Sedimentation of a Heterogranular Mixture: Experimental Lamination in Still and Running Water

GUY BERTHAULT

These experiments demonstrate that in still water, continuous depositing of heterogranular sediments gives rise to laminae which disappear progressively as the height of the fall of particles into water, and apparently their size, increases. Laminae follow the slope of the upper part of the deposit. In running water, many closely related types of lamination appear in the deposit, even superimposed.

INTRODUCTION

The author has previously performed experiments on lamination of sediments, resulting in a periodic graded-bedding subsequent to deposition,[1] thus contributing to the explanation of lamination of various sediments and sedimentary rocks. These sedimentation experiments were conducted in still water with a continuous supply of heterogranular material. A deposit was obtained, giving the illusion of successive beds or laminae. These laminae were the result of a spontaneous, periodic and continuous grading process which took place immediately following the deposition of the heterogranular mixture. The thickness of the laminae appeared to be independent of the sedimentation speed but increased with extreme differences in the size of the particles in the mixture.

Where a horizontal current was involved, laminated superposed layers developing laterally in the direction of the current were observed. The object of the new complementary experiments described hereafter was to study, first in still water, the influence of the height of the fall of particles into water, and the influence of a slope on lamination in the deposit; second, in running water, at a higher rate of particle discharge than in the initial experiment, the incidence on the structure of the deposit.

These experiments were undertaken at the request of the author, by MM. Penquer, Guillaume and Bertinier, at the 'Institut de Mécanique des Fluides de Marseille' (Institute of Fluid Mechanics, Marseilles).

INFLUENCE OF THE HEIGHT OF THE FALL ON LAMINATION IN CALM WATER

The first series of experiments was performed with a mixture of two types of sand; one white calibrated between 20–80μm, and the other coloured with methylene blue with the calibrations increasing in size. This mixture was poured from a variable speed screw distributor into a rectangular tube 200mm x 150mm x 4.7m deep, filled initially with 2m of water, then with 4.7m.

1. Height of fall of 2m

(a) Mixture 30% blue sand 250–315μm, 70% white sand. Three successive discharges were involved in the same experiment: 35, 100 and 170cm^3/5 min.

(b) The same mixture with blue sand sized 315–400μm. Three discharges similar to the preceding experiment.

In both experiments, three superimposed beds were observed (see Figure 1) showing millimetre thin, fairly regular laminae, becoming more defined as the discharge was increased.

2. Height of fall of 4.7m

(a) Mixture 25% blue sand, 75% white sand. Four experiments were performed with a constant discharge of 40cm^3/min, with four increasing sizes of blue sand particles. For the blue sand sized 200–250μm, millimetre thin laminae of medium definition were observed (see Figure 2). For the blue sand sized 250–315μm and 315–400μm, laminae were irregular, not well-defined and rather thin at the places where they appeared. For the blue sand sized 400–500μm the laminae practically disappeared.

(b) Three new experiments were performed with lower

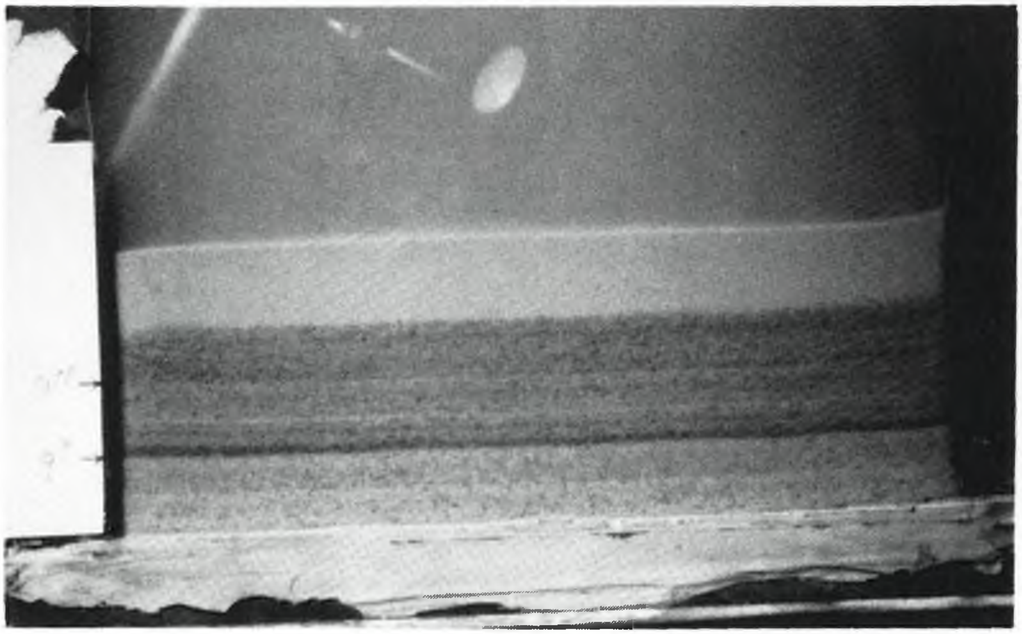

Figure 1. Laminations under 2 M of water, discharge 35 to 170 cm ³/5 m.

Figure 2. Laminations under 4.7 M of water, discharge 40 cm ³/mm.

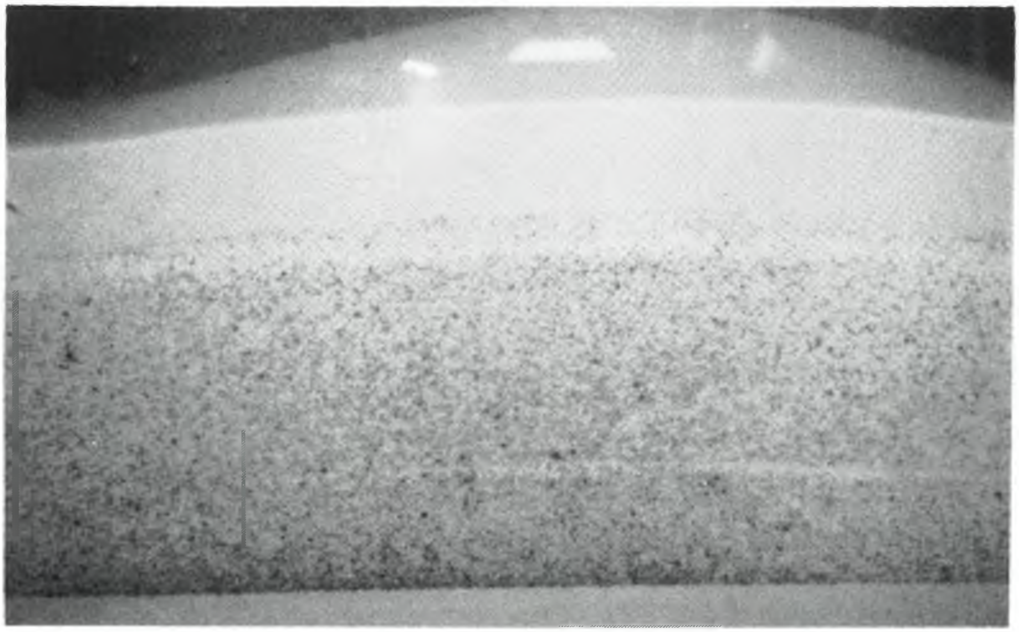

Figure 3. No lamination under 4.7 m, discharge 400 cm³/H.

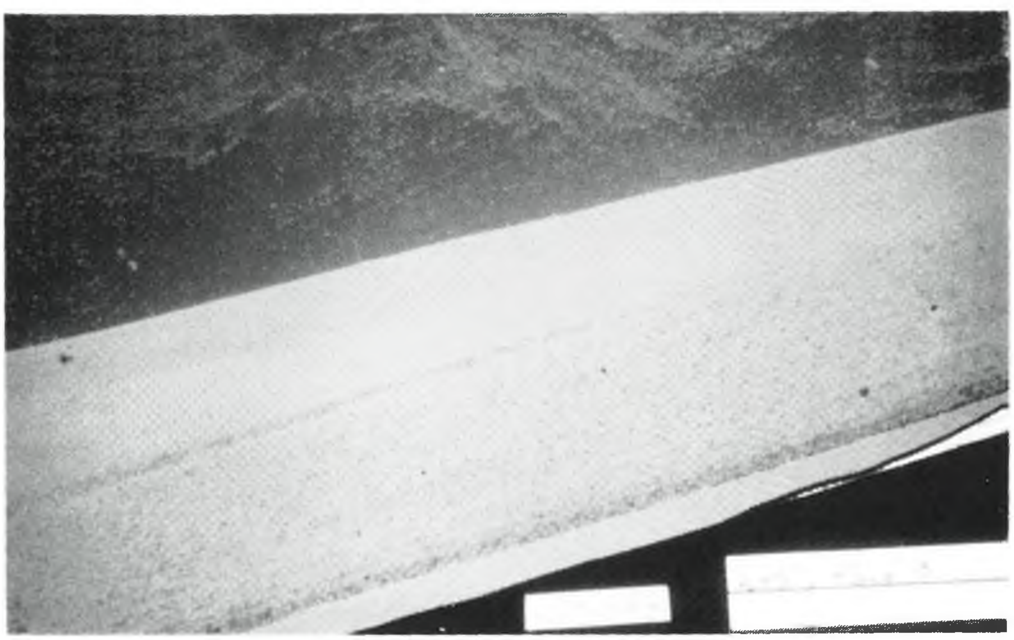

Figure 4. Lamination parallel to slope to 15°.

discharges to see if laminae appeared or not in the deposit. The mixture of 1/3 blue sand sized 400-500μm, 2/3 white sand discharged at 230g/hr produced no laminae. The same mixture discharged at 500g/hr also produced no laminae (see Figure 3). Similarly the mixture of 1/3 blue sand sized 150-212μm, 2/3 white sand discharged at 230g/hr produced no laminae.

3. **Interpretation**

The conclusion from these experiments on the influence of the height of the fall of a heterogranular mixture on the formation of laminae is of a subtle nature. Indeed, lamination in calm water is a phenomenon which seems quite credible to the extent that the laminations, although not well-defined, appeared during the experiments at a height of only 2m, which height seems, *a priori*, to be sufficient for the effects resulting from the discharge to be largely reduced.The results are however different, depending upon whether a height of 2m or 4.7m is used. There are two possible explanations, either:

(a) the eddying movements induced by a punctual discharge do not weaken within a distance of 2m, and therefore the apparition of lamination is closely linked to the presence of an 'agitation' of the carrying fluid; or

(b) although the experimental conditions (discharge, proportions of sands) are similar, the vertical division of concentrations in white sand in the tube is modified by the height of the water.

It is possible that the fluid uplifts created by the discharge maintain part of the white sand in suspension very far from the surface of the deposit. At the level of the deposit the proportion of the concentrations, white sand/blue sand, would be considerably diminished. However, during such an experiment at a height of 2m, the average concentration in white sand at the level of the deposit is an increasing function with time, especially as at that level the vertical flux of the sand is inferior to the massive flux at discharge. Yet, at a height of 2m, a lamination appears shortly after the beginning of the experiment. This tends to refute the hypothesis (at a height of 4.7m) of a concentration of white sand, at the level of the deposit, insufficient to allow the lamination to appear.

However, the experimental series performed at a height of 4.7m seems to prove that the energy dissipated by the fall of a heterogranular mixture of sands is sufficient in itself to affect the deposit with an anisotropic character, tending towards a horizontal sorting, without asserting there is a lamination.

On the other hand, the appearance of laminae seems all the more probable if the total concentration of the sand is high. These various observations lead us to think that lamination, when it appears, is due partly to the correlation between a turbulent agitation of the fluid and the concentration at the level of the deposit, or to phenomena of instability due to sedimentary fall of a hyperconcentrated mixture, or a combination of both the abovementioned phenomena.

INFLUENCE OF A SLOPE ON LAMINATION IN CALM WATER

The next step in the experiments was to produce deposition on a slope in order to examine the effect of a slope on lamination. A tank with four transparent sides was used, having the same dimensions as the PVC tube, and a variably sloped bottom. The height of the water was 1.10 m.

1. **Slope of 6°**

(a) Mixture 25% blue sand 315–400μm, 75% white sand 20–80μm. A lamination appeared, not very distinct, inclined on the lateral sides of the tank and practically invisible on the front and back sides. Moreover, a cone effect was seen, which was the result of sand sliding, shown by the difference of thickness between the deposits at the bottom and the top of the slope. At this height of sedimentary fall, the size of the larger particles used was at the upper limit that permits laminae to be obtained.

(b) The same mixture with blue sand 250–315μm. A fairly distinct lamination appeared, except at the bottom of the slope. On the lateral faces of the tank, the lamination was nearly parallel to the slope.

2. **Slope of 15°**

The same mixtures gave similar results (see Figure 4).

3. **Interpretation**

The slope of the basic surface has little influence on lamination, although it perhaps tends to favour it. The first laminae formed parallel to that surface. In every case, the upper lamina was parallel to the upper part of the previous deposit. The angle between those two planes was reduced as the size of the particles decreased and the slope was reduced.

INFLUENCE OF RUNNING WATER ON LAMINATION

1. **Introduction**

The objective of the next part of this investigation was to study the phenomena of internal lamination resulting from heterogranular sedimentation occurring within a lateral current.

2. **Equipment**

The experiments were performed in a recirculating flume, 10m long, 29cm high and 0.5m wide, equipped with lateral viewing windows to observe the depositional structures. The flume is located at the Institut de Mécanique des Fluides (Institute of Fluid Mechan-

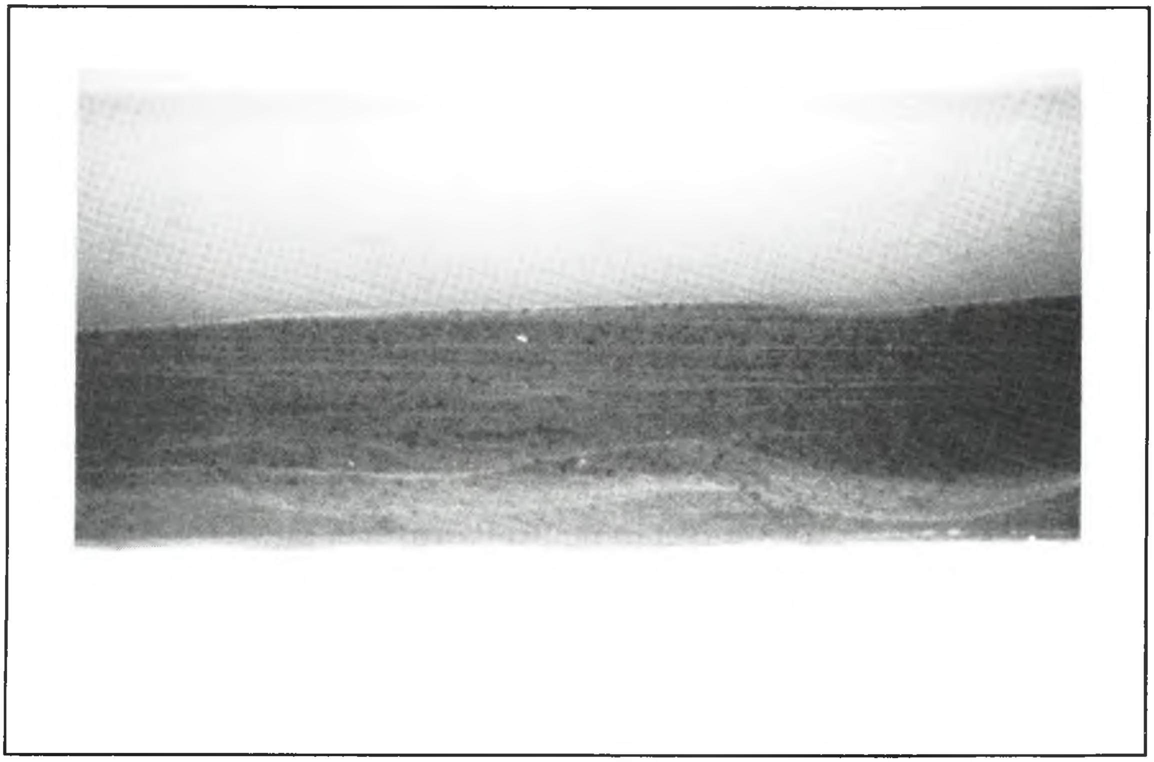

Figure 5. Cross laminated ripples surmounted by horizontal laminated.

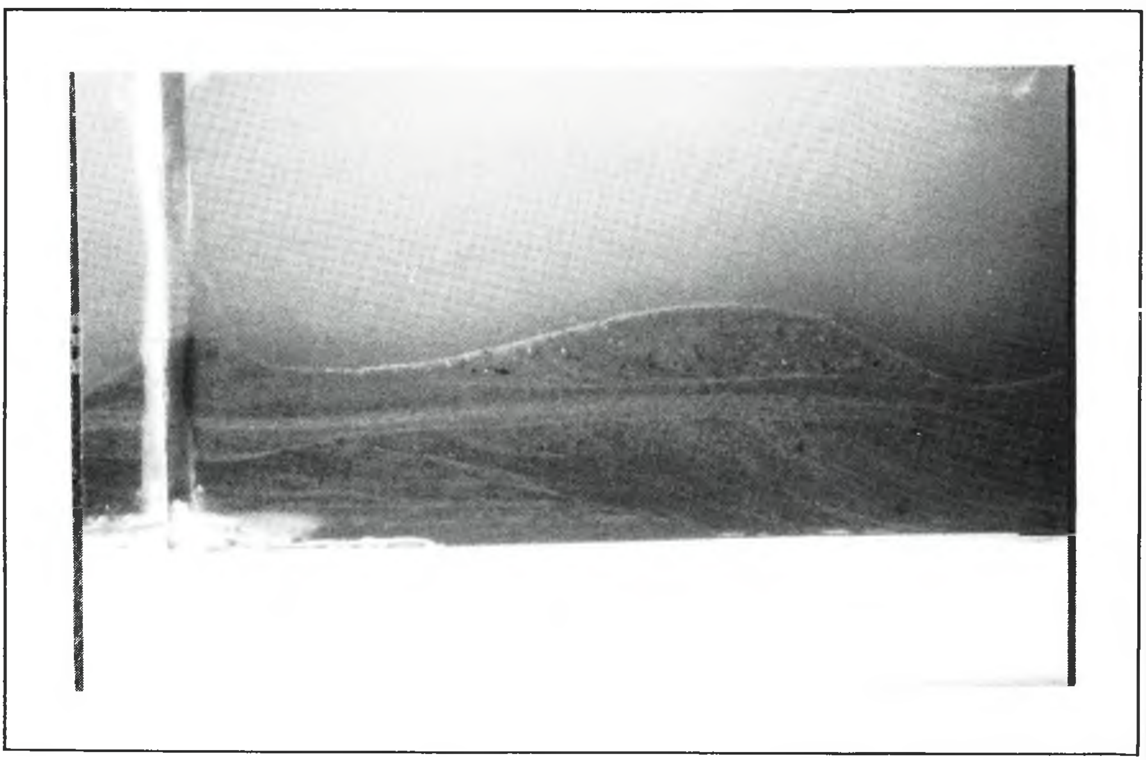

Figure 6. Cross laminated ripples split by a layer of horizontal laminae.

ics), Marseilles, France. The slope was 1.2×10^{-3} and the coefficient of frictional force on the smooth bottom was 0.016.

A Flight pump, equipped with a paddle, allowed the water discharge to be varied from 16 to 70 litres/sec. A Pitot tube, on an instrument carriage, allowed the velocity to be measured at every point of flow. The verification of the obtained data was effected by the measurement of the surface velocity by means of a floater. The depth of water flow was determined by means of rulers affixed to the viewing windows. The discharge of sand was achieved through a hopper located above the flume.

3. **Experiments on internal lamination**

Two experiments were performed

(a) A mixture of 120kg of blue sand 100–150μm and 240kg of white sand 20–80μm was discharged from the hopper in 3hrs.

(b) A mixture of 80kg of blue sand 150–210μm and 240kg of white sand 20–80μm was discharged in 2hrs 30mins.

The characteristics of the flow at the beginning was:

(i) Mean velocity of flow U, given by exploration of the median vertical plane of the flume.
  (a) 38.4 cm/sec; and
  (b) 39.6 cm/sec.

(ii) Surface velocity of (a) and (b): 40cm/sec.

(iii) Maximum height of water:
  (a) 9.9cm; and
  (b) 8.8cm

(iv) Average height h :
  (a) 9.7 cm; and
  (b) 8.9 cm

(v) Minimum height of water:
  (a) 9.5cm; and
  (b) 9cm.

From those data the following calculations could be made:

(vi) Discharge, $Q = U \times h \times 1$
  (a) 18.6×10^{-3} m^3 /sec.
  (b) 17.6×10^{-3} m^3 /sec.

(vii) Coefficient of frictional force
  $\Lambda = 8 \times g \times h \times l \times i/U^2(2H+1)$
  (a) 0.045
  (b) 0.039

(viii) Reynolds number, $R = Uh/\upsilon$
  (a) 37,250
  (b) 35,240

(ix) Froude number, $F = U\sqrt{gh}$
  (a) 0.394
  (b) 0.424

(x) Stream power, $P = U\tau$
  (a) 0.44 joules/m^2/sec.
  (b) 0.416 joules/m^2/sec.

where τ is the shear stress of the sand grains under the water.

These characteristics varied during the experiments. The velocity, for instance, increased with the thickness of the deposit, while the height of water decreased.

In both experiments, many types of lamination were observed — cross and horizontal, juxtaposed, and superimposed (see Figures 5, 6 and 7), or disordered.

4. **Experiments to produce laminae at the surface of the deposit**

Four experiments were performed with only white sand. After the second experiment, the resulting deposit consisted of ripples, the partial desiccation of which, when seen from above, looked like alternating dry and wet lines, which appeared to result from an oblique repetitive sorting.

The same experiment was repeated with the same mixture of blue and white sands of experiment (b) above, at a velocity of 0.4 m/sec. The deposit dried up after the flume was emptied. It consisted of ripples, on the surface of which laminae could be seen (see Figure 8).

5. **Interpretation**

The dip of cross-lamination seemed to depend upon the height of water above the deposit. Therefore, the dip of cross-lamination depended on all other parameters that varied with variations in the height of water above the deposit. Otherwise, internal lamination seemed to crop out at the surface when ripples were produced there.

CONCLUSIONS

1. **Confirmation of experimental lamination**

These experiments in calm and running water confirmed that the continuous deposition of a heterogranular sediment can give rise to horizontal and cross lamination, provided that a minimum disturbance of water is involved. In calm water, laminae were horizontal or parallel to the dip of the upper part of the deposit induced by a basic slope. No penetration of coloured grains through the surface of the deposit was observed during these experiments, contrary to the observations I made during one of my initial experiments, which was certainly accidental. In running water, horizontal and cross laminae were observed placed together and sometimes superimposed.

2. **Discussion of the possible mechanism of lamination**

Campbell and Bauer[2] have demonstrated that a dry flow of a mixture of powders gave rise to a segregation of particles of the same size. Such segregation in calm and running water is induced by the disturbance of water, however slight. Lamination resulting from such segregation can therefore result either from the correlation between turbulence of water and the concentration at the level of the deposit, or from instability phenomena resulting from the sedimentary fall of a hyperconcentrated mixture, or from the conjugation of these two factors.

3. **Prospects**

These results should be compared with flume experiments by Guy, Simons and Richardson,[3] and Williams,[4] the object of which was not the study of structure, despite some remarks on it, but the configuration of deposition. They should also be compared with the investigation by McKee, Crosby and Berryhill[5] of structures in sediment deposits from the Bijou Creek flood, where horizontal and cross laminae similar to those of these experiments were observed. Thus it is necessary to pursue such experiments in larger flumes in order to reproduce flow sedimentation and study the variations of depositional structures with all the determining parameters. These experiments, no doubt, will lead to a better understanding of laminar sedimentation, both in sedimentary deposits and in sedimentary rocks.

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