

Introduction to Colloid Science

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Applications to sediment characterization

Claire Chassagne



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*“Who do not
honour the small things
is not worth the big ones”*

[Dutch saying]

Foreword

This book is meant as an introduction to the field of colloid science, i.e. the study of the behaviour of micrometric particles in a fluid (or a gas). The book was written with a special emphasis on sediment particles. Sediment particles are complex colloidal particles due to their composition, shape and interaction with their environment. Characterization of the colloidal fraction of sediment is done by recording, among others, the particles' size, shape and electric surface charge and evaluating their interactions. These properties are important for civil engineering applications, even though the size range of these particles and their interactions is microscopic. Large-scale sediment transport models for example require as input the settling velocity of individual particles. In concentrated areas, this velocity becomes a function of the particles' concentration and particle-particle interactions lead to the creation of larger particles, called flocs. These flocs can settle and, when reaching the bed, consolidate in time. All these aspects, and related models, are treated in the present book.

The book was written for students having no special beforehand knowledge in colloid science, and a limited knowledge in physics and chemistry, the two main disciplines relevant to this branch of science. The mathematics are also kept minimal. They are given when the derivations present no particular problem. The more lengthy derivations, often very elegant (but sometimes rather tedious) can be found in the references given as footnotes in the different chapters.

Key words are highlighted in the text, which will enable the reader to find further information by searching for them in a web browser.

I take the opportunity to thank the colleagues that reviewed this book, and helped with their comments to improve it. To the present reader, I would like to say: do not hesitate to report any mistake or unclarity to me.

Claire Chassagne
Delft, spring 2019

Chapter 1

**Introduction, general definitions
and some properties of
clayey material**

Introduction

Mud and clayey systems have from origin been studied in the field of soil science¹, i.e. the branch of science concerned with the formation, classification and fertility properties of soils. In soil science, the classification of soils is of prime importance, as the properties of a soil are used by farmers to decide which types of crops, livestock and soil management are best for their piece of land. The information obtained by a soil survey can also be used by an architect or a builder to determine whether a given soil is suitable for a specific type of construction.



1350 BC, Egypt : thanks to the fertile soil of the river Nile, Egypt became a powerful and long-lasting civilisation

In agriculture, soils are primarily viewed for their chemical properties, i.e. their ability to bring nutrients to plants. At the beginning of the 19th century chemical studies were extensively conducted which confirmed for instance the role of phosphate, nitrogen and potassium in plant growth, and commercial fertilizers were developed. The composition of a soil is also determinant for the type of plants that are growing on it. The first report that clearly related the soil properties to the different climates, vegetation and parent rocks from which the soils were formed was written by Dokuchaiev in 1883². Many of the chemical changes occurring in a soil are related to the

action of bacteria. At the end of 19th century it was for instance discovered that the bacteria which live in nodules on the roots of legume plants absorb nitrogen from the air and convert it to a form which plants can utilize. The differences in soil characteristics are connected not only to the (bio)chemistry but also to the mineralogical and physical properties of soils. These properties are important for construction, but also to the farmer as the porosity of a soil governs gas exchange with the atmosphere, water penetration and root growth. The porosity of a soil is strongly connected to the particle size distribution of the grains forming the soil and the soil's state of consolidation. The mineralogical composition of a clay, which can be determined from X-ray crystallography and electron microscopy tests, will tell if a clay soil is prone to weathering, swelling and retain or exchange cations³. This last property is pH-dependent. This shows that both chemical and physical properties

¹ We will focus on natural soils. Another important research concern is the use of clays in ceramics, cosmetics and drugs which will not be discussed here.

² Dokuchaiev, V.V. (1883) Russian chernozem, Monograph, Sankt-Peterburg. See also Greenland, Dennis James, and Michael Hilary Bermingham Hayes. *The chemistry of soil constituents*. Wiley and sons (1997).

³ a cation is a positively charged ion; an anion is a negatively charged ion.

Chapter 2

Settling, diffusion and stabilisation

Fine (colloidal) particles can remain in suspension for an extremely long (sometimes infinite) time. In this chapter, we are going to explain why and when these colloidal particles remain in suspension and how they diffuse and settle. We will primarily address **dilute** suspensions i.e. suspensions containing a limited amount of colloidal particles. The settling behaviour of **concentred** suspensions will be discussed in **Chapter 8**.

Stokes' settling velocity

In **Chapter 1**, we have already stated that in colloid science the typical length scale for a particle is 1 μm . By this, we mean *of the order of* 1 μm which means a particle somewhere in the range between 0.01 μm and 10 μm .

Let us now consider a particle of any size > 1 nm in water. Three forces are exerted on this particle: the force of gravity, the force of Archimedes and the force of friction. We furthermore assume that

- 1) the water far from the particle is at rest
- 2) we have reached the regime where the particle's velocity is constant (the initial acceleration is not considered)
- 3) the velocity is small enough for the fluid to be in the **laminar** regime.

The fact that a flow is laminar or not can be evaluated by the estimation of the **Reynolds number**¹³ Re which represents the ratio of inertial forces (which create turbulence) to viscous forces (which create friction):

$$Re = \frac{v\rho L}{\eta}$$

where v is the fluid's velocity, L is a characteristic length (in our case the size of studied particle, as the particle is setting the fluid in motion) and the kinematic viscosity is given by η/ρ where η is the viscosity and ρ the density of the fluid. The laminar regime is defined by a low Reynolds number ($Re < 10$ for a sphere), implying that the friction force is dominating, in accordance with our initial assumption. The balance of forces gives:

$$mg = 6\pi\eta av$$

where m is the mass of the particle, compensated for Archimedes, g the gravitation constant, η the viscosity of the water, a the radius of the particle and v its velocity. The fact that the force of friction might be expressed as $6\pi\eta av$ for a spherical particle in a laminar flow is due to the work of **Georges Stokes** (1819-1903). We have

¹³ The number has been invented by Stokes but is named after Osborne Reynolds (1842-1912) who popularised its use.