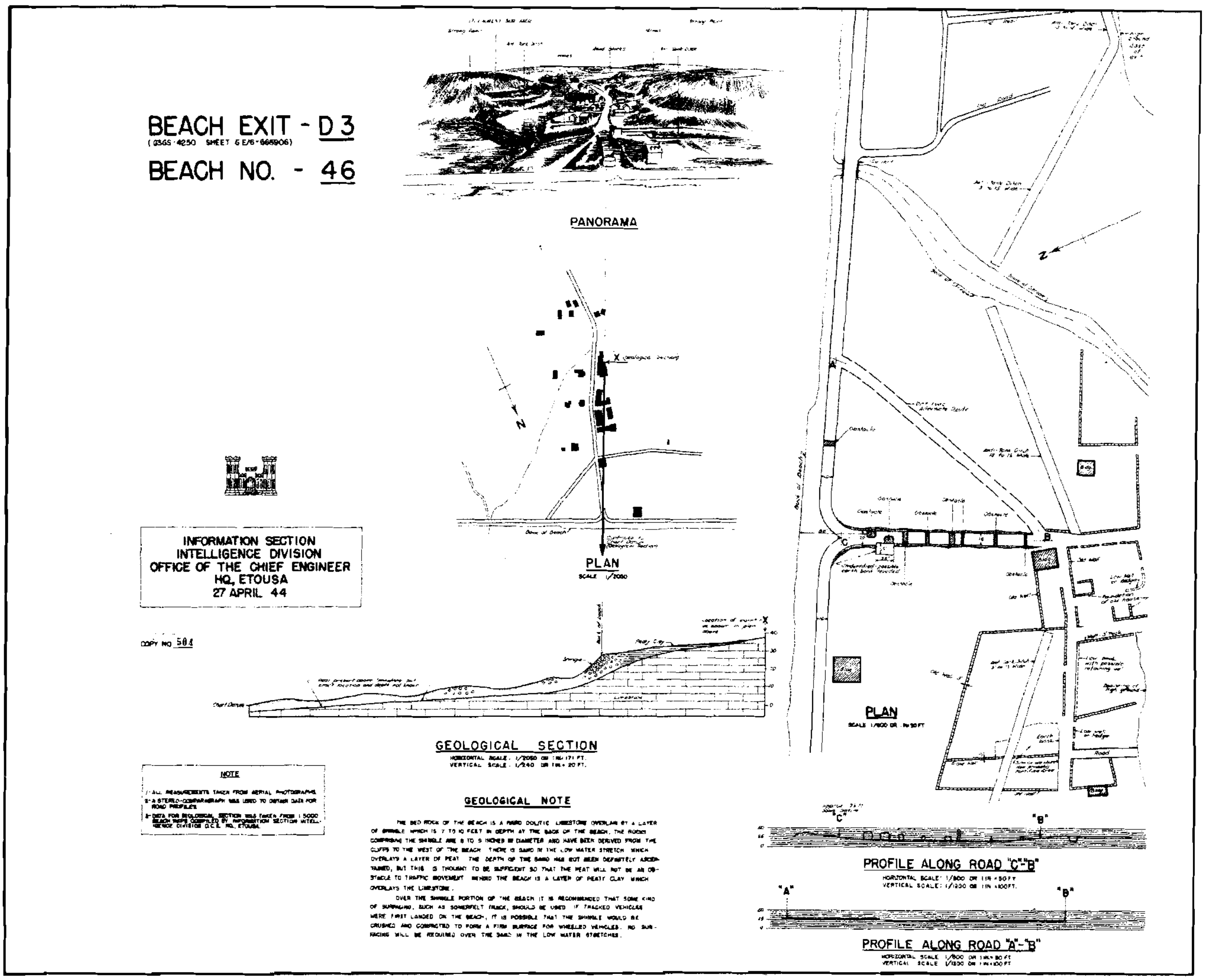


Figure 8. Large scale map, prepared by US Corps of Engineers, showing one of the exit routes from Omaha Beach. (Preparation and classification data stamped on the original map have been deleted, for clarity.) One of a set of at least six such maps prepared for exit routes from the American (Omaha and Utah) landing beaches. Courtesy of the Cartographic Branch, National Archives and Records Administration, College Park, MD, USA

The British Library file also contains 12 sheets of the same and adjacent areas at the same scale which lack beach information but show topographic features (including provisional contours at 10 m vertical interval) in black, water in blue, and woodlands in two shades of green.[19] Some are designated 'First Edn Feb 44', others '2nd ed April 44'. However, none shows indication of any geologist assistance in preparation. These maps were all drawn, according to marginal data, 'by 62nd Engrs Topo Co U.S.A.', and 'prepared on a base enlarged five times from an Air Survey Map. The standard of accuracy is therefore the same as that of the 1:25,000 map. Additional detail has been supplied from large scale air photographs.' Printing was by Map Reproduction Section 14, in April 1944.

Clough (1952, p. 595) has described how 'A small section of topographical draughtsmen was formed at the G. H. Q. Home Forces Survey Directorate. They started work on 30th April, 1942, on a programme of beaches selected by the planning staff. The objective was to provide technical beach data from which the Admiralty Hydrography Department would produce beach-gradient charts.' Later, US Engineers formed a Beach Intelligence sub-section, which established liaison with ISTD at Oxford, and the Hydrographic Department of the British Admiralty (Clough, 1952, p. 598). Early in April 1944, a photographic interpretation team specially trained in the development of information about beach areas was attached to the sub-section. Chasseaud (2001) has described how beach maps at a scale of 1: 5000 were produced by a combined US-British section at Kew (alongside 660 Engineer Topographical Battalion of the US Army) for 21st Army Group – but neither Clough nor Chasseaud refer specifically to the versions of beach map (e.g. Figure 7) made possible by Shotton's geological input.

That the Americans did use geology in formulating beach appraisals before the D-Day landings is evident from map sheets (e.g. Figure 8) preserved, as part the records of the European Theater of Operations of the United States Army, at the National Archives and Records Administration in the USA (Richard H. Smith, pers.com., 2005). Six of these map sheets are also known from copies preserved in the Map Room of the Bodleian Library at Oxford in the UK.[20] Four relate to Omaha Beach, 'Beach No. 46', and provide data for beach exits D-1, D-3, E-1 and E-3. Two relate to Utah Beach, 'Beach No. 49', and provide data for beach exits S-9 and T-7. Each was compiled by 'Information Section, Intelligence Division, Office of the Chief Engineer, HQ, ETOUSA [European Theater of Operations United States Army], 27 April 44' and provides a panorama diagram illustrating the exit; a plan at small scale (1:3000 to 1:1800); a plan at large scale (1:600); one or two profiles with vertical scale of 1:1200 and horizontal scale of 1:600; a geological cross-section; and an explanatory 'geological note'. A note printed on each sheet affirms: 'All measurements taken from aerial photographs. A stereo-comparagraph was used to obtain data for road profiles. Data for geological section was taken from 1:5000 beach maps compiled by Information Section Intelligence Division OCE [Office of the Chief Engineer] HQ, ETOUSA.' However, none of these American-compiled beach maps is known from collections in the UK.

The 'geological note' on each sheet provides both a brief description of the ground materials and an assessment of their trafficability in different style to that on the beach maps with input credited to Shotton, e.g. that for the D-3 sheet for Omaha Beach (Figure 8):

'The bed rock of the beach is a hard oolitic limestone overlain by a layer of shingle which is 7 to 10 feet in depth at the back of the beach. The rocks comprising the shingle are 6 to 9 inches in diameter and have been derived from the cliffs to the west of the beach. There is sand in the low water stretch which overlays a layer of peat. The depth of the sand has not been definitely ascertained, but this is thought to be sufficient so that the peat will not be an obstacle to traffic movement. Behind the beach is a layer of peaty clay which overlays the limestone.

Over the shingle portion of the beach it is recommended that some kind of surfacing, such as Somerfelt Track, should be used. If tracked vehicles were first landed on the beach, it is possible that the shingle would be crushed and compacted to form a firm surface for wheeled vehicles. No surfacing will be required over the sand in the low water stretches.'

## AIRFIELD CONSTRUCTION SUITABILITY MAPS

According to a report by the Chief Engineer 21st Army Group,[21] one of whose six original 'secret' copies is preserved in the Royal Engineers Library at Chatham: 'Suitability for rapid airfield construction was one of the main factors in the selection of the area for OVERLORD. In 1943 a map, to 1:1,000,000 scale, shewing suitability of country in N. W. Europe was prepared by S.O.2 (Geology) for the guidance of the general staff in the selection of areas and for the general planning of the operation.'

The report further states that: 'For planning, and for later issue to formations and units concerned, airfield intelligence was compiled in the following forms

(i) Map of N. W. EUROPE shewing suitability of country for rapid airfield construction, scale 1:1,000,000.

(ii) Schedules of potential airfield sites, selected from map and normal air photo examinations, including the following details.
Place and map reference.
Number and direction of strips.
Nature of soil and geologist's classifications.
Extent of clearance required.
Dispersal areas.

(iii) Multiplex maps of selected areas, scale 1:10,000.

(iv) Overlays to 1:250,000 and 1:50,000 maps, shewing potential airfield sites, existing landing grounds and airfields.'

The 1:1000 000 map of northwest Europe thus seems to have been the primary planning aid – although a check reconnaissance at the close of hostilities[2] summarized criticisms that it was 'too generalised to be reliable, is deceptive in certain areas, and tends to under-estimate the possibilities of an area for airfield sites' so was necessarily superseded by maps at more detailed scale.

Several copies of a 1:1000 000 map (Figure 9)[22] are present in the Shotton Archive, and, although these lack a printed caption or statement of origin, one bears the pencil annotation 'airfield construction probability map' and another the typed label 'map showing the suitability of country for the rapid construction of airfields'. It is clear from the printed key (Figure 10) that this is indeed what it is. Blue horizontal rulings of increasing colour density are used to indicate four categories of decreasing possible sites in an area, judged on levelness and openness of country, in conjunction with red vertical rulings of increasing colour density which indicate four decreasingly suitable categories of soil types, these governing permeability and drainage within the regions. The potential land use is therefore depicted in terms of 16 categories for northwest Europe as a whole – and the contrasting areas in Normandy (Figure 11) are made readily apparent, the areas with least density of colour being those most suitable for temporary airfield construction. One of the copies in the Shotton Archive has been annotated to show what are presumed to be airfield sites proposed or later actually developed across the region. It lacks an index to explain the significance of the symbols used, but may have served as a draft for an annotated topographical map preserved in the British Library (Figure 12).[23]

It seems that the map in the Shotton Archive must be the map cited in the Chief Engineer's report.[21] Minutes of a meeting largely of ISTD and air force officers held on 24 November 1943[24] record that suitability of country for landing grounds had always been a feature of ISTD reports; that a map of 1941 had illustrated ground in terms of four grades (from unlimited to almost no possibilities); that from May 1943 the importance of soil suitability had been stressed; and that 'a map was produced for North France by Lt. Col. King (21 Army Group) in collaboration with I.S.T.D.' The map can thus be firmly attributed to Bill King, and its preparation to about mid 1943.

This map was influential in focusing more detailed studies on particular areas. The Chief Engineer's report[21] summarizes the procedure as: 'The topographical intelligence available for eng[ineer] planning was based on map and air photo examination of the whole area. In this

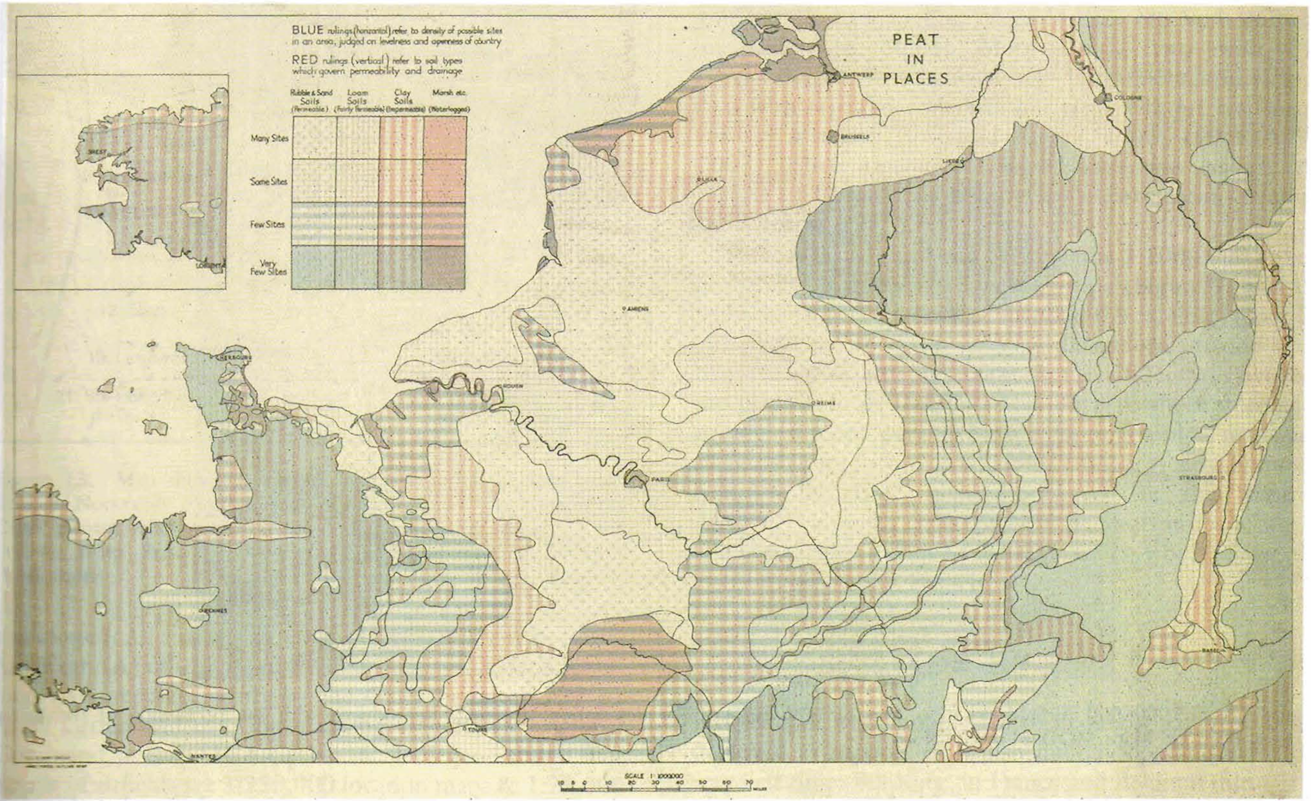


Figure 9. Airfield construction probability map (of NW Europe), according to a title pencilled on one copy, in Shotton's handwriting. Marginal data, additional to the scale of 1:1000 000, record only printing by 'C[hief] E[ngineer] 21 Army Group', as 'Home Forces Outline Map No. 67'. For key, see Figure 10. From the Shotton Archive, courtesy of the Lapworth Museum

examination, the chief problem was to find a method of measuring accurately the slight gradients which are the limiting factor in rapid airfield construction. After tests to determine its suitability the Multiplex method was employed and areas selected from normal air photo cover examination were surveyed in detail by this method. Maps to 1:10,000 scale, with spot levels and contours at 5 ft vertical interval were prepared. A total of 277 sites were considered and were classified according to suitability; of these, Multiplex maps were prepared for 103 sites. The exact degree of accuracy obtained by the Multiplex method was a matter of some uncertainty, although experimental

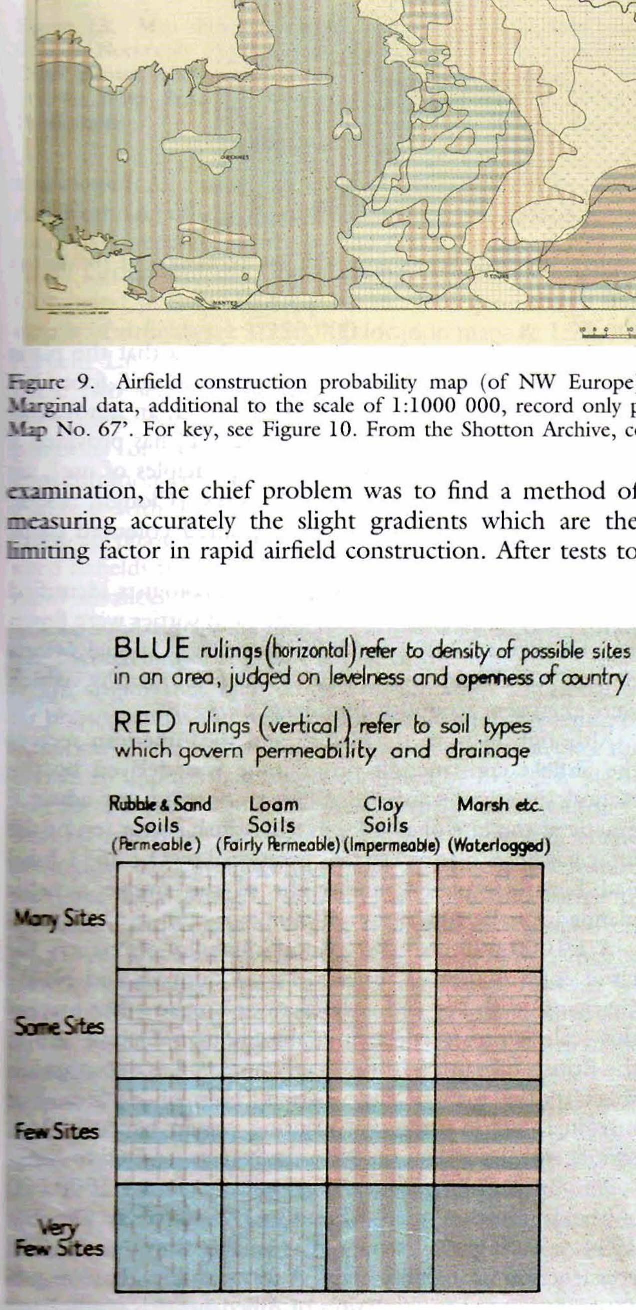


Figure 10. Enlargement of key printed on Figure 9

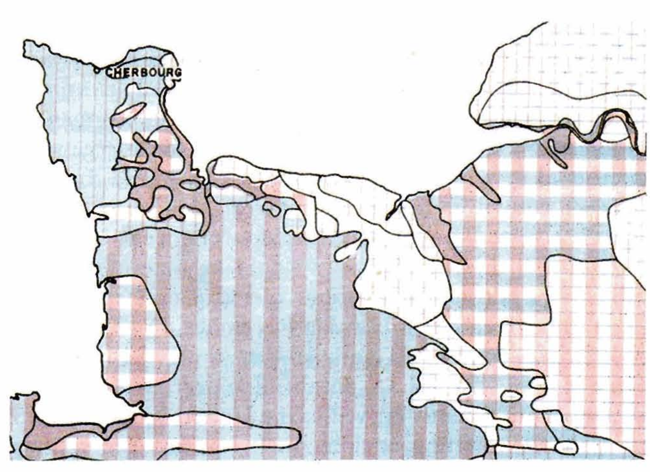


Figure 11. Enlargement of Normandy area printed on Figure 9. Largely unfavourable ground dominates the Cherbourg peninsula, contrasting with relatively favourable ground inland from the Calvados coast, eastwards to the River Orne estuary

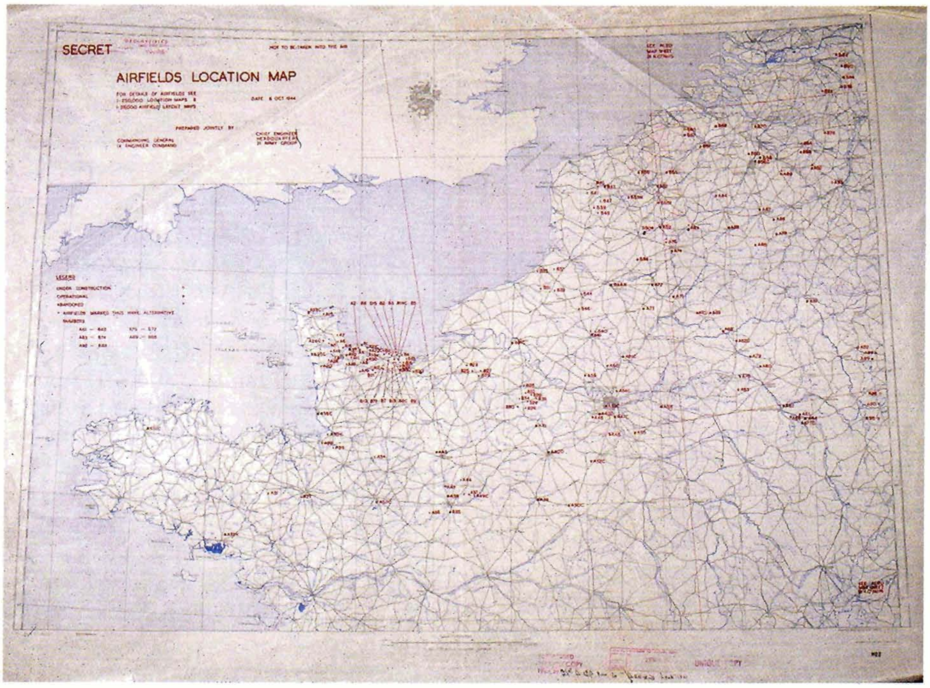


Figure 12. 1:1000 000 Airfields location map of NW Europe. For description, see text. Reproduced with the permission of the British Library, from file Maps MOD 21 A Gp No 6

and theoretical work, carried out with the assistance of the R.R.L. [Road Research Laboratory], elucidated some of the factors of a complex problem

'Geological appreciations were made of all sites selected from air photo interpretation. The suitability of various soils and geological formations for rapid airfield construction was considered and classifications were prepared …

'Potential airfield sites were classified according to topographical and geological suitability.'

The report concludes: 'In the event the intelligence for airfield construction was found to be accurate. Sites which had been examined by Multiplex corresponded, in fact, very closely to the classifications prepared in planning and geological intelligence and appreciations also were found to correspond very closely with actual ground conditions.'

The importance of Multiplex as a means of stereoplotting physiographical features from air photographs is well known. Clough (1952, p. 448) has described its importance for determining potential airfield sites in Normandy, noting that 'The specific requirement was for a large scale contoured map of each selected site which would show all relevant natural and artificial features. Along each provisionally selected runway spot heights were needed at close intervals, so that the gradients could be determined and estimates made for the amount of excavation and filling likely to be required. ... It was in December, 1942, that this project was formulated and, at that time, the mapping company of the U.S. 660th Engineer Topographic Battalion had recently arrived in the United Kingdom with its Multiplex plotting equipment. It was installed at Kew and was working in close liaison with the [British] Directorate of Survey Home Forces. The plotting of detail and height determination from air-photos by Multiplex offered possibilities of obtaining the required standard of accuracy. ... It was [after tests] agreed also that the plans should be at 1/10,000 scale, with contours at 5-foot [1.6 m] vertical interval.' Using Multiplex, then an innovation within the UK (for which Gordon [2001] has provided a recent illustration of equipment and principles of use), air photographs of upwards of 120 sites (Clough, 1952, diagram 12) formed the basis of printed coloured maps (e.g. Clough, 1952, plate 55).

According to Hore (2004, p. 42), 'geologists identified potential [airfield construction] sites and sorties were flown at a height of 12,000 ft (3600 m) using a special 6-inch camera' to obtain appropriate aerial photographs, which were then sent to 660th Engineers.

Although in both the British and the American sectors the airfield construction programme was delayed by the tactical situation – for the Allied troops did not advance exactly at the rate planned – in the British sector ten of the fifteen airfields planned to be operational by D+25 [1 July] had been completed, and eight of the twelve airfields planned for the American sector.

A 1:1000 000 map captioned 'Suitability of country for rapid construction of airfields: Low Countries and N. W. Germany' with key and style identical to the other map of this scale is preserved both in the Shotton Archive and at the British Library.[25] It was clearly prepared as a companion sheet to the map of the western (Normandy) area, but marginal data indicate that printing was in January 1944, significantly later than the Normandy map credited to King.

The British Library does, however, contain a 1:1000 000 'Airfields location map' (Figure 12)[23] dated 6 October 1944 covering the same area as the Shotton 'airfield construction probability map'. A topographical base map is annotated in red to show sites of Allied airfields symbolized in three categories: under construction, operational, and

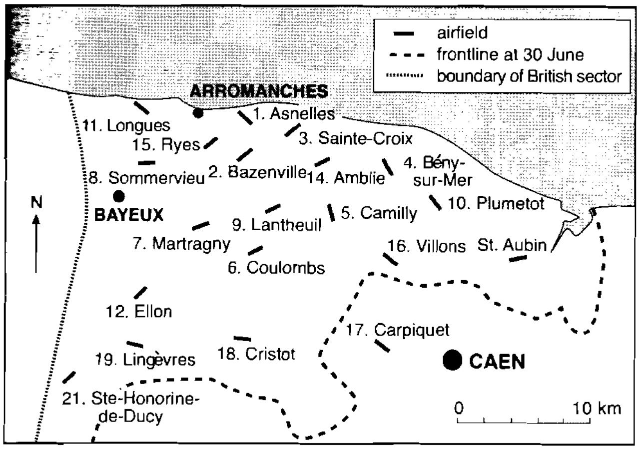


Figure 13. Map showing position and orientation of British airfields in Normandy completed by 13 August 1944 – all west of the Orne estuary, shown to the NE of Caen. After Rioult *et al.* (1994); from Rose and Pareyn (1995), courtesy of Blackwell Publications

abandoned. All airfields are labelled with their British (B) or American (A) official numbers. Map data indicate that this map was prepared jointly by the Chief Engineer HQ 21 Army Group and the Commanding General IX Engineer Command, as map '21 A Gp No. 6'. Its legend states: 'For details of airfields see 1:250,000 location maps & 1:25,000 Airfield Layout maps', confirming the prior existence of these two series. The map serves to illustrate the close correlation between King's 'probability' map and the positions of airfields actually used. That the greatest concentration of airfields is in Normandy (compare Figure 9 with 12, 11 with 13) is indicative of the slow build-up phase early in the campaign. The more sparsely sited airfields to the east are consistent with the subsequent rapid advance of the Allied forces.

Two similar maps are included in the same British Library file[26] which show areas to the east of this region.

The importance of geological information additional to air photographic and topographic map data in the siting of temporary airfields was explicitly documented soon after the War in an unpublished report compiled by Brigadier H. de L. Panet, Deputy Chief Engineer Airfield Construction.[27] This records that 'The value of detailed topographical and geological study in selecting airfield sites in the beach-head area was fully proved .... The most valuable forms of specialised Int[elligence] were 1/100,000 geological overprints ... prepared by the Geologist'. Additionally, he noted: 'Geological study enabled calculated risks to be taken in forecasting the rate of import of airfield surfacing stores. Based on geological information provision was made for surfacing only 50% of the airfields in the British sector as against 75% in the US sector, where more clay was expected. This enabled the stores demand in the British sector to be reduced by over 400 tons a day for the first 30 days of invasion, when every ton was of great importance. Even with this 50% reduction, airfield stores made up nearly 25% of the total planned tonnage of Engineer stores to D+30'.

Nineteen British airfields had been constructed in Normandy by 13 August (Figure 13), and by the end of the month twenty-three were in use, ten with runways surfaced with Square Mesh Track, two with PBS (Prefabricated Bitumenized, or Bituminous, Surfacing), two with repaired concrete, but nine without any special runway material (Rose and Pareyn, 1995, 1996a, 1998, 2003). Their operational significance was quickly the subject of German air photographic assessment (Bauduin and Charon, 1997).

There is broad similarity between the 1:1000 000 airfield probability map for northwest Europe (Figure 9) and the bedrock (solid) geological map at this scale (Figure 2), indicating that bedrock geology did indeed provide some basis for airfield site prediction. But the differences between the maps indicate that data additional to those from such geological maps were also used. Topographical maps and air photographs were certainly important, as already noted. Additionally, from copies preserved in the Shotton Archive,[28] it seems clear that at least Shotton made use of maps at 1:600 000 and smaller scales which show the distribution of peat bogs in France.

## WATER-SUPPLY MAPS

Problems of water supply led to geologist expertise being deployed in support of British military operations for the very first time: Bill King, in France and Belgium during the First World War. Following the outbreak of the Second World War, King was quickly called up and appointed to a Regular Army Emergency Commission in the Royal Engineers (Rose & Hughes, 1993a; Rose & Rosenbaum, 1993b). Sent in the rank of 'local major' again to France, with the British Expeditionary Force, during the winter and spring of 1939/1940 he worked on a variety of problems such as the siting of airfields, the provision of stone and gravel as construction materials, and water supply – before the Force's evacuation from Dunkirk in June 1940. On return to England, he was attached to Northern Command for a year, and then from 1941 to 1943 to GHQ Home Forces – the precursor of 21st Army Group – before being released in October 1943 to take up appointment as Professor of Geology at Cambridge. King was thus the most senior and experienced British military hydrogeologist of the Second World War.

Shotton (1947) has recorded that in the year-long planning stage which preceded the Normandy landings, geological activities included the preparation of water intelligence maps, and that water supply intelligence work continued and developed after D-Day. According to King (1951b, p. 115), maps on the scale of '1/50,000 or thereabouts' were prepared for all the bridge-head areas of Normandy before D-Day, showing with respect to the main aquifers: (1) where small springs might be expected but where boring was unlikely to produce large supplies; (2) the main outcrop area with, where possible, water table contours; and (3) subsurface contours on the top or base of the aquifer to indicate depth of boring. A distinction was made between groundwater expected to be of good quality and that expected to be saline. Explanatory notes were provided, including geological terms. King stated that these maps were a development of the Ground Water Inventory

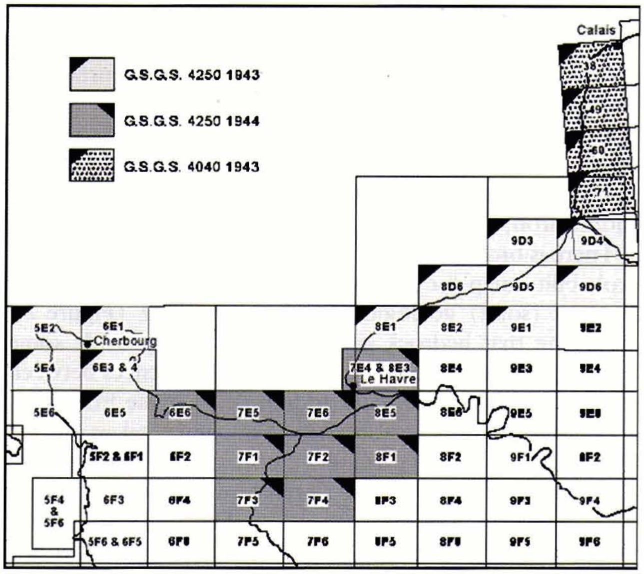


Figure 14. Index to water trace maps prepared in 1943 and 1944 to fit 1:50 000 topographical maps of series GSGS 4250 or 4040; data for topographical maps derived from GSGS map catalogue of October 1945 held by the Bodleian Library, Oxford. See Table 3 for details of water trace map compilation and printing

Maps of the Ground Water Provinces of the United States – but gave no further description, or any illustration.

From examples in the Shotton Archive[29] (Table 3 and Figure 14) and duplicates of about half of these at the Imperial War Museum, it can now be demonstrated that 'water supply maps' were prepared for many areas of northern France, especially Normandy. All were tracing overlays prepared to fit corresponding topographical map sheets. For the GSGS 4250 series of topographical maps at scale of 1:50 000, at least eleven traces were prepared in September 1943 – and so presumably by Bill King, although authorship is not explicitly stated on the traces themselves. Ten other 4250 series maps, which notably include some key areas inland from the invasion beaches, are of later (March or April 1944) date – consistent with the evolution of the plan to invade via the Calvados coast rather than the Cherbourg peninsula or Dover–Calais straits. These all show preparation by 'G.S.I. R.E. 21 Army Gp. in conjunction with Major F W Shotton S O 2 (Geology) 21 Army Gp.' Marginal preparation data mostly indicate that 250 copies were printed, mostly in March 1944, by Map Reproduction Section 15, mostly as task number 121.

The trace for the Creully area (Figure 15) has a legend which distinguishes (from top to bottom) only four rock types, according to their water-bearing properties:

1. Dune sand: insufficient to give [water] supplies to well points.

2. Marsh and peaty alluvium: dug wells will give only poor yields of bad quality water.

3. Limestone: little surface water except in main valleys, numerous dry valleys. Where shaded as at b [small brick ornament] boreholes will give good supplies. Where shaded as at a [large brick ornament] yield will be too small to justify boreholes.

4. Clays: not suitable for borings except where shaded as at b [closely spaced horizontal lines] where the water-bearing limestone will be found beneath.

Additionally, the legend notes that river 'terrace deposits' are not indicated, the formations which underlie these

Table 3. Water trace maps prepared at scale of 1:50 000 to fit topographical maps series GSGS 4250 (21 sheets, numbered 5E/2 to 9D/6) and GSGS 4040 (4 sheets, numbered 38 to 71), as indexed on Figure 14

| Sheet no. | Sheet name | Date/compiler | Printer | Copies |
|---|---|---|---|---|
| 5E/2 | Beaumont-Hague | Sep 43 – King? | 13 S/287 | 150 |
| 5E/4 | Les Pieux | Sep 43 – King? | 13 S/283 | 150 |
| 6E/1 | Cherbourg | Sep 43 – King? | 13 S/370 | 150 |
| 6E/3&4 | Valognes | Sep 43 – King? | 13 S/371 | 150 |
| 6E/5 | Le Haye du Puits | Sep 43 – King? | 13 S/378 | 150 |
| 6E/6 | Isigny | Mar 44 – Shotton | 15 MRS/121 | 250 |
| 7E/5 | Creully | Mar 44 – Shotton | 15 MRS/121 | 250 |
| 7F/1 | Caen | Mar 44 – Shotton | 15 MRS/121 | 250 |
| 7F/3 | Aunay-sur-Odon | Mar 44 – Shotton | 15 MRS/121 | 250 |
| 7E/6 | Trouville | Mar 44 – Shotton | 15 MRS/121 | 250 |
| 7F/2 | Troarn | Mar 44 – Shotton | 15 MRS/121 | 250 |
| 7F/4 | St-Pierre-sur-Dives | Mar 44 – Shotton | 15 MRS/121 | 250 |
| 7E/4&8E/3 | Le Havre | Mar 44 – Shotton | 15 MRS/138/65 | 700 |
| 8E/5 | Pont Audemer | Apr 44 – Shotton | 15 MRS/156/82 | 250* |
| 8F/1 | Lisieux | Apr 44 – Shotton | 15 MRS/156/82 | 250* |
| 8E/1 | Fécamp | Sep 43 – King? | 13 S/375 | 150 |
| 8D/6&8E/2 | St-Valery & Cany | Sep 43 – King? | 13 S/372 | 150 |
| 9D/3&4 | Eu Abbeville | Sep 43 – King? | 13 S/377 | 150 |
| 9D/5 | Dieppe | Sep 43 – King? | 13 S/374 | 150 |
| 9E/1 | Neufchatel | Sep 43 – King? | 13 S/373 | 150 |
| 9D/6 | Gamaches | Sep 43 – King? | 13 S/376 | 150 |
| 38 | Calais | Sep 43 – King? | 13 S/284 | 150 |
| 49 | Boulogne | Sep 43 – King? | 13S/286 | 150** |
| 60 | Montreuil | Sep 43 – King? | 13 S/285 | 150 |
| 71 | Rue | Sep 43 – King? | 13 S/369 | 150 |

*Sheets 8E/5 and 8F/1 both show preparation by 21 AGP/INT/1407/B

**A second version of part of Sheet 49, Boulogne-sur-Mer – water, prepared by R.E. (Int) G.S.I. CIS GHQ HF March 22 '43, shows features of water supply rather than hydrogeology

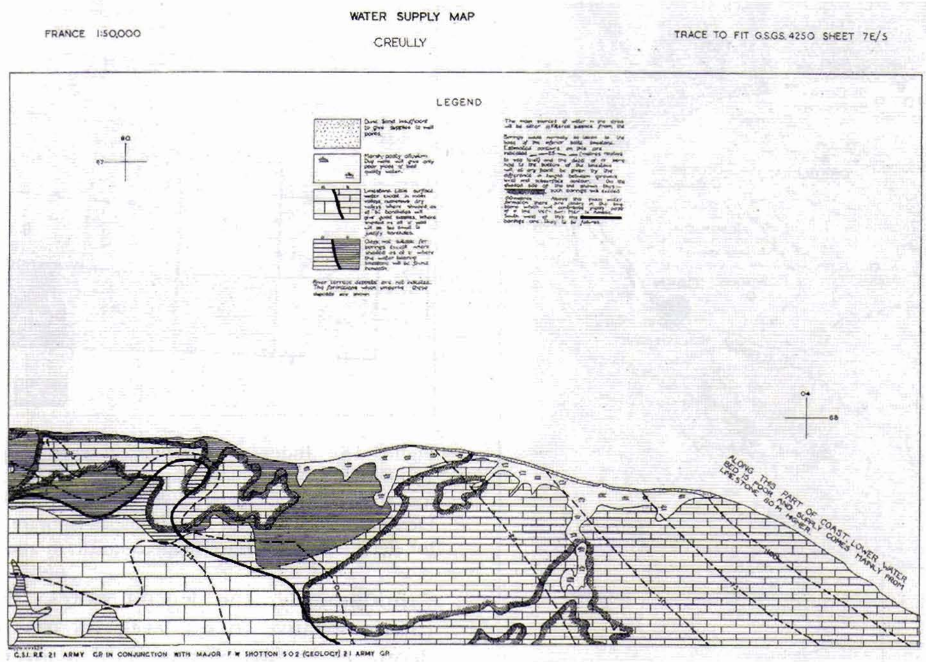


Figure 15. Water supply map: Creully. Trace to fit GSGS 4250 sheet 7E/5, France 1:50 000 – see Figure 14. For explanation, see text. From the Shotton Archive, courtesy of the Lapworth Museum

deposits being shown. Also, that 'Borings would normally be taken to the base of the ... limestone. Estimated contours on this are indicated [by contour lines at 25 metre vertical intervals relative to sea level] ... and the depth of a borehole to the bottom of the limestone will, at any point, be given by the difference in height between ground level and subsurface contour. On the shaded side [of a broad hatchured line] ... such borings will exceed 50 metres. Above this main water formation there are others in the limestone which will contribute yields east of a line Ver-sur-Mer to Amblie. South west of ... [the solid black line on the map] borings are likely to be failures.'

The rock types depicted on this overlay are those which can be derived by simplification from the 1:80 000 geological map of the area (the northwest region of the map depicted as Figure 6).

The trace for the Caen area immediately to the south (Figure 16) reveals a greater range of rock types. The legend (in top right margin of Figure 16, from top to bottom) distinguishes nine units:

1. Marsh and alluvium. When overlying limestone, alluvium may be bored through and cased off, and a [water] supply obtained from [the] limestone.
2. Clays, or clays and limestone. Not suitable for boreholes.

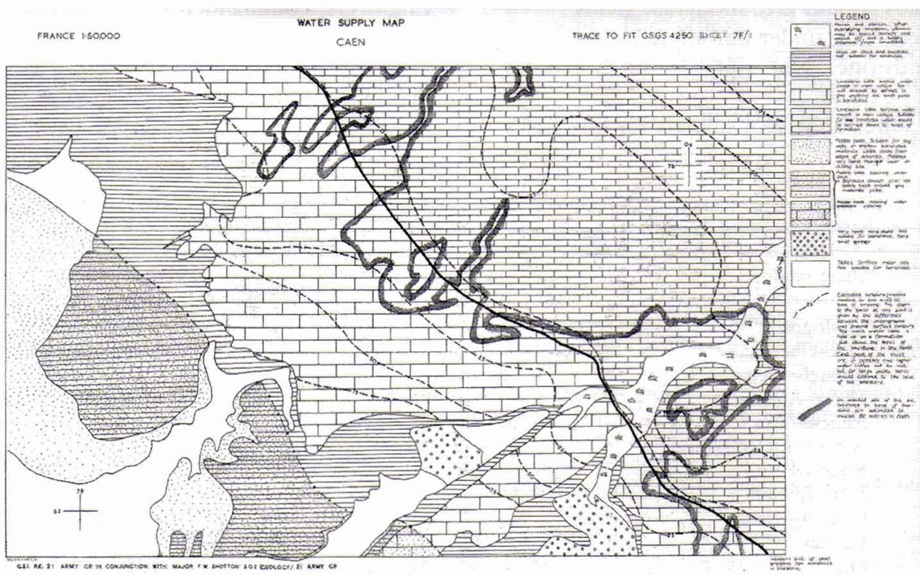


Figure 16. Water supply map: Caen. Trace to fit GSGS 4250 sheet 7F/1, France 1:50 000 – see Figures 14 and 15. For explanation, see text. From the Shotton Archive, courtesy of the Lapworth Museum

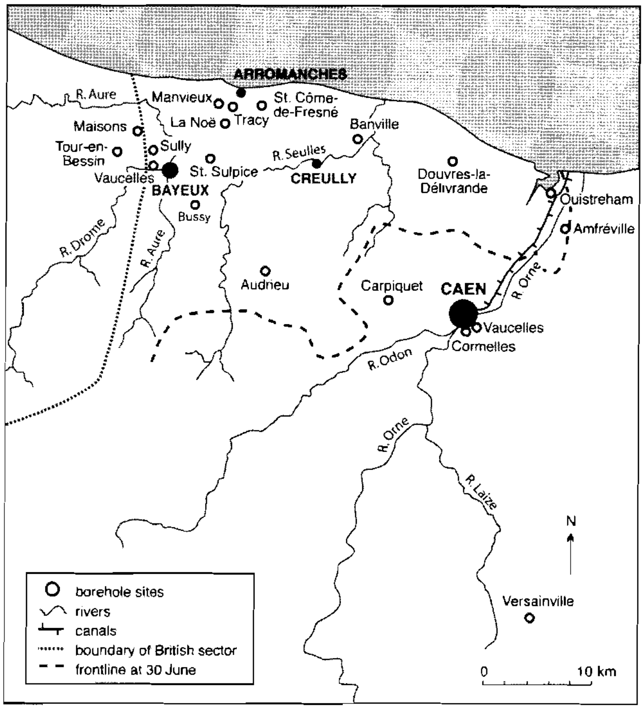


Figure 17. Map showing positions of main rivers and military boreholes through Jurassic strata in Normandy, 1944. See Rose and Pareyn (1996b, 2003) for borehole depths and yields. Amended from Rose and Pareyn (1995), courtesy of Blackwell Publications

3. Limestone. Little surface water except in main valleys. Too well drained by springs to give anything but small yields in boreholes.

4. Limestone. Little surface water except in main valleys. Suitable for boreholes which should be carried down to the base of the formation.

5. Pebble beds. Suitable for dug wells or shallow boreholes, moderate yields away from edges of outcrops. Pebbles are hard, heavy wear on drilling bits.

6. Pebble beds occurring under clays. Boreholes through cover into pebble beds should give moderate yields.

7. Pebble beds occurring under limestone outcrop.

8. Very hard sandstone. Not suitable for boreholes. Some small springs.

9. Slates. Surface water only. Not suitable for boreholes.

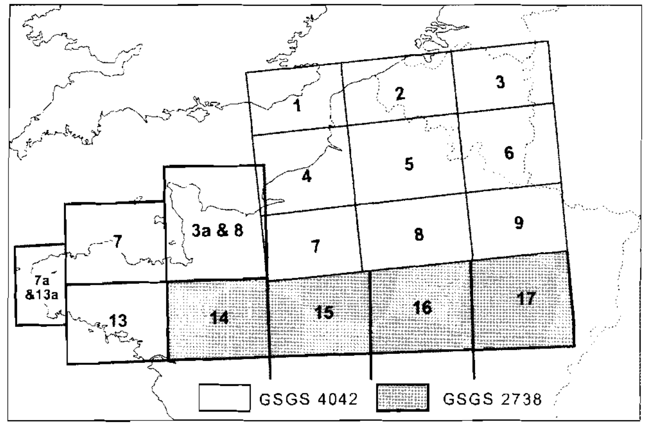


Figure 18. Index to water trace maps prepared in 1944 to fit 1:250 000 topographical maps of series GSGS 4042 and 2738; data for topographical maps derived from GSGS map catalogue of October 1945 held by the Bodleian Library, Oxford. See Table 4 for details of water trace map compilation and printing

Additionally, the legend notes 'Estimated contours (metres relative to sea level) on base of limestone. The depth to the base at any point is given by the difference between the underground and ground surface contours. The main water table is held up on a formation just above the base of the limestone. In the North East part of the sheet one or possibly two higher water tables will be met, but for large yields, bores should continue to the base of the limestone.' A final (hatchured line) symbol is annotated 'On shaded side of this line, boreholes to base of limestone are estimated to exceed 50 metres in depth'.

As for Figure 15, the rock types depicted on this overlay are those which can be derived by simplification from the geological map of the area (a western part of Figure 6).

The Creully and Caen sheets illustrated here (Figures 15 and 16) cover much of the area in which boreholes were actually put down to supply British troops, notably 25 boreholes through Jurassic limestones (Figure 17). These were mostly drilled by No. 8 Boring Section Royal Engineers, commanded by Lieutenant A. K. Pringle RE – who postwar became Professor of Applied Geology at Strathclyde University (Rose and Pareyn, 2003) – and to depths up to 105 m, generally with satisfactory if modest yields (Rose and Pareyn, 2003, Table 3). Six shallow holes

Table 4. Water trace maps prepared at scale of 1:250 000 to fit topographical maps series GSGS 4042 (9 sheets, numbered 1 to 9) and GSGS 2738 (4 sheets, numbered 14 to 17), as indexed on Figure 18

| Sheet no. | Sheet name | Date/compiler | Printer | Copies |
|---|---|---|---|---|
| 1 | Boulogne | Aug 44/King | 13 MRS/1633 | 2.5 |
| 2 | Lille–Ghent | Aug 44/King | 13 MRS/1694 | 2.5 |
| 3 | Brussels–Liège | Aug 44/King | 13 MRS/1694 | 2.5 |
| 4 | Havre–Amiens | Apr 44/Shotton | 15 MRS/156/82 | 250 |
| 5 | Amiens–Mons | Aug 44/King | 13 MRS/1634 | 2.5 |
| 6 | Namur–Luxembourg | Sep 44/King & Black | 13 MRS/1724B | 2.5 |
| 7 | Rouen–Paris | ?/Shotton | ? | ? |
| 8 | Paris–Rheims | Aug 44/King | 13 MRS/1639 | 2.5 |
| 9 | Chalons–Nancy | Sep 44/Black | 13 MRS/1724A | 2.5 |
| 14 | Rennes | ?/Shotton | ? | ? |
| 15 | Orleans | Jun 44/Shotton | 13 MRS/1435 | 250 |
| 16 | Auxerre | Aug 44/King | 13 MRS/1639 | 2.5 |
| 17 | Epinal | Sep 44/King & Black | 13 MRS/1724C | 2.5 |

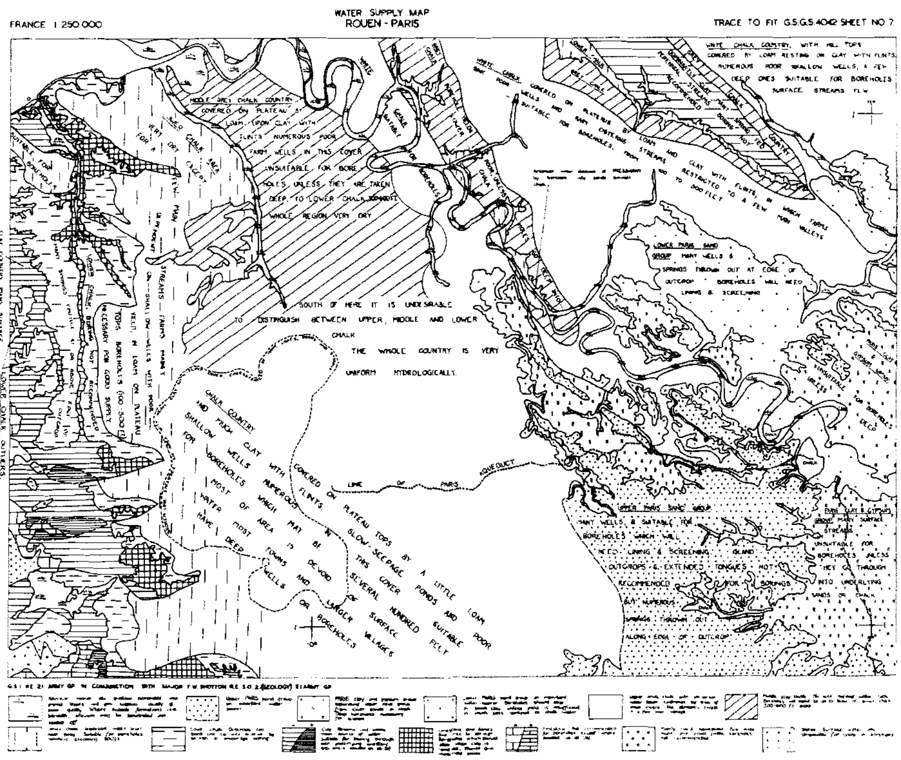


Figure 19. Water-supply map: Rouen–Paris. Trace to fit GSGS 4042 sheet No. 7, France 1:250 000 – see Figure 18. Prepared 'in conjunction with Major F. W. Shotton'. For key, see Table 5. From the Shotton Archive, courtesy of the Lapworth Museum

were also put down, in Quaternary alluvium near the River Drome, in ground unfavourable for deep boreholes but where the gravel of the alluvium effected a natural filtration, reducing the number of filtration plants and pumps required.

Both the Shotton Archive and the Imperial War Museum contain traces at the same scale to fit GSGS 4040 maps of regions east of Normandy (Table 3 and Figure 14). These are all dated 1943 and so were presumably prepared by Bill King. According to the Imperial War Museum catalogue, the base map is one of the 'rearmament' series of maps which GSGS initiated in 1936. Contracted out to the Ordnance Survey, the series was derived from a then new French 1:50 000 map series where it existed in the French frontier zone, otherwise from a variety of French, Belgian, British (1914–18 war), German and Dutch maps – newly-drawn material giving a very patchy effect.

The Shotton Archive also contains thirteen water supply maps[30] (and the British Library duplicate copies of seven of these) prepared as tracing overlays for areas covering the whole of northeast France at a scale of 1:250 000 (Table 4 and Figure 18) – presumably to aid the rapid advance of the Allied forces to Paris and beyond. The western four – Havre–Amiens, Rouen–Paris (Figure 19), Rennes, Orleans – show preparation by 'G.S.I. RE. 21 Army Gp. in conjunction with Major F. W. Shotton R.E. S.O.2 (Geology) 21 Army Gp.' and provide evidence of his continuing and widening responsibilities for water supply mapping. The others, for northern and eastern areas – Boulogne (Figure 20), Lille–Ghent, Brussels–Liège, Amiens–Mons, Namur–Luxembourg, Paris–Rheims, Chalons–Nancy, Auxerre, Epinal) typically show preparation by 'Engineer Section 0.1.2. G.2 (Int) Div., S.H.A.E.F.

Table 5. Key to Figure 19, from left to right, top row first

[1] Alluvium, marsh etc. shallow boreholes into gravel layers will give supplies usually of poor quality. Where suitable formations exist beneath, alluvium may be penetrated and sealed off.
[2] Upper PARIS sand group an important water-bearer.
[3] PARIS clay and gypsum group separating upper sand group from lower sands or chalk. Deep boreholes necessary for success.
[4] Lower PARIS sand group, an important water-bearer. Boreholes should stop in basal clay unless yield is insufficient, in which case continue to chalk water.
[5] Upper white chalk with universal water table controlled by level of main rivers. No streams except in a few main valleys.
[6] Middle grey chalk. No well defined water table. Boreholes will need to go to base of lower chalk 300–600 ft [100–200 m] deep.
[7] Lower chalk. Important water level near base. Suitable for boreholes, nowhere exceeding 300 ft.
[8] Lower chalk. Outcrops too small and too well drained by springs to encourage boring.
[9] Clay. Streams and ponds main source of water. Suitable for boring through into underlying limestone only where shaded as at (b) [right half of symbol shown in key].
[10] Limestone and sands. Give rise to springs. Boreholes which should stop when clay is reached, should give moderate yields.
[11] Limestone. Not recommended for boreholes except where shaded as at (b) [right half of symbol shown in key].
[12] Mainly hard sandstone. Dug wells might give small yields; boreholes not recommended.
[13] Slates. Surface water only. Unsuitable for wells or boreholes.

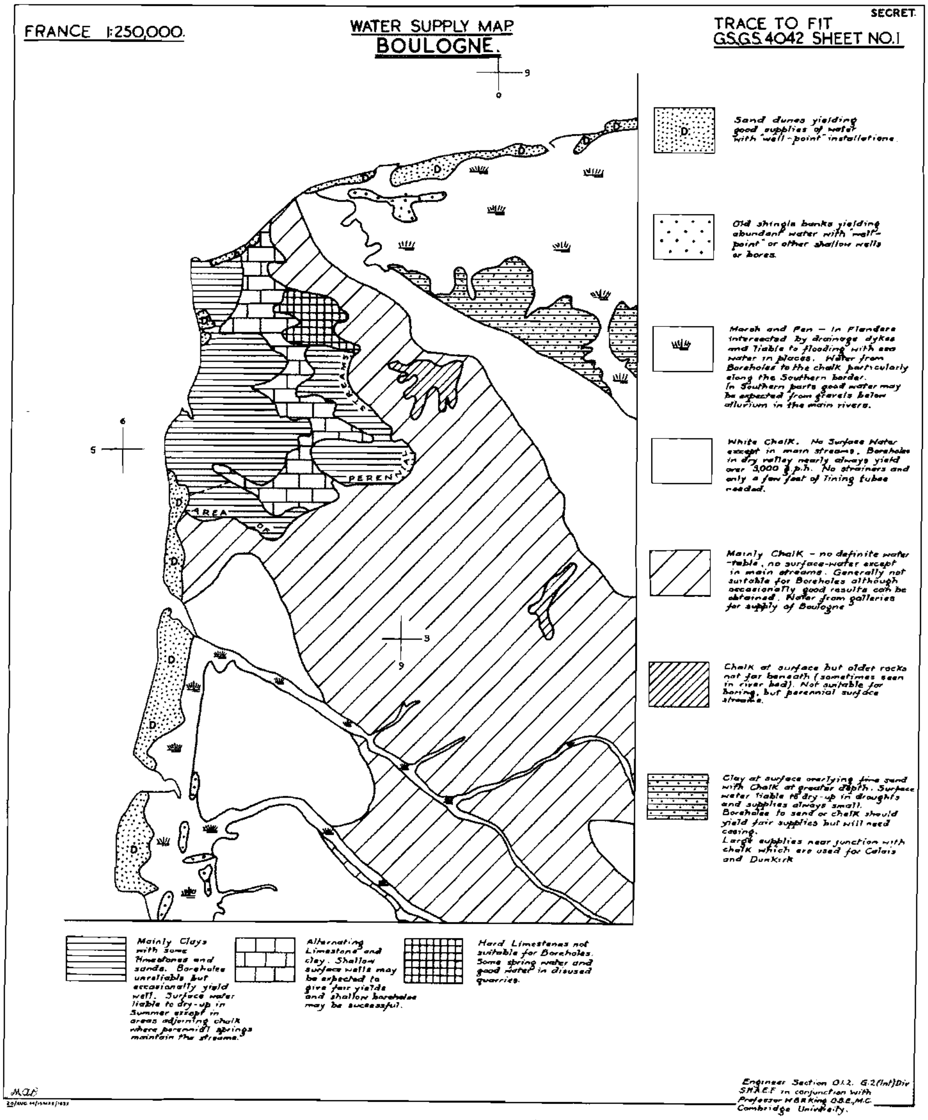


Figure 20. Water-supply map: Boulogne. Trace to fit GSGS 4042 sheet No. 1, France 1:250 000 – see Figures 18 and 19. Prepared 'in conjunction with Professor W. B. R. King'. For key, see Table 6. From the Shotton Archive, courtesy of the Lapworth Museum

in conjunction with Professor W.B.R. King O.B.E., M.C., Cambridge University' – evidence that, although he had relinquished military rank on moving to Cambridge, Bill King was still actively putting his specialist expertise at the service of his country, to help generate maps for the Supreme Headquarters Allied Expeditionary Force. According to the marginal data on the latest, most westerly, sheets of these maps, he was finally assisted at Cambridge

Table 6. Key to Figure 20, from top to bottom, then left to right

[1] Sand dunes yielding good supplies of water with 'well-point' installations.
[2] Old shingle banks yielding abundant water with 'well-point' or other shallow wells or bores.
[3] Marsh and Fen – in Flanders intersected by drainage dykes and liable to flooding with sea water in places. Water from boreholes to the chalk particularly along the southern border. In southern parts good water may be expected from gravels below alluvium in the main rivers.
[4] White Chalk. No surface water except in main streams. Boreholes in dry valley[s] nearly always yield over 3000 g.p.h. [gallons per hour]. No strainers and only a few feet of lining tubes needed.
[5] Mainly Chalk – no definite water table, no surface water except in main streams. Generally not suitable for boreholes although occasionally good results can be obtained. Water from galleries for supply of Boulogne.
[6] Chalk at surface but older rocks not far beneath (sometimes seen in river bed). Not suitable for boring, but perennial surface streams.
[7] Clay at surface overlying fine sand with chalk at greater depth. Surface water liable to dry up in droughts and supplies always small. Boreholes to sand or chalk should yield fair supplies but will need casing. Large supplies near junction with chalk which are used for Calais and Dunkirk.
[8] Mainly clays with some limestones and sands. Boreholes unreliable but occasionally yield well. Surface water liable to dry up in summer except in areas adjoining chalk where perennial springs maintain the streams.
[9] Alternating limestone and clay. Shallow surface wells may be expected to give fair yields and shallow boreholes may be successful.
[10] Hard sandstones not suitable for boreholes. Some spring water and good water in disused quarries.

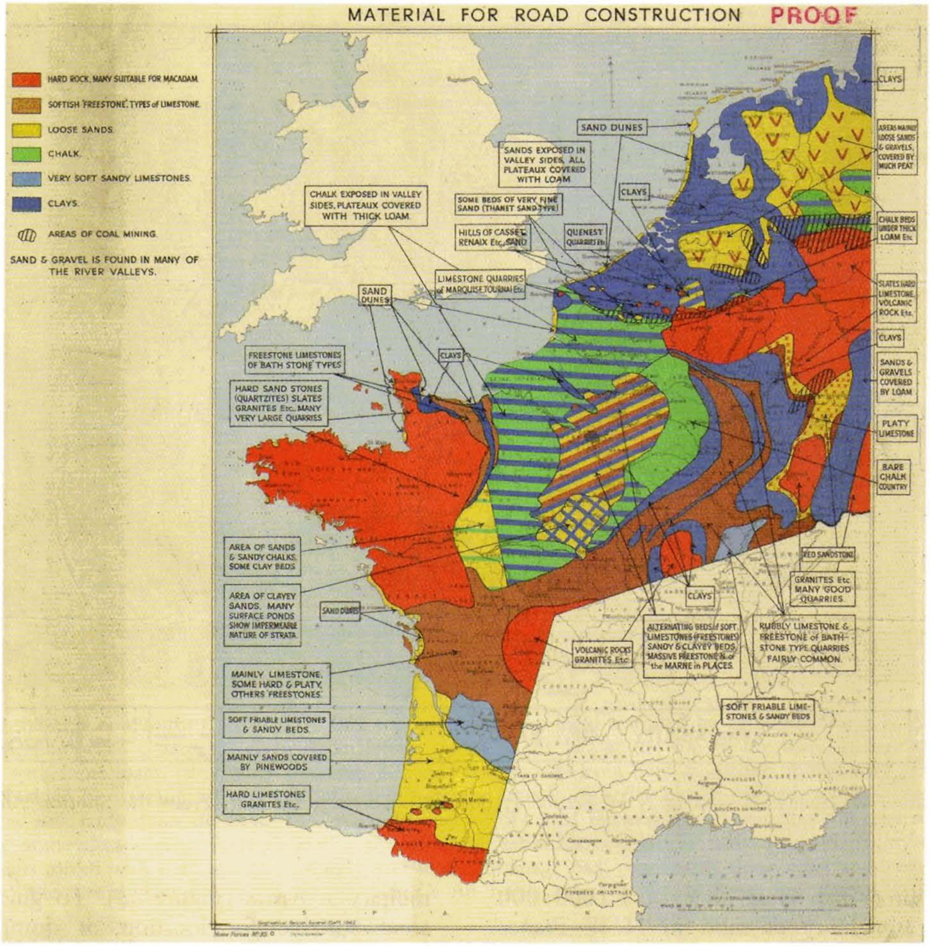


Figure 21. Material for road construction: western and northern France, Belgium and Holland. Proof copy of map at 1:2934 000 (46.3 miles to 1 inch) prepared for printing in May 1943. For key, see text. From the Shotton Archive, courtesy of the Lapworth Museum

in this respect by his academic colleague Dr M[aurice] Black – whose distinction as a sedimentologist and micro-palaeontologist became well known (D. H. R., 1974), but not his war service in preparation of these specialist maps.

Whether at a scale of 1:50 000 or 1:250 000, the rock units depicted on these maps can be derived from the geological maps at scales of 1:80 000 and perhaps (for the smaller-scale maps) 1:1000 000 printed as GSGS editions, interpreted in hydrogeological terms partly from first principles, partly it is assumed from data for northern France gathered by King whilst serving there as a hydrogeologist for most of the First World War, and the early part of the Second. For the 1:250 000 maps, apart from the Rouen–Paris and Rennes sheets prepared by Shotton (presumably earlier than the others, because of their proximity to Normandy) for which printing details are not recorded, and the Havre–Amiens sheet (again by Shotton, and in April 1944 the earliest dated sheet) which was printed, like the 1:50 000 maps, by Map Reproduction Section 15, printing was consistently by Map Reproduction Section 13 – initiated by June 1944 by Fred Shotton, followed in August by Bill King, who was joined by September by Maurice Black.

## CONSTRUCTION MATERIALS MAPS

The Shotton Archive contains two examples of construction materials (i.e. resources) maps.

One is a proof copy of a map at 1:2934 000 (46.3 miles to 1 inch) of western and northern France, Belgium and Holland showing material for road construction (Figure 21).[31] Marginal data show that the proof was printed in May 1943, and therefore before Shotton arrived to replace King as SO 2 (Geology) at 21st Army Group. The key at the top left of the map distinguishes six materials by colour, from the top down:

'Hard rock, many suitable for macadam.
Softish "freestone", types of limestone.
Loose sands.
Chalk.
Very soft sandy limestones.
Clays.'

Areas of coal mining are shown by diagonal lining, and the key ends with the note that 'sand & gravel is found in many of the river valleys'. Brief notes printed on the face of the map provide description of the rock types characteristic of the principal areas.

The data shown on this map are consistent with those provided by geological maps (e.g. Figure 2), amplified by remarks on the distribution and size of quarries (which could have been derived from larger scale topographic maps). Since the map is known only from a single proof, it seems that it was not deemed to be of sufficient military value to merit final printing as multiple copies.

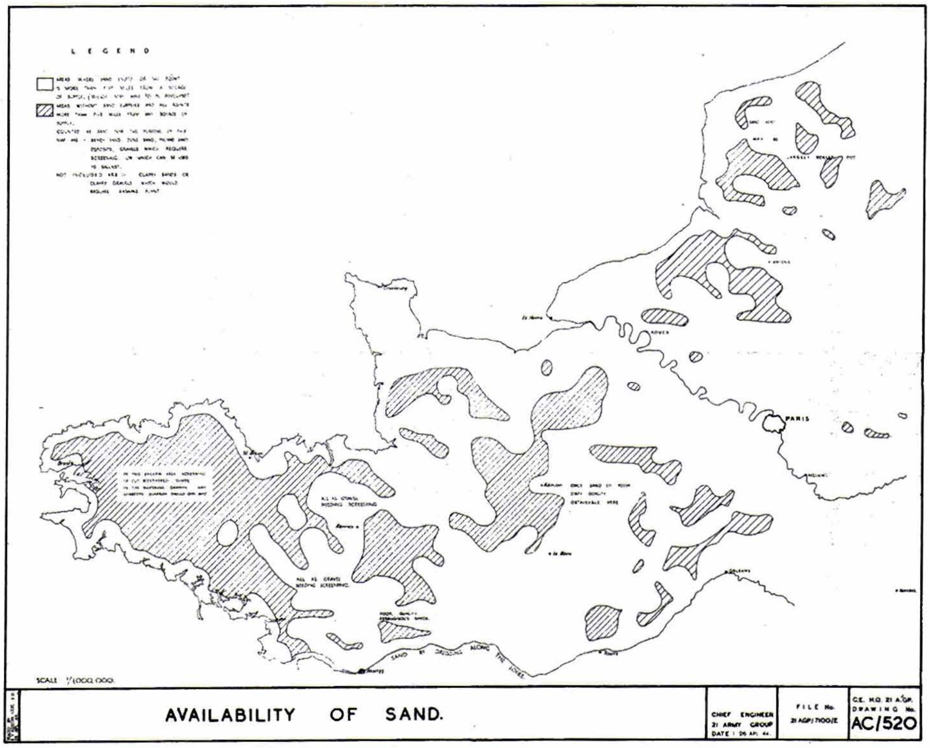


Figure 22. Map to show availability of sand in N W France 1:1000 000. For key, see text. From the Shotton Archive, courtesy of the Lapworth Museum

The second resource map is at scale of 1:1000 000 and indicates the availability of sand in N W France (Figure 22).[32] It distinguishes ground in terms of only two categories:

[blank] Areas where sand exists, or no point is more than five miles from a source of supply (which may have to be developed).

[diagonal lines] Areas without sand supplies and all points more than five miles from any point of supply.

A note to the key explains; 'Counted as sand for the purpose of this map are beach sand, dune sand, inland sand deposits, gravels which require screening or which can be used as ballast. Not included are clayey sands or clayey gravels which would require washing plant.' Wording on the face of the map provides more detailed comment for specific areas. Prepared as a tracing overlay, this map was atypically reproduced as a Royal Engineer drawing rather than printed by a Map Reproduction Section. Classified 'secret', the copy in the Shotton Archive is numbered 51.

Although preparation of maps showing the availability of building construction materials was a standard task amongst German military geologists (Rose and Willig, 2004: Rose, 2005), these two maps are seemingly unique examples of such British military geological work for or during the early months of the northwest European campaign of 1944.

## SOIL MAPS

Following D-Day, the terrain immediately inland from the beach areas was intensively utilized for a wide range of military activities (Figure 23). To guide the selection of areas suitable for location of dumps for stores and ammunition, at least two 1:50 000 maps were prepared which categorized ground conditions according to whether surface soils were well or poorly drained: Creully (Figure 24) and the Caen sheet (Figure 25) immediately adjacent to the south. These two sheets bear marginal

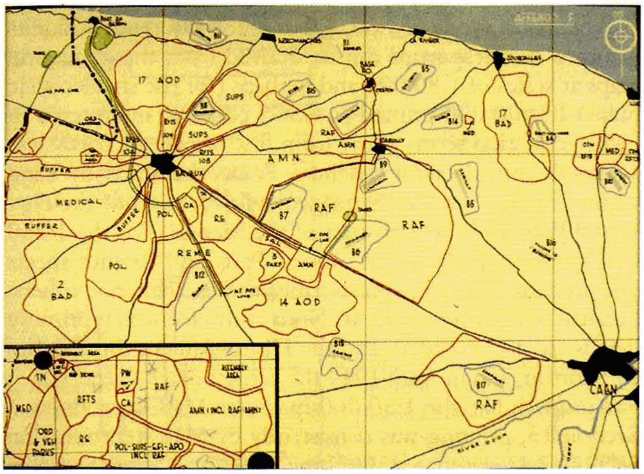


Figure 23. British military use of land inland from the Normandy landing beaches. Areas occupied by the Royal Air Force are mostly outlined in blue. Army areas, outlined in red, are largely for ammunition (Base Ammunition Depots), fuel (Petrol/Oil/Lubricants), stores (Army Ordnance Depots), hospitals (Medical), and vehicle and equipment maintenance (Royal Electrical and Mechanical Engineers). From Anon. (1945), courtesy of the Royal Engineers Library, Chatham

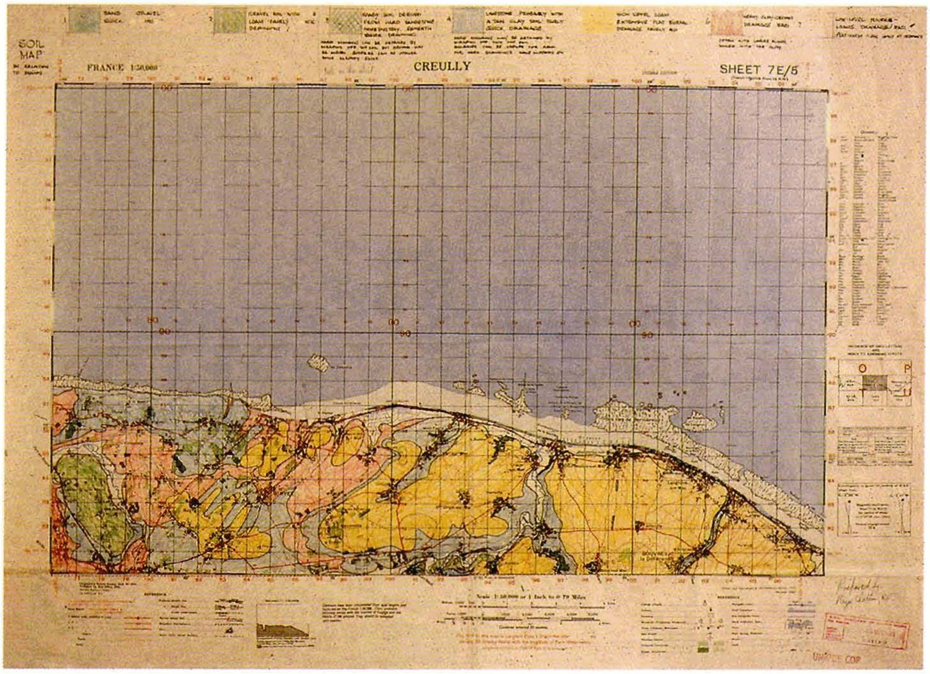


Figure 24. Soil map in relation to dumps: Creully. 1:50 000 topographical map hand-coloured by geologist Major F. W. Shotton in 1944 to distinguish areas according to seven categories, given (from left to right) in the key at the top of the map: 1. Sand and gravel soil, quick draining. 2. Gravel soil with some loam, fairly quick draining. 3. Sandy soil derived from hard sandstone immediately beneath, quick draining; hard standing can be obtained by scraping off top soil but ground may be uneven; quarries can be opened, some already exist. 4. Limestone, probably with a thin clay soil, fairly quick drainage; hard standing may be obtained by scraping off thin top soil; quarries can be opened for rock for hard standings, some already exist. 5. High level loam, extensive flat surfaces, drainage fairly quick. 6. Heavy clay ground, drainage bad; often with large flints mixed with the clay. 7. Low-level river-loams, drainage bad; peat-marsh along coast at Meuvaines. Donated by the Ministry of Defence to the British Geological Survey. © NERC. All rights reserved. From Rose and Pareyn (2003), courtesy of the Geologists' Association

annotation handwritten in blue ink that preparation was by Major F. W. Shotton. There are, however, no examples of such maps in the Shotton Archive. The only two maps currently known were donated by the Defence Geographic Agency to the British Geological Survey, and are now preserved in the Survey archives at Keyworth, Nottingham.[33] The pattern of rock distribution shown on these maps is so similar to the pattern shown on the corresponding parts of the 1:80 000 geological map that

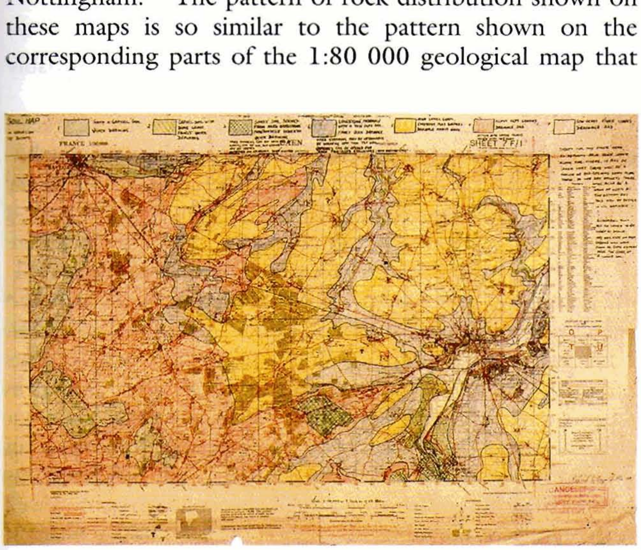

Figure 25. Soil map in relation to dumps: Caen. For key, see Figure 24. Donated by the Ministry of Defence to the British Geological Survey. © NERC. All rights reserved. From Rose and Pareyn (2003), courtesy of the Geologists' Association

the maps are seemingly only simplifications of the geological map, with rock types grouped and classified according to 'suitability for dumps', and nothing more: compare Figures 24 and 25 with western areas of Figure 6. Comparison with Figures 15 and 16 shows how the geology of exactly these two areas can also be interpreted in terms of hydrogeology rather than soil properties.

Both the Shotton Archive and the British Library contain a 'generalised soil map' for the Rouen–Paris area, to the east of Normandy, at a scale of 1:250 000 (Figure 26).[34] The key in the bottom margin distinguishes six categories of material:

1. [Yellow] well-drained soils, e.g. sands, sandstones, limestone, chalk.
2. [Green] loam soil.
3. [Blue] heavy clay soil (includes much clay-with-flints).
4. [Red] marsh and areas liable to flood.
5. [Vertical lines of green alternating with yellow] alternations of sand and clay.
6. [Black diagonal lines] rock may be expected a short distance below soil.

Marginal data show that the map (sheet 7) was printed in August 1944. Precisely the same area was interpreted by Shotton in hydrogeological terms (Figure 19), and it is clear from maps (partly hand-coloured by crayon and so evidently in course of preparation) of the three adjacent areas which are preserved in the British Library that these 'soil' maps were also prepared by Shotton: sheet 4 bears the endorsement 'legend as for sheet 7' and is signed in ink 'F.

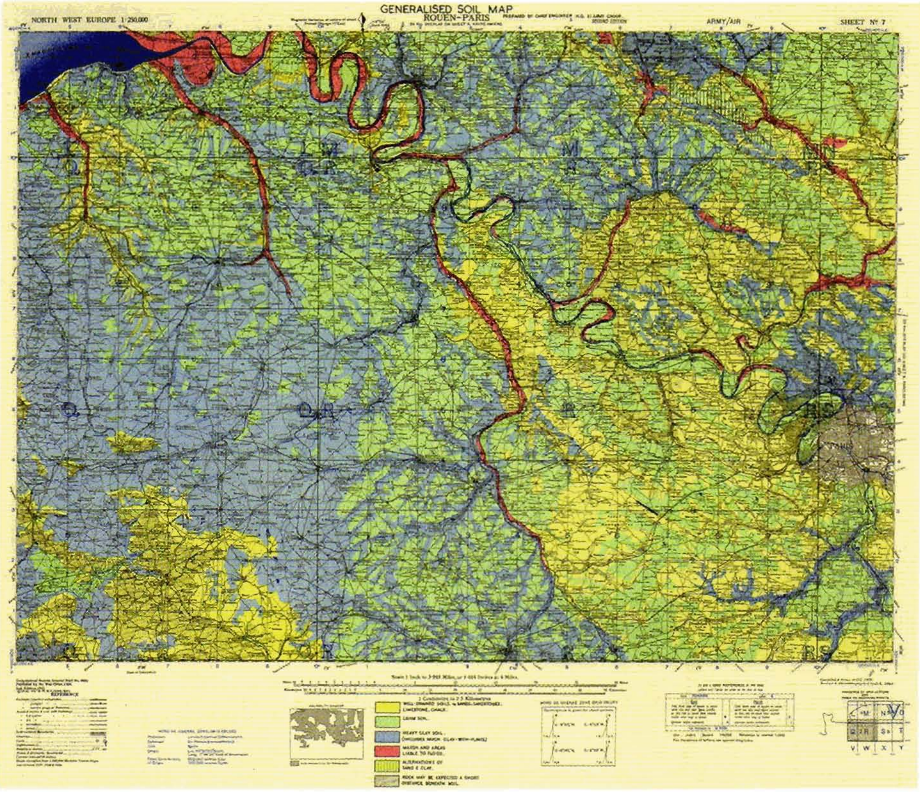


Figure 26. Generalised soil map North West Europe 1:250 000 sheet no. 7 Rouen–Paris. For key to colours, see text. From the Shotton Archive, courtesy of the Lapworth Museum

W. Shotton' and dated 13 August 1944, sheet 8 is endorsed in pencil 'legend as on previous sheets' in Shotton's handwriting. Since the British Library maps are accompanied by a two-page typescript 'Notes on generalized soil maps. Suitability for airfield construction. 1:250,000 GSGS 4042 Sheet No 7' dated 26 August 1944, it appears that these soils maps were prepared to aid siting of temporary airfields rather than to indicate the suitability of the ground for cross-country vehicular movement. Allied forces advanced eastwards quickly in August – seemingly more quickly than the 'soil' maps could be prepared for printing.

Documents in the Shotton Archive show that as early as 1943 Bill King had provided detailed comments on the feasibility of producing a soil map of Normandy at scale of 1:250 000 to indicate conditions favourable or unfavourable for cross-country movement of tanks, and such maps were further considered by Fred Shotton in association with other specialists meeting under ISTD auspices in early 1944.[35] That a series of such soil maps was not in fact produced is presumably an indication of the low priority their preparation was given in the planning phase of the invasion. The road network inland from the coast was apparently deemed to be sufficiently good for ground conditions likely to affect cross-country mobility not to be of major concern.

## CROSS-COUNTRY MOVEMENT AND 'GOING' MAPS

There is one map – for Creully – at scale of 1:25 000 (Figure 27)[36] in the Shotton Archive that, although it lacks a caption, shows features of natural terrain likely to influence cross-country movement of troops or vehicles. Marginal data note that details have been plotted from air photographs, specifically from sorties flown in September, October, and December 1943, and in January 1944. In addition to topographical features printed in black, water bodies in blue, and contours brown, the map uses a colour wash to denote three categories of ground condition:

1. [Red] ground probably soft.
2. [Purple] flooding, depth 6 inches or over.
3. [Green] ground appears uncultivated and probably suitable for assembly area (minefields not considered).

Solid red lines are used to denote natural tank obstacles inland, dashed red lines natural vehicle obstacles inland. Roads and tracks over six feet [2 m] wide are shown in heavy black. Symbols printed on the map indicate for each road if there is a bank on one or both sides (B1, B2), a ditch on one or both sides (D1, D2), a hedge on one or both sides (H1, H2), and the width of the road 'excluding sidewalks and verges' in feet (R plus number). Bridges are shown with load classification (CL), and overall length in feet (L plus number). Streams have the width at water level shown in feet (W plus number). There is no indication on the map that either Shotton's expertise or geological information in general was used to generate this map – although regions where the ground is shown as probably soft correspond well with regions of alluvium depicted on the 1:80 000 geological map (Figure 6). The area depicted on this map can be compared directly with the geology as depicted on part of Figure 6, the water supply trace for the larger area reproduced as Figure 15, and the 'soils' map of Figure 24.

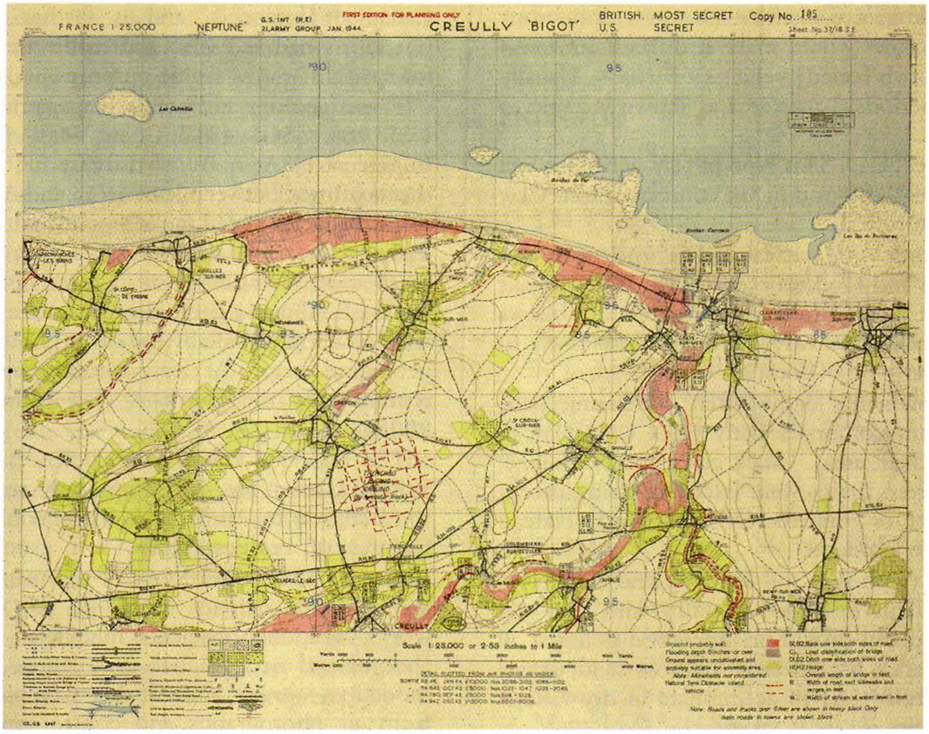


Figure 27. Seemingly a cross-country movement map, classified 'Bigot': France 1:25 000, sheet no. 37/18 S.E. Creully. Prepared for 'Neptune' [the landings component of Operation Overlord] by G.S. Int. (RE), 21 Army Group, January 1944. Marked 'First edition for planning only'. For description, see text. From the Shotton Archive, courtesy of the Lapworth Museum

In contrast, one other map in the Shotton Archive,[37] at 1:100 000 and from a report generated by or for the 1st Canadian Army, quite specifically relates geology and 'going' for the Caen–Falaise area (Figure 28). The key in the left hand margin distinguishes five rock types by black ink ornament, with going in wet and in dry conditions tabulated to the right, from the top downwards:

1. [Horizontal dashes] alluvium (mixed peat, clay, loams, silt). This country, except where marsh and peat

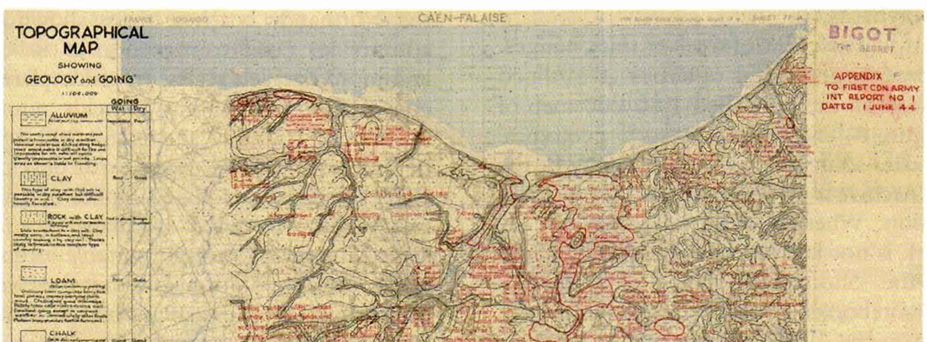


Figure 28. Topographical map showing geology and going 1:100 000, sheet 7F Caen–Falaise. Appendix F to First Canadian Army Intelligence Report No. 1, dated 1 June 1944. For description, see text. From the Shotton Archive, courtesy of the Lapworth Museum

prevail, is traversable in dry weather. However, numerous ditches along hedgerows would make it difficult for tanks and impassable for 'wh'[eeled] vehicles off roads. Usually impassable in wet periods. Large area as shown is liable to flooding.

2. [Vertical dashes] clay. This type of clay-with-flint soil is passable in dry weather but difficult country in wet. Clay areas often heavily forested.

3. [Dots alternating with vertical dashes] rock with clay (clay soil with rock and sandstone outcrops). Slate breaks down to a clay soil. Clay mostly concentrated in hollows and level country making a heavy clay soil. Tracks likely to break in this rougher type of country.

4. [Crescent ornament] loam (often containing pebbles). Ordinary loam comprises fairly thick level plateau country overlying chalk areas. Chalk gives good drainage. Pebbly loam near rivers drains well. Excellent going except in very wet weather or immediately after frosts. Plateau loam provides fertile farmland.

5. [Blank] chalk (with thin soil covering and also loam, sand, gravel, etc.) This limestone country with thin soil cover is well drained and should provide good going at all times. Some small areas are covered by loose sand, gravel and broken flint which tend to accumulate in dry valleys. These are no obstacles if care is taken.

Features shown in red ink, according to the key, are those of slopes (impassable, and passable but difficult), woods (impassable, and passable but difficult), rivers (width of water, depth of water, height of banks above water, and nature of bottom), and the maximum extent of flooded areas. Two notes at the bottom of the key record that: (1) where an obstacle is shown crossing a road, the road is not impassable but constitutes a gap through the obstacle; and (2) the term 'farming community' indicates a small compact collection of houses, each with small fields or gardens and small orchards, the field, garden or orchard usually surrounded by a dense row of trees or thick hedges.

The similarity between geological outcrops as outlined on this map and those on the published 1:80 000 map of the Caen area (Figure 6) indicates that such geological maps were primary data sources. Presence of a copy of the map in the Shotton Archive is evidence that he was aware of the map's preparation. Whether or not he was actually involved in this work is not known, but a pencil draft of a memorandum in the Shotton Archive[38] (in one of Shotton's personal notebooks) provides 'a classification of soils likely to result on the 1/80,000 sheets 28, 29 & 45 given to Second Army Intelligence as a basis for forming "going" maps. The classification has been somewhat condensed in the going map of the Caen–Bayeux area which resulted. It is the opinion of the writer, however, that it is undesirable to group types of ground into too limited a number of categories ...' The memorandum lists the stratigraphical lettering on the three geological map sheets numbered, and how the soil classification corresponds to these geological units.

The British Library possesses a map not present in the Shotton Archive which also shows geology and going at 1:100 000 scale, but for the adjacent area to the northeast: sheet 8E Le Havre – Pont-Audemer.[39] This too was prepared for the Canadian Army, specifically by the Royal Canadian Engineers, and is further evidence that the Canadians had access to and made use of geological data for specialist cartographic purposes.

These 'geology and going' maps are very different to the 1:25 000 GSGS 4347 Going Maps prepared by 660th Engineers USA. A British Library file[40] contains thirteen sheets printed between June 1943 and April 1944 which do show obstacles in red (solid line for natural tank obstacles, dashed line for vehicle obstacles), streams in blue (with width at water level in feet), and soft ground as a red wash – but no geological features as such. These maps were seemingly made by use of air photographs rather than geological maps. At least one sheet was captured and reprinted by the Germans (Ian Mumford, pers. com., 2005).

The 1:25 000 GSGS 4347 Defences Maps, in the same British Library file, had commonly reached a second or third edition by April 1944. These too possessed a key to features of bridges, roads, soft ground, obstacles and streams, but on the reverse of the map provided a key to an additional defence legend in ten categories: defence works, weapons, obstacles, minefields, demolitions, naval [booms and nets], signals installations, personnel accommodation, storage, and airfields. Compilation was explicitly from air photographs and control provided by existing French triangulation – with no apparent geological input.

## CONCLUSION

Maps preserved in the Shotton Archive reveal that Major (later Lieutenant Colonel) W. B. R. King and more significantly Major F. W. Shotton, as successive members of the planning team at HQ 21st Army Group, in the role of Staff Officer Grade 2 (Geology), helped to compile a series of beach maps at 1:5000 scale to guide landings on the Normandy beaches; maps showing the suitability of country for rapid construction of airfields at 1:1000 000 and more detailed scales, to guide plans for the siting and construction of temporary airfields; numerous map overlays at scales of 1:50 000 and 1:250 000, to guide deployment of well boring units tasked with development of groundwater to ensure adequate supplies of drinking water for the troops; a few so-called 'soil maps' to guide site-selection of areas with good drainage, suitable locations for 'dumps' of stores and ammunition; and that they were aware of the use of geology in the generation of maps that interpreted terrain in terms of impediments to potential military cross-country movement – 'going'.

As described recently by Rose and Willig (2004), German geologists when planning a cross-Channel amphibious assault earlier in the war, into south east England, had also prepared beach maps – but with less time and fewer data sources available, these were at smaller scale and showed far less detail. Both sides generated groundwater maps primarily at a scale of 1:50 000, but the German maps were more simplistic in format (to aid instant military comprehension of 'go', 'no go' and 'slow go' areas), and designed primarily to guide emplacement of shallow wells rather than boreholes. The British were different in that a high priority was given to preparation of maps showing the suitability of ground for construction of temporary airfields

– whereas the Germans do not seem to have used their army geologists in this way at that time. The Germans, however, did use their military geologists to compile specialist building resources maps – whereas with the exception of a map showing availability of sand, the British expected Royal Engineer officers of the Quarry Group to make use of geological maps as such, if necessary with help from the geologist at HQ 21st Army Group. Neither side at this stage gave great priority to preparation of 'going' maps which incorporated geological data, presumably since both recognized good road systems existed in the area of scheduled operations. Both sides were to develop such maps later, for other operations.

At the close of hostilities, ISTD geologists were quickly tasked with appraising the value of military geological output both British and German.[3] An appraisal of the specialist maps generated by British geologists for the D-Day landings and operations in Normandy[2] drew four conclusions:

1. 'Where a country is covered by geological maps, such as the G.S.G.S. copies of the 1:80,000 French Geological Maps, together with abundant geological literature, as in France, Geological Military Intelligence can be both reliable and useful when interpreted by an experienced geologist.

2. Suitable scales for presenting information should be adopted early in a campaign.

3. Geological intelligence becomes unreliable, misleading and almost useless when presented to a scale of 1:1,000,000.

4. The scales adopted should not be less than 1:250,000 for generalised work; 1:50,000–1:100,000 for more detailed work; 1:10,000 for the actual planning of airfields ... [and 1:5000 to 1:25,000 for useful beach maps].'

Maps which reliably predicted ground conditions affecting cross-beach mobility, airfield construction, and water supply were thus confirmed as having military value in the Allied campaign which culminated in victory and the end of the war in Europe.

## ACKNOWLEDGEMENTS

We are grateful to Elise Hall, Lapworth Scholarship Student, who prepared a catalogue of the Shotton Archive for our use; owners of copyright, as acknowledged in figure captions, for permission to reproduce the specified illustrations; librarians at the British Library, Bodleian Library, Imperial War Museum, British Geological Survey, and the Cartographic Branch of the National Archives and Records Administration at College Park, Maryland, USA, for access to maps in their collections; staff at the National Archives, Kew, for help, as yet unsuccessful, to locate similar maps in their extensive holdings of 21 Army Group and Operation Overlord files; the Defence Geographic Centre, Feltham, for confirmation that the Ministry of Defence Geospatial Library no longer holds copies of the maps described herein; Anne Ankcorn of the School of Geography, University of Birmingham, for drawing figures 14 and 18; Professor Paul Smith, Director of the Lapworth Museum, for advice and assistance in photographing maps in the Shotton Archive; and Ian Mumford plus an anonymous referee for their comments on the paper as first submitted.

## ENDNOTES

1 Shotton Archive, in the Lapworth Museum of Geology, University of Birmingham: accession no. 124-1 (part).

2 National Archives, Kew: WO 252/150. ISTD/CR/2 Northern France Check Reconnaissance: Geology. ISTD, January 1946.

3 Shotton Archive: accession no. 171 (part). Farrington, J. L. (1946). **History of the Geological Section of the Inter Services Topographical Department October 1943 – June 1946**. Unpublished report, ISTD.

4 British Library: shelfmark Maps 14315.(34.).

5 British Library: Maps 15.c.17.

6 British Library: Maps 35.f.7. (87.). Strategic Engineering Study 87.

7 Shotton Archive: accession nos. 9, 16-1, 16-2, 176. Marginal data (500/8/43/BJO) indicate that 500 copies were printed in August 1943 by the Ordnance Survey. The British Library contains a 1948 reprint: Maps 14315. (18).

8 British Library: Maps 14315.(6.).

9 GSGS 4326, sheets 1 to 90, less sheets 18, 26, 37–39, and 54–56, which cover marine rather than land areas: see British Library, Imperial War Museum and Bodleian Library catalogues; also the **Directorate of Military Survey and Geographic Section, General Staff, catalogue of maps** published by the War Office in October 1945, a copy of which is held in the Map Room of the Bodleian Library, Oxford.

10 National Archives: WO 252/1462. ISTD/CU/1007. List of Reports Issued. ISTD, May 1945.

11 National Archives: WO 252/583. CB 4096 J. ISIS Report on France. Volume 2. Normandy west of the Seine. ISTD, January 1943. For description of coast north of Le Havre and inland regions north of the Seine, see also WO 252/582. BR 876 J. ISIS Report on France. Volume 1. North East France. ISTD, December 1942.

12 The address was later selected as one of the two papers reprinted by Betz (1975) to represent military geology in a volume of (largely American) benchmark papers in environmental and engineering geology. Published in the USA, with introductory remarks by the editor, this reprint is the version best known in North America.

13 British Library: Maps MOD 21 A Gp No 21.

14 Shotton Archive: accession nos. 4 to 8. Marginal data for all sheets: 350/4/44/15M.R.S./167/94.

15 Shotton Archive: accession nos. 1 to 3. Marginal data: 403/3/44/14M.R.S. for all sheets, but final project numbers 235, 236, and 237 for sheets 67 Vierville, 68 Colleville, and 69 Ste. Honorine respectively.

16 National Archives: WO 203/3164 (part). Résumé of geological work in MEF [Middle East Forces] and East Africa and 21 Army Group. [A typescript prepared by Major F. W. Shotton].

[17] The Shotton Archive (within accession no. 64) contains translations of several extracts from papers published in the **Société Linnéene de Normandie Bulletin**, and a translation from the **Academie des Sciences, Arts et Belle-Lettres de Caen Mémoires**.

[18] Shotton Archive: accession no. 57-1 section across Broomhill Beach near Lydd 18 December 1943; 57-2 geological cross-sections of Pett Beach near Hastings 16 December 1943; part of 124-1, notebook containing *inter alia* studies on beach sediments and calculations of the effect on vehicles of a peat-fronted beach under different tidal conditions; part of 124-2, Brancaster beach surveys [section], horizontal scale 1″ = 10 m, vertical scale 1″ = 1 m, signed F. W. Shotton, Major RE.

[19] British Library: Maps MOD 21 A Gp No 21. Sheets 70 Port-en-Bessin, 73 Arromanches-les-Bains to 82 Ouistreham consecutively, and 86 Houlgate. An index on the map margin indicates that sheets 68 and 69 had also been prepared, but not 71 or 72. Duplicates of all but the Arromanches sheet are held by the Bodleian Library: C21:37(26).

[20] Bodleian Library: C21:37(27) – copies numbered individually between 547 and 573. Copies are also held by the US National Archives and Records Administration, College Park, MD, as part of Record Group 498 ETOUSA, France, beach exit profiles, landing beaches.

[21] Royal Engineers Library, Chatham: accession no. 2776. Anon. (1944). **1 Corps Engineer Report. Normandy 6th June 1944 to 31st July 1944**. 18 sections (unpaginated), drawings A-M.

[22] Shotton Archive: accession no. 52-2. Marginal data state only 'CE [Chief Engineer] 21 Army Group. Home Forces Outline No. 67', with no indication of map title, print run, date of production, or printing unit.

[23] British Library: Maps MOD 21 A Gp No 6.

[24] Shotton Archive: accession no. 124-1 (part).

[25] Shotton Archive: accession no. 52-1; also British Library: Maps MOD 21 A Gp No 17. Marginal data: 300/1/44/13 M.R.S./820.

[26] British Library: Maps MOD 21 A Gp No 6.

[27] Royal Engineers Library, Chatham: accession no. 4562WD. Panet, H. de L. (1945). **Lessons on the Campaign in Europe 1944–45. Airfield construction**.

[28] Shotton Archive: accession nos. 58-1 Carte générale des tourbières et des principaux gisements de tourbe en France 1:600 000, 58-2 Esquisses paléogéographiques des tourbières de France au Quaternaire récent. From Chouard (1931a, b).

[29] Shotton Archive: accession nos. 23 to 26, 39 to 44, 45B, 45D (part), 63-1; the Imperial War Museum, London, also preserves ten sheets for GSGS 4250 (6E/1, 6E/3+4, 6E/5, 7E/4+8E/3, 7E/5, 7E/6, 7F/2, 7F/4, 8E/5, 8F/10), and all four for GSGS 4040 (38, 49, 60, 71).

[30] Shotton Archive: accession nos. 27 to 38, 45A, 45D (part); also British Library file Maps MOD GSGS 4042 contains sheets 1–3, 5, 6, 8, and 9 only.

[31] Shotton Archive: accession no. 124-2 (part). Marginal data Home Forces No. 35. 0. /5/43/523 RE/687. DRWG. 13 M.R.S. RE/1.

[32] Shotton Archive: accession no. 194. Availability of sand. Chief Engineer HQ 21st Army Group drawing no. AC/520, dated 26 April 1944.

[33] Archives, British Geological Survey Library, Keyworth, Nottingham.

[34] Shotton Archive: accession no. 49. Marginal data: GSGS 4042, 2nd edition 1943 (for base map), 10/Aug 44/15 M.R.S./230/341 (for soils map as such). British Library: Maps MOD GSGS 4042 [soils] contains printed sheet 7, plus hand-coloured sheets 4, 5 and 8.

[35] Shotton Archive: accession no. 124-1 (part). See, for example, 'Soil maps as affecting "Going"' [queries addressed to Major King, and his reply, undated]; 'Soil maps and tank travel' [notes of discussion at ISTD, Oxford, on 16 February 1944].

[36] Shotton Archive: accession no. 21. Marginal data: GSGS 4347, 800/2/44/16 M.R.S./211. Classified 'most secret'; numbered as copy 105.

[37] Shotton Archive: accession no. 22. Marginal data: 21 A Gp No. 26. 1,000 / 5 / 44 /14 M.R.S. / 432 / 179. The topographical base map is shown as sheet 7F of the map series France 1:100 000, which can be identified from the 1945 GSGS map catalogue as GSGS 4249.

[38] Shotton Archive: accession no. 124-1 (part). Notebook containing draft in pencil of a memorandum marked 'Most Secret. Bigot. Copies to SO2 Engineer Section TIS [Theatre Intelligence Section], I (Tech) 21 Army Group, G(I) Second Army. I.S.T.D. Subject:- Soil Types, Overlord Area'. The contents follow a conversation on 4 February 1944 between the Chief Engineer Second Army, the Staff Officer Royal Engineers Grade 2 Intelligence of the Second Army, and the SO2 (Geology) 21 Army Group [i.e. Major F. W. Shotton].

[39] British Library: Maps MOD GSGS 4249 (Going).

[40] British Library: Maps MOD GSGS 4347.

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