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Composition and bulk properties of Dorset river gravels.

P.A. Carling

CONTENTS

SUMMARY

1. The Dorset river gravels examined are bimodal. The grain size distribution may be resolved into two near-normal frequency distributions interpreted as representing a primary framework or lattice of gravel particles into which a secondary matrix population of sand particles has penetrated. Penetration may have been pene-contemporaneous as suspended sand was trapped in stabilizing bedload gravel or alternatively may have been a later infiltration into an open-work gravel deposit.

2. The mean grain size of the framework falls in the interval -4 to -5 ∅. Residual skewness results in a mode in the range -4 to -6∅.

3. The mean grain size of the matrix falls in the interval 0 to 2 ∅, whilst the mode is within the interval 0 to 1 ∅.

4. No grains larger than -7 ∅ were encountered and material finer than 4 ∅ i.e. silt and clay, on average represented less than 1% of the total sedimentary material.

5. A deficiency in the grain size interval -1 to -2 ∅ (R. Piddle and Tadnoll Brook) or 0 to -1 ∅ (Bere Stream) represented the saddle separating the two sedimentary populations of framework and matrix.

6. The surface 20 cm of gravel had low matrix percentages, i.e. they were cleaner than basal gravels.

7. Gravels are better sorted and have a higher porosity than gravels in upland Teesdale, only 29% of the potential void space was filled with sand.

8. The organic content of the matrix was low ~ of the order of 1% by weight.

9. A tufa-like deposit commonly filled void space in basal gravels.

INTRODUCTION

In the autumn of 1982, freeze-samples of gravel were obtained in Dorset streams. Data were required on the depth of salmonid egg pockets and were part of a broader investigation of regional variation in the independent variables of salmonid fish length, gravel size, current velocity and the resultant dependent variable~egg burial depth.

The above aspects will be published at a later date when comprehensive data are available. Preliminary data are given by Ottaway et al. (1981).

Considerable interest has been expressed in the composition of the stream gravels, the movement of bed materials and the relationship of sediment composition, packing and siltation of void space to invertebrate ecology by the F.B.A. River Laboratory staff. Consequently, relevant aspects of the investigation are made available here in unpublished form.

Summary data on grain size composition, bulk properties and organic content are presented. A physical explanation for the bimodal grain-size frequency distribution is advanced and comparisons are drawn where appropriate with other published information.

In this report the use of the word siltation and similar words refers to the process of infilling of gravel void space by sand and finer particles. No specific size category such as delineated in the Wentworth-Lane terminology (i.e. silt < 0.063 mm) is intended. Otherwise grain-size nomenclature follows Wentworth-Lane (Pettijohn, 1975).

METHODS

Twenty-five undisturbed samples of gravel were obtained in salmon and sea trout redds using a freeze-sampling method described elsewhere (Carling & Reader, 1981). Three streams were sampled; the River Piddle at N.G.R. SY 798941 and 806937; the Bere Stream at SY 856928 and 857927 and the Tadnoll Brook at SY 774871.

Where distinct stratigraphic differences were evident in the cores, samples were split accordingly. Alternatively, where pockets of fish eggs occurred, cores were also split into sections representing gravels above the eggs and gravels below the eggs. Several cores displayed no stratification and were analysed in bulk. A total of 37 samples and sub-samples was examined.

Samples were dried to room temperature and sieved mechanically on a Fritz Analysette. Sieving time was 10-15 minutes using an intermittent mode of amplitude sufficient to mobilise the coarsest particle.

As grain-size distributions are logarithmically distributed, samples were sieved at 1 phi ∅ intervals in the range 4.0 ∅ (0.063 mm) to -7.0 ∅ (129 mm). The use of the phi ($\log_2$) conversion is common practice and effectively normalises grain-size distributions prior to statistical analysis. The phi scale is shown in relation to the grain size in millimetres in Table 1. A fuller description is given by Sumner (1978).

Samples were bimodal. The coarse mode (<0 ∅), here termed the framework, contained no organic detritus. The fraction containing the fine mode (>0 ∅), here termed the matrix, was ashed at 550°C for 2 hrs to ascertain the loss on ignition. The percentage weight loss was taken to represent the approximate combustible organic content.

Seven high quality cores from the R. Piddle at Affpuddle were used to derive estimates of particle density, void ratio and similar bulk properties.

Some basal gravel contained a diagenetic concretion. A sample was analysed by X-ray diffraction to determine mineral composition.

RESULTS AND DISCUSSION

Granulometry

As will be indicated below most samples were bimodal and gravel void space was partially silted. There were no open-work gravels (sensuo - Cary, 1951).

Identification of bimodality is dependent on the magnitude of a secondary peak in the sand range that can be accepted as a genuine secondary population. Minor fluctuations may occur in the cumulative frequency curve resulting from sieving errors and the inevitability of treating continuous series data as group frequency data. Experience had shown that these should only be expected to be of the order of 1 or 2%. A cut-off point was adopted such that a secondary mode would only be identified if it contained $>$5% more by weight than in the adjoining interval.

Using the above procedure, thirty-three sub-samples were bimodal. The remaining four samples were unimodal. Three of these had the mode in the coarse gravel whilst the remaining sample, with a mode in the sand size sediment, represented a sandy organic deposit; either a flaser or a buried vegetal mat (p. 7).

The coarse mode in the bimodal sediments commonly fell in the -4 to -6 range, whilst the fine mode fell in the 0 to +1 ϕ range. The saddle between the two populations was in the 0 to -1 ϕ range or occasionally in the -1 to -2 ϕ range. There was little variability from this rule.

Taking the mid-point in each modal class (in millimetres) as a representative grain-size diameter for the matrix (d_m) and the framework (d_f), the ratio d_m/d_f varied little, variation being mainly associated with changes in the d_f value (see also Potter, 1955). For 33 analyses 52% of ratio values = 0.0313, 30% = 0.0156 with 18% constituting other values. Extreme values were 0.0078 and 0.0625. The significance of the ratio is discussed below (p. 6).

Although graphical statistical measures have been used to describe bimodal sediments (Dyer, 1972), these are of little value if the bimodal population may be disassociated rationally into component parts. For example, the mean or median grain size may be poorly represented in a bimodal population, whilst skewness is largely a measure of the magnitude of the population modes. Consequently the populations were disassociated and statistical parameters calculated for each modal population (Table 2). Although the resolution of mixed frequency distributions into near-normal components may be based on numerical or semi-graphical methods (e.g. Mundry, 1972; Harding, 1949), the common deficiency of fluvial sedimentary grains in the size-range 0 to -1 ϕ (Pettijohn, 1975, p. 42) as noted here suggests the juxta-position of hydraulically "independent" populations, broadly representing a traction population $< 0\ \phi$ and a suspension population $> 0\ \phi$. Plotting two contiguous normal distributions as a cumulative frequency curve on probability paper results in a distinctive sigmoidal curve (Harding, 1949). The bimodal sediments reflected this model (Fig. 1).

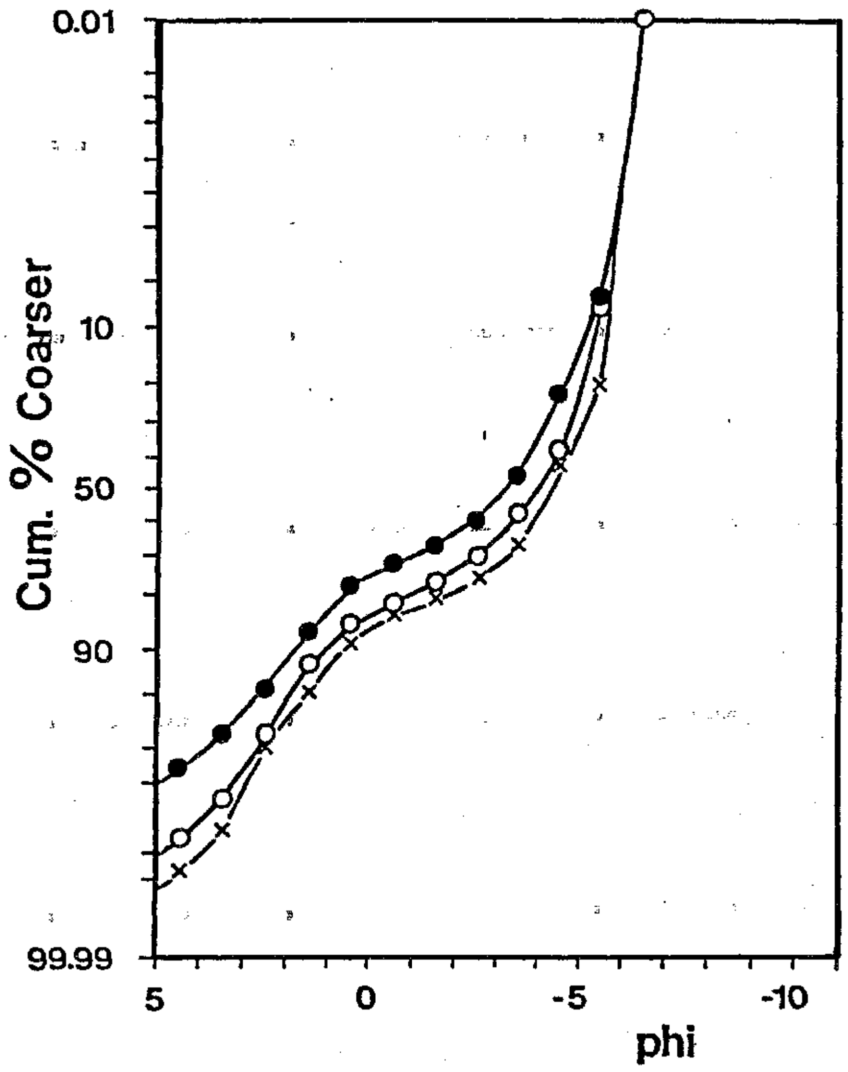

Fig. 1 Cumulative frequency distributions of Dorset river gravels.
● R. Piddle, O Bere Stream, X Tadnoll Brook. The sigmoidal curve reflects the mixing of two normally distributed populations of sediments.

Because of the little variation between samples, samples were averaged for each stream to produce one grain size frequency curve. The resultant curves were disassociated into a matrix population and a framework population by fitting normal distributions around each population mean (Fig. 2). Distributions were truncated at the saddle frequency, this interval not being used in any calculations. The method is described by Bliss (1967, p. 156). Observed frequencies were compared with expected values using the Kolomogorov-Smirnov test (Siegel, 1956). None of the component distributions was significantly different from normal at the 0.01% level. Descriptive statistics for each observed population are given in Table 2. Slight residual log normality in the distributions, despite phi-transformation, is evident in the probit plots and skewness values, although kurtosis approaches normality. The gravel framework in the Piddle is closest to a normal distribution whilst the Bere Stream gravels are skewed with the mean and mode in separate class intervals. The Tadnoll Brook data are also skewed but are only based on two cores (four sub-samples) which may not be a representative sample.

Assuming the deposits are a two component system of spheres of equal density, i.e. gravel and sand, the sand can only represent up to 22% of the total deposit weight if the gravel particles are contiguous and tightly packed or 32% if the gravel, still in contact, is loosely packed (Fraser, 1935). Any additional percentage weight of sand would indicate that the sand and gravel were deposited contemporaneously and many gravel particles would be isolated in a sand mass. Smaller percentages would indicate either contemporary deposition or later infiltration of sand into a stable gravel bed. The matrix represented between 4 and 61% by weight. The majority of values were low yielding a mean value of 19%(s.d. 13%). Basal sections of compacted sediment had high values 25% (s.d. 17%) whilst surface gravels were cleaner ~ 13% (s.d. 8%).

In a similar vein the ratio d_m/d_f for a compact gravel cannot exceed 0.154 (Fraser, 1935) if the matrix was a later infiltration population, otherwise deposition was contemporaneous.

These data are interpreted as representing, contemporaneous deposition of coarse gravel from traction with some suspended sand being trapped in the stabilising framework (e.g. Smith, 1974) and later, partial infilling of the void space by fine sand infiltrating the stable bed. The few high percentage values represent sand deposits with additional gravel mixed in. The cleaner surface gravels may be low in matrix component owing to the digging activity of fish, hydraulic winnowing by scour and a propensity for find sand to settle and fill gravels from the base upwards (Beschta & Jackson, 1979).

Bulk properties

The density of particles of bed material was 2.45 g cm^{-3} (s.d. 0.0447), bulk density was 1.60 tonnes m^{-3} (s.d. 0.19).

The gravels are better sorted than gravels in Teesdale where bimodality is not ubiquitous (Carling & Reader, 1982). The degree of sorting and low sand content result in low bulk densities and consequently in high void ratios (E) and porosities (λ) (Table 3).

The few data for Dorset are plotted in Figs. 3 + 4 in relation to the Teesdale data presented in Carling & Reader (1982). Values of λ are better described by Komura's relationship than by the Teesdale curve in terms of median diameter. A discrepancy between the Teesdale and Dorset data also exists in terms of the percentage of silt and clay in the deposits. The high porosity is clearly reflected in the proportion by volume of the potential void space filled by sand (i.e. the ratio between the sand volume and the sand and void volume combined) where on average only some 29% of the potential void space is filled.

Organic content

Organic detritus was finely comminuted (< 1 mm). In only one sample were any large wood or reed fragments found. Two samples, which were very black and apparently organically rich, were dominated by sand; the organic percentage only being 3-4%. These deposits may represent decayed vegetal mats which entrapped sand and were subsequently buried by gravels, or alternatively, flasers of sand deposited with fine organic detritus in hollows in the gravel bed.

The matrix infilling the gravel framework had organic percentages in the range 0.42 to 3.46%. The mean value for all deposits was 1.14% (s.d. 0.79%).

Diagenetic concretion

The X-ray diffraction analysis showed the concretion to be calcite, with small amounts of quartz. The latter probably represent small sand grains in the calcareous deposit. The material resembles tufa which is formed by evaporation (Pettijohn, 1975, p. 357). The possible mechanism of formation for these sub-aqueous deposits is precipitation from a super-saturated solution.

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TABLE 1. Grain size distribution of Dorset stream gravels.

Size interval (mm)	ø	Average percentage by weight: Piddle	Bere	Tadnoll
64 -128	-6 - 7	6.59	7.94	20.42
32 - 64	-5 - 6	16.36	27.98	22.54
16 - 32	-4 - 5	23.56	23.11	25.10
8 - 16	-3 - 4	14.03	11.84	8.59
4 - 8	-2 - 3	7.59	7.02	4.71
2 - 4	-1 - 2	4.94*	4.78	3.67*
1 - 2	0 - 1	5.36	4.06*	4.47
0.5 - 1	0 + 1	9.47	5.54	5.33
0.25 - 0.5	1 + 2	6.79	5.22	3.21
0.125- 0.25	2 + 3	2.77	1.86	1.62
0.063- 0.125	3 + 4	1.23	0.41	0.23
$\angle$ 0.063	+4	1.32	0.28	0.12

* saddle interval (see text)

TABLE 2. Summary statistics for Dorset stream gravels.

	$\bar{d}$	s.d.	skewness	kurtosis
Piddle framework	-4.50	1.13	0.07	2.31
Piddle matrix	1.10	1.31	0.90	3.39
Bere framework	-4.54	1.31	0.66	2.79
Bere matrix	1.35	0.92	1.19	4.47
Tadnoll framework	-5.06	1.14	0.43	2.47
Tadnoll matrix	0.71	1.08	0.76	3.24

TABLE 3. Bulk properties of R. Piddle gravel.

Sample No.	Bulk density ($t\,m^{-3}$)	Void ratio	Porosity	$\frac{\text{Matrix vol.}}{\text{Matrix + void vol.}}$
1	1.48	0.64	0.39	0.36
2	1.45	0.64	0.39	0.26
3	1.70	0.44	0.31	0.14
4	1.74	0.44	0.31	0.34
5	1.72	0.46	0.32	0.32
6	1.83	0.35	0.26	0.34
7	1.31	0.84	0.46	0.24

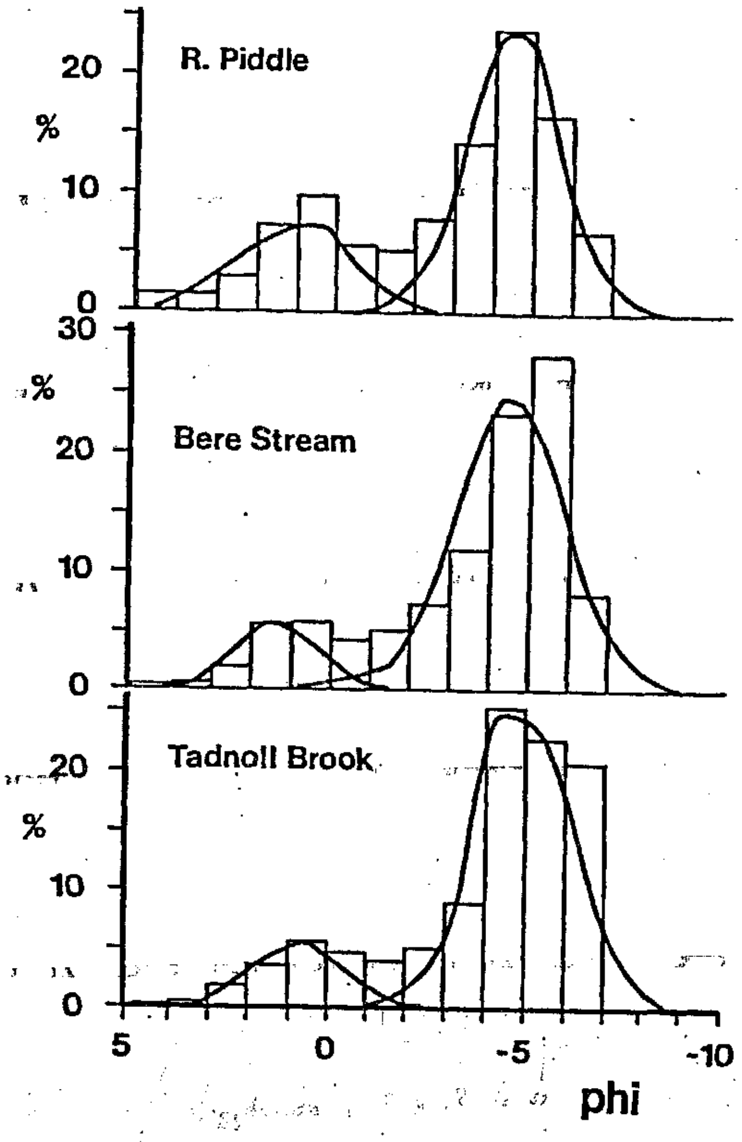

Fig. 2 Frequency distributions of Dorset river gravels, showing the bimodal distributions. Calculated normal distributions for the sub-populations of framework and matrix are shown as continuous curves.

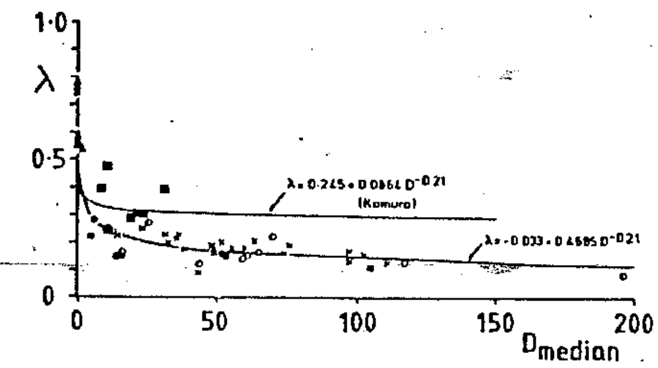

Fig. 3 Porosity (λ) of R. Piddle gravels, ■, plotted in relation to the median grain size of the deposits. Other symbols and curves are from Carling & Reader (1982) see text.

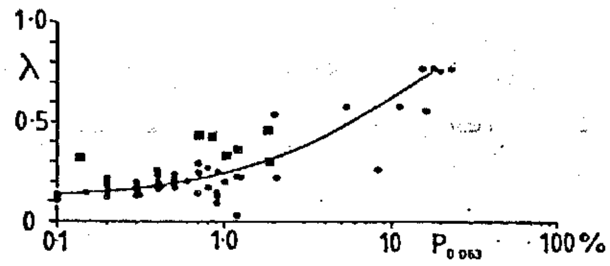

Fig. 4 Porosity (λ) of R. Piddle gravels, ■, plotted in relation to the percentage of material less than 0.063 mm in the deposits ($P_{0.063}$). Circles and curve are from Carling & Reader (1982) see text.