THE GEOLOGY OF A POSSIBLE SITE FOR THE M42/RIVER TRENT CROSSING AT SWARKESTONE, DERBYSHIRE

by

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Summary

A preliminary geological investigation of the site suggested a complex geological structure existed in the area and a seismic refraction survey and further boreholes were used to elucidate the fault pattern in strata considered to be Upper Carboniferous in age (Namurian - Westphalian A). Many of the new boreholes were inclined at 45°, arranged in pairs, the boreholes of each pair being inclined towards each other. New evidence was obtained on the thickness of the alluvial flood plain deposits, the character of the bedrock and the position of the faults. The possibility of earthquakes and their effects, in this area, are briefly discussed.

Introduction

The proposed route of the M42 Birmingham-Nottingham Motorway (Castle Donington Section) was published by the Department of the Environment in September 1972. The published route showed a crossing of the River Trent at a site near Swarkestone in Derbyshire. Reference to the 1 inch to 1 mile Institute of Geological Sciences Sheet 141 of the Loughborough area suggests that, at the proposed bridge site (SK380274), under the cover of flood plain sands and gravels, Upper Triassic rocks on the north side would be faulted against those of the Upper Carboniferous (Millstone Grit Group) on the south, by a fault trending in a more or less east-west direction. The fault is drawn close to the River Trent. A second fault, parallel to the first, on the north side of the flood plain cuts the Triassic rocks, whilst a third fault, trending north-west to south-east, close to King's Newton, although shown on the one inch map terminating before reaching the River Trent, might produce a small disturbance further to the north-west and would then intersect the main fault close to or at the proposed bridge site.

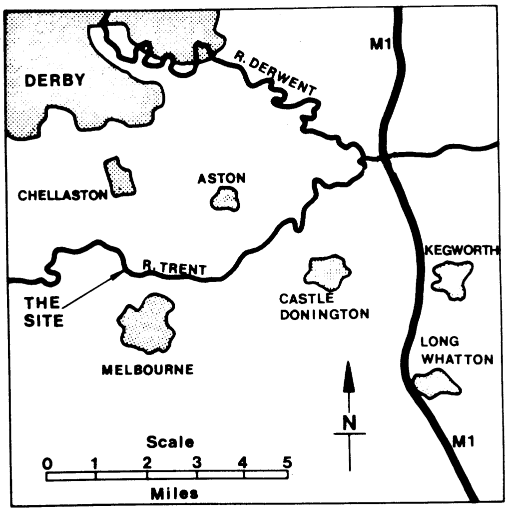
During the course of preliminary investigations carried out in 1971 (including boreholes 34-37, text-fig. 2) and a subsequent seismic refraction survey in 1972, it became clear that whilst the general geology shown on the one inch map and outlined on text-fig. 2 was essentially correct, the details were more complex, particularly those affecting the faulting, which would have to be accurately determined should bedrock foundations for the bridge be considered necessary in the final analysis.

This paper is concerned mainly with the details of the bedrock geology, although the characteristics of the flood plain deposits have been studied as possible founding materials for the bridge.

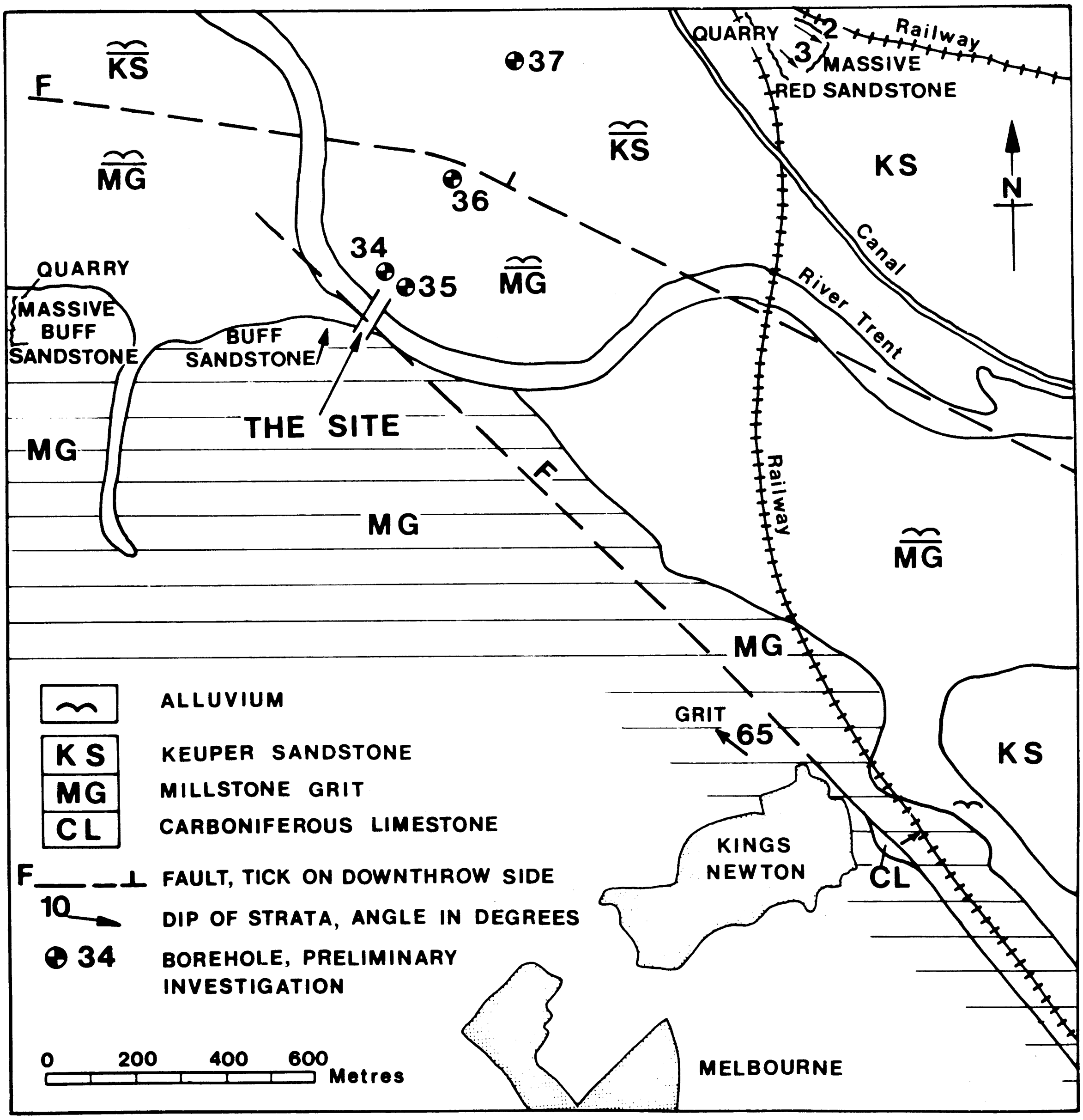
Preliminary Geological Survey

Surface investigation of the site revealed an extensive flood plain, up to 1000 m wide. On the south side, the flood plain is marked by a river cliff 7 m in height, made up of coarse buff sandstone with occasional small pebbles, a typical Millstone Grit lithology. To the north, there is an old quarry exposing fine-medium red sandstone, well bedded and considered to be of Upper Triassic (Keuper) age. Boreholes 34 to 37, north of the river encountered below

Mercian Geologist, Vol. 6, No. 1, 1976. 25-31, 4 text-figs.



Text-fig. 1. Location map.



Text-fig. 2. Outline geology map and bore-hole sites of the preliminary survey.

the alluvial sands and gravels various lithological types associated with the Millstone Grit Group - buff sandstones, grey siltstones with plant remains and grey and black mudstones. The rocks in borehole 35 indicated exceptionally high dips.

The Seismic Survey

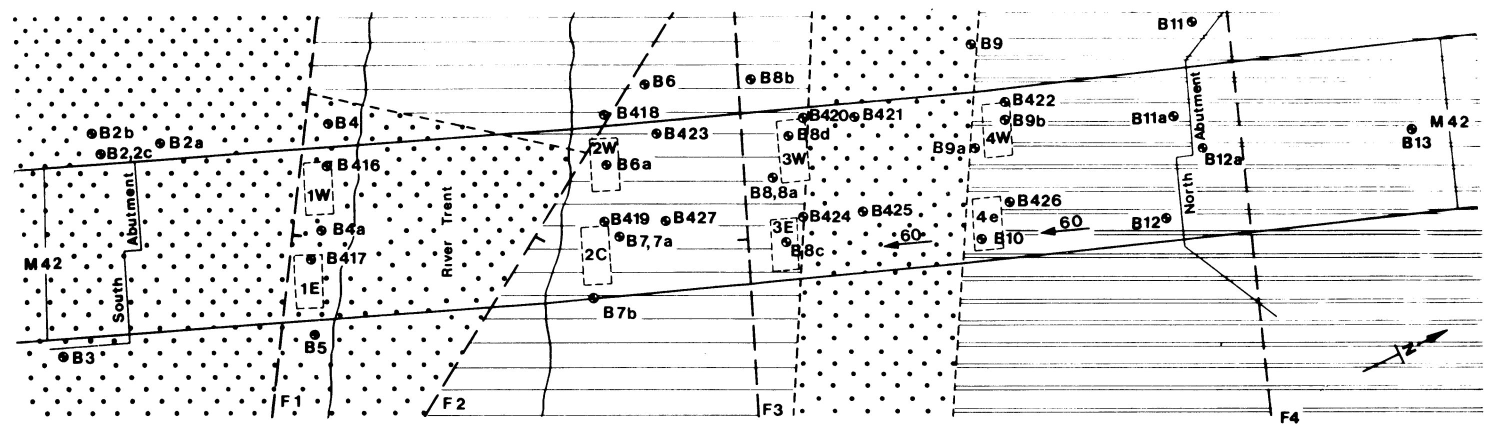
The preliminary survey now indicated that the main Carboniferous/Triassic fault (or unconformity) was to the north of borehole 36 and south of borehole 37. The steep dip of the beds in borehole 35 indicated the presence of a large fault close to this position. Furthermore, little was known about possible variation in the thickness of the alluvial deposits. In order to determine this and to precisely locate the position of the fault or faults, a seismic refraction survey was commissioned along the line of the proposed route and bridge crossing. The method consists essentially of introducing a pulse of energy into the ground and measuring the travel times of the pulse between its source and a line of detectors (geophones) embedded in the ground surface. By plotting time/distance graphs the seismic velocities of the sub-surface strata may be calculated, and in suitable geological situations the thicknesses of layers of different seismic velocities determined.

The detection of geological faults by the seismic method depends on either, the rock formations on the two sides of the fault having different seismic velocities, or, the broken and fractured rock in the fault zone having a lower seismic velocity than the sound rock on either side. In the latter case the fault zone would have to be at least as wide as the geophone separation to ensure detection.

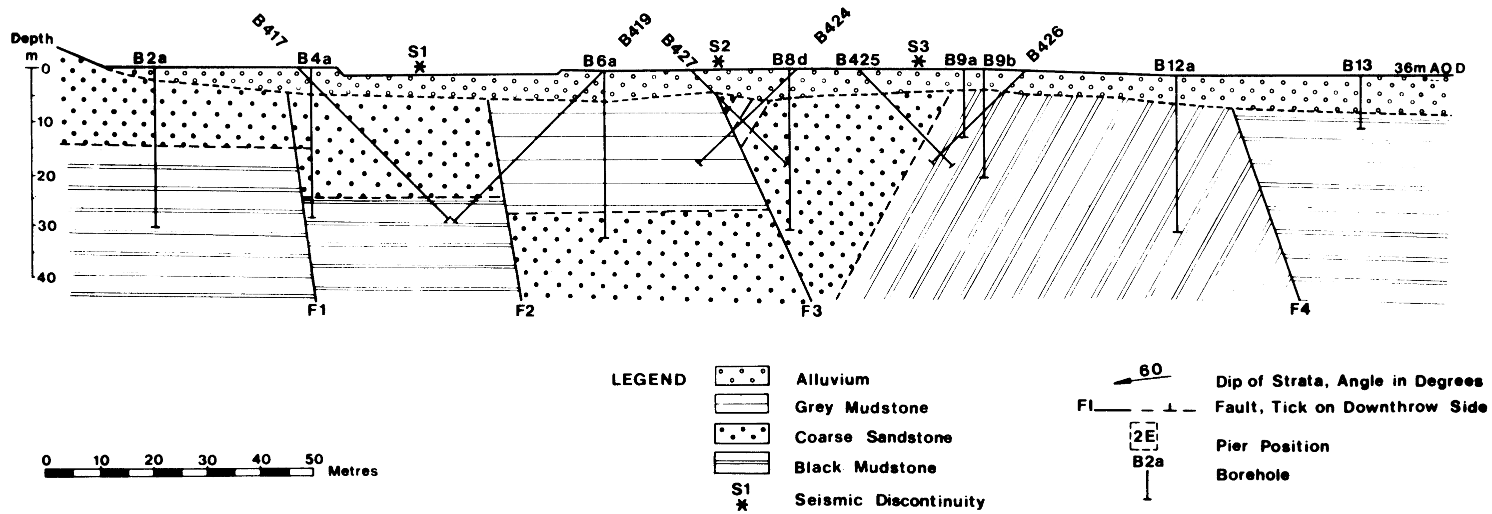
A Dresser SIE RS4 12-channel seismograph with associated geophones, hydrophones and cables was used for the survey. It was carried out by shooting a series of seismic refraction spreads along pegged traverse lines. Each spread consisted of 12 geophones (or hydrophones in the case of the cross-river spreads), spaced 5 metres apart. This relatively close spacing of the geophones was selected to give the best possible definition of the position of any seismic velocity change which might indicate a fault in the bedrock. The energy was provided by the detonation of a small charge of gelignite ($\frac{1}{4}$ to 1 lb weight) buried about 1 metre below the ground surface. Five charges were normally fired for each spread, one at each end and one in the middle of the spread, offset 3 metres from the line of geophones, and two out-shots located 30 to 70 metres beyond the ends of the spread, also offset 3 metres from the extended line of geophones. Successive spreads were laid end to end, the last geophone of one spread becoming the first geophone of the next. For the spreads across the River Trent, the seismic cable was suspended above the water surface and pressure-sensitive hydrophones were anchored on the bed of the river. The charge at the centre of these spread was fired in the water. A total of 17 seismic spreads was completed during the survey, consisting of 1, 55 m spread across the river and 16 spreads on the river banks, aggregating 863 m. The data obtained from the seismic survey, combined with the results of the preliminary boreholes, indicated the thickness of the alluvial deposits and the positions of three possible faults on the site, in positions S1 - S3, text-fig. 4.

Detailed Site Investigation

A more detailed borehole programme was now planned to determine the characteristics of the alluvial deposits, the bedrock geology and the position of the faults. As the position of one of the faults (S1) was indicated below the channel of the River Trent, boreholes inclined at 45° were proposed, intersecting at depth below the channel to cut the fault plane. The method was extended to establish the position of the other faults S2 and S3. Additional vertical cored and percussion boreholes are shown on text-fig. 3, B2 - 13. The interpretation of the new evidence obtained is shown in plan, text-fig. 3 and by the horizontal section, text-fig. 4.



Text-fig. 3. Plan of the M42/River Trent Crossing (legend below).



Text-fig. 4. Section along the mid-line of the M42/River Trent Crossing.

Alluvial Deposits

These were found to consist of thin layers of predominantly cohesive soil occasionally underlain with organic (peat) deposits and overlying thick gravel and sand deposits, with layers of cobbles and occasional boulders. Layering within the gravel was irregular, the lithology and thickness of the layers being highly variable. The irregularity of the deposits in this part of the Trent Valley is undoubtedly demonstrated by the sinuous route of the present Swarkestone Road Bridge and Causeway which crosses the flood plain a few hundred metres to the west of the proposed site.

The Bedrock Geology

The following sequence of Carboniferous strata is established from lithological evidence only. (The borehole cores were not available for exhaustive palaeontological examination as they were also required for extensive engineering tests.) Plant fossils were located at a number of points in the mudstones but there was no obvious marker horizon. The exact age of the rocks is thus still in doubt.

Sandstone, fine to medium grained, located in B419 only.	less than 1 m
Mudstones, predominantly grey in colour, becoming darker with depth; laminated red and green in places with frequent thin siltstones and sandstone.	15 m
Coal; core broken, mixed with mudstones.	1 m
Sandstones, coarse, often pebbly; variable grain size near top, with thin siltstone and mudstone bands. (Outcrops on south bank of River Trent.)	18 m
Mudstones, black in colour, often with a distinctive brown weathering on joint and bedding surfaces, with laminated layers and occasional siltstone bands.	30 m +

The main types are described below:-

Upper Group of Grey Mudstones

The grey colour of these rocks may be due to sub-aerial weathering before deposition of Triassic rocks, later removed by erosion. Red and green beds suggest oxidation of iron. The mixed lithology of the group is sufficient to distinguish it from the lower group of mudstones.

Sandstone Group

The sandstones below the grey mudstone form a single 'Millstone Gritstone Unit' and are labelled as a single unit 'coarse sandstone' on text-figs. 3-4. It is a typical arkose with occasional pebbles up to 1 cm diameter. Many surfaces through the cores showed slickensides - grooves and ridges resulting from movement - and were coated with a white mineral, probably kaolin.

Lower Group of Black Mudstones

The black mudstones at the base of the sequence form a major lithological unit. The rocks have an irregular fracture and bedding is often indistinct. This is usually indicated by occasional laminated beds or thin siltstone seams. In boreholes B9, B9a, B422 and B426 the mudstones displayed highly polished surfaces, indicating movement along these planes.

Distribution of the Rocks

The distribution of the rocks is represented in text-figs. 3 and 4. Beneath the alluvium, the sandstones are located south of the river and to the south of fault F2. A thin cover of grey mudstones covers the sandstones beneath the river, west of the bridge site. The younger group of mudstones are mainly developed between faults F2 and F3 in the centre of the site. The older group of mudstones is seen, below the alluvium, at the north end of the site.

Structural Geology

South of the fault F3, the dip of the beds is relatively shallow and variable in direction. North of fault F3, steep dips to the south, in excess of 45° were noted. The dip in B13 was difficult to determine; it was thought that the beds were horizontal, but the length of this core was only a few metres. Reference has already been made to signs of movement in the rocks, indicated by polished surfaces and slickensides in the sandstones. The difficulty in establishing a lithological sequence in such a small area must be due to faulting. The structure is probably too complex for an accurate picture of the faulting to be determined on the available evidence, but four main faults are indicated:-

Fault F1

South of the River Trent, the Sandstone/Black Mudstone junction was seen to be at a depth of about 15 m, but below the river, the angled boreholes indicated a depth of 28 m. Borehole B4A cut the junction at 26 m depth. The dip of the beds south of the river is only slightly to the north and beneath the river the dip increases by merely a few degrees. The junction in B4A was highly inclined and it is concluded that the borehole here passed very close to the main fault plane. Minor faults, indicated by slickensides, occurred throughout the sandstone part of the core. Most faults in the local Carboniferous rocks are 'normal faults', that is, the fault plane is inclined towards the downthrown side of the fault. If this is the case, the sub-alluvial position of the fault would be just to the south of the pier 1 positions.

Fault F2

The occurrence of this fault was indicated by the presence of a thin sandstone sequence in B419, with part of the sandstone faulted out, and the low position of the sandstone in B6, B7, B7a and B7b. The full sandstone sequence was found in B418 and its position indicated the upthrown side of the fault. The other boreholes and the new borehole B6A are on the downthrown side. The fault is now positioned, being controlled by B418, B6 and B6A and must pass close to Pier 2W, possibly just cutting the south-west corner of the structure.

Fault F3

The B8 group of cores all show that the coarse sandstone is now directly below the gravel and its position is controlled by the angled boreholes B427, B424, B420 and the B8 series. As indicated previously, the fault passes south of the pier 3 positions.

Fault F4

Lack of information on the thickness of the Black Mudstone Group makes the determination of this fault tentative. It was initially invoked to account for the change of dip from 45° - 60° in B9, B10, B422 and B426 to horizontal or nearly so in B11, B12 and B13. The three latter boreholes only cored a few metres and the dip was difficult to determine. The new hole B12A shows that the steep dip continues to the north and may well continue to the contact with the Triassic rocks north of the bridge site. The high dip and polished surfaces on the mudstones suggest movement and deformation and there was ample evidence for this in B9. However, in the absence of a definite fault plane in B9, B9a, B9b, B10 or B12A, the junction of the highly inclined beds and the horizontal strata of B13 has been moved north of the north abutment.

Earthquakes

Of considerable interest from the point of view of bridge engineering is the not infrequent report of earthquakes from this area. The last authentic record appears to have been in 1957 (Dollar 1957). The reported movement was not severe, sufficient to be felt by people but not causing structural damage in well-maintained buildings. The earthquakes have been attributed to movement along the north-west to south-east trending faults bordering the North Leicestershire South Derbyshire Coalfield, and the Charnwood Forest area, of which the King's Newton fault is one and the Thringstone fault another. Earth tremors may cause foundations in gravels to be unstable. Movement on the fault lines would cause instability in the bedrock. Although on present evidence any movement (measured in mm) on the fault planes, would be expected to the south of the bridge area, the tremors would affect a wider area including the bridge site. It was for this reason that interest in the bedrock geology was maintained although preliminary results indicated that foundations in compact gravel might be feasible.

Conclusion

From extensive seismic and borehole surveys of a geological complex setting, it is concluded that four main faults intersect Millstone Grit strata at the proposed bridge site. Precise location of these faults has been necessary in order to ensure that, as far as possible, the bridge piers are sited so as to be off faulted areas where the rocks are likely to be broken, with poor bearing capacity and with possible water problems. Analysis of earthquake evidence, whilst indicating a slight risk only, would favour foundation on bedrock rather than in the gravel deposits.

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