

EXPERIMENTS ON STRATIFICATION

GUY BERTHAULT
28, BOULEVARD THEIRS
78250 MEULAN, FRANCE

KEYWORDS: Superposition, Strata, Laminae, Stratigraphy, Bedding planes.

ABSTRACT

The principle of superposition requires that superposed strata in sedimentary rocks form from successive layers of sediments. The principle of continuity asserts that each layer has the same age at any point. These principles apply a relative chronology to superposed strata. The correlation between strata and time allowed Charles Lyell to establish the first geologic column in 1830.

From his examination of sediments in the Gulf of Naples in Italy a century ago, Johannes Walther, one of the founders of sedimentology, formulated his law of correlation of facies: "As with biotopes it is a basic statement of far-reaching significance that only those facies areas can be superposed primarily which can be observed beside each other at the present time" [3]. Walther's law, which gave rise to the modern sequential analysis of facies, is not in agreement with the principles of superposition and continuity. His law, as well as the observations of the Bijou-Creek deposits, suggested that the contradiction might be due to the belief that superposed strata are the same as successive layers.

The author's first experiments on lamination and those performed at the Colorado State University in large flumes showed that stratification under a continuous supply of heterogeneous sand particles can result from: segregation for lamination, non-uniform flow for graded beds, and desiccation for bedding plane partings.

In the flume experiments superposed strata were always distinct from successive layers, and neither the principle of superposition nor the principle of continuity applied to the strata.

Due to the mechanical nature of segregation and the presence of sediments and non-uniform flow in oceans and rivers being the same factors producing strata formation in the flume, the experimental results might have some application to the genesis of stratified rocks.

As the experiments cast doubt upon the use of the principles of superposition and continuity for interpreting the origin of sedimentary rocks, it would perhaps be preferable to follow the modern approach of sequential analysis, although on a larger scale. Such an approach should necessarily take into account the present series of experiments.

INTRODUCTION

Stratification is the general term for layering in rocks. A stratum is a single layer of homogeneous or gradational lithology deposited parallel to the original dip of the formation. It is separated from adjacent strata or cross-strata by surfaces of erosion, non-deposition, or abrupt change in character. A stratum includes bed and lamination which carry definite thickness connotations [1].

The principle of superposition states that layers having been deposited one upon the other, each layer superposed upon another is younger than the one underneath it [2].

The principle of continuity states that each layer has the same age at any point [2].

It follows from the above two principles that superposed strata are successive layers with each layer having the same age at any point. A relative chronology is thus attributed to superposed strata.

The correlation between strata and time allowed Charles Lyell to construct the first geologic column in 1830.

SEDIMENTOLOGICAL DATA

(1) Johannes Walther's law of the correlation of facies

At the time of the pioneering of stratigraphy, little was known about sediments. It was not until 1875, with the sea-floor core sampling of the "Challenger" vessel that sedimentology started to develop. It was the observations made by German sedimentologist Johannes Walther [3] of the littoral sediments in the Gulf of Naples that provided further data. He noted that, as one moved out from the coast to the open sea, the characteristics or facies of the sediments on the sea bottom changed. From a vertical boring, he observed that the succession of facies was identical to the superposition of facies. Walther's explanation was simple. Gradually, the gulf was filled in by fluvial, marine, detrital, chemical and organogenetic sediments. The sea floor thus spread laterally towards the open sea. This movement is called "progradation" (see Figure 1).

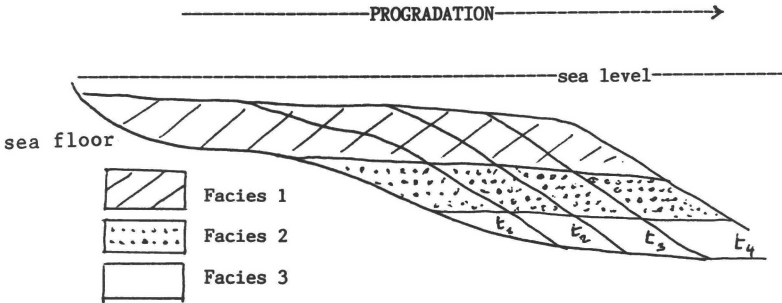


Figure 1. Progradation.

The facies 1, 2 and 3 prograde together toward the open sea at t1, t2, t3, t4 (t = time), and superpose each other.

The 'differentiation' of facies arises in two ways. First from the sedimentary particles undergoing a sorting process due to the action of the waves, tides and currents, whereby the larger particles are deposited near the shore and the smaller ones farther away. Second, the progressive substitution of the terrigenous sediments, from the coast to the sea, by organic deposits. These latter sediments originate from benthic species at specific depths and migrating species of plankton giving rise to chemical deposits and organodetrital sediments at various levels and distances from the shore.

Walther formulated his observations on the correlation of facies into the following law:

As with biotopes, it is a basic statement of far-reaching significance, that only those facies areas can be superposed primarily which can be observed beside each other at the present time.

Since Walther's time, sedimentologists of his school have sought an explanation for the superposition of facies in ancient sedimentary ocean basins. Being unable to observe sedimentation following the major transgressions and regressions of the past, they adopted a reasoning, based upon contemporary coastal transgressions and regressions caused by tropical hurricanes. Referring again to Figure 1, if the sea level falls abruptly at each of the times t1, t2, t3, and t4, then the level of the sediments will fall in the same way. The result is shown in Figure 2 below.

It can be seen from Figures 1-4 that superposed facies in a sequence, deposited at the same time, do not follow either the principle of superposition or the principle of continuity. These facies, however, can be composed of superposed strata. It follows that the two principles cannot apply to such strata. Consequently, such strata are not successive layers nor do they have the same age at any point.

REGRESSION (discontinuous)

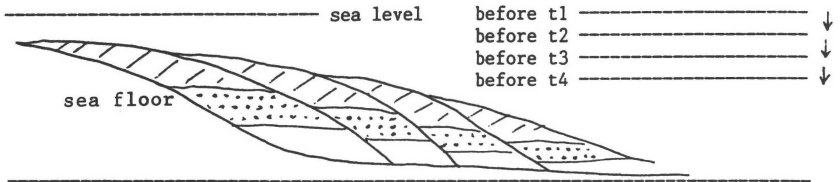


Figure 2

If, however, the sea level falls continuously from T1 to T4, then the situation will be as shown in Figure 3.

REGRESSION (continuous)

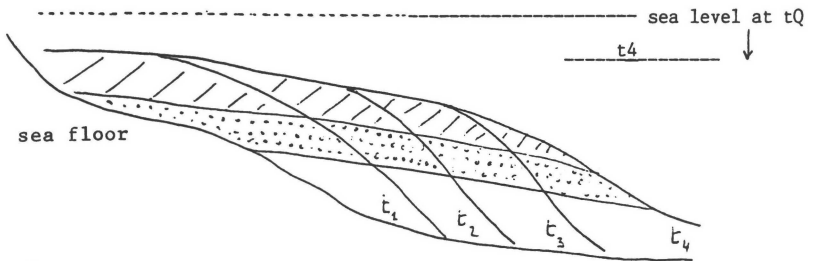


Figure 3

If, however, the sea level rises, the order of superposition of facies will be reversed. See Figure 4.

TRANSGRESSION (continuous)

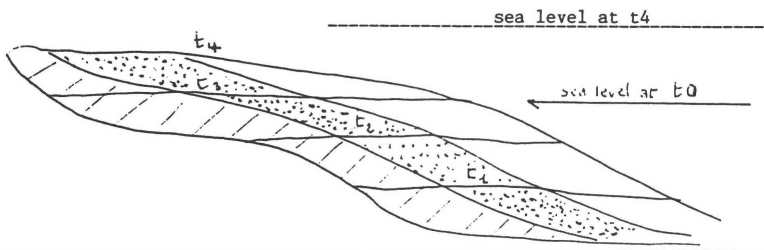


Figure 4

Figure 2. *Discontinuous regression.*

Figure 3. *Continuous regression.*

Figure 4. *Continuous transgression.*

(2) BIJOU-CREEK Flood - field data source

The 1965 Bijou-Creek flood in Colorado, after forty-eight hours of rain, produced a deposit of sediment twelve feet in thickness in some places. After the water had receded, E.D. McKee, Crosby and Berryhill studied the site [4]. They dug trenches in the sediment in order to examine their structure and texture. They found that 90-95% of the sediment consisted of horizontal laminated strata. The external vertical face of the sediments deposited on the original bank, perpendicular to the river bed, showed strata separated by virtually horizontal cracks resembling bedding plane partings found in rocks (see photo-figure below).

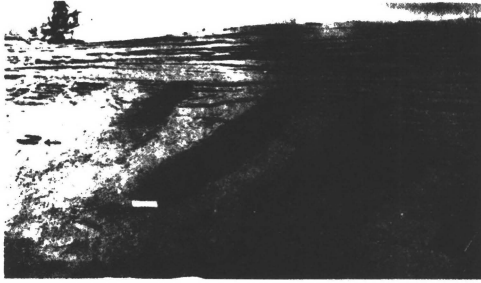


Figure 5. 1965 Bijou Creek sediment deposit.

As the flood only lasted forty-eight hours, it seemed that the cracks were caused by desiccation of the sediments after the water had receded.

EXPERIMENTS ON STRATIFICATION

The study of the facies sequences and cracks in the Bijou-Creek deposits gave rise to questions which were addressed by an attempt to reproduce similar deposits in the laboratory.

(1) First series of experiments on lamination

The object of the experiments was to study lamination in continuous sedimentation in the air, in still water and water subject to a current. Up until these experiments, lamination had been interpreted as a superposition of successive layers.

Samples of laminated friable rock were crumbled to reduce them to the original particles of varying diameter that made up the rock. The particles were sorted by sieving, and the largest particles were colored. They were then remixed with the noncolored particles and allowed to flow continuously in recipients, first in the air, then in water. The experiment was repeated in a small flume in which water was circulated. The results were summarized in the abstract of the 1986 report [5]:

These sedimentation experiments have been conducted in still water with a continuous supply of heterogranular material. A deposit is obtained giving the illusion of successive beds or laminae. These laminae are the result of a spontaneous, periodic and continuous grading process, which takes place immediately following the deposit of the heterogranular mixture. The thickness of the laminae appears to be independent of the speed of sedimentation but increases with extreme differences in the size of the particles in the mixture. Where an horizontal current is involved, thin laminated superposed layers developing laterally in the direction of the current are observed.

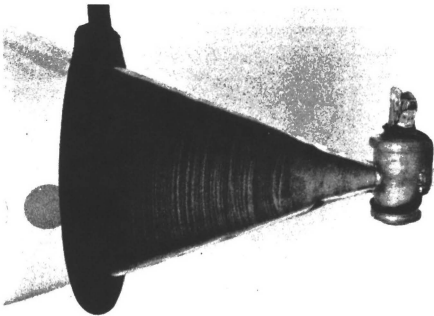


Figure 6. Laminations resulting from flowing of dry sediments.[5]

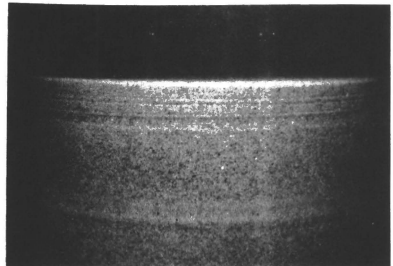


Figure 7. Laminations resulting from flowing in water.[5]

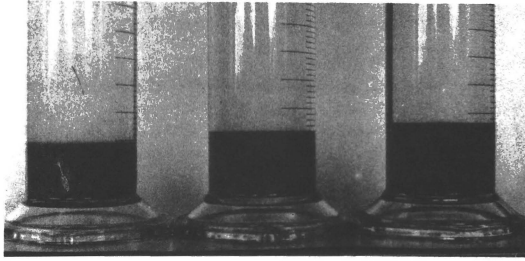


Figure 8. The thickness of laminae is independent of the speed of sedimentation.[5]

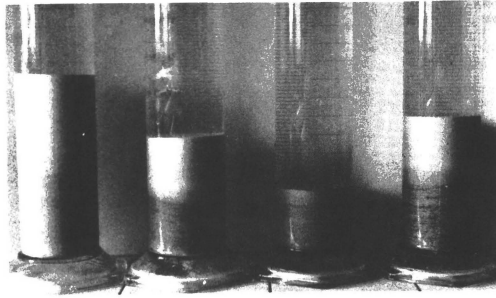


Figure 9. The thickness increases with wide difference in the size of the particles.[5]

Similar experiments were conducted at the 'Institut de Mecanique des fluides' in Marseilles (France). The results were summarized in the abstract of the 1988 report [6]:

The experiments demonstrate that in still water, continuous depositing of heterogranular sediments give rise to laminae which disappear progressively as the height of the fall of particles into water, and apparently their size, increase. 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.

(2) Experiments in collaboration with Colorado State University

The project terminated by two series of experiments at the University of Colorado, the first from 1988 to 1990, and the second during 1993.

The results of the first series were summarized in the abstract of the 1993 report [7]:

Superposed strata in sedimentary rocks are believed to have been formed by successive layers of sediments deposited periodically with interruptions of sedimentation. This experimental study examines possible stratification of heterogeneous sand mixtures under continuous (non-periodic and non-interrupted) sedimentation. The three primary aspects of stratification are considered: lamination, graded beds, and joints. The experiments on segregation of eleven heterogeneous mixtures of sand size quartz, limestone and coal demonstrate that through lateral motion of a sand mixture, the fine particles fall between the interstices of the rolling coarse particles. Coarse particles gradually roll on top of fines and microscale sorting is obtained. Microscale segregation similar to lamination is observed on plane surfaces, as well as under continuous settling in columns filled with either air or water. The formation of graded-beds is examined in a laboratory flume under steady flow and a continuous supply of heterogeneous sand particles. Under steady uniform flow, the velocity decrease caused by a tailgate induces the formation of a stratum of coarse sand particles and two strata of laminated fine particles. Over time, a thick stratum of coarse particles thus progresses downstream between two strata of laminated fine particles, continuously prograding upward and downstream. Laboratory experiments on the desiccation of natural sands also show

preferential fracturing, or joints, of crusty deposits at the interface between strata of coarse and fine particles.

Rather than successive sedimentary layers, these experiments demonstrate that stratification under a continuous supply of heterogeneous sand particles results from: segregation for lamination, non-uniform flow for graded-beds, and desiccation for joints. Superposed strata are not necessarily identical to successive layers.

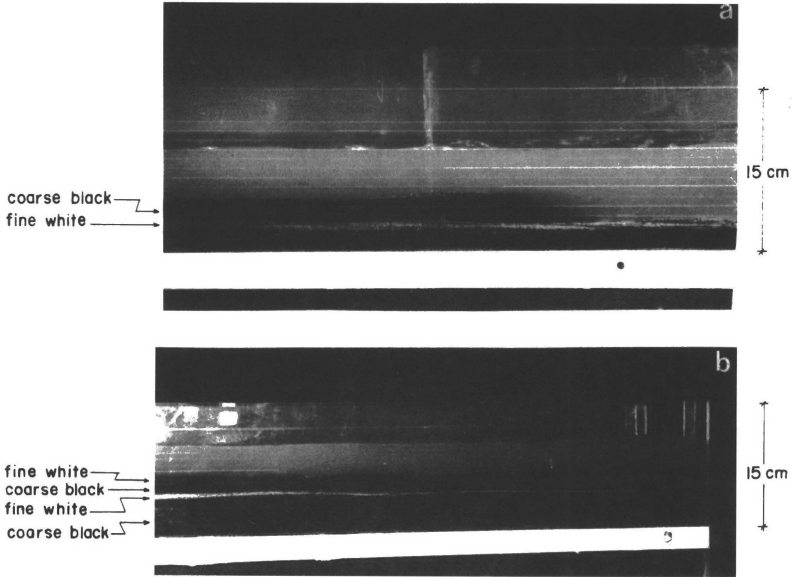


Figure 10a. Example of graded-beds with first tailgate.[5]
 Figure 10b. Example of graded-beds with second tailgate[5]

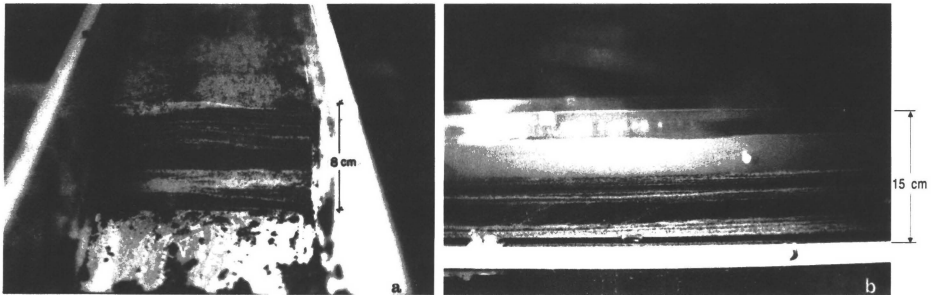


Figure 11a. Typical cross-sectional view of deposit.[5]
 Figure 11b. Typical longitudinal view of deposit (flow from right to left).[5]

The second series was summarized under the title "Fundamental experiments on stratification" in the 1993 report [8].

"Laboratory experiments cover three aspects of stratification:

SEGREGATION. The kinetic energy of spherical particles rolling on a plane surface at a constant velocity increases with particle mass and particle size. Particle segregation results from lateral motion of an heterogeneous mixture.

LAMINATION. Clear lamination forms from repetitive segregation in air, under water, or under vacuum. Particle lamination essentially depends on the mechanical interaction between particles of different size, density and shape.

GRADED BEDDING. A large laboratory flume measuring 20m long and 1.30m wide recirculates 30 cubic meters of water and 8 tons of an heterogeneous sand mixture. A continuous supply of coarse sands and fine sands is maintained under steady discharge. During et typical delta experiment, the coarse-grained for-set slope propagates in the downstream direction and covers the fine-grained bottom-set slope downstream between two consecutive times. A stratum defines preferential accumulation of coarse or fine particles. The formation of -a delta in the laboratory demonstrates that sediment layers are not identical to strata. Isochrons correspond to the interface between successive layers, and not the interface between strata. The chronological formation of the sedimentary deposit is therefore correlated to layers, not strata.

During the experiments, superposed strata formed under continuous settling. They were not younger than the underlying strata nor older than the overlying strata. The strata were not the same age at all points."

CONCLUSIONS

The experiments could provide a new model for explaining the formation of stratified rocks. Strata developed in the experiments wherever a non-uniform flow of water was present. The current sorted the sediments into graded beds. It appears, therefore, from the various parameters used in the experiments that the mechanism for stratification depends upon non-uniform flow of water and supply of sediment.

Due to the mechanical nature of segregation and the presence of sediments and non-uniform flow in oceans and rivers being the same elements producing strata in the flume, the experimental results might have some application to the genesis of stratified rocks.

As the experiments challenge the use of the principles of superposition and continuity as it basis for relative stratigraphic chronology, there is a need to reconstitute, as far as is possible, the true genesis of sedimentary basins. The hydraulic conditions originating the basins could perhaps la determined from the study of stratified rocks, sedimentological observations and the experiments in sedimentology.

An approach of this kind already exists in the form of sequential analysis derived from the works of Walther. It is a field that needs to be developed. The experimental fact that a continuous supply of sediment produces stratified deposits should dissipate the illusion that superposed strata result from an intermittent succession of layers taking millions of years to deposit.

My view as a Christian is that the enormous sedimentary basins covering the earth could have resulted from the Great Flood.

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