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# Loess as a collapsible soil: Some basic particle packing aspects☆

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ABSTRACT

Loess is the most important collapsible soil; possibly the only engineering soil in which real collapse occurs. A real collapse involves a diminution in volume – it would be an open metastable packing being reduced to a more closely packed, more stable structure. Metastability is at the heart of the collapsible soils problem. To envisage and to model the collapse process in a metastable medium, knowledge is required about the nature and shape of the particles, the types of packings they assume (real and ideal), and the nature of the collapse process – a packing transition upon a change to the effective stress in a media of double porosity. Particle packing science has made little progress in geoscience discipline – since the initial packing paradigms set by Graton and Fraser (1935) – nevertheless is relatively well-established in the soft matter physics discipline. The collapse process can be represented by mathematical modelling of packing – including the Monte Carlo simulations – but relating representation to process remains difficult. This paper revisits the problem of sudden packing transition from a micro-physico-mechanical viewpoint (i.e. collapse imetan terms of structure-based effective stress). This cross-disciplinary approach helps in generalization on collapsible soils to be made that suggests loess is the only truly collapsible soil, because it is only loess which is so totally influenced by the packing essence of the formation process.



## 1. Introduction

In the world of engineering geology and geotechnical engineering collapsible soils still present problems. These are usually metastable soils which can collapse when loaded and/or wetted. The original soil structure collapses to form a more stable soil structure. The initial packing of soil particles which produced the original structure is disturbed and a new, more stable packing is developed. Thus a study of soil collapse might be seen as a study of packings and the changes in the disposition of the particles comprising the packings.

Terzaghi et al. (1996) listed four types of natural collapsing soils; they were essentially: (1) loess and similar ground materials; (2) very sensitive soils, the so-called quick-clays; (3) residual sands with very weathered structures; and (4) submarine delta deposits of silty material. Of these the loess soils were seen as by far the most widespread and important; the other three are basically smaller more local deposits. The extent of collapsible soil systems has been shown in the map by Kriger (1986) – page 42 – which emphasises the importance of loess deposits. The world of collapsing soils research was surveyed by Derbyshire et al. (1995) and the status of collapsing soil studies has been reviewed by Rogers (1995) and Xie et al. (2015). There is an extensive literature on the testing of collapsible soils and this has recently been reviewed by Okwedadi et al. (2015). There is a very extensive literature on the development of collapsibility, much of this is in Russian and has been reviewed by Trofimov (1999, 2001). See, in particular, important studies by Kriger (1986), Minervin (1993), Krutov (1974) and early work by Denisov (1953). The Soviet Union covered vast areas of collapsing loess ground and special institutes to study this problem were set up in various regions, in particular in Tashkent and Kyiv. The problem of the cause of collapsibility has proved remarkably

☆ "The particles forming detrital sediments assume at deposition a certain mutual relationship, the geometry of which is their primary packing. A packing may be described either by reference to the relative amount of the particles and by its relative emptiness, or in terms of local variations in the amount of particles, or again by a statement of the average number of contacts between a particle and its neighbours." J. R. L. Allen (1982).

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resistant but recently some significant advances have been made, see, in particular, Milodowski et al. (2015) and Assadi-Langroudi and Jefferson (2013), see also Derbyshire et al. (1994), Smalley and Markovic (2014), and Xie et al. (2015).

Loess is the most important ground material in a collapsing soils context and the current studies are built around an appreciation of the nature and properties of loess; initially loess deposits as assemblages of loess material i.e. predominantly 10–50 μm subangular coarse well-sorted quartz silt (Smalley et al., 2011), which then reworks to loess ground as a packing of loess particles i.e. clusters of silt bonded together directly and indirectly with clay, sesquioxides and carbonates.

Loess is a collapsing/collapsible, metastable, unsaturated, macroporous with double porosity, silty soil/ground. It should respond to study as a packing; certain aspects should be able to be modelled via certain packing aspects and properties.

The science of particle packing, centred around sits the collapse mechanism, has made little progress in geoscience discipline – since the seminal work of Graton and Fraser (1935) – but is relatively well-established in the soft matter physics discipline. The difference is profound in part because the physics literature is mostly concerned with homogeneous laboratory-produced physical packings, and also because in this laboratory setting focus has settled on the various processes by which the packings are produced, and then examined/disturbed. In the granular matter literature the two most influential early works are those of Reynolds (1885), who introduced the notion of dilatancy, and Bernal (1959), who popularized the notions of random close packing (RCP) and random loose packing (RLP). Basically, it is found that granular matter exists with packing fraction between roughly 0.5 and 0.74. Arbitrarily low densities are mathematically possible, but the study of granular matter seeks to understand so-called 'random' packings produced by simple bulk means, and it does not seem possible to get much below 0.5 (RLP) by such processes. Reynolds already noted that, when sheared, random packings collapse if their initial density is low and expand if it is high. The dividing point has been found, relatively recently, to be around 0.6 (Bratberg, 2003).

The aim of this brief (and rather subjective) cross-disciplinary review is to revisit the problem of sudden transition of packing from micro-physico-mechanical viewpoint (i.e. collapse in terms of structure-based effective stress), to complement the review of particle packing by Rogers et al. (1994a) and the studies on collapsible soils of Derbyshire et al. (1995) and the assemblage of material on hydroconsolidation in loess ground by Rogers et al. (1994b), and to propose some tentative generalizations. It might also serve as a link between speculative and imaginative packing studies and real observations on collapsing ground which now, at last, seem to be revealing the exact nature of the collapse mechanism see Assadi-Langroudi and Jefferson (2016), Milodowski et al. (2015), Smalley and Marković (2014), and Xie et al. (2015).

## 2. Graton and Fraser developed

Fundamental studies on particle packing commenced by Smith et al. (1929) who preceded Graton and Fraser (1935) and did, in fact, influence them. The study of particle packings in the geosciences begins with Graton and Fraser (1935). This was the seminal paper which defined some basic structures and introduced some useful terminology. It was not a particularly systematic treatment; the systematic approach was provided by Smalley (1971) who gave some rigorous definitions and set out the limits for the definable 'simple' packings. Pettijohn (1975) – Page 72 – in his classic study of sedimentary rocks has a section on particle packing and this is very much based on the Graton and Fraser (1935) work (see Fig. 1). Pettijohn bases his entire section on this paper. He wrote that "The study of packing requires a closer definition of packing, the development of a suitable measure of 'closeness' of packing, and an assessment of packing in the post-depositional period". This is still the aim of packing studies, it certainly informs the material in this paper.

The definitive reviews of particle packing in the earth sciences are those by Allen (1982) – p.137–177 – and Rogers et al. (1994a). Allen tackles the problems of description and nomenclature and concludes that the best descriptive system to apply to Graton and Fraser type packings is that defined by Smalley (1971). The Smalley (1971) system of 'simple' packings was designed to advance the Graton and Fraser approach and make it a little more rigorous. The Graton and Fraser packings are 'simple' packings; this means that they are composed of equal spherical particles which are arranged in regular packings such that every sphere is equivalent in terms of number and orientation of contacts. The number of contacts (on

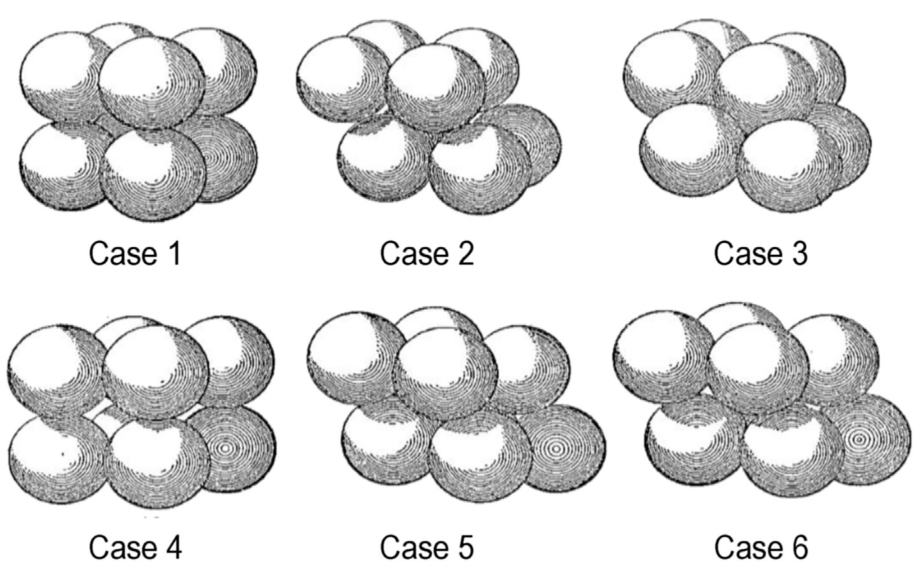


**Fig. 1.** Packings by Graton and Fraser (1935 p.796). These are unit cells from the seminal paper as reproduced by Pettijohn (1975 p.74). Four definable packings are shown: Case 1 is the 'cubic' packing, 600 in 'simple' notation; Case 6 is 'rhombohedral' 006 packing; Cases 2 and 4 are the same- 402; Case 3 is 204- essentially the same as Case 6; Case 5 is 024.

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