TABLE III

	Anterior lobe/Posterior lobe (ratio)
Cattle ..	2·3 to 2·8
Sheep ..	8 to 11
Pig ..	1·2 to 2·0

In the case of the ox pituitary of European animals where the whole gland weighs 2·5 g., it has been reported that the posterior lobe weighs only 0·5 g., so that the ratio of anterior to posterior lobe should be 4. In the case of the Indian cattle, therefore, although the total weight is nearly half, the proportion of the posterior lobe is considerably higher, so that they appear to be ideal for the preparation of the posterior pituitary products. Sheep pituitary will be seen to be a very poor source of the posterior lobe; it is, on the other hand, best suited for the preparation of the anterior pituitary hormones.

It is interesting to note that the glands of the three classes of animals, cattle, sheep and pigs, used for slaughtering, not only show marked variations in size and shape, but also in their contents of some of the essential chemical constituents. Data for three of these constituents, *viz.*, vitamin C in the case of the whole adrenal and pituitary glands, adrenaline in the case of the adrenal glands and iodine contents of thyroids, some of which have already been reported in publications appearing from this laboratory from time to time, are collectively presented below (Table IV).

TABLE IV

	Vitamin C content of the adrenals (mg./g. of fresh tissue)	Vitamin C content of pituitary (mg./g. of fresh tissue)	Adrenaline content of adrenal glands (mg./g. of fresh tissue)	Iodine content of thyroid (% of desiccated glands)
Cattle	1·24	1·43	2·24	0·91
Sheep	1·36	1·75	1·60	0·66
Pig	..	..	0·8	0·84

It will be noted that sheep glands are richer in vitamin C than the corresponding glands of cattle and again the pituitary is richer in this vitamin than the adrenal.

Our thanks are due to the authorities of the Madras Corporation for facilities for the collection of the various glands from the Slaughter House and to the Superintendent of the Slaughter House for help in the cellection and identification of the glands. We are also deeply indebted to Rao Sahib Chelva Aiyangar of the Madras Veterinary College, for his invaluable instructions in the methods of identification and dissection of the glands. The expenses of this investigation were met by a grant from the Board of Scientific and Industrial Research, to whom our thanks are due.

THE ORIGIN OF CURVES IN RIVERS

BY MOHAMED SALEH QURAISHY, B.E., PH.D., D.I.C.

INTRODUCTION

IT is well known that in most cases, natural water-courses, flowing freely through incoherent material, adopt a sinuous or meandering course, with curves alternating with right and left. There are various hypotheses purporting to explain the origin of this somewhat universal characteristic of natural streams. By way of illustration, we have one of these explaining this phenomenon as due to the earth's rotation, referred to as Baer's Law (Baer, 1857-58) or Coriolis' Effect (Coriolis, 1835); according to the other, the curves are initiated by alternate eddies of the type generated behind a bluff body (Stanley, 1881; Exner, 1919); according to James Thomson (1877), the development of curves is due to secondary flow; according to Moller (1883), an initial asymmetry of the cross-section is responsible for the origin of curves; according to many (amongst whom are also hydraulicians), the curves are due to the river having been initially deflected from its straight course by either an obstacle (Dubuat, 1786; North, 1928) or an initial incurvation (Exner, *op. cit.*; Tiffany and Nelson, 1939); whereas according to some, this tendency is due to the river becoming old and infirm, when in carrying its sedimentary burden, it rambles about.

The question occupies an exceptionally important position in River Engineering and I have investigated it experimentally. I find that Thomson's explanation, which strictly speaking concerns *the development of any existing curves*, is true, as far as it goes. As for the initiation of curves, observations show that the earth's rotation could not be the concerned cause (Quraishy, 1943), whereas the presence of an obstacle, initial incurvation, initial asymmetry of the cross-section, etc., is not necessary to the occurrence of the curves.

The curves originate even in a channel with the sides quite straight and the bed very even. They actually arise as a result of certain interactions between the flowing water and the sediment particles, by a series of easily ascertainable actions.

A study of these actions supplies quite a rational explanation of such formations as convex shoals and secondary channels and also explains many other interesting phenomena, ordinarily speculated upon. A short account, describing how the curves come into being, is given here, whereas a fuller discussion (including also an investigation on the nature of the interactions) is incorporated in a paper to be published elsewhere.

Apparatus

The experiments were performed in an open welded steel flume, 30 ft. long and of rectangular cross-section, 2 ft. 6 in. wide by 1 ft. 6 in. deep. Two jack-screws, one at each side, supported it at its upper end. By these, the channel could be given a variety of initial slopes.

In the channel bottom, wet sand of mean grain diameter 0·70 mm. was placed to a depth of 6 in., and the working channels (straight and with even bed), in this sand, were swept out by wooden templets of the necessary dimensions. Water was supplied at a uniform rate from an overhead tank and so was dry sand, representing 'bed-load', by a device, which was suggested to the author by Dr. C. M. White.

Its construction rested upon the principle that any incoherent material, when free to flow, always tends to assume its angle of repose. And so, no sooner one lot is removed away, than another automatically takes its place. The sediment was stored in a box with an adjustable slit, through which it flowed out freely and was removed away by a flue brush driven at a regular speed by a small motor.

Besides these, use was made of a measuring tank, a thermometer, a point gauge, a spirit level and a balance, to record various details.

Bed Deformation: Formation of the Skew Scales

Generally, with the commencement of an experiment, the topmost grains began to roll and skip all over the bed, moving in jerkey but on the whole, straight paths parallel to the channel sides. But within a short time, sometimes almost as soon as the experiment commenced, there was vigorous local scour of the bed close to the channel sides, alternating with left and right, in all probability due to vortices suspected to be skewed out of the vertical.

These seemed to originate in consequence of the breaking up of the stream at these positions, due to its being deficient in energy and momentum. Experiments, where the formation of ripples was suppressed, without arresting the sediment motion, by sucking away the retarded stratum close to the bed, lent strong support to this view.

The material appeared to be scooped out and pumped towards the centre where it came to rest in a systematic manner. When carefully examined, the fish-scale pattern was found to be twisted towards the one or the other side of the channel, something like Fig. 1 A. We call these *the skew scales.*

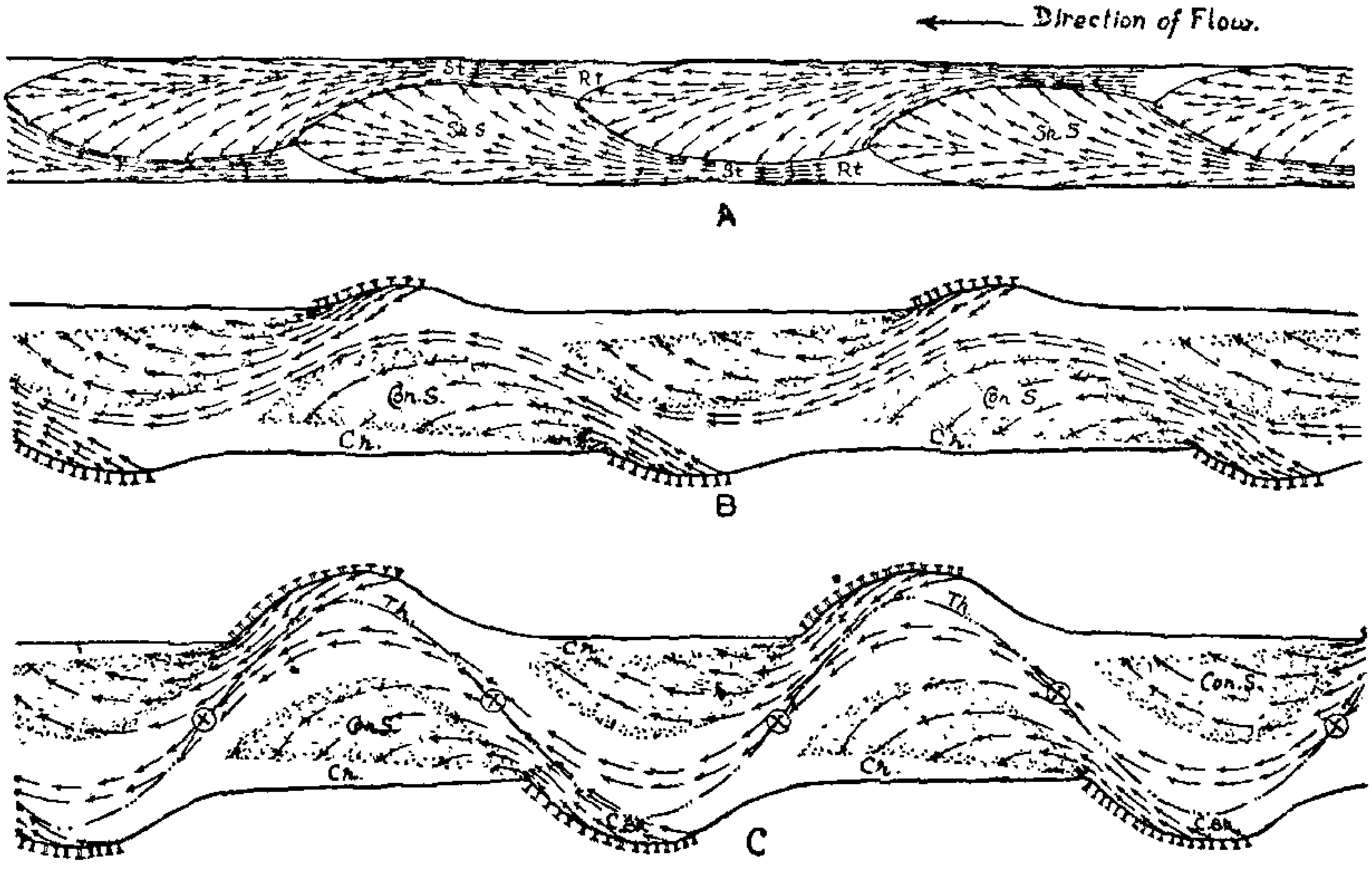

Fig. 1. Illustrating the Sequence of Features Leading up to a Meandering Stream

A shows well-developed skew scales, *i.e.*, skew shoals. The tracks of particles coming from the stems (*St.*) are curvilinear. As the skew shoals attain an optimum size, bights develop and the finer details of the shoals get masked. This is illustrated by *B*. Then the curves develop. As shown in *C*, the material removed from the concave banks follows the arrows and is mostly deposited downstream as indicated. Between the shoals and the channel bank, there are secondary channels or creeks (*Cr.*), where would gather foam and dirt.

C. Bk.—Concave Bank; *Con. S.*—Convex Shoal; *K.*—Kink; *Rt.*—Root; *Sk. S.*—Skew Shoal; *St.*—Stem; *Th.*—Thalweg; ⊗ Crossing; ╥╥╥ Caving Bank; ← Particle Track.

These skew scales were just a few grains thick but their pitch was anything from 50 to 500 times their thickness. Slowly they grew up, as they were continuously nourished by the scoured material from places which in Fig. 1 A are denoted by *St.* We name these *the stems.* For purposes of standardisation, we call the upper ends of these *the roots.* The position of these roots lay nearly opposite to a kink, marked in the figure as *K*. The paths of sediment grains coming from these stems were curvilinear: the strokes in Fig. 1 A have been drawn to exemplify these paths.

This sequence was, however, found in experiments in which the variables were fairly well represented. In other experiments, there were some intermediate formations, hardly like the skew scales, but all invariably leading to the skew shoals (advanced stage of the skew scales).

There were also cases, where the skew scales appeared successively. For example, they would originate upstream and migrate downstream, till the whole channel bed had been covered with them, or again initiate at the downstream end first and appear elsewhere subsequently. All such processes were, however, very slow and this peculiarity had some bearing upon the subsequent behaviour of the stream—upon the manner in which the particles moved and upon the various associated phenomena. It seemed to us as though the more rapid movements produced close consilience, whereas the slower ones gave rise to dissimilarities.

The Skew Shoals and the Initiation of Curves

All such skew scales, with more or less a constant pitch in the flow direction, bulged out in other directions. In their mature form, they looked something like long-drawn out dunes, in which state we name them *the skew shoals*. As soon as the height and breadth of these shoals became sufficiently great, the channel sides began to be scoured alternately, just opposite the widest part of the shoals. Simultaneously, it appeared as though the forward migration of the shoals had ceased: the well-defined skew shoals had been deprived of their beautiful pattern and now presented only a smooth, washed out appearance (Fig. 1 B).

This marked the initiation of curves. Both the skewness and the curvature of the shoal boundaries seemed essential for this to happen. But the mechanism involved appeared somewhat complicated and could not be fully grasped. What was, however, clear was that a type of secondary flow was set up: the faster fluid moved outwards and scooped out material from the bank. Once this action started, the effect was progressively intensified due to the outer boundary becoming more and more curved, so that, ultimately we had a channel like the one illustrated in Fig. 1 C, where the arrows, once again, depict the tracks of the sediment particles.

Other Interesting Facts

Fig. 2 A, reproduced from a previous note by the author (1943), shows such a channel with the water flowing through it, whereas Fig. 2 B shows the same channel with the water drained off. In this laboratory river, one can clearly observe all the prominent features generally associated with large rivers (*cf.* Fig. 1 C). These include concave banks, convex shoals, secondary channels or creeks, deeps, shallows, crossings, etc.

The secondary channels or creeks, often erroneously adduced by river engineers to the inequalities in the settlement of suspended silt, when the flood waters subside, are the result of the peculiar manner in which the particles are transported and deposited and come into

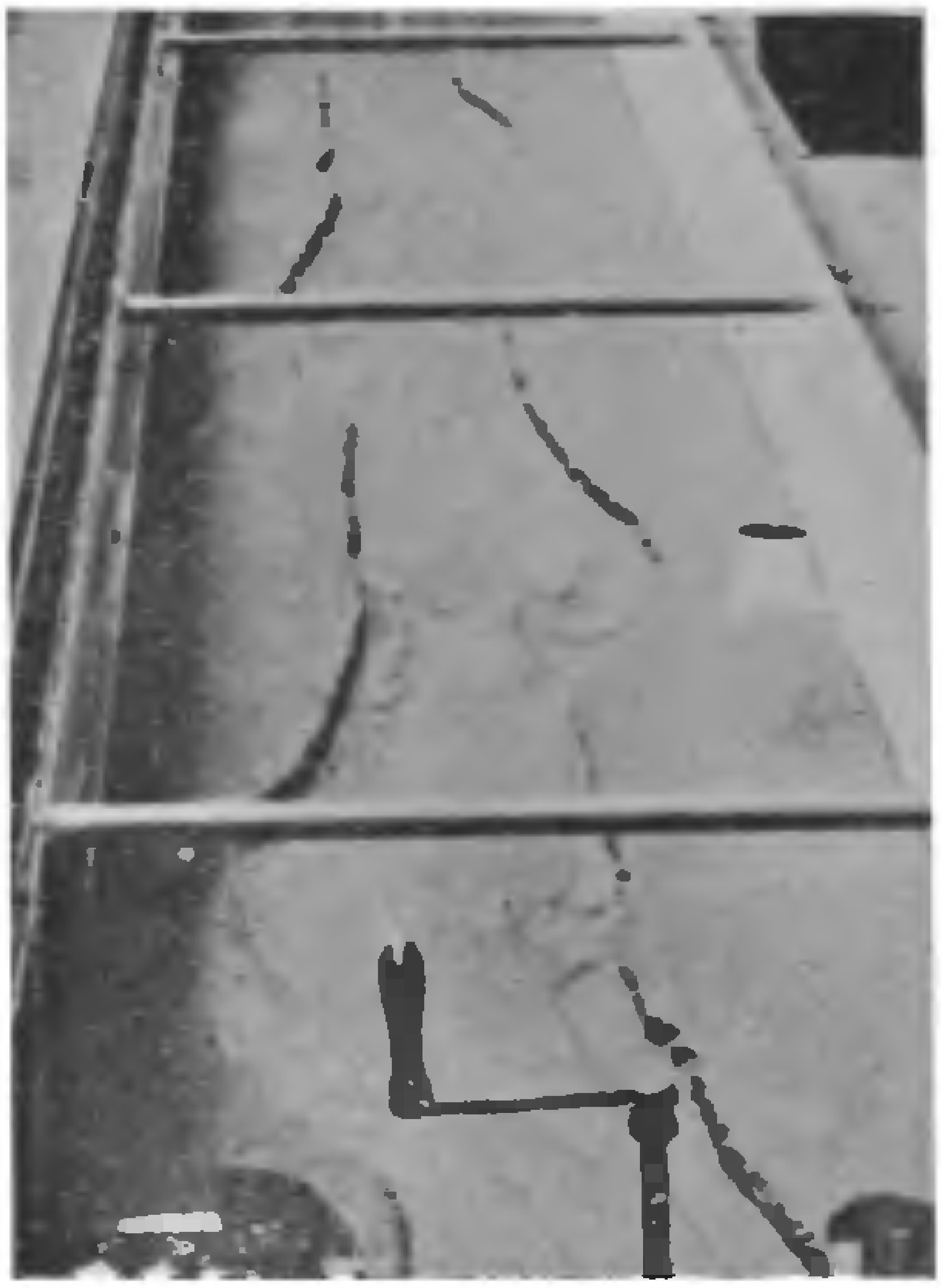

FIG. 2. Photographs of a Meandering Stream

A—With water; *B*—Without water

being as soon as the scales are formed (*vide* Fig. 1 A). These were filled with retarded water and remained opened at their downstream ends. An effect of surface tension could be seen in the accumulation of foam and dirt on the surface of this retarded water: in the photograph in Fig. 2 A, bright bands against the banks (just below the concave banks) are due to this.

The edges of these creeks appeared to move outwards, towards the banks. But whereas we are apt to think of the creeks ultimately fading away, we saw that in actual fact this was not so: there was a certain increase in the amplitude and the shoals continually travelled downstream, so that the triangular creeks maintained their identity.

The concave banks (Fig. 1 C) appeared to cave in: the material was either wholly washed into water or slipped down. The banks became more or less vertical, with their toes curved, and the particles caught and moved forward, were distributed as shown. As a result of this kind of radial and tangential erosion, the curves expanded radially and simultaneously migrated downstream. Fig. 3 is an example of the sequence of the water surface profiles, in plan, assumed progressively with time. The insets show cross-sections at typical places, with the water surface elevated towards the concave sides, due to the centri-

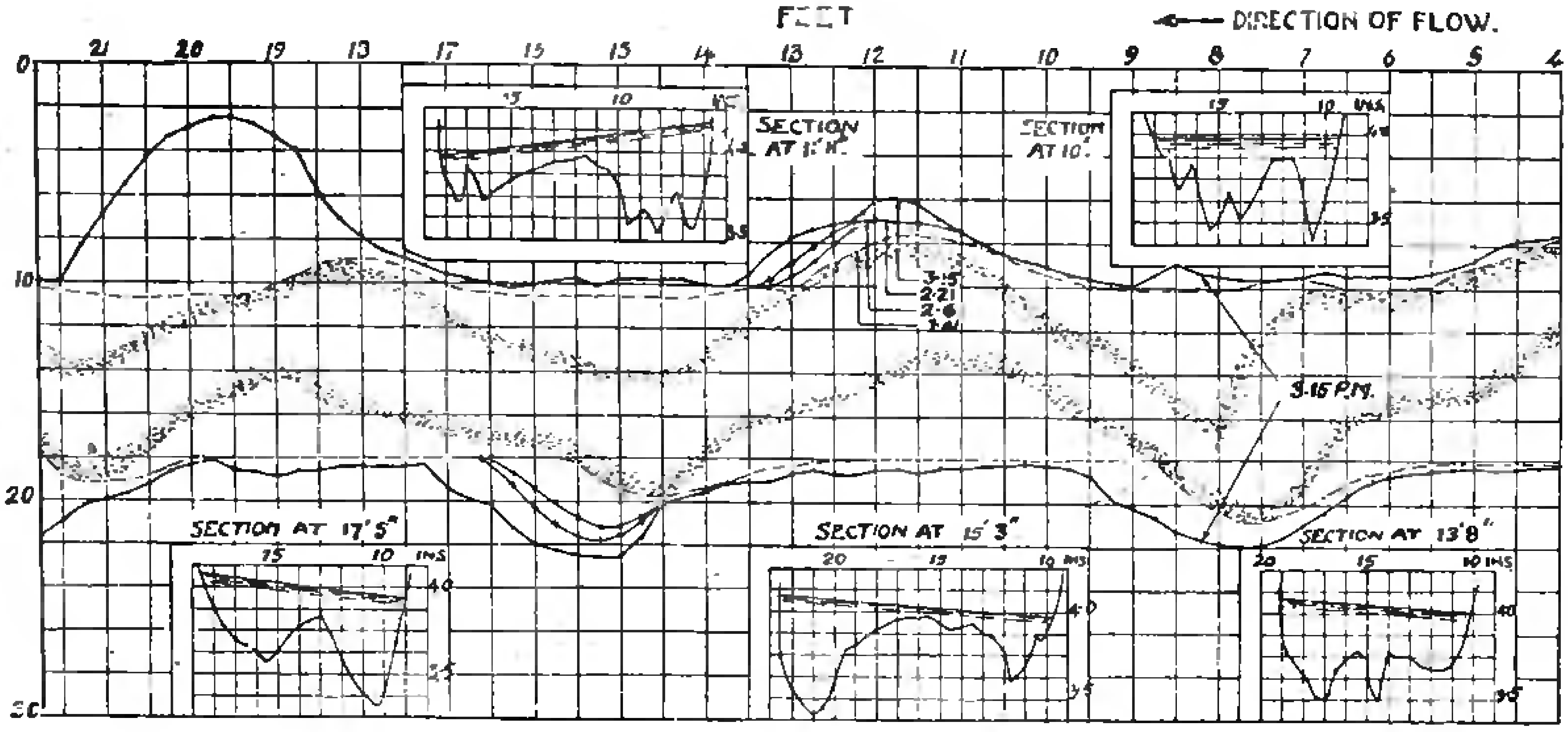

FIG. 3. Periodical Profiles in Plan of a Typical Meandering Stream

(Discharge 0·021 cusec., sediment feed 1·0 gm./sec, initial channel slope 1 : 300, and initial width at the bed 6 in.)

Region within dotted border presents channel bed where the sediment motion was extremely lively at that stage. Bold lines mark the position of water surfaces at the times indicated by the attached figures. These illustrate also the lateral and tangential expansion of the curves.

fugal force (in virtue of the curvature of the curves).

Critical Tests

Critical tests were made to determine with certainty that the skew shoals preceded the initiation of curves. In these first one and then both sides were reinforced. The photograph in Fig. 4 shows the skew shoals with fine sand, approximately 0·21 mm. in diameter. The channel had both sides rigid and was barely 2 in. wide. It was given a very steep slope, but the discharge was just a few c.c. per second.

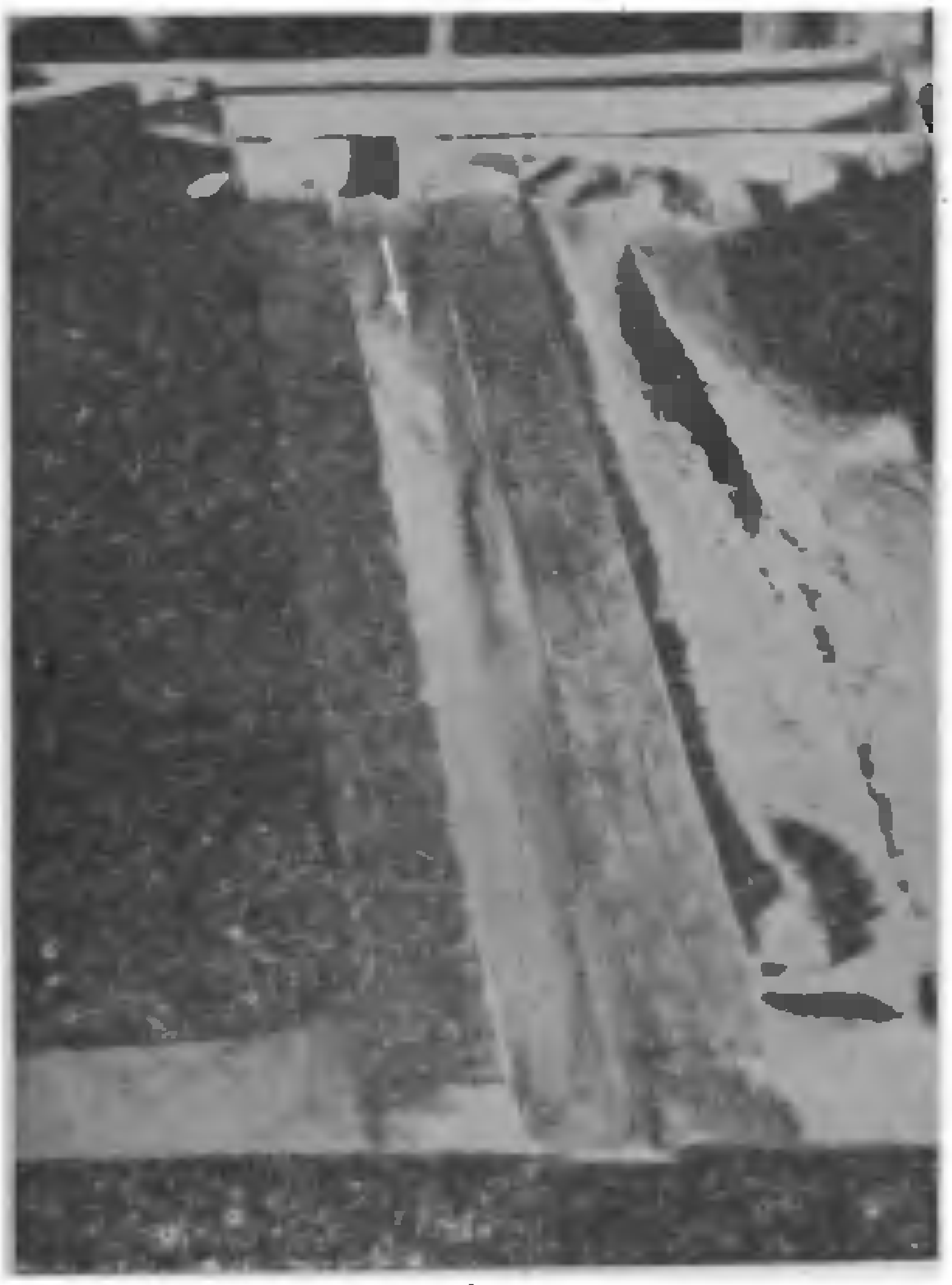

FIG. 4. Photograph Showing the Skew Shoals

All these tests led to the conclusion that the skew shoals were precisely responsible for the origin of curves in rivers, which initially can be quite straight and have an even bed.

Acknowledgments

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