

**Colloidal social theory:
thinking about material animacy and sociality beyond solids and fluids**

Bronislaw Szerszynski

Lancaster University

bron@lancaster.ac.uk

Author final version, forthcoming in *Theory, Culture and Society*

Abstract:

This paper argues that an exploration of colloids can help us situate human social life within a wider understanding of the sociality and animacy of matter. Colloids are substances such as sols, foams, powders, gels, doughs and pastes that exhibit complex and shifting macroscale physical properties that do not conform to standard conceptions of solids, liquids or gases. Colloids can behave in complex and creative ways because of their topological enfolding of dispersed and continuous matter, in different phases, at a 'mesoscale' intermediate between the scale of molecules and that of the macroscale substance. I relate colloids, with their twin phenomena of 'repetition' and 'mediation', to an understanding of social life as reducible neither to the interaction between separate individuals nor to a transindividual whole. I suggest that human social life participates in a colloidal 'metapattern' of repetition and mediation that is manifest across diverse material substrates and spatial scales.

Keywords: colloids, topology, mediality, materiality, mesoscale, animacy, physical chemistry,

Introduction

In this paper I seek to situate human social life within a wider choreography of organic and nonnorganic sociality and liveliness. I do so by attending to 'colloids': complex substances such as mist, mud, slime, dough, foam, paste and gels, which confound conventional categories of solid and fluid. I will explore colloidal species – and their many subspecies – in dialogue with other accounts of animate matter, especially Manuel DeLanda's 'nonorganic life' (1992), Jane Bennett's 'vibrant matter' (1997) and Tim Ingold's animate materials (2011). I will suggest that thinking about and amongst clouds of dust and mist; avalanches of rock, sand or snow; sponges, froth and foams; flowing mixtures of matter in different states; and creams, pastes and doughs will help us understand how it is that matter is able to behave in complex and surprising ways – behaviours on which organic life builds. I will argue that colloids do not just have their own kind of animacy but also have a particular connection to sociality. If we are to make sense of Gabriel Tarde's talk of 'cellular societies ... atomic societies ... [and] societies of stars' (2012: 28), then we need to understand colloids. Societies are not just more-than-human, heterogeneous assemblages. They are also more-than solid, and more-than-fluid. Colloids are social and sociality is colloidal.

In the next section I will focus on Ingold's work, because of his particular focus on social life. Ingold will help us to locate social life both more *precisely* – as neither bottom up 'interaction' nor top-down 'regulation' – but also more *broadly*, including the more-than human. I then explore the need for social theory to move beyond a narrow language of solidity and fluidity, to first engage more precisely with the complex phenomenology of rigid bodies and flowing substances and their diverse powers of memory and forgetting, and then to go further by considering colloids, with their strange shifting and creative behaviours. In the following section I draw attention to the crucial role of the mesoscopic or 'mesoscale' – a scale bridging the macro-world of objects and masses and the micro-world of molecules – in enabling colloids to behave the way that they do. I then look at the particular colloidal topologies that occur at this middle scale, combining continuous and dispersed matter in different phase states, and how colloids as a category has been expanded beyond the original focus on colloidal suspensions to include a wider family of complex substances. I then explore how the twin phenomena of repetition and mediation are distributed across the dispersed and continuous matter within colloids, and how this gives them their social character. I move on to look at colloids as dynamic, lively substances in which the individual repeated elements 'correspond' with each other in ways mediated by the enveloping medium, in a choreography and economy of intensive forces that produces emergent behaviour at the macroscopic scale. I conclude by suggesting that colloids can guide us in new directions in understanding the emergence of complexity in inorganic, organic and social life.

Social life

What does it mean to extend the idea of the social to matter more generally? Gabriel Tarde argued that the term 'society' properly applies to all of the manifestations of matter studied by the various branches of modern science, each of which involve matter divided into populations of discrete entities, but also the patterns of collective behaviour that makes science possible. 'All sciences', he suggested, 'seem destined to become branches of sociology' (Tarde, 2012: 28). But where exactly could we *find* the social in material substances? In the properties of the discrete members of 'populations' of entities making up a substance? In the interactions between them? As a transindividual superentity that regulates the behaviour of its individual members? Or is being 'social' reducible neither to a substance's individual constituent parts nor its continuous whole?

In reflections spanning four decades, Tim Ingold has introduced a rich new vocabulary for talking about the nature of social life, and of life generally. In a text originally published in 1986 (Ingold, 2016: 184-241), he argued that there have been two dominant ways of conceiving of the social in the social sciences, which should be familiar from conventional contrasts between Weberian and Durkheimian sociology. The first he calls the *interactive* paradigm that sees social life as made up of interactions between individuated human beings. In this paradigm, if there is a shared culture, it is a culture that has to be instantiated and carried around within each individual. In the second, *regulative* paradigm, society is regarded as a set of positions or roles that stands over and above the individuals that occupy these roles, and which regulates their behaviour.

Against both of these, Ingold argued for a third approach to the social, that sees it as happening in the midst of things – in the 'in-between'. He calls this approach '*constitutive*', and describes it as seeing social life as a phenomenon that is neither bottom-up nor top-down, but 'the unfolding of a continuous field of intersubjective relations in which persons ... constitute one another through the history of their mutual involvement.' (2016: 203). In later work, Ingold uses the metaphor of 'growing' and the language of the grammatical 'middle voice' (neither active nor passive) to describe this view of the social: 'social life is not something the person does but what the person undergoes: a process in which human beings both grow and are grown, undergoing histories of development and maturation ... within fields of relationships established through the presence and activities of others' (Ingold, 2015: 125).

Ingold has also further developed this view of sociality and animacy through the concept of the 'line'. Here, Ingold extends animacy far beyond the boundaries of biological life in a way that is broadly similar to those of Bennett and DeLanda. Ingold understands the animacy of matter in specifically *social* terms, as 'the dynamic, transformative potential of the entire field of relations

within which beings of all kinds, more or less person-like or thing-like, continually and reciprocally bring one another into existence' (Ingold, 2011: 68). For Ingold, the topology of this animacy is not the bounded 'blob' of the individual element or the mass object as a whole, but the *line*. 'Blobs have volume, mass, density: they give us materials. Lines have ... torsion, flexion and vivacity. They give us life' (Ingold, 2015: 4). Neither are Ingold's lines ones that bound or connect individual entities or points; they are lines of movement, growth and transformation – threads and filaments, paths and traces, that can each be transformed dynamically into each other (Ingold, 2007; 2015). They are tangled not into a network of interacting entities but into a '*meshwork* of entangled lines of life, growth and movement' (Ingold, 2011: 63, emphasis added). More recently again, Ingold has introduced the language of 'correspondence' – 'the process by which beings or things literally answer to one another over time' – to describe such processes (Ingold, 2017: 14; see also Ingold, 2020a).

My own thinking about the social ontology of colloids is consistent with Ingold's third space of the constitutive, in which the location of the social is neither in or between individual elements, nor in a supervening and directing whole, but, as he puts it, in the 'in-between', midway, within an ongoing stream of becoming. However, to reap the benefit of thinking colloiddally about the social we will need to expand our topological thinking not just beyond bounded blobs, but also beyond trajectories of growth and motion, and knots of entanglement; we need to attend to surfaces that wrap through substances, constituting the discontinuous and the continuous, and to the twin phenomena of repetition and mediation. Thinking colloiddally will also require us to pay attention to the mesoscale, to the ontological role played by elemental media not just *around* but also *within* entities and materials, and to that played by intensive forces in colloids' dynamic, self-organising and creative powers.

Solidity, fluidity and complex matter

Let us start with the question of how colloids such as mist, mud and jelly present at the scale of the human body: as more-or-less formless substances that exhibit a curious and often shifting blend of solid and fluid powers and properties. In order to better understand the significance of this, we need first to explore what we mean by calling something 'solid' or 'fluid', to use this to map out an even wider space of rigidity, elasticity, plasticity, fluidity and viscosity, and to understand the way that these material properties involve processes of remembering, forgetting and creativity.

The language of solidity and fluidity has often been used metaphorically by social theorists to describe social forms. For example, in Zygmunt Bauman's analysis of contemporary 'liquid modernity', the solidity of collective forms like markets and classes are seen to be melting away, leaving isolated personal projects as the only unit of society, with only temporary bonds between them (Bauman, 2000). Parisi and Terranova (2000) for their part argue that late capitalism is a society not of disciplined bodies and solid institutions but of controlled flows. AnneMarie Mol and John Law suggest that social life exhibits three main topologies – the solid region, the reticulated network and the fluid space with no clear or stable boundaries (Mol and Law, 1994). Ingold's and Bennett's accounts of matter's animacy often use the language of constant fluid motion, while in DeLanda's 'neo-materialist' redescription of human society and history through the lens of far-from-equilibrium thermodynamics a crucial role is played by dissipative flows of energy and matter (DeLanda, 1997).

However, while applying the language of 'solid' and 'fluid', structure and flow to the social has often been very productive, it will only get you so far – and the reason for this has little to do with any absolute ontological divide between the phenomena studied by the physical and the social sciences respectively. For it is not only in respect of human social life that a simple distinction between solid and fluid is problematic. On close inspection of the matter around us, any simple classification of substances into 'solids' and 'fluids' starts to founder (Barry, 2010: 93).

What we call 'solids' are substances that exhibit the physical property of 'rigidity' – the tendency to resist change in shape, even when stress (outside force) is applied – at least on the timescales and under the conditions that humans generally inhabit (see Bennett, 2010: 58). However, no substance is infinitely rigid, and solids depart from perfect rigidity in various ways. 'Brittle' substances are typically very rigid, but when any applied stress exceeds a certain point, they fracture. Other things classed as solids may be either 'elastic' or 'plastic': once moderate applied stress is released, elastic substances such as wood or rubber return to their original conformation, whereas plastic substances such as copper retain their new shape.

Gases and liquids are even further from rigidity – they exhibit various degrees of 'fluidity', or ease of flow. In a 'perfect' or 'ideal' fluid, with infinite fluidity, the individual molecules would move around freely, with no resistance to alterations in their mutual arrangement. Such a state of affairs would fit what Ingold calls the interactive model of the social – behaving as a gas, with only short-range and short-lived correlations that emerge from direct interactions between particles. The inverse of fluidity is 'viscosity', conceived in the physical sciences as a frictional force generated within the fluid as the molecules move past each other, so that the fluid resists change in the relative position and

velocity of its adjacent constituents. So-called Newtonian fluids have a constant viscosity, which depends on their composition: ‘thin’ fluids like water or petroleum have low viscosity, ‘thick’ fluids like treacle or pitch high viscosity.

All of these properties of matter can be thought of as different powers of material memory and forgetting (Szerszynski, 2019). For example, whereas a rigid substance resists deformation, an elastic one allows ‘reversible’ deformations because of its ability to store its macroscopic shape in its molecular bonds. Ductility, malleability and fluidity, by contrast, are different kinds of irreversible forgetting that destroy or transform long-range order and shape.¹ However, fluids’ power of forgetting also gives them the capacity to generate new forms ‘on the fly’ – flow shapes such as spheres, waves and vortices, which can also appear frozen in solid form (Schwenk, 1965).

But colloids are substances that confound even this complexified picture of solidity and fluidity, memory and forgetting. Just as human social life never takes the form of a totally rigid structure of total recall, nor a pure flow of absolute forgetting and amnesia, so too do (other) colloids exhibit more diverse forms of ‘auto-affection’ – of relation to themselves over time (Deleuze, 1988: 107). At the human scale, some colloids (gels, foams) seem more ‘solid’ – or better ‘rigid’; others (sols, aerosols, froth) present as more ‘fluid’. But colloids typically exhibit behaviours which make them as difficult as any human social formation to classify as either solid or fluid: a given colloid might sometimes be rigid, sometimes flowing; sometimes exhibit low viscosity, sometimes high; sometimes elastic, sometimes plastic. Here we are moving into the realm of ‘rheology’, the study of complex, non-Newtonian flow behaviours (Everett, 1988). Granular materials such as sand can sometimes be solid enough to walk on, but at others let things sink into them; they can flow – and when agitated even behave as a gas. Liquid foams can keep their shape for a while, but also float and flow; some solid foams can exhibit all the various properties of solids yet have the mass and conductivity of a gas, and even – for example the built environment, with its rooms and cupboards, corridors and tunnels, arches and doorways – have flows passing through them.

Why do colloids behave like this, in ways that confound a simple contrast between solid memory and fluid forgetting? And, apart from their shared anomalousness in respect of the behaviour of matter in different phases, what do they all have in common that allows us to treat them as a single family of substances? What can colloids tell us about the animacy of matter discussed by DeLanda, Bennett, Ingold and others? And how does this relate to sociality? To answer such questions we need to start in the middle: to focus our gaze on the mesoscale.

Room in the middle

In 1959 the physicist Richard Feynman gave a lecture at the California Institute of Technology that laid the ground for the later technological idea of 'nanotechnology'. In 'There's plenty of room at the bottom' (Feynman, 1960), the 'bottom' he was referring to was the nanoscale – around and below the nanometre (nm, or 10^{-9} metres), the scale of the atoms and molecules of matter, dominated by Brownian motion, inter-molecular forces and quantum effects. The 'top' implied in Feynman's title is the macroscopic, inertial world inhabited by human bodies and the things with which they can directly interact – tools, buildings, devices, other bodies and the regions of fluid (gas or liquid) that surround such entities. This is matter in 'mass' form, made up of huge amounts of atoms. We might position the 'top' as around the 1 m point, say 1 cm up to 10 m.

This macroscopic world of bodies and the microscopic world of molecules, our scalar 'top' and 'bottom', are worlds that are in many ways insulated from each other, separate 'causal domains', and this for a number of reasons. The first reason is itself scalar: the difference in size and mass between entities at these two levels make it all but impossible for them to interact directly with each other. The second is numerical: the micro-scale is not just the level of the small but also of the many; the law of large numbers means that the effects of all but the most 'redundant', dominant micro-fluctuations are cancelled out statistically at the level of the macroworld.² The third reason is temporal: micro-fluctuations typically occur on a time scale that is usually too rapid and out of joint with macroscale processes to make fine-grained interactions possible (Lautrup, 2005: 3-7; Deacon, 2012: 199-200).

In 1917 the chemist Wolfgang Ostwald describes colloids as inhabiting a 'middle country' – by which he meant not just a *behavioural* 'middle' in their mixing of solid and fluid behaviours discussed in the previous section, but also a *scalar* middle, a 'world of neglected dimensions' between the macro and the nano, from which 'remarkable phenomena' arise that are governed by the laws of neither realm (Ostwald, 1917: 218-9). For the 'classic colloids' that are studied by physical chemistry, the mesoscale is roughly between 1 nm and 1 micron (10^{-9} to 10^{-6} m). However, as we expand our notion of colloids, we will see that the 'position' (i.e. the scalar size) of the middle can move – and can sometimes even be moved by colloids themselves.

This mezzanine is where the 'top' and the 'bottom' touch and interact; it is at this mesoscale that the material interactions take place that make possible colloidal matter's self-composing powers. In *The Fold* (1993), Gilles Deleuze's sustained engagement with the thought of Gottfried Leibniz and the baroque, he hints at this mezzanine when he observed that it is the intermediate folds of matter bridging the levels of the molecular and the whole organism that make life possible (Deleuze, 1993:

6-7). Bennett and DeLanda are also not unaware of the importance of the mesoscale. Bennett discusses the ‘primordia’, Lucretius’ constituent parts of being (although she tends to equate these with the molecular level); elsewhere she explores at length how the macroscale properties of metals depends on their mesoscale grain structure (Bennett, 2010: iv, 58-9).³ DeLanda for his part discusses a range of examples where there are mesoscale, ‘intermediate’ structures that bridge other scales in consequential ways (2002: 43-4, 49, 85).⁴ A more sustained investigation of the range of ‘species’ of colloidal matter will make it clearer what exactly goes on in this ‘middle country’.

Colloidal topologies

If colloids are medial in their phenomenology, inhabiting a middle space between solid and fluid behaviour, then underlying this is another mediality, that of a middle scale between two otherwise separate scalar and causal realms. But a third form of mediality – which is the condition of possibility for the way that ‘classic’ colloids present phenomenologically at the scale of human life – takes place at that mesoscale. Even if colloids such as mist or mud may appear fairly homogeneous and structureless at the macroscale, at the middle scale they are highly heterogeneous and structured. Rather than being either pure ‘molecular’ solid, liquid or gaseous substances, or hybrid ‘compounds’ or ‘solutions’ mixed at the atomic or molecular level, they are medial between these; surfaces are folded throughout the substance, permitting a complex mediation between matter in different phase states, allowing the colloid to draw on the properties of both – and to generate further properties by the interaction between them.

The first scientific investigation into the mesostructure of a colloid was carried out in the 1850s by Michael Faraday, who was exploring what we now call colloidal gold. ‘Colloid’ is still mainly used to refer to ‘complex’ or ‘multiphase’ fluids: substances that behave mainly like fluids, but which, like colloidal gold, hold in suspension small particles that neither settle out nor dissolve. However, the term has been extended in two main ways.

The first extension – which produces the full range of what I call ‘classic’ colloids – was to see colloids as a wider set of combinations of two or more substances in different phases of matter, in topological configurations at a scale intermediate between that of molecules and macroscopic bodies, in which one substance is continuous and the other dispersed – for example foams (continuous liquid/dispersed gas), aerosols (gas/solid), gels (solid/liquid) and sols (liquid/solid).⁵ It is this internal topology that makes a colloid a colloid, and makes it a member of a particular colloidal species. (This also makes it possible to treat colloids as ‘substances’ not just in the material-science

sense, but in the philosophical sense of being fundamental ontological entities that cannot be disaggregated without ceasing to be what they are.)

As we saw above, some colloidal species present more like complex or multi-phase fluids. Let us start with those with *gas* as the continuous phase or medium. If the dispersed phase is made up of smaller solid particles of a mesoscale size, so not big enough to settle immediately out of the gas, it is a *solid aerosol* – for example smoke, or dust dispersed in air. In *liquid aerosols* the dispersed phase is liquid, such as spray, fog or mist. In other complex fluid colloids, the continuous medium in which the other phase is dispersed is *liquid*. These include *sols* – tiny solids dispersed in liquid, such as (ordered from the more ‘liquid’ to the more ‘solid’) colloidal suspensions, paints, slurries, muds and pastes. *Foams* are bubbles of gas dispersed in liquid, such as froth. Then there are *emulsions* in which the dispersed phase is itself also a liquid, but one that is immiscible in the medium, for example oil or fat (liquid) in water (liquid).

But as we saw above, some colloids present at the macroscale more like solids. Many of these, such as wet sand or clay, have a fluid continuous phase, but the dispersed solid phase is at such a small scale and so close-packed that the presence of water, rather than making them flow, binds them together through surface tension into a rigid configuration that will resist a certain degree of applied force. In other, even more ‘solid’ colloids, there is a continuous solid phase with a dispersed fluid phase, either gas or liquid. *Solid foams* include rock with internal pores (such as sandstone or pumice), clathrates (gas held in ice) and the human built environment; *gels* are predominantly liquid by volume, but the liquid phase is held in a solid matrix. The hard and soft parts of vertebrate bodies are basically solid foam (e.g. bone) and gel (e.g. cartilage) respectively. Some substances such as colloidal glass, and heterogeneous alloys such as steel with its mesoscale ‘grains’ of different crystalline structures, are solid-solid colloids. The homogeneous metals and alloys discussed by Bennett (2010: 58-9), in which all the constituent grains are of the same compound but whose macroscale properties still depend on their mesoscale granular structure, could be seen as single-phase solid colloids.

Thus the combination of phase and topology enables us to expand our gaze outwards from the original solid-in-liquid colloids to a much broader phylum of colloidal ‘species’ organised around a mesoscale situated between the nanometre to the micron, in touch with both molecular and mass worlds. But a second extension of the term, slightly less common, is to use it in an even broader sense for a wider range of hybrid forms of matter on various scales that are continuous and homogeneous at one scale but heterogeneous at a smaller one. The actual size of the mesoscale here is relative to the substances that are heterogeneously combined at the mesoscale – but also to

the intensive forces that are at play. For example, physical scientists often include as colloids granular materials such as sand, pebbles or grain, especially when in motion. On the Earth's subaerial surface the mesoscale of flowing granular colloids is typically from around 100 microns (10^{-4} m) up to a few millimetres.

And we can go further 'up' the scalar dimension to include anything with hollows or cellular structures – mountains, buildings, animal bodies, institutions – or mass flows of reiterated, ostensibly separate but in some way exchangeable entities such as traffic, clouds, crowds, nations, flocks of birds or planetary rings. This extension – which becomes most useful when there are clear emergent effects due to topological folding at this higher mesoscale – enables us to see common colloidal 'metapatterns' (Bateson, 1979: 11; Volk, 1995) occurring across very different physical substrates (Duran, 2000: 3). The scalar position of the meso-world is relative to other scalar dimensions (the top and bottom) appropriate to the mereology (the relation of wholes to parts) of the colloid in question – but as we shall see the exact scalar positions of top, bottom and middle do not pre-exist the colloid but are produced immanently by its internal dynamics.

Repetition and mediation

One existing concept that should be discussed in relation to colloids is the Deleuzo-Guattarian 'assemblage' (Deleuze and Guattari, 1987). Both DeLanda (2006) and Bennett (2010) use this concept to try to capture the way that material animacy is not a property of the individual members of a 'population' or 'confederation', nor of some overarching whole, but emerges from the interaction between different members. Invoking a contrast similar to that Ingold makes between interactive and regulative ideas of the social, DeLanda explicitly posits the assemblage as an alternative both to atomistic explanation in terms of the powers of individual component parts, and to an organismic approach in which components parts are constituted by their role within the whole. Whereas the members of an organism are constituted by their 'internal' relations, the parts of an assemblage have only 'external' relations to the assemblage and its other parts, since they can leave it without ceasing to be what they are (2006: 9-12). However, this emphasis on external relations leads Ingold to dismiss the assemblage concept as 'agglutinative' – too close to the atomistic 'interactive' model in its neglect of the way that parts can 'answer' to and constitute each other without forming an overarching 'whole' (2015: 7, 23). The internal topology of the colloid – neither a totalistic organism nor a mere aggregation of individual entities – is an alternative way into these questions.

The topology of colloids at the mesoscale – the folded surface that separates the dispersed and continuous media – has important consequences. Firstly, the dispersed phase exhibits *repetition*; whether it takes the form of grains of suspended dust, or drops of water, or bubbles of gas in rock or water, birds in a flock or human beings moving and interacting in shared space, there are *many* of these. As DeLanda puts it, ‘assemblages always exist in *populations*, however small, the populations generated by the repeated occurrence of the same processes’ (DeLanda, 2006: 16). But secondly, the continuous phase of colloids, by contrast, exhibits *mediation* – it manifests as a milieu that fills the space within the colloid between the iterations of the repeated discontinuous phase, surrounding them, separating them and mediating any interactions they have. Thirdly, the topological folding of the colloid also means that this repetition and mediation are not independent; rather, each provides and shapes the conditions of possibility for the other.

The repetition of the dispersed entities – dust, mist, or bubbles – is not just quantitative but qualitative, crucial for the emergence of rheological effects at the higher spatial scale that we will discuss in the next section, for example through dynamical and statistical processes. But it is also crucial for what I am arguing is the colloids’ *social* ontology, with something close to the internal relations of the parts of an organism. Mereologically, each colloidal grain, droplet or pore is part of a colloid *because* of its repetition – because it is not alone – and because of the way they all exist as nodes in dynamic networks of intensive forces and bring each other to take up roles that emerge from the interaction amongst bodies and the surrounding medium. To use Ingold’s language, a colloidal substance is not just one big (regulative) ‘blob’, and neither is it a collection of (interacting) ‘blobs’; it is more like a braided, dynamic set of correspondences and answerings. It is animate and ‘social’ – and the shifting phenomenology at the macroscale gives us clues about the forms of social co-constitution that are happening within the folds of the colloidal substance.

Of course, the repetition does not belong to the dispersed substance alone. The ‘continuous’ medium also participates in it, since its substance is interrupted by the reiterated dispersed substance. However, if the dispersed phase involves repetition, the continuous phase is more concerned with *mediation*. Firstly, the continuous medium mediates any interactions the dispersed iterations have with each other and with their wider environment.⁶ In sols and aerosols for example, where the continuous medium is the more fluid substance, apart from at high densities and energies, the particles in sols only feel each other’s presence through the medium. Human social life is no exception – it takes place in the context of the elemental medium of atmosphere, in both its material and hermeneutic sense (Sloterdijk, 2011; Adey, 2015; Ingold, 2015: 73-8).

But secondly it's important here not to fall into what Ingold called the 'interactive' view of the social. Elemental media are not just carriers of messages; they also provide conditions for existence, and condition relationships and habits. As John Durham Peters argues, '[m]edia are our infrastructures of being, the habitats and materials through which we act and are' (Peters, 2015: 15). In colloids, the continuous media that lie between the iterated dispersed elements constitutes the many *as* many, *as* what they are, and *as* in relation. Such media typically do their work by withdrawing: they are backgrounded, made infrastructural, forgotten (ibid.: 34) – including it could be argued by much assemblage theory – but they just as necessary to social life and animacy as are the dispersed population. In the human 'sol' – the 'suspension' of human bodies within the atmosphere of the social – the enveloping atmosphere is not merely a carrier of signals between the individual bodies; like all colloidal media it is also infrastructural, constituting human subjects and putting them into relation. As Luce Irigaray says of the medium of air, it 'gives itself boundlessly and without demonstration, ... [in it] everything will come to presence and into relation' (Irigaray, 1999: 43). For humans, like other animals, the medium is also an affective field. Affect is medial, transindividual, since it belongs first to events and situations, and only secondarily to the subjects within the event (Massumi, 2015: 94).⁷ What Bennett (2010: 61) calls an impersonal, more-than-human 'geoaffect' is located not merely in the individual things that participate in it, since it involves their immersion in an external and internal elemental medium. As Ingold puts it in relation to a stone, 'there is no way in which its stoniness can be understood apart from the ways it is caught up in the interchanges across its surface, between medium and substance' (2011: 32).

In foams and gels, the relation between repetition and mediation is slightly different. Here it is the most fluid phase that is reiterated in multiple pores, constituted by the solid walls that lie between them. In closed-cell foams and gels, the fluid's power of macroscopic flow is held in abeyance: it can only move within the cell, so that other characteristics of the fluid are made to contribute to the way the substance behaves on the macroscopic scale. And here, in foams and gels, it is the continuous substance's infrastructural role, rather than its mediating role, that seems most clear – even though the solid walls do mediate effects between the iterations of the fluid substance. Yet with both foams and gels it is not the continuous infrastructure but the *dispersed* phase that seems to withdraw: the iterations of the dispersed substance are often conceived primarily as a negation or lack, as gaps within the architecture of the otherwise solid continuous phase.⁸

Colloidal dynamism

We must now turn to the internal intensive dynamism of colloids, in order to see how the topologically folded mesoscale heterogeneity of colloids enables them to escape the dualities of bottom-up and top down determination, reversibility and irreversibility, (solid) memory and (fluid) forgetting, and thereby exhibit complex creative behaviours. Here my argument will be closest to that of DeLanda, who uses nonlinear thermodynamics to identify how matter can generate ‘simple machines’ beyond that of the regular crystal – machines such as attractors, coherent pulses, cycles and sorters – that themselves can combine to create more complex machines such as hierarchical systems of homogenous strata and more complex meshworks, ‘interlocking system[s] of complementary ... functions’ (1997: 16, 263, 39). Attending to colloidal dynamics can help us expand DeLanda’s phylum of machines, and focus on those that exhibit their own forms of sociality.

What Bennett (2010: 59) says of metals is true of colloids in general: in colloids the behaviour of individual iterations is not individually determined, but neither is there a pre-existing order that ‘regulates’ the actions of the individual iterations; instead, an order emerges from the meshwork of causal interactions amongst discrete and continuous matter, solids and fluids and spatial scales. But it is arguably *dynamic* colloids in which this dynamic is most clear, and that are revealed most clearly as social in Ingold’s sense – as not merely aggregations, networks or assemblages of separate, externally related iterations, but entangled ‘lines’ of activity (Ingold, 2015) or ‘gatherings’ (Ingold, 2020b).⁹ Due to the dense set of causal chains within them, dynamic colloids are able to partially liberate themselves from direct causal determination from outside (Louie, 2009) – even if only fleetingly achieving anything like the full autopoiesis available to biological organisms. Colloids can self-organise in ways that involve their different components – both the discontinuous iterations and the continuous medium – taking up distinctive behaviours and roles in ways that challenge the distinction between internal and external relations.¹⁰

For example, swarming behaviour is a pattern of collective movement that is available to a range of living and non-living populations (Vicsek and Zafeiris, 2012), one that arises in the midst of the interplay amongst multiple solids and the surrounding fluid. In human social life, each human body will react slightly different to the intensive microperceptions involved in the same event, so that an event will unfold in a way that is an emergent property of the interactions between each body and the surrounding affective milieu (Massumi, 2015: 53-6). But in other colloids too, iterations can be enrolled or entrained not just into an overarching situation, but also into an economy of internal diversity with divisions of labour. For example, avalanches on submarine slopes result in a mixture of rock particles and water that turns into a ‘turbidity flow’, heavier than the surrounding water, thus

flowing down the slope. As it does so it picks up more and more sediment in a runaway and self-sustaining dynamic, generating different rheological regimes within its dynamically generated body, in which particles play different roles; for example, some of the settling sediment particles squeeze up fluid between each other and thereby help to keep the particles above suspended (Leeder, 2011: 184-97).

The different metastable states or rheological regimes that colloids can occupy and explore generate different colloidal 'subspecies'. What determines a change of flow regime is not a change of substance, or of topology, or of scale as such; it is a change in *intensive forces*. The concept of the 'intensive' was first elaborated in scientific terms by the physicist Richard Chase Tolman (1917); Deleuze (1994) was later to link it Bergson's concepts of 'intensity', 'multiplicity' and 'the virtual' (1911; 1913). *Extensive* properties are divisible properties such as length, volume and mass, the properties that together comprise the stable, actual, completed form of an object. *Intensive* properties such as temperature, pressure and density, by contrast, cannot be divided or altered without introducing qualitative changes in kind or state. The intensive is primordial, generating the macroscopic world of form that we inhabit. As DeLanda puts it, 'an undifferentiated intensive space ... progressively differentiates, eventually giving rise to [discontinuous] extensive structures' (2002: 27). But where we find matter at its most lively, the macroscale extensive world is subtended not just by the intensive but also by colloidal topologies at the mesoscale.

The different intensive dimensions along which subspecies of colloids can be distributed can themselves be grouped into three families. First, the *size* of the different iterations of the dispersed, while itself an extensive, geometric variable, in colloidal matter becomes intensive, in that quantitative change produces qualitative shifts in the balance between the physical forces (such as molecular forces and inertia) active in that particular combination of substances. A second kind of intensive variable is the *volume fraction*, the ratio between the amount of volume made up by the dispersed phase and by the continuous phase, which can itself shift the balance of forces involved. For example, in complex fluids of solid particles in liquid, as the volume fraction made up by the dispersed solid particles increases – as they are pushed closer together, displacing the intervening medium – there is a shift first from isolated individual trajectories to hydrodynamic effects (where the two bodies feel each other through the play with the medium), and then finally towards a dominance of direct particle-particle interaction, involving collisions and friction (Everett, 1988). A third set of intensivities are *energetic* – involving shear, pressure or agitation (molecular temperature, or at a larger scale granular 'angoricity').

As these intensive variables pass thresholds or tipping points, a given region of a colloid will transition from one dynamic regime into another.¹¹ As DeLanda puts it in his discussion of nonorganic life, 'it is ultimately the intensity of each parameter that determines the kind of dynamic involved and, hence, the character or the structures that are generated' (1997: 264). In colloids, changes in levels of energy can also shift the position of the colloidal mesoscale up or down, allowing larger particles to engage in particular rheological behaviours. At higher agitation, individual particles might also overcome repulsive molecular forces between them and form temporary 'flocs' or longer-lasting 'coagula', or might conversely be broken up, thus altering the topology and overall behaviour of the colloid. This kind of effect produces the non-Newtonian behaviour of shear-thinning and shear-thickening colloids.

By combining different intensities, one can create a rheological 'flow regime' diagram, typically a two-dimensional space with different intensive variables on the 'x' and 'y' axis. In such diagrams, the planar possibility space is subdivided into regions; each region is a different flow regime or colloidal subspecies, and the lines between the regions represent moments of 'second-order' phase transition between them. For example, granular flow in either air or water can shift between a more 'gaseous' regime (such as a dry avalanche of pebbles), in which the motion is largely conditioned by the inertia of the particles and collisions and friction between them, and a regime that is more like a macro-viscous Bingham plastic (such as a mud slide) (Everett, 1988). Other colloidal species have very different families of flow regimes. Oil-water emulsions travelling in horizontal pipes have six flow regimes, depending on temperature, fraction and velocity (Jing et al., 2016). Gas passing through solid foam such as sedimentary rock exhibits four regimes, depending on the size of the pores and the density of the fluid, behaving sometimes like a continuous fluid and at others more like individual molecular 'grains' of gas (Darabi et al., 2012).

The ways that colloidal substances react internally to these intensive forces, finding different rheological 'solutions', determine how they present to us at the macroscopic scale. But the ways that their components react also change the balance of intensive forces at different points within the colloid, with cascading effects around the system, as intensive forces produce change in the 'extensive' variables of position, volume and velocity, which then affect the intensive dimension, and so on. A colloid which is unable to reach a static, equilibrium state can thus undergo an endless creative dance between extensive and intensive variables. Furthermore, when regions of colloids are near to second-order transitions between the flow regimes of a particular colloidal species, they can behave in complex, creative ways, generating complex structures at the macroscale. For example, a colloid consisting of fluid flow moving under pressure through a dense granular colloid has two main flow regimes: a fluid extreme of bubbles passing through the granular medium and a

frictional extreme of fractal cracking of porous media; however, if the intensive variables are maintained near the transition point, the colloid creates complex coral-like structures of branching bubbles produced by stick-slip processes (Sandnes et al., 2011).

But colloids also behave in interesting ways near to first-order transitions between colloidal species such as sol, gel and foam. For example, when the volume fraction or density of granular flows gets very high they undergo 'jamming', in effect turning into a solid foam (with limited rigidity), with all the particles pressed up against each other. But as a granular flow gets close to jamming, it starts to network, creating long-range collision chains between particles, long-range structures that propagate rapidly like spasms, arresting the flow (Gardel et al., 2009). As the flow gets even more compressed the composite has to find more and more tortuous paths to its lowest energy state, twisting and contorting (Forterre and Pouliquen, 2018: 276-7).¹² Then in the arrested state the grains are still linked by force chains, in which particular sets of grains are supporting each other and holding each other in place (Zhang et al., 2017).

These behaviours suggest that, if memory is the mapping of fluid novelty-generation onto solid durability, then the colloids, neither solid nor fluid, show how memory and forgetting themselves are simply sub-regions of a far wider possibility space of emergent order-generation in space and time.

Conclusion

There is growing recognition that a careful exploration of materials can help us understand social life as a more-than-human, more-than-biological phenomenon. As Bennett (2010: xiv) puts it, we need 'a cultivated, patient, sensory attentiveness' to materials' tendencies and powers. Thinking about materials can make us more aware of their important role as active participants in human social, cultural and political life (see for example Knappett and Malafouris, 2008; Braun and Whatmore, 2010; Schatzki, 2019). Paying more attention both to the specific details of how different kinds of matter behave, and also to the metapatterns of 'machinic solutions' that occur across different materials, is also an essential part of theorising matter's own kind of agency. But I have also argued that thinking through certain kinds of materials can also help us to rethink what sociality is.

In particular, I have argued for the importance of colloids: substances that appear at the macroscale as a continuous substance, but at a smaller mesoscale as a population of discrete, similar entities surrounded by an enveloping medium. Colloids, more than matter in simple phases of matter, are particularly relevant to thinking the social – and not just because of the presence of discrete

populations of entities at the mesoscale. The complex, shifting behaviour of a dynamic colloid is neither merely the sum result of individual interactions between its constituent parts, nor the result of a macroscale structure which determines these interactions; a colloid is a multiscale 'meshwork' of movements, transformations and causal chains, in the 'in-between' of which emerge a diverse range of structurings and relationships, resistant to either 'downward' or 'upward' reductionism.

A colloidal social theory can help us to be more sensitive to the animacy and sociality of matter and materials. Thinking in and across the whole family of colloidal species and their subspecies provides a framework for understanding and relating a wide range of material powers and behaviours. In the substance of the colloid, what Bergson called the *élan vital* derives its creativity by dividing itself not into individual entities and lineages, or into life's explosive force and the resistance of matter (Bergson, 1911: 109), but into solid and fluid, continuous and dispersed, and across causal domains at different spatial scales. As we have seen, the 'folded', topological nature of colloids is not merely a matter of the three extensive dimensions of space. Topological mediation between matter in different phases produces cascading folds of mediality into other, more intensive dimensions, in which folds constitute 'singularities' or points of transition between different dynamic regimes or subspecies of colloid. Colloids are thus made capable of creative behaviour, partially liberating themselves from causal determination by their environment. The result of all this is that colloidal species such as sols and foams can usefully be understood not simply as hybrid mixtures of more fundamental categories of matter but as substances in their own right – not organisms, but not aggregates with merely external relations either.

And colloids can also help us to theorise human society in new ways, as a particular manifestation of a wider colloidal sociality organised around mesoscale populations embedded within wider substances. Human sociality may not be amenable to the deterministic, nomological form of explanation favoured by a Galileo or a Newton – but neither are the internal lives of other colloids. Social theorists have used ideas of flow and far-from equilibrium nonlinearity to help situate human social life within the wider animacy of matter, but I would argue that thinking in terms of colloidal topologies and mesoscale phenomena is an important further step. Human social life can for example be seen as involving: a sol of human bodies and nonhuman objects and substances suspended in a material and affective atmosphere; buildings and social structures as more-or-less rigid foams which play an active role in shaping social life; individual subjectivities as substances whose behaviour emerges from the interaction of subpersonal populations of sensations, affects and habits; and larger-scale colloidal forms composed of populations of smaller colloidal forms – all shifting between different rheological regimes depending on changing intensive forces.¹³

Viewed colloidally, human history as a whole could be likened to a very slow submarine avalanche, a self-organising process of dissipation that has entrained more and more matter over the millennia. Through the proliferation of causal and functional relations between its constituent parts, human society has achieved a degree of autopoietic liberation from its environment. But this does not mean that human beings are totally powerless to steer the avalanche, or that the behaviour of other colloids are not relevant to the understanding of human society. The mesoscale constituent parts of a typical colloid cannot 'know' directly the macroscopic substance of which they are part, or its unfolding macroscale behaviour; they can just feel the local concatenation of forces around them, and take up their role in the emergent choreography. Human beings in their everyday lives similarly live at the mesoscale of the social fabric, that of intersubjective relations between individual human bodies and the spaces between and around them. But we humans are also unusual in also having the capacity to form ideas about the larger substance of which we are part. To paraphrase DeLanda, we need to get better at mapping the machinic processes that 'define our local destinies', so that we can better understand how to modulate them and actualise alternative future trajectories (1992: 161). In relation to such a task, colloids are good to think with.

Bronislaw Szerszynski is Professor of Sociology at Lancaster University. His research seeks to situate the changing relationship between humans, environment and technology in the longer perspective of human and planetary history, drawing on the social and natural sciences, arts and humanities. He is co-author with Nigel Clark of *Planetary Social Thought* (2021), author of *Nature, Technology and the Sacred* (2005), and co-editor of *Risk, Environment and Modernity* (1996), *Re-Ordering Nature* (2003), *Nature Performed* (2003) and *Technofutures* (2015).

Acknowledgements

Many thanks are due to Andrew Barry, Tim Ingold, Cristian Simonetti, Jamshed Anwar, Chris Arridge, Carolyn Deby, Peter Haff, Radek Przedpelski and the anonymous referees for very helpful comments on an earlier draft of this paper, though I take full responsibility for the final version. Thanks are also due to Nigel Clark, Bulent Diken, Peter Forman, Maxigas, Jonnet Middleton, Dalziel Ross, Ted Schatzki, Leandro Soriano Marcolino and Nigel Stewart for a very productive discussion of a spoken version.

Funding

This research received no specific grant from any funding agency in the commercial, public, or not-for-profit sectors.

Notes

¹ The combination of fluidity and viscosity is not only the source of fluids' creativity but also of their forgetfulness. Only fluids with either near-infinite fluidity (e.g. supercooled helium) or near-infinite viscosity (e.g. pitch) have forms of memory and reversibility to rival those of the solid.

² On statistical causality, see DeLanda (2006: 21-2).

³ Andrew Barry (2010: 92-3) has also pointed out the importance of the mesoscale in understanding the macroscale material properties of metals, and how the metallurgist has to work across scales in order to match metallic properties to applications.

⁴ DeLanda even briefly discusses colloidal matter itself, as increasing the number of possible behaviours available to matter (1992: 141).

⁵ There are also multiple colloids, with three or more phases, and networked or 'reticulated' colloids in which both phases are continuous – and I will also suggest that metals can be seen as a single-phase colloid. But most colloids are 'biphase', with a dispersed phase and a continuous phase.

⁶ For Aristotle, τὸ μεταξύ (*to metaxu*), the 'between' or 'medium', is where sensation takes place (Aristotle, 1993).

⁷ A similar in-between-ness is indicated in the way that a single non-dimensional number, such as the 'Reynolds number', can be used to characterise the whole situation of moving objects within a flow. Such numbers also reveal where situations involving radically different materials and spatial scales are drawing on the same 'machinic solution' available to planetary matter in general.

⁸ In networked colloids, particularly important in foams and gels, both phases are continuous and neither are wholly dispersed, and the relation between repetition and mediation is even more entangled.

⁹ Here I am closer to Ingold and DeLanda than to Bennett, in linking the animacy of matter to its powers of ordered motion, self-organisation and self-complexification.

¹⁰ DeLanda does allow for relations in an assemblage to sometimes become 'contingently obligatory', which comes close to splitting the difference between internal and external relations (2006: 11-12); however, I am going further here.

¹¹ Because of their topological nature, colloids can change their colloidal species – or depart the colloidal realm entirely – without changing their component substances, simply by changing their topology. Microbes are small enough that some can exploit this within their body 'on the fly', achieving locomotion by converting parts of their cytoplasm from gel (complex solid) to sol (complex fluid) and back again (Nishigami et al., 2013).

¹² Similar bursts of cooperative and imitative behaviour are seen in adjacent particles in colloidal liquids about to turn to glass (Weeks et al., 2000).

¹³ Such colloidal thinking can add further nuance to DeLanda's discussion of the nesting of human social assemblages into larger assemblages (DeLanda, 2006: 17-18, 33-4), of and human subjectivity as itself an assemblage of subpersonal elements (ibid.: 47-52).

References

Adey, Peter (2015) Air's Affinities: Geopolitics, Chemical Affect and the Force of the Elemental.

Dialogues in Human Geography, 5(1): 54-75.

Aristotle (1993) *De Anima: Books II and III with Passages from Book I*. tr. Hamlyn DW, Oxford:

Clarendon Press.

Barry, Andrew (2010) Materialist Politics: Metallurgy. In: Braun B and Whatmore S (eds), *Political*

Matter: Technoscience, Democracy, and Public Life. Minneapolis: University of Minnesota Press, pp. 89-118.

Bateson, Gregory (1979) *Mind and Nature: A Necessary Unity*. New York: Dutton.

Bauman, Zygmunt (2000) *Liquid Modernity*. Cambridge: Polity Press.

Bennett, Jane (1997) The Enchanted World of Modernity: Paracelsus, Kant and Deleuze. *Cultural*

Values, 1(1): 1-28.

Bennett, Jane (2010) *Vibrant Matter: A Political Ecology of Things*. Durham: Duke University Press.

Bergson, Henri (1911) *Creative Evolution*. tr. Mitchell A, New York: Henry Holt & Company.

Bergson, Henri (1913) *Time and Free Will: An Essay on the Immediate Data of Consciousness*. tr.

Pogson FL, London: George Allen & Company, Ltd.

Braun, Bruce and Whatmore, Sarah (eds) (2010) *Political Matter: Technoscience, Democracy, and*

Public Life. Minneapolis: University of Minnesota Press.

Darabi, Hamed, Etehad, A., Javadpour, F. and Sepehrnoori, K. (2012) Gas Flow in Ultra-Tight Shale

Strata. *Journal of Fluid Mechanics*, 710: 641-58.

- Deacon, Terrence W. (2012) *Incomplete Nature: How Mind Emerged from Matter*. New York: W.W. Norton & Co.
- DeLanda, Manuel (1992) Nonorganic Life. In: Crary J and Kwinter S (eds), *Zone 6: Incorporations*. New York: Urzone, pp. 129-67.
- DeLanda, Manuel (1997) *A Thousand Years of Nonlinear History*. New York: Zone Books.
- DeLanda, Manuel (2002) *Intensive Science and Virtual Philosophy*. London: Continuum.
- DeLanda, Manuel (2006) *A New Philosophy of Society: Assemblage Theory and Social Complexity*. London: Continuum.
- Deleuze, Gilles (1988) *Foucault*. tr. Hand Sn, Minneapolis: University of Minnesota Press.
- Deleuze, Gilles (1993) *The Fold: Leibniz and the Baroque*. London: Athlone.
- Deleuze, Gilles (1994) *Difference and Repetition*. tr. Patton P, London: Athlone Press.
- Deleuze, Gilles and Guattari, Félix (1987) *A Thousand Plateaus: Capitalism and Schizophrenia*. tr. Massumi B, Minneapolis: University of Minnesota Press.
- Duran, Jacques (2000) *Sands, Powders, and Grains: An Introduction to the Physics of Granular Materials*. New York: Springer.
- Everett, Douglas Hugh (1988) *Basic Principles of Colloid Science*. London: Royal Society of Chemistry.
- Feynman, Richard P. (1960) There's Plenty of Room at the Bottom. *Engineering and Science*, 23(5): 22-36.
- Forterre, Yoël and Pouliquen, Olivier (2018) Physics of Particulate Flows: From Sand Avalanche to Active Suspensions in Plants. *Comptes Rendus Physique*, 19(5): 271-84.
- Gardel, Emily, Sitaridou, E., Facto, Kevin, Keene, E., Hattam, K., Easwar, Nalini and Menon, Narayanan (2009) Dynamical Fluctuations in Dense Granular Flows. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 367(1909): 5109-21.
- Harman, Graham (2016) *Immaterialism: Objects and Social Theory*. Malden, MA: Polity.
- Ingold, Tim (2007) *Lines: A Brief History*. London ; New York: Routledge.
- Ingold, Tim (2011) *Being Alive: Essays on Movement, Knowledge and Description*. London: Routledge.

- Ingold, Tim (2015) *The Life of Lines*. London: Routledge.
- Ingold, Tim (2016) *Evolution and Social Life*. revised edition, London: Routledge.
- Ingold, Tim (2017) On Human Correspondence. *Journal of the Royal Anthropological Institute*, 23(1): 9-27.
- Ingold, Tim (2020a) *Correspondences*. Cambridge: Polity.
- Ingold, Tim (2020b) In the Gathering Shadows of Material Things. In: Schorch P, Saxer M and Elders M (eds), *Exploring Materiality and Connectivity in Anthropology and Beyond*. London: UCL Press, pp. 17-35.
- Irigaray, Luce (1999) *The Forgetting of Air in Martin Heidegger*. 1st edition, Austin: University of Texas Press.
- Jing, Jiaqiang, Sun, Jie, Tan, Jiatong, Huang, Min, Liang, Quansheng and Xue, Tao (2016) Investigation on Flow Patterns and Pressure Drops of Highly Viscous Crude Oil–Water Flows in a Horizontal Pipe. *Experimental Thermal and Fluid Science*, 72: 88-96.
- Knappett, Carl and Malafouris, Lambros (eds) (2008) *Material Agency: Towards a Non-Anthropocentric Approach*. New York: Springer.
- Lautrup, Benny (2005) *Physics of Continuous Matter: Exotic and Everyday Phenomena in the Macroscopic World*. Bristol: Institute of Physics.
- Leeder, Mike (2011) *Sedimentology and Sedimentary Basins: From Turbulence to Tectonics*. 2nd edition, Chichester: Wiley-Blackwell.
- Louie, A. H. (2009) *More Than Life Itself: A Synthetic Continuation in Relational Biology*. Frankfurt: Ontos Verlag.
- Massumi, Brian (2015) *Politics of Affect*. Cambridge, UK: Polity.
- Mol, Annemarie and Law, John (1994) Regions, Networks and Fluids: Anaemia and Social Topology. *Social Studies of Science*, 24(4): 641-71.

Nishigami, Yukinori, Ichikawa, Masatoshi, Kazama, Toshiya, Kobayashi, Ryo, Shimmen, Teruo, Yoshikawa, Kenichi and Sonobe, Seiji (2013) Reconstruction of Active Regular Motion in Amoeba Extract: Dynamic Cooperation between Sol and Gel States. *PLOS ONE*, 8(8): e70317.

Ostwald, Wolfgang (1917) *An Introduction to Theoretical and Applied Colloid Chemistry: The World of Neglected Dimensions*. tr. Fischer M, New York: John Wiley & Sons, Inc.

Parisi, Luciana and Terranova, Tiziana (2000) Heat-Death: Emergence and Control in Genetic Engineering and Artificial Life. *CTheory*.

Peters, John Durham (2015) *The Marvelous Clouds: Toward a Philosophy of Elemental Media*. Chicago: The University of Chicago Press.

Sandnes, B., Flekkøy, E. G., Knudsen, H. A., Måløy, K. J. and See, H. (2011) Patterns and Flow in Frictional Fluid Dynamics. *Nature Communications*, 2(1): 288.

Schatzki, Theodore R. (2019) *Social Change in a Material World*. New York: Routledge.

Schwenk, Theodor (1965) *Sensitive Chaos: The Creation of Flowing Forms in Water and Air*. tr. Whicher O and Wrigley J, London: Rudolf Steiner Press.

Sloterdijk, Peter (2011) *Spheres Vol.1: Bubbles: Microspherology*. tr. Hoban W, Cambridge, MA: MIT Press.

Szerszynski, Bronislaw (2019) How the Earth Remembers and Forgets. In: Bobbette A and Donovan A (eds), *Political Geology: Active Stratigraphies and the Making of Life*. London: Palgrave Macmillan, pp. 219-36.

Tarde, Gabriel (2012) *Monadology and Sociology*. tr. Lorenc T, Melbourne: re.press.

Tolman, Richard C. (1917) The Measurable Quantities of Physics. *Physical Review*, 9(3): 237–53.

Vicsek, Tamás and Zafeiris, Anna (2012) Collective Motion. *Physics Reports*, 517(3): 71-140.

Volk, Tyler (1995) *Metapatterns across Space, Time, and Mind*. New York: Columbia University Press.

Weeks, Eric R., Crocker, J. C., Levitt, Andrew C., Schofield, Andrew and Weitz, D. A. (2000) Three-Dimensional Direct Imaging of Structural Relaxation near the Colloidal Glass Transition. *Science*, 287(5453): 627.

Zhang, Lingran, Nguyen, Nho Gia Hien, Lambert, Stéphane, Nicot, François, Prunier, Florent and Djeran-Maigre, Irini (2017) The Role of Force Chains in Granular Materials: From Statics to Dynamics. *European Journal of Environmental and Civil Engineering*, 21(7-8): 874-95.