KEUPER MARL DETRITUS IN THE BED LOAD OF BRADGATE BROOK, CHARNWOOD FOREST, LEICESTERSHIRE

by

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Summary

Keuper Marl is being eroded from a cliff alongside Bradgate Brook in the form of pebbles and sand grains. This Keuper Marl detritus is a major component of the stream sediments below the cliff, but is progressively reduced further downstream as a result of abrasion during transport. Detailed analyses of the Keuper Marl content of the sediments in Bradgate Brook resulted in the discovery of a relationship between grain size and the Keuper Marl content of the sand fraction. Further investigation of this relationship suggests a method of measuring the rate of movement of bed load sediment in Bradgate Brook.

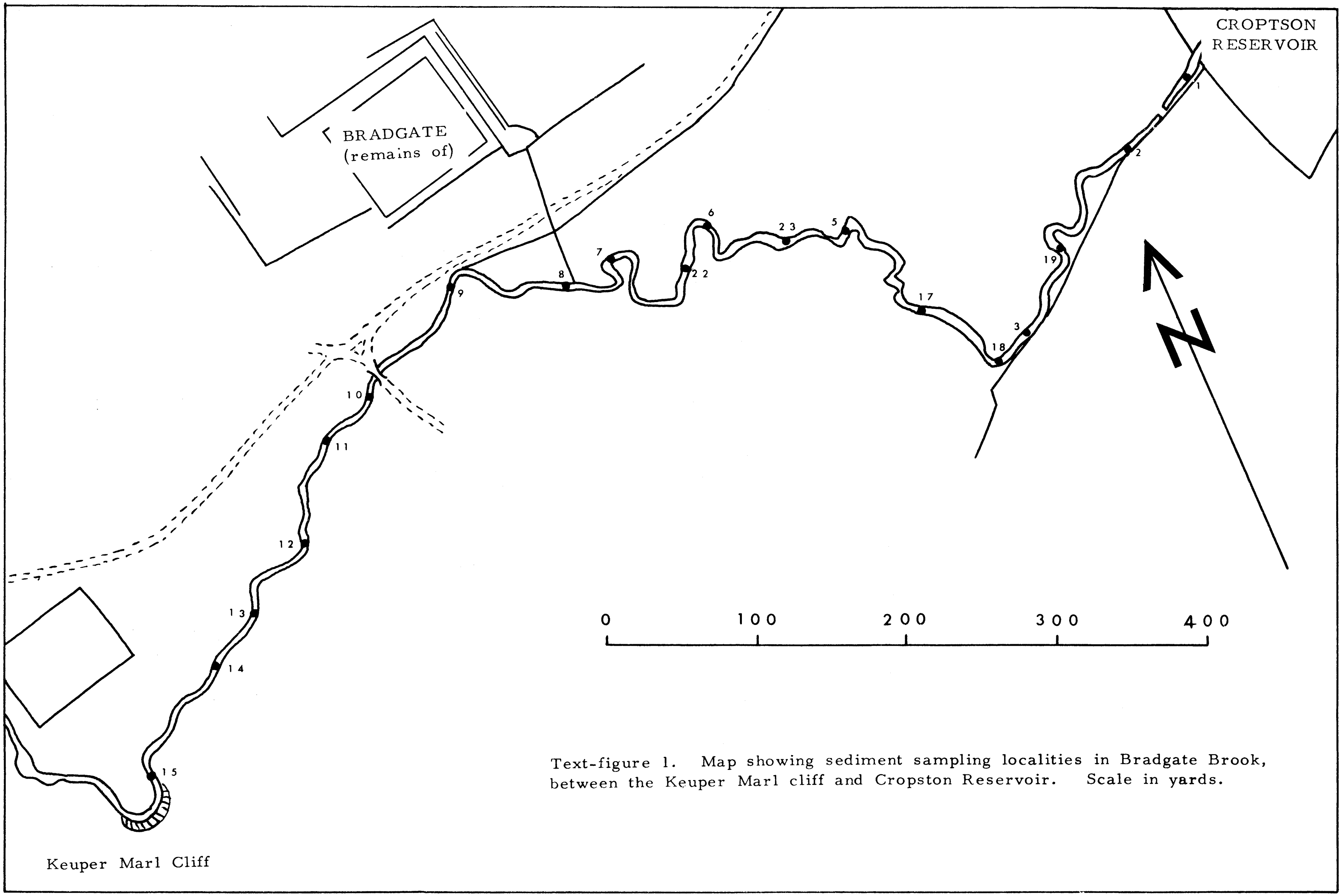
Introduction

Keuper Marl is being eroded along the right bank of Bradgate Brook, about three quarters of a mile upstream from Cropston Reservoir (Text-fig. 1). The marl is exposed in a cliff (SK 532099), about 40 feet high and 200 feet long, round the outside of a sharp meander in the stream. The Keuper Marl in the cliff is being broken down, mainly by mechanical weathering, into angular fragments of various sizes, ranging from several centimetres across downwards. The debris accumulates as a scree at the foot of the cliff. Normally the stream has little effect on this deposit but, when in flood, it cuts into the scree and carries the detritus downstream.

Downstream from the cliff, the bed of the stream is mainly gravel, with local small patches of sand. It is evident from field inspection that the deposits near the cliff contain a much higher proportion of Keuper Marl pebbles than do those further downstream: also the Keuper Marl pebbles in the gravels are rounded, whereas those in the scree at the foot of the cliff are distinctly angular. It is clear that the Keuper Marl pebbles are worn down rapidly by abrasion during transport.

The initial object of the investigation reported in this paper was to study, in greater detail, the rate of abrasion of Keuper Marl detritus during stream transport. With this is view, a series of samples was collected at intervals along Bradgate Brook (Text-fig. 1). They were collected during November 1965 and March 1966, shortly after floods, when the deposits were still fresh. Samples from the stream channel environment of Cropston Reservoir (Cummins and Rundle, 1968), deposited while the reservoir was empty in summer 1965, were also examined. The samples, each weighing a few hundred grams, were dried and shaken through a 2.5 mm. sieve to separate them into coarse (gravel) and fine (sand) fractions*. The two fractions were then examined

* The choice of sieve size was arbitrary. 2.0 mm., the generally accepted upper limit of the sand grade, would have been better from the point of view of naming the fractions.



Text-figure 1. Map showing sediment sampling localities in Bradgate Brook, between the Keuper Marl cliff and Cropston Reservoir. Scale in yards.

separately to determine the percentage of Keuper Marl detritus present. The methods and results of this investigation are given under the headings 'Gravel' and 'Sand'.

Detailed examination of the sand fraction revealed a consistent relationship between grain size and the Keuper Marl content of the sand. In every sample examined, the Keuper Marl content was lower in the medium sand than in coarser or finer sand (Text-fig. 4). This entirely unexpected relationship required an explanation and is considered later in the paper, under the heading 'Grain size and Keuper Marl content of sand fraction'. The explanation advanced involves the rate of supply of sand from upstream of the cliff; and this in turn leads to a possible method of measuring the movement of bed load sediment in the stream. This is discussed at the end of the paper under the heading 'Rate of movement of bed load sediment'.

Gravel

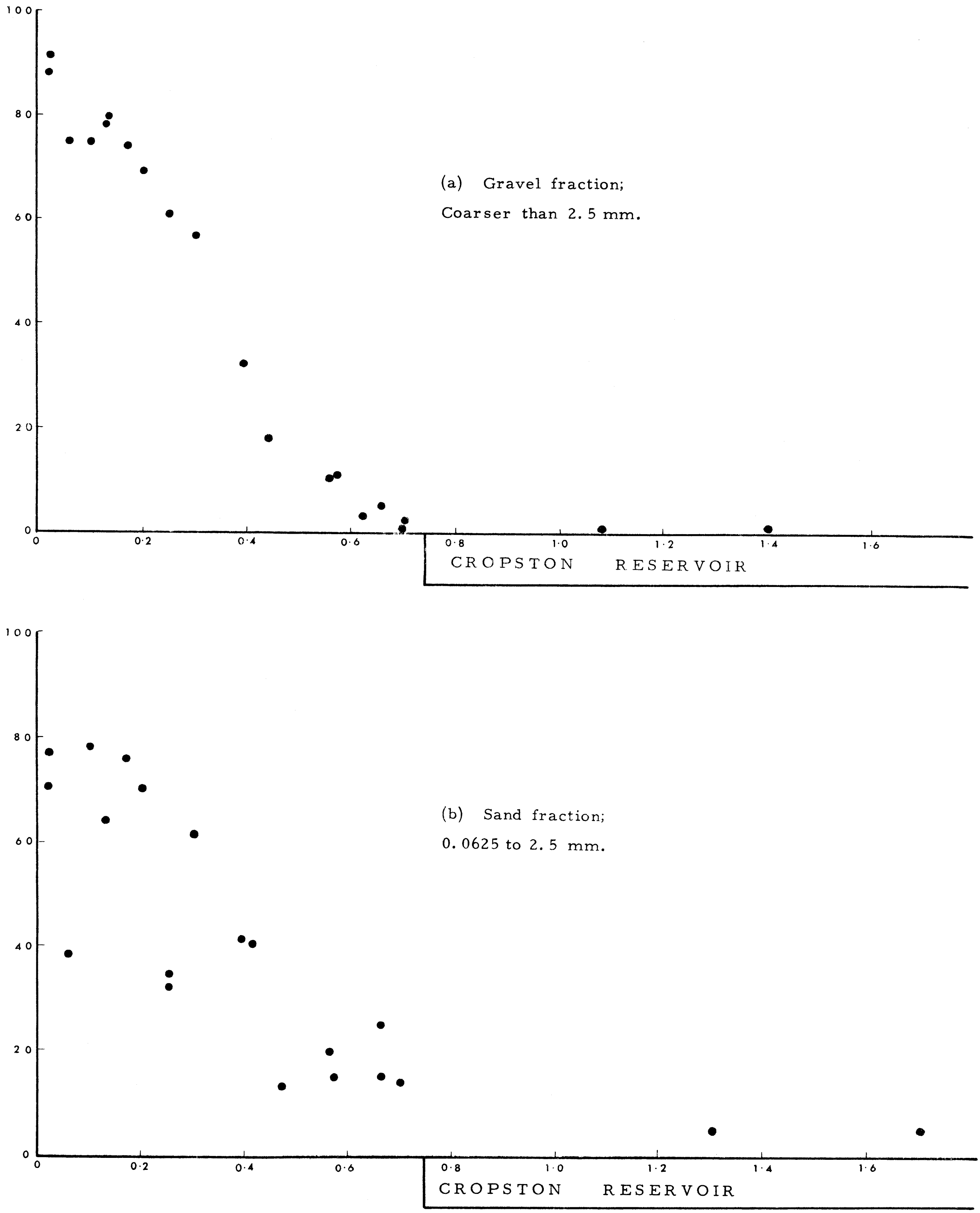
The examination of the gravel fraction was carried out visually. Each sample was spread out on a large sheet of paper and separated by hand picking into two categories: marl pebbles and other (hard) rock and mineral pebbles. The two parts of the sample were then weighed and the percentage of marl pebbles calculated. This percentage was considered as the Keuper Marl content of the sample. It was of course recognised that this does not fully represent the contribution of the Keuper Marl cliff, as skerry beds in the cliff certainly yield hard rock and mineral pebbles: but it is directlv related to the contribution of the cliff, as samples collected upstream of the cliff contained more pebbles at all.

The Keuper Marl content of the gravel fraction of the samples falls from 90% immediately downstream of the cliff to 1% just above the reservoir (Text-fig. 2a), a distance of three-quarters of a mile. Two factors contribute to this downstream decrease in Keuper Marl pebbles; abrasion during transport and weathering during the intervals between transport. Periods of significant movement of bed load (sediment moving close to the bed of the stream by rolling, sliding or bouncing) are of short duration. During the long intervals between movement, the gravels may be subjected to alternate wetting and drying by rising and falling water level in the stream and, when above water level, by rain and sun. This results in the mechanical breakdown of the marl pebbles into finer detritus.

Sand

Visual separation of the sand fraction into marl and non-marl components was impracticable, so an indirect method was used by which the marl grains were disaggregated and washed away as mud, leaving a marl-free sand fraction. The method of analysis described below is most conveniently applied to small samples, of 20 grams or less. The sand fractions of the samples collected weighed anything from 90 to 250 grams. They were accordingly split, before treatment, to more manageable sizes.

The sample to be tested was weighed and then put to soak in a N/100 solution of sodium oxalate (sodium oxalate has been widely used for the dispersion of fine grained sediments in preparation for grain size analysis). After soaking for a day or more, the sample was washed through a 0.0625 mm. sieve (lower limit of sand grade). The residue left on the sieve was then washed into an evaporating dish and rubbed with a rubber bottle stopper to break down any remaining marl grains. It was then again washed through the 0.0625 mm. sieve, and the process repeated until the residue was a clean, marl-free sand. This residue was then dried and weighed. The percentage loss in weight was calculated and taken as the Keuper Marl content of the sample. The relationship between this percentage and the actual contribution of the Keuper Marl cliff is similar to that already discussed in the previous section for the gravel fraction.



Text-figure 2. Keuper Marl content of sediments in Bradgate Brook, plotted against distance (in miles) downstream from Keuper Marl cliff.

The Keuper Marl content of the sand fraction of the samples falls from 77% immediately downstream from the cliff to 14% just above the reservoir. From there on a more gradual decrease is indicated by the samples from the stream channel environment of the reservoir, whose Keuper Marl content is about 5% (Text-fig. 2b). Of all the Keuper Marl grains which left the cliff as sand, over 80% have been lost in the first three quarters of a mile of stream transport and nearly 95% within a mile and a half of their starting point.

The scatter of points on the plots of Keuper Marl content against distance downstream from the cliff is much greater for the sand fraction than for the gravel fraction (Text-fig. 2). Several factors might be thought to contribute to this scatter:- (i) a proportion of the Keuper Marl pebbles in the samples might have broken down during storage and drying, thus adding to the Keuper Marl content of the sand fraction; (ii) the rate of abrasion of the Keuper Marl grains might be significantly different for the different grain sizes within the sand fraction; (iii) the distances shown in Text-fig. 2 are measured along the stream channel but, during times of flood, a good deal of the stream flow (and movement of sand grains) is along short cuts across the necks of meanders. These factors will be considered in turn below.

(i) If the Keuper Marl content of the sand fraction has been increased by the break-down of Keuper Marl pebbles, then it should be too great by an amount proportional to the weight of Keuper Marl pebbles in each sample. Reduction of the Keuper Marl content of the sand fraction by fixed percentages of the weight of Keuper Marl pebbles in the samples does not significantly reduce the scatter of points discussed above (Text-fig. 3a). It is concluded that this is not a main cause of the scatter in the results.

(ii) If the rate of abrasion is different for different grain sizes within the sand fraction, analyses carried out within more closely defined size units should produce less scatter. In order to test this, the sand samples were divided into a number of sub-samples according to grain size. Before treatment, each sample was mechanically shaken through a nest of sieves (1.0 mm., 0.5 mm., 0.35 mm., 0.25 mm., 0.175 mm., 0.125 mm., and 0.0625 mm.) and the portion retained on each sieve was weighed. The resulting sub-samples varied in weight from over 60 grams down to less than a gram. The larger sub-samples were split to more workable sizes and then all were treated in the manner described above (p.39). The Keuper Marl content of the smaller size units within the sand fraction still shows a considerable scatter when plotted against the distance downstream from the cliff (Text-fig. 3b).

(iii) The scatter of points on Text-fig. 2b does not seem to be an artefact resulting from the treatment of the samples (items (i) and (ii) above). It follows that the irregularity of the downstream decrease in the Keuper Marl content of the sand fraction is probably real and due to natural processes. Further field work would be needed to study the possibilities.

Grain size and Keuper Marl content of sand fraction

Treating the sand fraction in sub-samples of different grain sizes resulted in the discovery of an interesting and entirely unexpected relationship between grain size and the Keuper Marl content of the sand. In every sample examined, the Keuper Marl content of the sand was lower in the medium sand than in coarser or finer sand. In most samples the minimum Keuper Marl content was found in the 0.25 to 0.35 mm. grade. This relationship held in all samples, regardless of variations in the grain size distribution or the Keuper Marl content of the sand fraction as a whole. The samples analysed range from gravels, with less than 20% of sand, to sands, with no more than 2% of coarser material. The Keuper Marl contents of the sand fractions range from 77% down to 5%. No matter what the character of the sample as a whole, the relationship between grain size and Keuper Marl content is the same (Text-fig. 4).

Three factors must be considered in an attempt to interpret this relationship:- (i) the relative rate of supply of different grain sizes of sediment from the Keuper Marl cliff; (ii) the Keuper Marl content of the different size fractions derived from the cliff; (iii) the relative rate of supply of different sizes of sand from further upstream.

(i) Material eroded from the Keuper Marl cliff accumulates as a scree at the foot of the cliff and is only removed when the stream is in flood. During floods the stream cuts into the scree deposit and removes the debris completely, without leaving a lag deposit. Therefore, the relative rate of supply of different grain sizes of sediment from the cliff is given by the grain size distribution of sediment in the scree deposit. Grain size analyses were carried out on six samples of the scree sediment, within the limits 0.0625 mm. to 1.0 mm.. This was done by washing the sediment through a nest of sieves and then drying and weighing the portion retained on each sieve. The six samples gave consistent grain size distribution patterns.

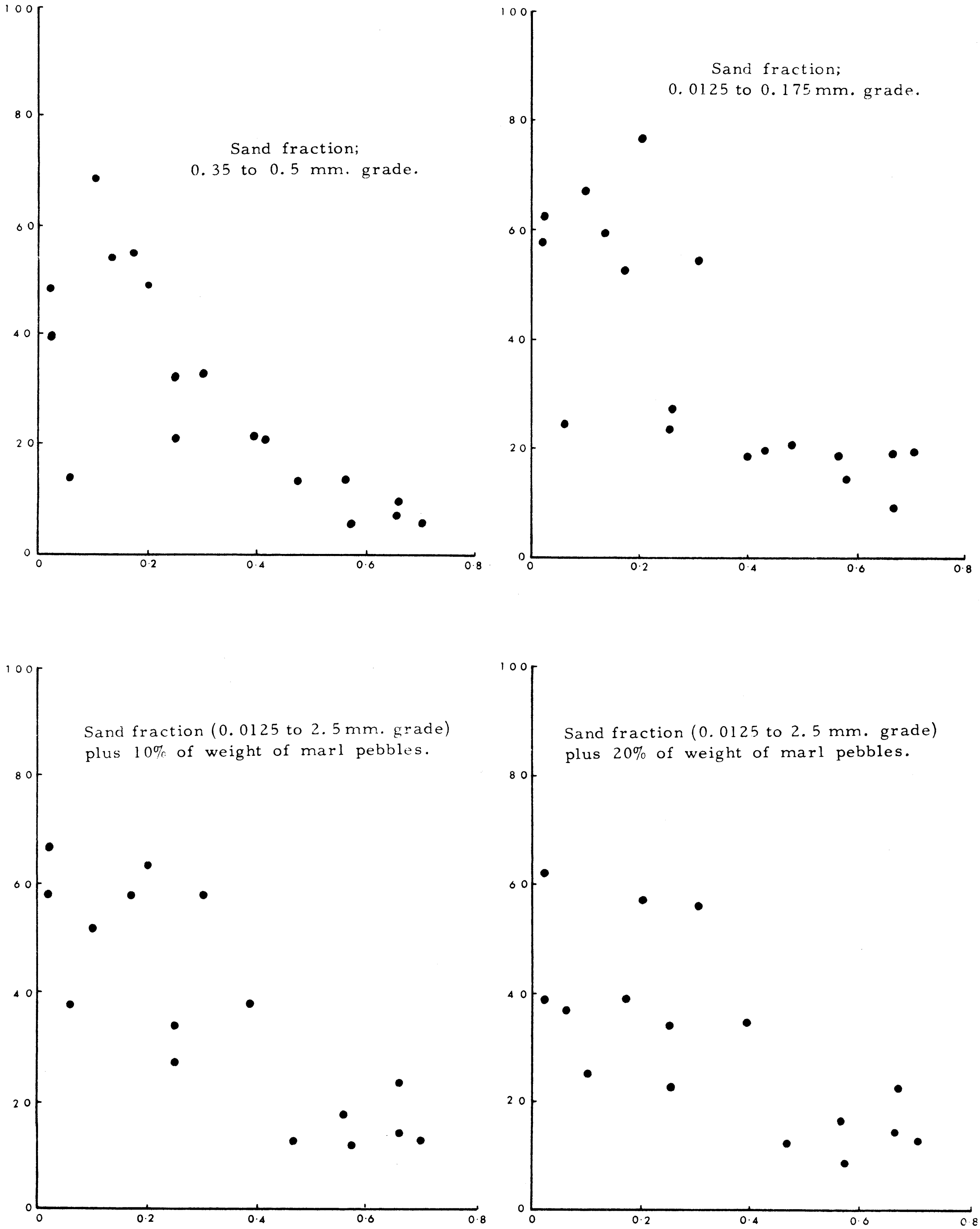
(ii) The Keuper Marl content of the different size fractions of the scree sediment was determined by the method described earlier for the stream sediment samples. The minimum Keuper Marl content, 72%, was found in the 0.175 to 0.25 mm. grade.

The grain size distribution of the scree sediments, within the range studied, is shown in a histogram (Text-fig. 5a). Each bar in the histogram is divided to show the Keuper Marl content (stippled) and the non-marl residue (blank). The stippled portion of this histogram represents the relative rate of supply of the Keuper Marl component to the different sand grades in the sediments of Bradgate Brook. A noteworthy feature of this result is that the maximum rate of supply is in the 0.25 mm. to 0.35 mm. grade, just where the Keuper Marl content of the stream sediments is at a minimum.

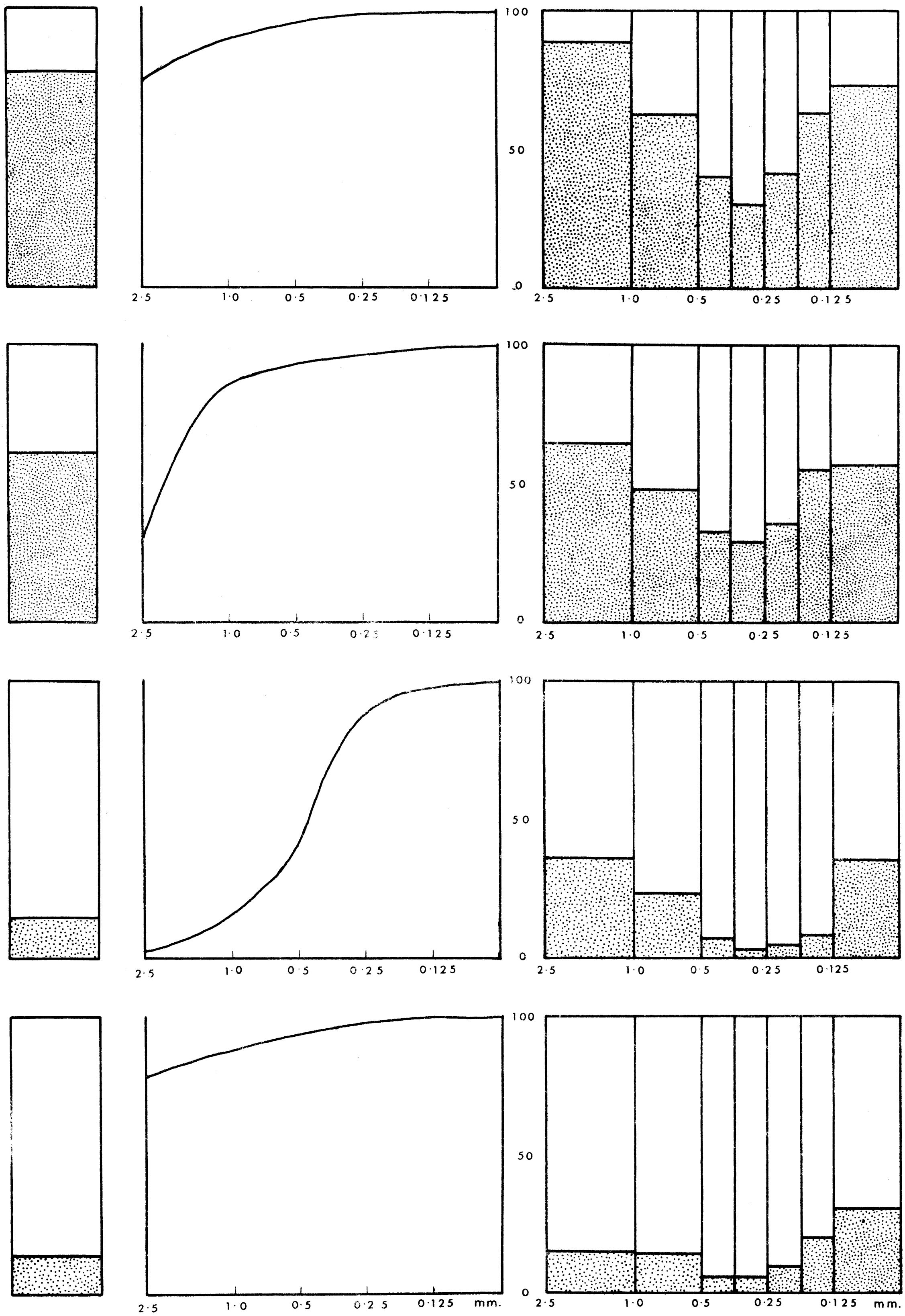
(iii) The relative rate of supply of different sand grades from upstream of the cliff would be difficult to measure. The sediments in the bed of the stream give little indication of this: they are mainly lag deposits, left behind by the more mobile part of the bed load. But, knowing the relative rate of supply of the Keuper Marl component to the different sand grades from the cliff (Text-fig. 5a) and knowing the Keuper Marl content of these sand grades in the sediments of Bradgate Brook below the cliff (Text-fig. 4 and 5b), it is possible to calculate the relative rate of supply of the different sand grades from further upstream (the only remaining unknown factor).

The relative rate of supply of sediment from the cliff is shown in Text-fig. 5a. The Keuper Marl contents of the various sand grades (stippled) are diluted by different amounts, according to the (unknown) relative rate of supply of marl-free sand from upstream. The result of this differential dilution is the relationship between Keuper Marl content and grain size in the sediments downstream of the cliff (Text-fig. 5b). Since the cliff is the sole source of Keuper Marl in the stream, the Keuper Marl contents, shown in Text-fig. 5b, must have been supplied in the ratio shown in Text-fig. 5a. The height of the bars in Text-fig. 5b may therefore be altered so that the stippled portions are the same height (or in the same ratio) as in Text-fig. 5a. In the resulting histogram (Text-fig. 5c), the height of the lower portions of the bars (stippled and unstippled) is related to the rate of supply of sediment from the Keuper Marl cliff (as in Text-fig. 5a); therefore, the height of the upper parts of the bars must be similarly related to the rate of supply of marl-free sand from further upstream. These upper parts are isolated in a separate histogram (Text-fig. 5d), which shows the relative rate of supply of the different sand grades from the stream above the Keuper Marl cliff, in other words the relative rate of movement of these sand grades past the cliff (in terms of weight of sediment per unit time).

The calculation illustrated in Text-fig. 5 made use of the mean Keuper Marl content of all the samples studied. The relative rate of movement of the different sand grades has also



Text-figure 3. Keuper Marl content of sediments in Bradgate Brook, plotted against distance (in miles) downstream from the Keuper Marl cliff.



Text-figure 4. Data from the sand fractions of four samples. Left: Keuper Marl content (stippled) of sand fraction. Middle: Part of cumulative grain size curve in the range 0.0625 to 2.5 mm. Right: Keuper Marl content (stippled) of subdivisions of sand fraction.

been calculated in relation to each sample individually. There is, however, little variation between the results from different samples and no systematic variation with distance downstream from the cliff.

The results of the analyses described above (Text-fig. 5d) show that of all the sand, within the size range 0.0625 to 1.0 mm. passing the cliff in the bed load of the stream, 39% falls within the 0.25 to 0.35 mm. grade, and 84% between 0.175 and 0.5 mm. The finest grades are poorly represented because they are relatively easily taken into suspension and removed from the bed load, together with the silt and clay grades. The coarsest grades are also poorly represented, because they are less easily moved by the stream and tend to be left behind as lag deposits. Apart from the sediment-transporting capacity of the stream, another factor affecting the result is the supply of sediment of different sizes to the stream along its length. In this last respect, the stretch of Bradgate Brook under consideration is distinctly artificial. About six hundred yards upstream from the cliff is the lowest of a series of five settling ponds: between them these trap about 18% of all the sediment coming down Bradgate Brook before it reaches the reservoir (Cummins and Potter, 1967, p. 37), including a very high proportion of the bed load of the stream.

Rate of movement of bed load sediment

The relative rate of movement of the different size grades within the bed load can be determined as described above. It is only a small step from this to a determination of the actual rate of movement of the bed load as a whole, in tons or kilograms per year for example. A discussion of this is included here because, although the results are not yet available for Bradgate Brook, the method may be of more general interest in view of the difficulties encountered in measuring the movement of bed load sediment directly (Hubbell, 1964). The method is summarised below.

(i) Grain size analysis of the scree sediments, over the whole range of sizes involved, gives the relative rate of supply of the different sizes of sediment from the cliff to the stream.

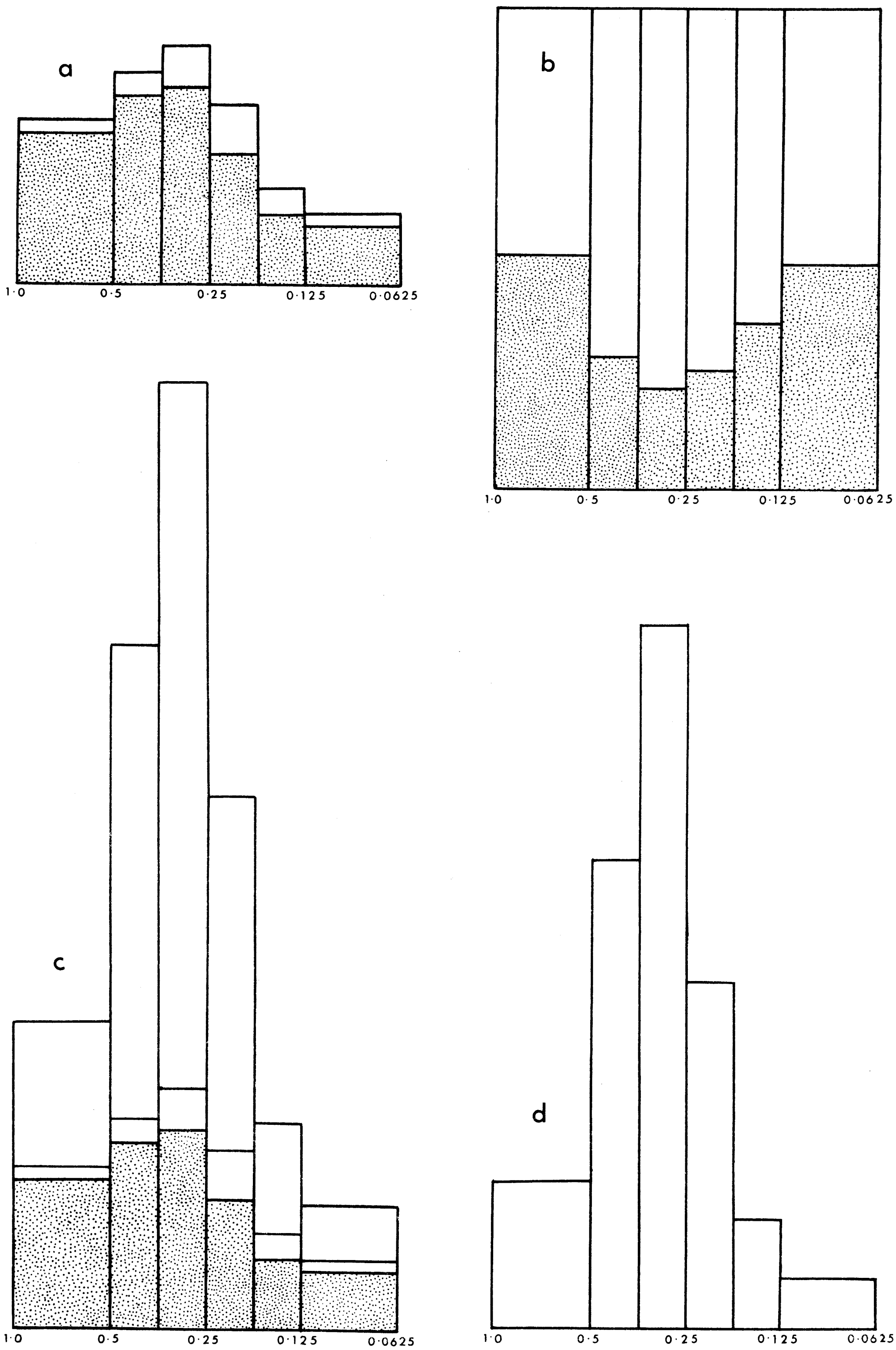
(ii) Keuper Marl content analyses of the different size fractions in the scree sediment gives the relative rate of supply of Keuper Marl grains to the different size grades of sediment in the stream.

(iii) Measurement of the rate of erosion of the Keuper Marl cliff permits the transformation of these relative rates to absolute rates. A study of the rate of erosion of the cliff over a period of two years will be completed early in 1969.

(iv) Keuper Marl content analyses, over the full range of grain sizes, of the stream sediments immediately downstream of the cliff will enable the rate of movement of the bed load to be determined, since the Keuper Marl content of these sediments is entirely derived from the cliff and the rate of supply from this source is known.

Conclusions

The investigation reported in this paper has no clearly defined beginning or end; indeed, as indicated in the previous section, it is not yet finished. It is really a series of investigations, connected by the fact that they are all concerned with the same material and recorded in the order in which they were carried out. The conclusions reached so far are summarised below:-



Text-figure 5. Keuper Marl content (stippled) and grain size, in the range 0.0625 to 1.0 mm. (a) Grain size distribution of Keuper Marl scree sediment; (b) Keuper Marl content of stream sediments; (c) Keuper Marl contents adjusted to the ratio supplied by the cliff; (d) Relative rate of supply of sand grades from further upstream.

(i) Keuper Marl pebbles eroded from the cliff are almost all worn away in the first three-quarters of a mile of stream transport from their source.

(ii) Keuper Marl sand grains suffer over 80% loss by abrasion in the first three-quarters of a mile of stream transport and nearly 95% within a mile and a half of their starting point.

(iii) The relationship between grain size and the Keuper Marl content of the sand downstream of the cliff is largely due to the different rates of supply of the various sand grades from further upstream.

(iv) This last conclusion suggests that, given a measurement of the rate of erosion of the cliff, the rate of movement of the bed load sediment can be determined.

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