S. infundibulum de Koninck.—Upper Beds of Dibunophyllum zone at Elbolton, Yorkshire; Hollington End, Derbyshire.

S. ingens Martin.—Upper beds of the Dibunophyllum zone.

SYN. *Solenocheilus pentagonalis* Phillips.

Little Limestone, Weardale, Durham; Bradbourne and near Ashford, Derbyshire; Astbury Old Quarry, Cheshire. Bathgate, Linlithgowshire, Closeburn and Kirtlebridge, Dumfriesshire, and Arden Quarry, Nitshill, Scotland.

S. derbiensis Foord.—Upper Dibunophyllum zone. Park Hill, Castleton, and Crowdecote, Derbyshire; Narrowdale, Staffs; 4 Laws Limestone, Combe, Northumberland; Poolvash, Isle of Man. I do not consider the variety named *S. derbiensis* var. *globularis* of Foord sufficiently distinct to be retained.

S. globosus Hind.—Millstone Grit, Lower Coal-measures. Caton; Sales Wheel, River Ribble; Bullion Coal, Carreheys, near Colne, Burnley Coalfield, Lancashire; the marine bed, Silica Quarry, Congleton Edge, Cheshire.

CYCLONAUTILUS Hind.

Cyclonutilus umbilicatus Hind.—Coal-measures. Roof of the Bullion Coal, Burnley.

On the Investigation of the Mechanical Constitution of Loose Arenaceous Sediments by the method of Elutriation, with special reference to the Thanet Beds of the Southern Side of the London Basin.

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(Continued from p. 370.)

LEADING CHARACTERISTICS OF ELUTRIATION-CURVES OF SEDIMENTS.

WITH regard to the laws governing the transport, sorting, and deposition of sediments, much has still to be learned, but one fact emerges clearly from the mass of present data. During the process of transport by water the load undergoes selective treatment, or, in other words, is sorted. The late Dr. G. K. Gilbert, in the course of his important work on the transportation of débris by running water,¹ carried out experiments with mixtures of several grades of detrital material and found that before the slope of the stream had been definitely established (i.e. before the attainment of uniformity of conditions), and especially when low velocities were used, the current tended to sort the débris, building deposits with the coarser part and continuing to transport the finer material. This fact has a special bearing on the study of natural sediments. The state of equilibrium, or of perfect uniformity of conditions, is seldom, if ever, completely realized in nature, and even when approximately reached is not, as a rule, of long duration. Further, in general, the detrital

¹ Gilbert, "The Transportation of Débris by Running Water": U.S. Geol. Surv. Professional Paper 86, 1914.

deposits of the geological column are the results of transport by and deposition from comparatively slow-moving currents. Deposits of torrential character are exceptional. Consequently, we should expect to find far-travelled natural sediments, which have been subjected to long-continued aqueous action before deposition, showing in a marked degree the results of selective treatment, and sediments deposited after a short career under transport showing very little evidence of sorting. The material composing arenaceous sediments deposited under marine conditions must, in general, have had an earlier history, during which it formed part of fluvial or estuarine deposits, and in view of the greater vicissitudes experienced should show the results of selective action in a high degree. On the other hand, a deposit such as a fluvial loam or brickearth, deposited after only a short career under transport, and not having been subjected to any special type of selective action, should show a marked absence of sorting. The expectation is verified. Fig. 3 shows, for purposes of comparison, the typical elutriation-curves yielded by fluvial, estuarine, and marine sediments. In the case of the fluvial deposit, its immaturity, from the point of view of its modification under aqueous action, is shown by the curve by the marked absence of a "hump" and by the very low grading factor. The marine sediment yields a curve with a pronounced "hump" and gives a much higher grading factor. The estuarine sediment is of intermediate type. Many more examples might be given to show the soundness of this generalization, but they are scarcely necessary at this point.

MECHANICAL CONSTITUTION OF THE THANET BEDS OF THE SOUTHERN SIDE OF THE LONDON BASIN.

The following summary of the leading features of the mechanical constitution exhibited by the Thanet Beds is based upon the results of a very large number of analyses of samples from a widespread area.

Everywhere along the southern side of the London Basin the Thanet Beds are always progressively coarser from the base upwards. A sample from the upper part of the Thanet Beds in any locality will always yield a higher Equivalent Grade factor than will another taken from a lower level. Samples taken from similar horizons in different localities do not, however (unless the localities are only a mile or two apart), yield corresponding figures. The Thanet Beds become finer in grain as we proceed both eastward and westward from the type district of West Kent. The Thanet Beds of East Kent, as shown by the sections at Pegwell Bay and Herne Bay, are the most fine-grained representatives of these deposits in the southern part of the London Basin (see Fig. 4). It is only, however, in the upper part of the beds that the transition from coarser to finer material, eastward and westward of West Kent, is steadily progressive. The lower part shows greater variation. The lower portion of the beds in the West Kent type area shows finer sediments

FIG. 3.—Types of elutriation curves of arenaceous sediments.

- A. Fluvatile. Pleistocene Loam, Cray Valley, Foot's Cray. $E = .095$ mm.
 $G = .140$.
- B. Estuarine. Woolwich Beds, Charlton; greenish loamy basement-bed.
 $E = .075$ mm., $G = .347$.
- C. Marine. Oldhaven Beds, Herne Bay. $E = .088$ mm., $G = .861$.

than those at corresponding horizons anywhere to the west and for many miles eastward. The Lower Thanet Beds of East Kent are, however, finer than the finest sediments of the West Kent sequence. Some of the very fine, indurated, muddy sediments of Pegwell Bay proved so refractory in the laboratory that no mechanical analysis was possible. The West Kent type of Thanet Beds shows the greatest amount of variation in mechanical constitution seen in these beds anywhere in the London Basin, the Equivalent Grade factor ranging from .059 mm. at the base of the deposit to .146 mm. at the top. The evidence suggests that early in Thanetian times special conditions obtained in the West Kent area, whereby loamy and silty beds, not possessing in any marked degree the

FIG. 4.—Diagram showing thickness of Thanet Beds and range in mechanical constitution, for various localities, from west to east, along the southern side of the London Basin.

characteristics of marine sediments, were being deposited locally, somewhat before the definite establishment of typical marine conditions. From the fact that the lower Thanet Beds eastward and westward of West Kent (excluding the East Kent area) are fairly well-sorted sediments, giving elutriation-curves of marine type, one is tempted to hazard the conjecture that the lowest beds in West Kent may be older than these.

Thickness of deposit, together with narrow range of variation in mechanical constitution, may be taken to indicate approximate uniformity of conditions of sedimentation, and comparative paucity of sediment with considerable lithological variation, the reverse.

Fig. 4 indicates the comparative instability of conditions of sedimentation in West Kent during the deposition of the Thanet Beds.

The diagram (Fig. 5) shows the rough, provisional classification of arenaceous sediments based upon values of Equivalent Grade and Grading Factor, in use by the writer. The value of the Equivalent Grade factor decides whether a sediment shall be classified as a sand, a silt, or a clay, the limit between sands and silts being taken at .08 mm., and that between silts and clays at .02 mm. The value of the Grading Factor decides whether a sediment shall be classified as a true sand or silt, or as a loam, since the characteristic of the loams is the low value of the Grading Factor. The limiting value of the Grading Factor which separates sands and silts on the one hand from loams on the other, is taken at .6. The classification seems to answer very well.

FIG. 5.—Provisional classification of the finer arenaceous sediments, based on Equivalent Grade and Grading Factor values.

Fig. 6 shows types of elutriation-curves yielded by the Thanet Beds of various localities along the southern side of the London Basin, and the table at the end of the paper gives a selection from a large number of mechanical analyses obtained by the writer.

The construction of a graph showing the relation between the Grading Factor and Equivalent Grade yields results of remarkable interest in the case of the Thanet Beds. When a series of field samples are taken from successive levels in the Thanet Beds at any one locality and mechanical analyses are carried out and the related values of Grading Factor and Equivalent Grade are plotted on a graph, it is found that the points obtained show a strong tendency to lie on a straight line. What is even more remarkable, however,

FIG. 6.—Elutriation curves (much reduced) of Thanet Beds of southern side of London Basin.

is that if this be done for a series of localities, the series of straight lines obtained show a strong tendency towards parallelism. (See Fig. 7.) This signifies that in the case of the Thanet Beds there is a tendency towards a simple linear relation between change of Equivalent Grade and change of Grading Factor. On investigating this point the writer was able to obtain the following remarkable result connecting two samples of the Thanet Beds :—

If sample 1 has Equivalent Grade E_1 and Grading Factor G_1 and sample 2 has Equivalent Grade E_2 and Grading Factor G_2 ,
then $G_2 = G_1 \pm 2.56 (E_2 \sim E_1)$.

Take + sign when $E_2 > E_1$ and — sign when $E_2 < E_1$.

FIG. 7.—Graph showing the relation between Equivalent Grades and Grading Factors of Thanet Beds material from various localities.

This evidence of steady change in the lithological character of the sediments with concomitant change in the degree of sorting of the material signifies the establishment of conditions under which more and more highly sorted material was being deposited. The degree of sorting of a sediment is probably, in general, a cumulative effect depending upon the total vicissitudes through which it has passed, and these vicissitudes are greatest in the case of material which, originally derived from the denudation of a land-area, has passed successively through the stages of having been incorporated in fluvial and estuarine sediments and has finally been deposited under marine conditions. In the striking feature of the Thanet Beds to which allusion has been made, we have, perhaps, the sign of the gradual and definite establishment of marine conditions.

TABLE OF MECHANICAL ANALYSES OF THANET

LOCALITY, ETC.	CLAY GRADE.	SILT GRADES.	
		Fine Silt.	Coarse Silt.
	< .01 mm.	> .01 mm. < .05 mm.	> .05 mm. < .1 mm.
Beddington, Surrey. Clack & Sons' pit. Upper part of Thanet Sand	% wt. 2.37	% wt. 2.25	% wt. 23.97
Beddington, Surrey. Clack & Sons' pit. Lower part of Thanet Sand	0.20	9.40	64.65
Charlton. Gilbert's pit. Upper Thanet Sand	1.45	0.67	3.97
Charlton. Gilbert's pit. Lower Thanet Beds (Blackfoot).	9.52	24.17	58.98
Plumstead Station. Upper part of Thanet Sand	2.57	1.50	5.28
Plumstead. Proctor's pit, east of Plumstead Common. Upper part of Thanet Sand	4.75	0.90	10.30
East Wickham. Tuff & Hoar's pit. Thanet Sand, upper part	3.72	1.58	8.48
East Wickham. Tuff & Hoar's pit. Thanet Sand, middle part	0.78	11.54	52.68
East Wickham. Tuff & Hoar's pit. Thanet Beds, lower part	2.90	26.20	70.90
East Wickham. Wickham Lane Brickfield. Thanet Sand, about 15 feet below junction with Woolwich Beds	4.28	4.92	59.66
The "Caves", East Wickham Valley. Lower Thanet Beds, about 10 feet above Bullhead Bed	8.24	3.24	75.54
The "Caves", East Wickham Valley. Lower Thanet Beds, immediately above Bullhead Bed	13.12	14.20	62.16
Abbey Wood. Roadside section, Knee Hill. Upper Thanet Sand, immediately below Woolwich Beds	5.64	2.37	12.10
Abbey Wood. Co-operative Society's Estate. Thanet Beds, about 15 feet above base	2.00	18.24	72.24
Old Bexley. Spring Place, Dartford Lane. Roadside section in Upper Thanet Sand	3.42	0.92	16.05
Erith. Norris's pit. Lower part of Thanet Beds	1.85	14.36	74.40
Joyden's Wood, near North Cray. Thanet Sand, about middle of deposit	3.07	1.65	51.17
Farningham Woods, southern part. Thanet Sand, fairly high up in deposit	4.40	2.02	58.70
Swanley. Railway cutting between Swanley Junction and Farningham Road Station. Thanet Sand, upper part	2.17	1.55	32.85
Swanley. Railway cutting between Swanley Junction and Farningham Road Station. Thanet Beds, lower part	6.27	7.72	76.77
Stone. Stone Court, No. 3 pit, west of Cotton Lane. Lower part of Thanet Beds, a few feet above Chalk	10.27	12.12	72.10
Darenth Woods. Fox and Hounds Lane. Lower Thanet Beds, just above Chalk	20.02	11.20	44.25
Hulbury, Lullingstone. Lee's pit. Thanet Beds, lower part	4.50	3.52	67.25
Bean. Mounts Wood denehole. Thanet Sand, upper part	4.25	2.52	54.75
Reculver. Cliff section. Thanet Beds, upper part	2.77	17.97	43.82
Pegwell Bay. Cliff section. Yellow loam, indurated. Highest Thanet Beds seen, but still in lower part of deposit	9.85	59.00	28.35
Pegwell Bay. Cliff section. Thanet Beds, lowest part, just above Chalk	11.87	64.62	22.87

SANDS OF SOUTHERN SIDE OF LONDON BASIN.

SAND GRADES.				Equivalent Grade. mm.	Grading Factor.	REMARKS.
1 mm. 125 mm.	> .125 mm. < .15 mm.	> .15 mm. < .2 mm.	> .2 mm.			
% wt. 19.99	% wt. 35.47	% wt. 12.36	% wt. 3.59	.119	.744	Buff sand.
22.65	3.10	—	—	.085	.781	Fine yellowish-buff sand.
6.59	57.04	20.12	10.16	.146	.834	Pale sand.
6.01	1.32	—	—	.059	.581	Greyish-buff coarse silty loam.
13.98	58.50	11.80	6.37	.134	.835	Pale-yellow sand.
67.75		15.00	1.30	.120	.800	Pale-buff sand.
29.86	50.26	4.22	1.88	.120	.834	Pale-buff sand.
29.62	4.90	0.48	—	.087	.751	Fine, pale-coloured sand.
—	—	—	—	.059	.693	Greyish-buff coarse silt.
22.34	8.32	0.48	—	.086	.761	Fine, pale-buff sand.
1.26	1.72	—	—	.076	.758	Pale-buff coarse silt.
7.88	2.64	—	—	.062	.592	Pale-buff coarse silty loam.
7.00	39.67	3.22	—	.110	.788	Pale-buff sand.
6.70	0.82	—	—	.066	.736	Buff coarse silt.
4.40	22.87	2.34	—	.109	.829	Pale-buff sand.
8.02	1.37	—	—	.070	.748	Greyish-buff coarse silt.
9.16	4.95	—	—	.094	.838	Fine yellowish-buff sand.
0.30	4.58	—	—	.090	.823	Fine yellowish-buff sand.
1.15	11.77	0.51	—	.102	.824	Pale-buff sand.
8.40	0.84	—	—	.073	.746	Pale-coloured coarse silt.
4.80	0.71	—	—	.064	.669	Greyish-buff coarse silt.
0.85	1.65	2.03	—	.067	.469	Greyish-buff coarse silty loam.
3.10	1.63	—	—	.086	.798	Fine yellowish-buff sand.
6.50	1.98	—	—	.090	.801	Fine greyish-brown sand.
3.87	1.57	—	—	.080	.656	Very fine yellowish-buff sand.
2.80	—	—	—	.042	.558	loam. Yellow, calcareous, medium silty
0.64	—	—	—	.037	.555	Pale yellowish-grey fine silty loam

This remarkable feature in the Thanet Beds, although apparently universal in Kent, appears to be wanting farther west, in Surrey. From an examination of samples in that area the writer noted that in the upper part of the Thanet Sand an increase in the Equivalent Grade value was accompanied by a diminution in the Grading Factor. This feature was traced as far east as Charlton, where the writer found that the extreme top of the Thanet Sand, whilst giving the highest Equivalent Grade value of any Thanet Sand analysed, gave a somewhat lower Grading Factor than was expected. It seems likely that the readjustment of conditions which resulted in the succeeding Woolwich and Reading Beds being of marine type in East Kent, and of estuarine and freshwater type farther west, commenced before the deposition of the Thanet Beds had been completed.

(To be continued.)