The dynamics of aggregate breakdown as a function of dispersive energy

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Abstract
This paper reports on the distribution of soil aggregates for Vertosols and Ferrosols as a function of the energy involved in dispersion, known as the dispersive energy. For Vertosols showing an aggregate hierarchy, the breakdown of aggregates is modelled using the aggregate liberation and dispersion characteristic curve indicating a stepwise breakdown of soil aggregates. Meanwhile, for Ferrosols, during dispersion the 2-50 μm aggregates increases monotonically with increasing dispersive energy, which is indicative of the direct release of silt and clay from the disruption of aggregates. The exponential decrease in ultrasonic power over time for the Ferrosols, as opposed to the prominent drop or steps in the curves for the Vertosols, confirms the lack of a prominent aggregate hierarchy.

Key Words
Aggregate hierarchy, dispersive energy, ultrasonics, comminution dynamics, soil structure, aggregate stability

Introduction
The interaction between soil particles has a significant effect on a range of soil physical properties such as stability, pore size distribution and erodibility. Its description has resulted in the development of concepts and models, which describes a system of aggregation as hierarchy or non-hierarchy. Determining the hierarchical order of soil aggregation has attracted considerable investigations.

But not all soils display the hierarchical system (Oades and Water 1991). In the work by Oades and Water (1991), the Oxisols were not found to have the hierarchical order. Golchin *et al.* (1998) states, the aggregate hierarchy may have universal application for soil where organic matter is the main stabilizing agent. Although this hierarchical model may hold for organically stabilized soil, the presence of individual hierarchical levels of the micro-aggregates and resulting macro-aggregates may vary in non-organic soil or those with greater clay contents.

Several methods have been developed to judge if aggregate hierarchy exists or not. Oades and Water (1991) pointed out that if aggregates are disrupted in a stepwise fashion then a hierarchy exists, but if aggregate breakdown results in direct release of silt and clay size materials there is not a hierarchical order. In the work of Field and Minasny (1999), aggregate liberation and dispersive curve (ALDC) is developed to describe the stepwise breakdown of an aggregate hierarchy for Vertosols subjected to ultrasonic agitation, which implies the hierarchy for Vertosols. Furthermore, the ratio between the rate constants in the ALDC model can be used to establish if there is a stepwise breakdown of larger aggregates, a criterion required to establish the presence of an aggregate hierarchy (Field *et al.,* 2006). The energy reported in the above work using ultrasonic instruments is not the energy required to disrupt soil aggregates but in terms of total energy applied as determined calorimetrically, and thus the aggregate breakdown dynamics under a certain dispersive energy is still not clear.

Recently, a technology for measuring soil aggregate dispersive energy using ultrasonic dispersion was proposed by Zhu *et al.* (2009a) , and its method was developed to characterize the aggregate dispersion characteristic curve (Zhu *et al.,* 2009b) . This paper furthers the method to take insight into aggregate breakdown dynamics by simultaneously modelling the dynamics of aggregates in a range of soil particle-sizes (<2 μm, 2–50 μm, 50–2000 μm) as the increasing dispersive energy of aggregates by ultrasonics.

Materials and Methods
Surface samples from the top 300 mm of soil from five sites throughout New South Wales, Australia, were collected for this study. The Vertosols were collected from Narrabri (149°32'E, 30°11'S) and the Namoi valley (149°28'E, 30°15'S). The Ferrosols were obtained from Wongarbon (148°40'E, 32°15'S) and Mt.

Wilson (150°23'E, 33°30'S).

All the samples were air-dried and then gently ground and sieved to obtain a 0.25 to 1 mm fraction. The air-dry equivalent of 3g of oven-dry (105°C) soil was immersed in 30 ml de-ionized water in a 50 ml beaker. Samples were sonified in the beaker which was insulated with polystyrene materials. Ultrasound was applied via a conical probe, and each suspension was treated with ultrasound for various time periods up to dispersion. The effect of sonification on aggregate breakdown was determined by measuring the size distribution of aggregates and particles (<2 µm, 2–50 µm, 50–2000 µm) as described in Field *et al*. (2006). The dispersive energy is derived by measuring the total input power of the ultrasonic device (active power with a resolution of 0.05 W) and the energy used to heat the system (calorimetrically using platinum resistors with a resolution of 0.01°C). The procedure for deriving the dispersive energy is described in Zhu *et al.* (2009a).

Results and discussion

The dynamics of aggregate breakdown as a function of dispersive energy is summarized in the aggregate disruption characteristic curves (ADCC, particles 50–2000 µm), soil dispersion characteristic curves (SDCC, particles <2 µm) and aggregate liberation and subsequent dispersion curves (ALDC, aggregates 50–2000 µm) as presented in Figure 1.

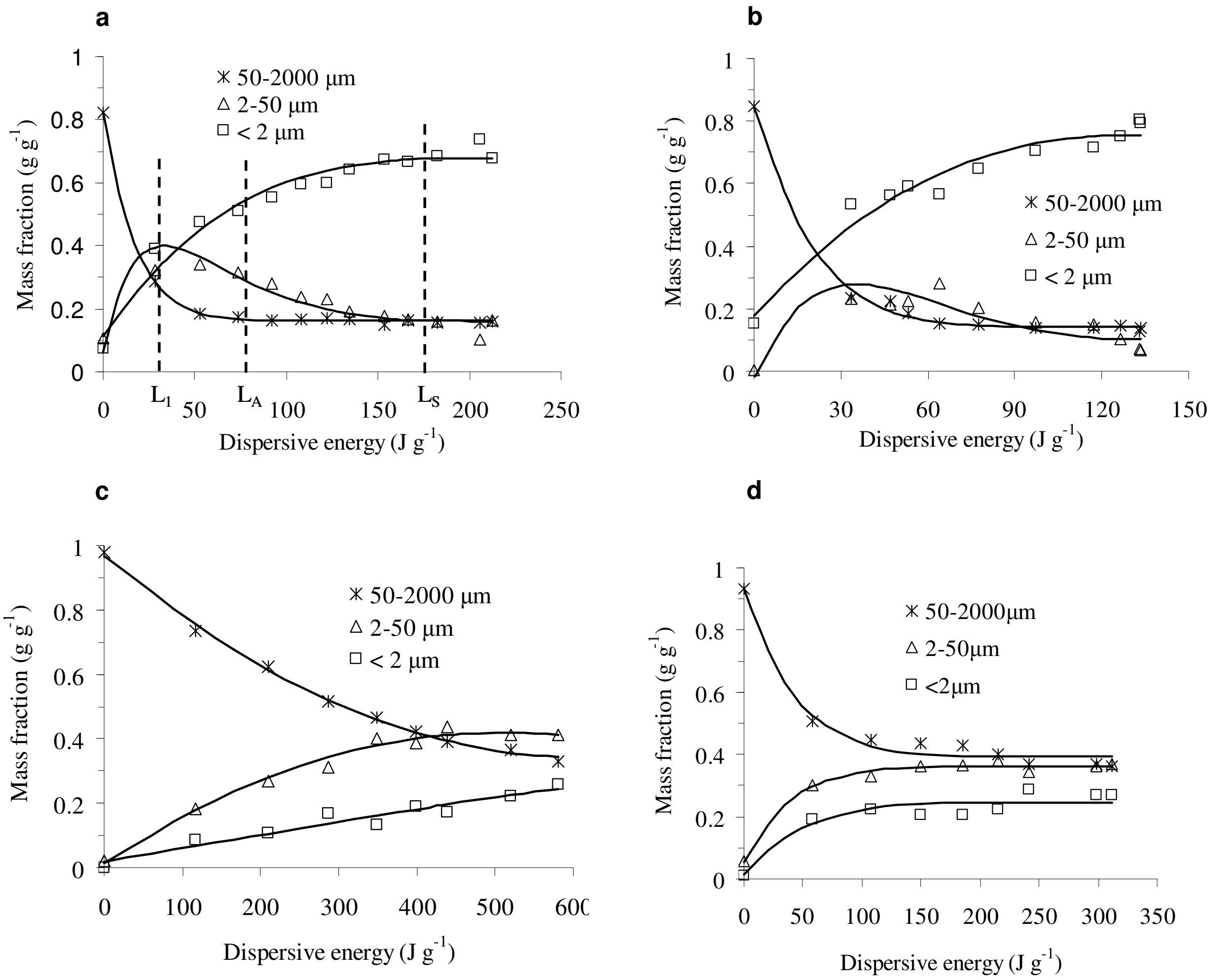

Figure 1. Particle-size distribution of soil related to dispersive energy for (a) Narrabri Vertosol, (b) Namoi Vertosol, (c) Mt. Wilson Ferrosol, and (d) Wongarbon Ferrosol

For the Vertosols (Figure 1a and b), the observed trends in the aggregate liberation and dispersion is consistent with Field *et al*. (2006), indicating that the rate of aggregate liberation is greater than dispersion until the energy input exceeds L_1, where the rate of dispersion exceeds aggregate liberation. By comparison the ALDC's for the two Ferrosol samples do not exhibit an observable inflection in the curve (L_1)

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characteristic of a non-hierarchical aggregated soil (Figure 1c, d). This implies that the breakdown of macro-aggregates in the Ferrosols results predominately in either the direct release of discrete particles or the redistribution of aggregates in and out of the particle size range at a similar rate. The notation of L_A and L_S on Figure 1a highlights when the all macro-aggregates (50-2000 µm) are disrupted and all micro-aggregates (2-50 µm) are all dispersed, respectively.

The evolution of dispersive power as a function of input energy is illustrated in Figure 2 for all samples with the corresponding ALDC curve superimposed. The power used for successive sonifications to disperse the aggregates generally could be described as decreasing exponentially. An important point to notice is that the Vertosols (Figure 2a, b) exhibit prominent steps in the dispersive power resulting in discontinuities. These steps coincide with the condition when the 2-50 µm aggregates were completely dispersed. Meanwhile for the Ferrosols (Figure 2c, d) the dispersive power curve decreases exponentially, without any observable steps.

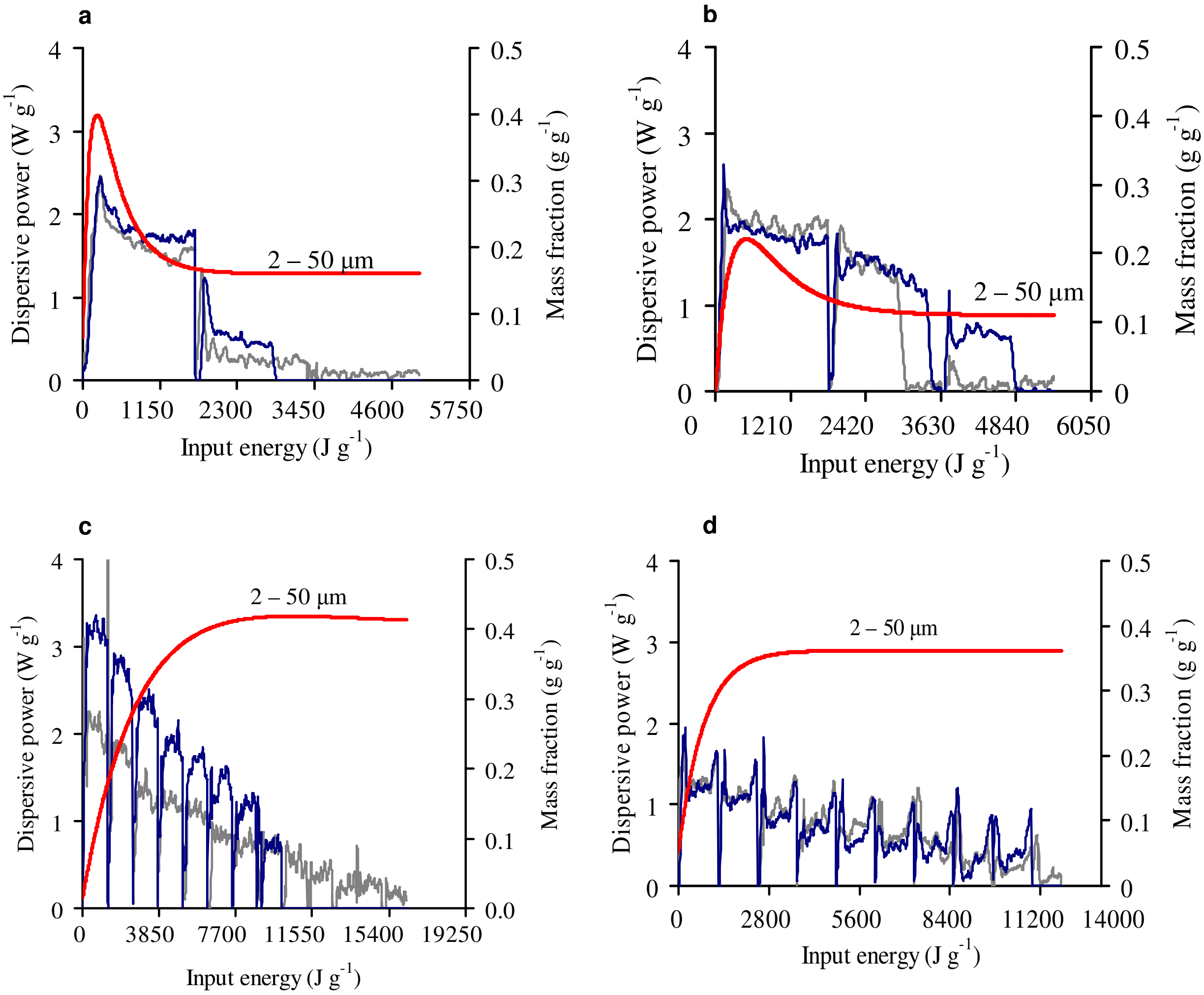

Figure 2. The relationship between dispersive power and input energy with the corresponding aggregate liberation and dispersion curve superimposed for (a) Narrabri Vertosol, (b) Namoi Vertosol, (c) Mt. Wilson Ferrosol, and (d) Wongarbon Ferrosol.

Conclusion

This work investigates the hierarchy of soil aggregates by modelling their breakdown under a certain dispersive energy. For the Vertosols and Ferrosols used in this study, the relationship between dispersive energy and input energy is not linear. The Vertosols show hierarchy for that the aggregate liberation and subsequently dispersion under dispersive energy exists indicating the aggregates break down in a stepwise fashion under ultrasonic agitation. As for the Ferrosols, they don't have the character above because their aggregates directly release out silt and clay when broke down under dispersive energy.

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