CHAPTER 4

SEDIMENT MOVEMENT BY FLUID FLOW

4.1 FUNDAMENTALS OF FLUID FLOW

Introduction

Before discussing the transport and sorting of sediment and the formation of sedimentary structures, some attention must be given to the part of the dynamic environment often neglected by the geologist—the fluid. The term *fluid* includes both liquids and gases. A fluid is a substance that is deformed by a shear force, no matter how small the force may be; that is, it is a substance that has no strength.

The forces that act on solid or fluid bodies are vectors that may be resolved into components normal to and parallel with the surface of the body. The components of force, per unit area, normal to the surface are called *pressure*; those parallel to the surface are called *shear stress*. It is convenient to distinguish certain *body forces* that act equally on every particle composing the body—for example, gravity or inertia. Gases, including air, respond to change in pressure by expansion or contraction; that is, they are compressible fluids and, at high speeds, the density cannot be treated as constant. Liquids are only slightly compressible, however, and for a given temperature the density may be considered to be constant.

Apart from the density, the other main property of fluids controlling the way the fluid flows is the dynamic viscosity. As noted earlier, this is defined as the coefficient in the equation relating the shear stress acting on a fluid to its rate of shear. In many dynamic equations the ratio of dynamic viscosity to density (μ/ρ) appears, and this ratio is called the *kinematic viscosity* ν (nu). These parameters have dimensions as indicated in Table 3-4.

Air and water are the two fluids of greatest geological importance. They differ substantially in their density and dynamic viscosity with water being some 800 times as dense as air and having a much larger dynamic viscosity. At 20°C the dynamic viscosity of water is almost exactly 0.001 kg $\text{m}^{-1}\ \text{s}^{-1}$, which is about 55 times that of air. The kinematic viscosity of air (at 20°C) is, however, 15 times that of water (Fig. 4-1). Both air and water are fluids that obey Newton's law of viscosity:

$$\tau = \mu \frac{dU}{dy} \tag{1}$$

Viscosity of H_2O: $\frac{1\ \text{gr}}{\text{m sec}}$

For pure water or air, the dynamic viscosity μ is a constant at constant temperature (see Chap. 3). Water may, however, become mixed with substantial concentration of clays—for example, in mud flows. High concentrations of clay not only greatly increase the viscosity (Fig. 4-2) but also change the way in which the suspension responds to shear stress so that the coefficient of viscosity is no longer a constant. Such substances are described as *non-Newtonian fluids.*

At high sediment concentrations muds may acquire strength so that they can no longer be sheared by very low shear stresses. At shear stresses in excess of this strength such muds behave like viscous fluids. Substances that behave in this way are described as *pseudo-plastics.* Some of their properties are discussed further in Chap. 5.

The behavior of Newtonian fluids is described by the equations of fluid dynamics, based on Newton's law of viscosity and the laws of Newtonian dynamics. The basic equations are (a) the equation of *continuity*, which simply expresses the law of conservation of mass for a fluid, and (b) the three *Navier–Stokes* equations, or equations of motion, which express how Newton's dynamic laws must apply to a fluid. Together they make up a system of four partial differential equations that express, in principle, how a viscous fluid must behave in any and all circumstances in which Newtonian dynamics are valid.

The ideal explanation of any fluid phenomenon (including all sedimentation phenomena) is to show how the phenomenon may be deduced from the four equations, plus a statement about the shapes of the fluid boundaries (the "boundary conditions"). Nature is generally too complicated to permit the solution of these equations, although it can be done for a few simple cases, including the very slow movement of a sphere through a fluid. Here Stokes' law, discussed on p. 63, was actually derived from the basic equations of motion by Stokes in 1851.

Dimensionless Numbers

One very important application of the basic equations is to derive the proper criteria for making scale models of fluid flow that correctly represent phenomena