

**Continuum mechanics.** The formulation of constitutive equations is probably the early goal of rheology. At the beginning of the 20<sup>th</sup> century, the non-Newtonian character of many fluids of practical interest motivated Professor Bingham to coin the term *rheology* and to define it as the study of the deformation and flow of matter. The development of a convenient mathematical framework occupied the attention of rheologists for a long time after the Second World War. At that time, theoreticians such as Coleman, Markovitz, Noll, Oldroyd, Reiner, Toupin, Truesdell, etc. sought to express rheological behavior through equations relating suitable variables and parameters representing the deformation and stress states. This gave rise to a large number of studies on the foundations of continuum mechanics (Bird *et al.*, 1987). Nowadays the work of these pioneers is pursued through the examination of new problems such as the treatment of multiphase systems or the development of nonlocal field theories. For examples of current developments and applications to geophysics, the reader may consult papers by Hutter and coworkers on the thermodynamically consistent continuum treatment of soil-water systems (Wang & Hutter, 1999; Hutter *et al.*, 1999), the book by Vardoulakis & Sulem (1995) on soil mechanics, and the review by Bedford & Dambeller (1983) on suspensions. A cursory glance at the literature on theoretical rheology may give the reader the impression that all this literature is merely an overly sophisticated mathematical description of the matter with little practical interest. In fact, excessive refinements in the tensorial expression of constitutive equations lead to prohibitive detail and thus substantially limit their utility or predictive capabilities. This probably explains why there is currently little research on this topic. Such limitations should not prevent the reader (and especially the newcomer) from studying the textbooks in theoretical rheology, notably to acquire the basic principles involved in formulating constitutive equations.

Two simple problems related to these principles will be presented in Chapter 2 to illustrate the importance of an appropriate tensorial formulation of constitutive equations.

**Rheophysics.** For many complex fluids of practical importance, bulk behavior is not easily outlined using a continuum approach. It may be useful to first examine what happens at a microscopic scale and then infer the bulk properties using an appropriate averaging process. Kinetic theories give a common example for gases (Chapman & Cowling, 1970) or polymeric liquids (Bird *et al.*, 1987), which infer the constitutive equations by averaging all the pair interactions between particles. Such an approach is called *microrheology* or *rheophysics*. Here we prefer to use the latter term to emphasize that the formulation of constitutive equations is guided by a physical understanding of the origins of bulk behavior. Recent developments in geophysics are based on using kinetic theories to model bed load transport (Jenkins & Hanes, 1998), floating broken ice fields (Savage, 1994), and rockfall and granular debris flows (Savage, 1989). It is implicitly recognized that thoroughly modelling the microstructure would require prohibitive detail, especially for natural fluids. It follows that a compromise is generally sought between capturing the detailed physics at the particle level and providing applicable constitutive equations. Using dimensionless groups and approximating constitutive equations are commonly used operations for that purpose. In Chap. 3, we will consider suspensions of rigid particles within a Newtonian fluid to exemplify the different tools used in rheophysics. Typical examples of such fluids in a geophysical context include magma and mud.

# Theories Of Fluids With Microstructure An Introduction

**Minjie Lin**



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