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Introducing Solid Fluids

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Abstract
This issue opens an inquiry into the tension between solidity and fluidity. This tension is ingrained in the Western intellectual tradition and informs theoretical debates across the sciences and humanities. In physics, solid is one phase of matter, alongside liquid, gas and plasma. This, however, assumes all matter to be particulate. Reversing the relation between statics and dynamics, we argue to the contrary, that matter exists as continuous flux. It is both solid and fluid. What difference would it make were we to start from our inescapable participation in a world of solid fluids? Is solid fluidity a condition of being in the midst of things, or of intermediacy on a solid-fluid continuum? Does the world appear fluid in the process of its formation, but solid when you look back on things already formed? Here we open new paths for theorizing matter and meaning at a time of ecological crisis.

Keywords
Anthropocene, continuous matter, duration, flux, hydraulics, rheology, solidity

> *Il peut être utile de se rappeler que le doux dure plus longtemps que le dur*. [It is worth remembering that the soft lasts longer than the hard.] (Michel Serres, 2009)[1]

From Fluid to Solid and Back . . . to Liquid?

Solidity can mean many things. A solid ground is one that bears your weight. It is hard or firm; you will not sink, as in marshland, or fall, as into the waters of a lake. A solid object, like a cricket ball, is of one continuous, undivided mass; it is not hollow like a tennis ball. Solid metal, such as gold, is pure, not contaminated by mixture with other

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minerals. A talk can last solidly for hours, while bored listeners remain solidly asleep. A geometrical solid is a figure in three dimensions rather than two. More than area, it has volume. These multiple aspects of solidity – hardness, undividedness, duration, purity and volume – while they might not share any unitary essence, nevertheless form a kind of semantic cluster which points to a certain convergence in experience. It is the experience of a life that, far from running every which way, has settled into the grooves of custom. Indeed the Latin dictionary renders the original meaning of the verb *solere*, from which 'solid' is derived, as 'to be accustomed'.

In antiquity, as still today, custom revolved in the first place around trade and markets. The merchant would seek a hard bargain, look for firmness or reliability in his trading partners or customers, and an assurance that goods are genuine rather than void or counterfeit. If using currency, he would want to be sure that the coin was of pure metallic substance, traditionally gold, and that its value was guaranteed by the authority of the realm. He would look for deals that last. And of course one of the most important skills of any trader was to be able to estimate by eye the volume of goods sold by the barrel or basket.[2] Thus every aspect of solidity would be in play. It is perhaps unsurprising, then, that the common coin of the late Roman Empire, of relatively low value, was called a *solidus*. Army personnel, whose salaries were paid in solidi, were called soldiers. Many centuries later, in France, you might still measure your petty cash in *sous*, while on the other side of the Channel, it would have been in shillings. In Italy, the balance on your account is *saldo*. We easily forget today that all these words go back to 'solid', and that they speak to the custom of commerce.

But what of its purported opposite, fluid? As with solid, the word is of Latin origin, from *fluere*, 'to flow'. Surely, what does not flow – what is stuck, or fixed firmly in place – is, ipso facto, solid. Yet curiously, all that is not solid doesn't flow. When we look at the many meanings of solid, and consider their opposites, not one of them carries any connotation of fluidity at all. An object that is not solid is hollow, but hollowness coops up what lies inside rather than allowing it to run. An impure substance is contaminated, but many metals are rather soft in their pure state, and a degree of impurity is necessary to harden them up. That's why even the Roman solidi were only around 95 per cent gold. In geometry, while a polygon on a plane surface has area but no volume, its constituent lines connect fixed points; there is no movement in them. The two remaining aspects of solidity, hardness and duration, are particularly perplexing. A hard winter frost solidifies the ground and turns water into solid ice. When the weather warms in spring, the ground becomes soft, and the ice melts back to liquid water. Yet neither softness nor liquidity implies flow. Marshy ground is treacherous precisely because its water content remains stagnant. Liquid is fluid only when it runs, and it will not run if contained. And in the case of duration, solidity and fluidity are not opposed at all, but mutually implicated. The opposite is interruption, which breaks the flow, whether of talk or sleep.

It seems, then, that while we might start with the fluid and derive the solid as its converse, turning the conversion around – far from taking us back to where we started – would lead us somewhere else altogether: not to fluidity but to hollowness, contamination, planarity, liquidity and interruption. In short, while solid entities can be formed or configured against the ground of the fluid, the reverse does not appear to hold. Stone pebbles rest on a riverbed, icebergs float in the ocean, mountains stand firm amidst the swirling mists and pouring rain. But how could a river be locked in a petrified landscape, or the ocean be contained in an icefield, or the weather in the theatre of a mountain range? A world already secured in solidity cannot accommodate the flow from which it once was formed yet which now portends its dissolution. Its regions of non-solidity are instead configured as gaps, spaces and hollows, as in a Swiss cheese. They can be filled, but the filling doesn't flow.[3] To see this, you only have to place a jar in a running river: you can catch a sample of water, but you cannot catch the current. Nor can you catch the wind in a bottle. In one case liquid, in the other gas, is held within the hollow regions of a solid.

Yet the world we inhabit, and that we know from our experience, does not resemble a Swiss cheese. It is not full of holes (Ingold, 2011: 24). Nor, conversely, are its solid regions immune to the flows that envelop them. Stones are ground into their forms by the forces of the river current; ice is sculpted by the ocean; mountains by weather. The earth, indeed, seems solid and fluid at the same time. How can that be? Perhaps, if we cannot regain fluidity by opposing it to the solid, it might nevertheless be found as the constitutive dynamic of the solid itself. Could solids retain something, in their very constitution, of the flux of which they were formed? Can the solid itself be intrinsically fluid, even as the fluid solidifies? Recall that it is precisely in the concept of duration that solidity and fluidity merge. Duration is about how things last, about how they carry on as they are both formed within and hold out against the flow. It is a word that links the two senses of hardening and continuity in time. And it is only by introducing the work of time, we suggest, that the conundrum of solid fluidity, or fluid solidity, can finally be resolved.

As this introduction and the articles to follow will show, the conundrum is not merely of concern to physical scientists tasked with unravelling the secrets of matter. For it is already implicated in an understanding of the physical world, foundational to modern science, as a domain of reality whose intrinsic hardness, receding at once into the infinite and the infinitesimal, resists the efforts of softer minds, bound by the rhythms of time and life, to fathom it. The distillation of reality that has allowed the solid to settle as a material substrate from the fluid matrix of its generation is part of the same bifurcation that has divided mind from nature, meaning from matter, and indeed the disciplines of the humanities from the physical sciences. The conundrum of solid fluidity cannot be resolved on one side of the division or the other. Nor is it a question of analogy, of treating the material world as a reservoir of metaphorical resources for concept formation and the construction of meaning. It is the division itself that requires critical attention. Amplified by techno-political forces, it has had fateful consequences for the sustainability of life on earth. By bringing together the solid and the fluid in the fullness of time, our aim is to undo the division, and to bring matter and meaning together again. This, we contend, must be an essential first step in finding a way through an environmental crisis that affects us all.

The Phases of Matter

In the physical sciences, 'solid' has acquired a very specific meaning as one of the possible phases of matter. Others include liquid, gas, plasma and a strange condition known as the 'Bose-Einstein Condensate'. Of these, the first two are familiar from everyday experience; the remaining two are not, though plasma may, in fact, be the prevailing phase of matter in the universe at large. Common to all, however, is the premise that matter is comprised of elementary particles of one sort or another. The particles may be of different scales of magnitude, from ions, atoms or molecules to grains. Different phases, then, depend on how these particles are compounded. With solids, they are so tightly bound that their freedom to move is severely constrained. From this it follows, first, that solid volumes are resistant to the pressure of deformation. We experience this as hardness. Secondly, because of this, the shapes they assume do not adjust to the shapes of any containers in which they may be placed. With liquids, by contrast, while the constituent particles are still close, they are not so tightly bound and have more freedom to move. So although, like solids, liquids occupy a determinate volume, they nevertheless hold to no shape and adjust to the shape of any container. But with gases even the volumetric constraint is lifted. Not only can they fill a container of any shape; they can also be compressed into a smaller volume or expand into a larger one.

So-called 'phase transitions', from solid to liquid, or from liquid to gas, are achieved by adding energy, typically in the form of heat. The more energetic the particles of matter, the more restless they become, and the looser their configuration. Heat a solid and it eventually melts, at the point when the ties between its kinetically energised particles eventually break. Heat a liquid, and it begins to vaporise, as the particles lose any connection and spread out into the space available. Heat it still further, and the particles themselves break up, stripping away electrons so as to leave them positively charged, or depositing them, so as to charge them negatively. With this, the gas is turned to plasma. Though naturally rare on earth, gases such as neon, argon and helium can be ionised into the plasma state by charging them with electricity, as in some modern lighting applications. The Bose-Einstein Condensate (BEC) goes to the other extreme, where matter is cooled close to the point of absolute zero, such that its particles have virtually no kinetic energy at all. At this point, the particles are no longer distinguishable from one another; rather, they appear to collapse into one super-particle which, paradoxically, has the properties of a superfluid. Though long predicted in theory, not until 1995 was the laser technology perfected that would make it possible to create the BEC in practice.

The BEC is but one of a number of peculiar phases of matter recently identified at the low energy extreme. While unobtainable under normal terrestrial conditions, it nevertheless suggests that fluidity could be a constitutive property of matter even in its most solid state – that what we take to be particles, divided from one another yet undivided on the inside, are really the vortices of a flow, with each vortex a locus of spin rather than an externally bounded entity. Could the different phases of matter, then, be variations on the theme of solid fluidity? Could all matter be fundamentally viscid (Simonetti, this issue)? Other, less extreme examples are not hard to find. Indeed, whether we take a material to be fluid or solid may simply be a matter of granular scale. A particle of sand may be solid with regard to its crystalline structure, but sand en masse, as in a desert, in dunes, or even pouring though the waist of an hourglass, behaves very much as a fluid as it is sculpted into forms of movement such as whirls, waves and swellings. Mudslides, avalanches and surging glaciers are among many natural examples in which apparently solid matter gives way to flow, often with devastating consequences. In other cases, it is a question of time. In a famous experiment commenced at the University of Queensland in 1927, a quantity of heated pitch was poured into a funnel with a sealed neck and allowed to settle for three years. The seal was then cut, allowing the pitch to pour. It took eight years for the first drop to fall, and since then they have continued to fall at the rate of roughly one per decade (Edgeworth et al., 1984). The ninth drop fell in 2014.

Glass is another example of a material that defies any opposition between solid and fluid (Engelmann, this issue). Heated to over a thousand degrees Celsius in the furnace, it can be moulded or blown to any shape. When it cools, however, its molecular constituents remain trapped in their disordered, liquid configuration, causing such internal stress that it is liable to shatter or explode unless it is properly annealed. In the annealing process, the glass is kept for a period at a steady temperature of around 500°C, where it hovers between solid and liquid phases: sufficiently hard to retain its shape but soft enough for its internal tensions to be gradually relieved. Whether, given enough time, glass continues to flow even when finally cooled remains a matter of debate. Measurements of glass in the windows of ancient buildings, such as cathedrals, seemed to show that it is thicker towards the bottom and narrower towards the top, leading to the belief that the material had, over the centuries, slowly and inexorably sunk under its own weight. Though this belief has been comprehensively discredited (Zanotto, 1998), the liquid solidity of glass remains an enigma, and is hotly contested by materials scientists.[4] Like glass, metal also flows, and the fluid-solid threshold is the special domain of the metallurgist, who occupies the cusp between the two, alternately heating and quenching his material as he works on it. Even volcanic lava never fully loses its fluidity on cooling, and in the long course of time the hardest of igneous rocks, such as granite, exhibit plastic properties.

Perhaps the most ubiquitous instances to combine properties of fluidity and solidity are to be found in the formation of colloids (Szerszynski, this issue). A colloid is a mixture in which particles of one substance are suspended in the medium of another, without actually dissolving into it. Colloids of different kinds can then be classified according to whether the suspension on the one hand, and the medium on the other, is solid, liquid or gas. Though 'gas-in-gas' appears inconceivable, since the level of dispersal is such that no separation between suspension and medium could be sustained, it is not difficult to find homespun examples of every other possible combination. In smoke, for example, solid particles are suspended in gas; in volcanic pumice, gas is suspended in solid. In fog, liquid particles are suspended in gas; in foam, gas is suspended in liquid. In ink, and in blood, solid particles are suspended in liquid; in gels, liquid particles are suspended in solids. Liquid-in-liquid gives us emulsion, while solid-in-solid gives us what is known as 'ruby glass', in which gold salts are added to molten glass, giving it a distinctive colour when cooled. The case of solid-in-solid, however, is of wider geomorphological significance, since it bears directly on our understanding of processes both of fossilization and of the formation of sedimentary rock.

Reversing the Relation between Statics and Dynamics

Already in the 17th century, the Danish natural philosopher Nicolas Steno addressed the perplexing question of how solid objects can be suspended in a solid medium. His dissertation, *De solido intra solidum naturaliter contento* ('On a solid body naturally contained within a solid'), published in 1669, laid much of the foundation for the science of stratigraphy (Lucas, this issue). Key to it was the idea that what appear to us now, as successive layers of rock, were formed over the ages through the slow sedimentation of particles held in liquid suspension. Petrified inside the accumulating sediment would be the skeletal remains of ancient life forms (Simonetti and Ingold, 2018). Yet as subsequent generations of geologists were to show, starting in the 18th century with the Scottish naturalist James Hutton (1795), these solid layers have been tilted and folded by forces operating over immense spans of time, which operate today as they have always done in the past. The earth, for Hutton, is not – and never was – fully formed, but ever in formation. In this formative process, not only does solid rock emerge from liquid suspension, but the rock itself is also semi-fluid in its susceptibility to contortion. As with a slab of marble, the very texture of rock can preserve these contortions in its wave-like folds.[5]

The turn, here, from solid to fluid reverses the relation between statics and dynamics, putting movement, as it were, up ahead rather than in the wake of the forms to which it gives rise. To depart from the solid earth is to see it as having already precipitated out from the processes of its formation; to appreciate its fluidity is to enter into these formative processes, and to go along with them (Simonetti, 2019b). This turn has been at the root of many celebrated debates in science. In the field of glaciology, for example, it lay at the heart of a bitter feud between two of its most prominent mid-19th century pioneers: David Forbes, who maintained that the glacier moved as a continuous viscous fluid, and John Tyndall, who insisted, to the contrary, that glacial movement was due to the fracturing, repositioning and refreezing of solid ice under pressure (Simonetti and Ingold, 2018; Simonetti, this issue). Around the same time, a similar argument raged among astronomers who, for the first time, had developed telescopes powerful enough to observe the forms of distant nebulae. What did they see? Was the nebula a multitude of discrete stellar objects held together by loose attraction, or the fluid formation of a continuous gaseous material? William Parsons, third Earl of Rosse – whose giant reflecting telescope, nicknamed 'The Leviathan', was at the time the biggest in the world – took the first view. With his Leviathan, he claimed, he had already managed to resolve the celebrated Orion nebula into its individual stars, and he proceeded to draw it thus, with a stippled, pointillist effect. His contemporary and rival John Herschel, however, took the second view, and drew the nebula as a wispy and vaporous cloud, including no discernible objects at all (Nasim, 2013).

As these examples indicate, rather more is wrapped up in the idea of fluidity than the liquid phase of matter. For as we have already suggested, fluidity comes before solidity; liquidity afterwards. It is the difference, if you will, between formation and break-up. Forbes saw the glacier, as Herschel saw the nebula, as undergoing continuous formation within a fluid if viscous medium. But Tyndall and Rosse, starting from the imagination of a world already condensed into solids, saw them smashed into myriad fragments, jostling for position in a collectivity that, by virtue of the looseness of their attachment, was perceived to behave like a liquid, or even like a gas. From one perspective, the materials of the glacier or the nebula *cohere*, flexibly going along together in increasingly sticky unison; from the other, their respective fragments *adhere*, momentarily attaching to one another only to break away and reattach in other positions. In 'coherence' and 'adherence', the prefixes *co*- and *ad*- align with the distinction between viscous formation, on the one hand, and punctuated break-up and reattachment on the other. There are countless examples of word pairings where these prefixes, of Latin derivation, do the same work, including 'congregation/aggregation', 'conjoin/adjoin', 'comply/apply', 'contract/attract', and so on. Underlying them all is a fundamental contrast between *with*-ness and *at*-ness. 'With' means accompanying things in their passage through time. Everything has its story, its particular temporal pathway. 'At', however, cuts transversally across these pathways: it marks, in the felicitous phrase of geographer Doreen Massey, 'the simultaneity of stories so far' (Massey, 2005: 10–12). In short, at-ness offers a snapshot of proximity; with-ness endures (Ingold, 2020: 24).

The turn from at-ness to with-ness marks a perspectival shift: from the being of materials to their becoming, from succession to duration, from the identity of elements to the heterogeneity of substance, from thinking in terms of stability and change to thinking in terms of growth and movement. There is more to this shift, however, than any simple opposition between statics and dynamics might suggest. Classical approaches in rigid-body dynamics, hydrodynamics and aerodynamics still start from the assumption that matter is made up of discrete particles, such that its solid, liquid and gaseous phases depend on the strength or looseness of their attraction. The dynamics of motion, then, are derived from the stable properties of particulate matter, in statistical aggregate. But to put the relation between statics and dynamics in reverse is to start from the opposite assumption, namely that all matter is continuous, and that its structure depends on the manifold ways in which the continuum can be folded, stretched, twisted, spun or otherwise contorted. With the continuum assumption, indeed, fluidity is not a special case; rather 'flux is reality itself' (Deleuze and Guattari, 2004: 398). All matter is fluid, insofar as its contortions give rise to distinct forms, but it is also viscous, insofar as these forms last long enough to be recognizable. A world of becoming, therefore, is not composed of different phases of matter, either singly or in combination, but is rather emergent from within a field of forces constituted by the interplay of plasticity, viscosity and elasticity. Such is the world of continuum mechanics.

Within the continuum, a wide range of conditions can be distinguished. On the one extreme is material so solid that, even if temporarily deformed by the application of stress, it will instantly spring back to its original shape once the stress is removed. On the other extreme is material so liquid that no amount of beating, shaking or stirring will affect its runniness. Water at room temperature is a good example, albeit not a perfect one. In between, however, lie a plethora of materials from ostensibly solid yet nevertheless plastic materials that, once deformed, will return to shape only gradually, if at all, to ostensibly liquid materials, such as a suspension of starch in water, which thickens or even solidifies under pressure.[6] These materials, which defy any division between solid and liquid phases, are the special preserve of the branch of continuum mechanics known as rheology (from the Greek *rhéo*, meaning 'flow'). As much concerned with the fluid formation of solid bodies as with their deformation, rheology effectively dissolves the conventional distinction between solid and fluid mechanics, uniting the plasticity of solids with the viscosity of liquids within a single matrix of variation.

Even phenomena that appear to result from the interaction of discrete entities, such as the behaviour of cars in traffic, can be modelled rheologically as a continuum of variable and fluctuating density (Szerszynski, this issue). Rheology is most at home, however, with the kinds of substances we might describe as ductile, including muds, sludges, suspensions and polymers. It is also applied to organic materials, including bodily fluids and soft tissues. Indeed, many of the materials we commonly work with in everyday life are of a rheological, solid-fluid nature: think, for example, of wood, an apparently solid substance whose undulating grain attests to its former life as part of a living tree; or of wool, spun from hairs that once grew on the backs of sheep; or of silk, a material that deforms under tensile load but slowly and eventually returns to its original shape after the load is released. In fact, one of the first studies to depart from the classical postulates of Newtonian physics was by German physicist Wilhelm Weber, published in 1835, on the visco-elastic properties of silk (in Walters, 2010). Common foodstuffs, too, are ductile, or else we could neither chew nor digest them. This includes cereals, milk, butter, honey, eggs, meat and fish. In food preparation, operations such as heating, simmering, shaking and stirring can make ingredients more or less runny or sticky, smooth or lumpy. Much of the art of cookery lies in the precise management of these transitions.

The Materials of the Living World

Yet while cooking, a rheological art par excellence, inhabits the solid-fluid continuum, we nevertheless routinely distinguish between liquid and solid foods, especially in connection with feeding human infants who, at the start of life, have neither the dentition nor the digestion to cope with tough materials. It does not take children long to learn that eating is one thing and drinking another, and that they call for different operations of the mouth, such as chewing and sipping. In these and countless other examples, solidity and liquidity are revealed, in our experience, less as *states of matter* than as *properties of materials*, all of which are variations of fluidity. And when we shift our point of view from the physical to the life sciences, it is these properties that come to the fore.

Matter is constitutive of the *physical world*; materials make up the *environment* for animate beings, whether human or nonhuman, engaged in certain forms of life and equipped with particular capabilities of action (Gibson, 1986: 8; Ingold, 1992). The emphasis here is not so much on what materials are as on what they do – on what they afford for those who would make use of them, or on how they behave in response to their interventions. Fresh water, for example, affords drinking for a thirsty human, but for the fish it affords swimming, and for the water-boatman that skims the surface it affords support. What matters in the first case is its ingestible substance, in the second its fluid dynamics, and in the third its surface tension. Thus, unlike phases of matter, the properties of materials always point both ways: both to the stuff itself and to the capacities of the organisms whose lives depend on them. For humans, these properties are found as the predicates of such action verbs as (in English) strike, bend, squeeze, break, rub, cut, slice, scrape, grind, dig, stir, pour, and so on. If you say 'break', you know the material is hard and brittle; if you say 'bend', you know it is soft and pliable; if you say 'stir', you know it is runny. At the dinner table, the knife is for cutting, the fork for spearing, the spoon for scooping. But you can no more cut or spear liquids than you can scoop solids. These properties, and others, are not given in matter as such, but are immanent in the ways in which materials are historically conjoined with real lives, depending on the manner of their engagement with the surroundings, the dynamics of movement and gesture, and the tools and techniques brought to bear.

Here, solidity and fluidity, understood as material properties of an environment rather than as states of the physical world, take on different and decidedly double-edged meanings. They can both assist life and impede it. Any living creature, as it makes its way in the world, has perforce to strike a balance between its more solid and more fluid materials. For terrestrial creatures like ourselves, a solid ground affords support, yet only so long as it remains beneath our feet. Fluidity, by contrast, affords movement, yet only so long as it remains above ground, in the atmosphere. Were fluidity to invade the space of support, or solidity the space of movement, disaster could ensue, as when solid ground gives way to marsh or quicksand, engulfing the traveller, or where we find ourselves stuck, as on the road in the gridlock of a traffic jam or out at sea in frozen Arctic ice. In practice, we have to make the most of what the earth offers for support and of what the atmosphere offers for movement without either sinking in or getting stuck. For so long as anything lives, there is no keeping the two apart. For things to grow, rainwater must percolate into the earth even as vegetation breaks the ground to reach the light. There is indeed no more fertile medium than a viscous colloidal mud or sludge formed of solid, nutrient-rich particles in fluid suspension, as found, for example, in alluvial river deltas (Krause, this issue) or on land subject to irrigation.

Sludge, however, is anathema to the modern project, the overriding aim of which is to build a sedentary civilisation on solid foundations, superseding the fluid, wandering life of hunter-gatherers and wild beasts, or of pastoral nomads and their herds. Most contemporary polities adopt a riverine perspective that constructs the landscape as a mosaic of solid grounds, suitable for settlement, dissected by channels for draining surplus water. From this perspective, solid fluidity, or fluid solidity, comes to be regarded more as a condition of anomalous hybridity than as one of original undifferentiation. The division between solidity and fluidity is not, however, given a priori, as a fact of nature. Quite to the contrary, it takes considerable feats of environmental engineering to wrest solidity from the earth, and to drive out its more unruly, fluid elements (Gruppuso, this issue). Land reclamation and urban paving require liquid residues to be contained, and their runs to be restricted to streams, canals and pipes, lest they erode or dissolve the fabric of the city. Yet lively materials, ever on the move, are prone both to have their say in how solidity is engineered and to subvert the intentions of its agents as soon as the work is done, or once maintenance turns to neglect (Meulemans, this issue). Flooding events, occurring today with increasing frequency, serve as forcible reminders of the fragility and impermanence of the foundations on which we build.

Floods are not of course the only extreme environmental events that shake our confidence in the solidity of the ground. Both heavy rains and earth tremors can trigger landslides and mudflows, sometimes engulfing entire communities. The poor, lacking the resources to reclaim or consolidate their lands, are invariably at greatest risk, for the distribution of access to reliably solid ground maps closely onto global inequalities of wealth and power. Yet none can escape the fact that human civilisation, in its entirety, rests on the thinnest and most unstable of crusts, covering the inexorably churning mass of hot, viscous rock making up the upper layer of the earth's mantle (Clark, this issue). During earthquakes the crust itself behaves as a fluid, conducting seismic waves that rock buildings like ships at sea. The ancients knew to build in ways that would ride the storm (Tonna et al., 2018). Earthquake damage has increased in the degree to which builders have assumed foundations to be solid by default. This assumption, however, has proved increasingly difficult to sustain as anthropogenic climate change, leading to sea-level rises, more frequent flooding and melting permafrost, overwhelms our efforts to keep the solid and the fluid apart. Are we perhaps, in this epoch of the Anthropocene, finally rediscovering what was obvious to our predecessors, namely, that in a habitable world, solidity and fluidity are inseparable?[7]

This is a lesson we can still learn from many of the world's indigenous peoples, who experience the ground not as a solid basis of support, separating the earthly substance below from the aerial medium above, but as a zone of interpenetration in which earth and atmosphere mix and mingle in the ongoing generation of life (Ingold, 2011: 115–25). For the inhabitants of this zone, it is not enough to say of the land, as did Karl Marx (1930: 173), that ‘it provides the worker with the platform for all his operations’ (Simonetti, this issue). In the experience of indigenous peoples, there is more to the land than a solid surface to stand on. It is rather a milieu suffused with vitalities of all kinds. Along with its nonhuman denizens and elemental powers such as rivers and glaciers, it is sensate and responsive to human endeavours (Cruikshank, 2005). Yet this responsiveness is imperilled by the relentless expansion of solid infrastructure and the consequent disruption of those very flows upon which the continuity of life depends. What difference would it make if, instead of persisting with ever less sustainable endeavours to extract solidity from the fluid, we were to follow premodern and indigenous precedent, and to take, as our point of departure, our inescapable participation in a solid-fluid world? To make a start in answering these questions, we return to rheology.

Intermediacy and Scale

The founders of rheology envisaged a world in which everything flows, even things which to mortal eyes appear solid. Among these founders was the Israeli scientist and engineer Marcus Reiner. Reiner liked to invoke the Old Testament story of the prophetess Deborah, who sang of how even ‘the mountains melted from before the Lord’.[8] According to Reiner:

> Deborah knew two things. First that the mountains flow, as everything flows. But, secondly, that they flowed before the Lord and not before man, for the simple reason that man in his short lifetime cannot see them flowing, while the time of observation of God is infinite. (Reiner, 1964, in Walters, 2010: 92)

Reiner went on to propose what he called the ‘Deborah number’, defined by the ratio of the ‘time of relaxation’ to the ‘time of observation’. There is the time it takes for a material to adjust to an applied force through the dissipation of tension throughout its mass. And there is the time available for the observer to witness the process. Depending on the ratio, Reiner explained, a material will appear more or less solid. The mountain appears solid to human eyes because its time of relaxation is vastly in excess of the span of human life. But it appears fluid in the eyes of God, who has all the time in the world to watch. Likewise, permafrost appears stably solid within the timeframe of human engineering, but chronically unstable when viewed over longer spans of earth history (Krause, this issue). Under the concept of the Deborah number, then, the solid and the fluid appear to merge in a single continuum of variation. Indeed, Reiner was convinced that with his number he had laid the foundation stone of rheology (Walters, 2010). Combined in it, however, are two, somewhat contrary impulses. On the one hand is the scientific aspiration to attain a God's-eye view. Evidently, Reiner saw rheology as part of the ambition of science to transcend the perceptual horizons of mortal life. On the other hand, however, lies an acknowledgement that a rheological take on reality can only be relative to the capabilities of the observer. This duplicity continues to compromise attempts to come to terms with the material world through concepts of space, time and environment.

A case in point is psychologist James Gibson's ecological approach to visual perception. Where Reiner was at pains to distinguish the mortal from the God's-eye view of the mountain, Gibson distinguished the 'environment' from what he called the 'physical world'. We have already seen how this distinction separates a focus on the properties of materials, typical of the life sciences, from the preoccupations of physical science with the phases of matter. The reality of the physical world is there, in and for itself, regardless of the presence or absence of any living inhabitant. This is the reality that a modern science like physics affects to grasp, on scales ranging from the sub-atomic to the inter-galactic. Environmental reality, by contrast, exists only as its material constituents are drawn into the way of life of the organism whose environment it is. It is, in that sense, fundamentally relational, and as such the subject of study in the psychology of perception. The physical world, in short, is reality *of*; the environment is reality *for* (Ingold, 1992: 44; 2011: 30). That is why, as Gibson (1986: 8) puts it, 'the term *physical environment* is ... apt to get us mixed up'. It conflates the two realities, respectively objective and relational.

Yet Gibson, too, is not innocent of mixing things up, for he promptly goes on to distinguish the environment from the physical world on an altogether different criterion, namely that of metric scale.

> The world of physics encompasses everything from atoms through terrestrial objects to galaxies. These things exist at different levels of size that go to almost unimaginable extremes. The physical world of atoms and their ultimate particles is measured at the level of millionths of a millimetre and less. The astronomical world of stars and galaxies is measured at the level of light-years and more. Neither of these extremes is an environment. (Gibson, 1986: 8)

Environments, Gibson explains, are of an 'intermediate' scale, on a par with the size-range of the animals in relation to which they are constituted. And as such, they nest within phenomena of larger scale, while nested within them are phenomena of a smaller scale. Even on its own, intermediate scale, the fine-grained structures of an environment nest within those of a coarser grain. However, the totality of this nested structure, from the gigantic to the infinitesimal, can only come within the purview of a vision that transcends the world, not one that is situated within it. You cannot see 'nesting' from the inside. It is therefore inevitable that as he turns from defining the environment in relation to the organism to defining it as of intermediate metric scale, situated between the extremes of micrometres and light years, Gibson ends up relinquishing an organism-centric perspective for the universalising perspective of physical science.

What Gibson does here for space, the anthropologist Claude Lévi-Strauss does for time. At issue here is the intermediacy of history, in a nested series of temporal scales. For the historian wishing to escape the dilemma that every gain in interpretative nuance entails an equivalent loss of explanatory power, there are – according to Lévi-Strauss – but two ways out:

> either from the bottom, if the search for information leads him from a consideration of groups to one of individuals, then to their motivations, which belong to their personal history and temperament, that is, an infrahistorical domain ruled by psychology and physiology; or from the top, if the need for understanding provokes him to put history back into prehistory and this into the general evolution of organized beings, which can only be explained in terms of biology, geology, and finally cosmology. (Lévi-Strauss, 2020: 298)[9]

But these two ways are really one: a single movement of reduction that takes us from the domain of situated, historical experience, through various levels of biology (developmental and molecular) to chemistry and physics. At each stage in the reduction, short-term elementary events and interactions become even shorter, and the long-term they occupy even longer: the approach towards zero in the former is also an approach towards infinity in the latter (Ingold, 2016: 141–2). In science, temporal attenuation and extension, nuclearity and deep time, are two sides of the same coin (Simonetti, 2019a; Engelmann, this issue).

Now whether, with Gibson, we treat the environment as spatially intermediate, or, with Lévi-Strauss, we regard history as intermediate on the axis of time, this logic indexes a shift in the meaning of intermediacy, from the relational quality of observers being *in among* the matters of their concern to the *middle range* on a quantitative scale of diminution or enlargement, running from micro to macro. In terms of the traditional hierarchy of academic disciplines, this is a shift from 'soft' to 'hard'. Might we find a corresponding shift in the meaning of solid fluidity, or fluid solidity, from the intermediacy of life *in medias res* to a scale of reckoning on which lie the most durable of solids and the most liquescent of fluids, and all points in between? And could it lie behind the conversion of Deborah's prophecy into a number? God, after all, is not a scientist, nor is the world, in any sense, an object of His creation. When Deborah sang that mountains melt before the Lord, perhaps she was professing how, in the presence of God, she felt the infinite immensity of His creation at the very core of her being. Perhaps she, too, mortal though she is, could bear witness to the original flux of the earth, as it were from the inside, enfolded into every moment of existence.

Indeed, sounding very much like a latter-day Deborah, the Victorian critic and connoisseur John Ruskin demanded of the artist just such a vision: one that enters into 'the deep, the calm and the perpetual'. Who can tell me, Ruskin intoned,

> of the forms and precipices of the chain of tall white mountains that girded the horizon at noon yesterday? Who saw the narrow sunbeam that came out of the south and smote upon their summits until they melted and mouldered away in a dust of blue rain? Who saw the dance of the dead clouds when the sunlight left them last night, and the west wind blew them before it like withered leaves? (*Modern Painters, Vol. 1*, 3.343–8, 1843, reproduced in Ruskin, 2004: 9–10)

The artist, for Ruskin, is one whose senses are so attuned that they find an eternity enfolded in every moment, deep perpetuity in a never-to-be-repeated present. To catch that instant when the rain shower melted the mountain summits is to feel the pulse of time everlasting. Or as the philosopher Maurice Merleau-Ponty (1964: 168) would put it, it is as though, in that eternal moment, the eyes of the painter, like those of a newborn, were opened for the very first time: 'the painter's vision is an ongoing birth'.

Feeling Forward, Looking Back

The mathematician and philosopher Alfred North Whitehead, a man of deep religious conviction, believed that attending to the continuous birth of the world, witnessing its creation from within, was tantamount to entering into the presence of God. But such attention was equally fundamental, for him, to the attitude of science. Whitehead was keen to emphasise the difference in perspective that comes from relinquishing our view of the world from the outside, as a *fait accompli*, for a position from the inside of its coming-into-being. From the outside you see things of this kind and that, precipitated from the flux of their formation, and arrayed in an environment. But from the inside each thing turns out to be none other than the process of its own self-creation, a process that, at each and every moment, enfolds an entire universe into a singular nexus.[10] The world, then, appears fluid when you enter intuitively into its formative process, but solidifies in the instant that you turn your back on it, viewing it through the eyes of an intellect which – as Whitehead's contemporary, Henri Bergson, would put it – 'are ever turned to the rear'. The intellect, according to Bergson, is constitutionally averse to the 'fluid continuity of the real', and promptly solidifies anything with which it comes into contact (Bergson, 1911: 48–9, 319). Thus does the rearward view of science break up the irreversible flow of temporal experience into solid fragments, to be strung out in a time that is now abstract and reversible, like beads on a necklace.[11]

Could the distinction between fluidity and solidity, then, come down to the direction of travel? Is it the difference between feeling one's way forward, improvising a passage through a world undergoing perpetual birth, and looking back, reconnecting discrete entities, now closed in on themselves, along a route already travelled?[12] This, precisely, is what William Blake, poet and visionary, proposed in a stanza of his epic work *Milton*, dating from 1804:

> The nature of infinity is this: That every *thing* has its
> Own Vortex; and when once a traveller thro' Eternity
> Has passed that Vortex, he perceives it roll backward behind
> His path, into a globe itself infolding; like the sun:
> Or like a moon, or like a universe of starry majesty,
> While he keeps onwards in his wondrous journey on the earth.
> (Blake, 1907: 11)[13]

Thus the fluid vortex into which you enter appears to turn, as it recedes in your wake, into a solid body. But Blake had illustrious predecessors. One was the Roman poet-philosopher Titus Lucretius Carus. In his treatise *De Rerum Natura* ('On the Nature of Things') of circa 50 BCE, Lucretius argued that there are things in the world only because slight deviations in the flux of matter, raining ever downwards like water over a fall, create regions of turbulence wherein it is pulled aside and, albeit only for a while, revolves on itself before re-entering the flow. We mortals perceive the resultant forms, but not the movement that gives rise to them. That is why, as Lucretius explains, despite the veritable commotion of its material constituents, 'the universe itself seems to be standing still' (Lucretius, 2007: 45). In a world where movement is all, and all is in flux, we see ourselves surrounded by immobile solids.

From Lucretius, a direct line leads to Bergson. If there's a difference, it is that for Bergson the great flux of matter, out of which everything is formed, rises upwards, like a blast of hot air, rather than cascading downwards as in a waterfall. But for Bergson, too, living things are formed when the material flux, deflected from its otherwise rectilinear course, temporarily goes into a spin.

> Like eddies of dust raised by the wind as it passes, the living turn upon themselves, borne up by the great blast of life. They are therefore relatively stable, and counterfeit immobility so well that we treat each of them as a thing rather than as a progress, forgetting that the very permanence of their form is only the outline of a movement. (Bergson, 1911: 128)

The line from Lucretius to Bergson, in the eyes of philosopher Michel Serres, describes nothing less than an alternative history of the physical sciences – alternative, that is, to the mainstream narrative rooted in the solid mechanics of Galileo – founded on the premise of the fundamental fluidity of matter. Every being, for Serres, is a vortex, 'a dispersal that comes undone' (Serres, 2000: 37). It was from Serres that philosopher Gilles Deleuze and his collaborator, psychoanalyst Felix Guattari, sourced their idea of a 'hydraulic science' that, 'rather than being a theory of solids treating fluids as a special case, ... is inseparable from flows' (Deleuze and Guattari, 2004: 398). A world of vortices within vortices, as Deleuze puts it in *The Fold* – his study of Leibniz and the Baroque – yields an 'infinitely porous, spongy or cavernous texture ... caverns contained in caverns' (Deleuze, 1993: 5; see Szerszynski, this issue).

Hydraulic science, say Deleuze and Guattari, has always existed alongside, and in an uneasy tension with, the solid science of the state. While the state, in seeking to exert sovereign control over a territory, contrives to channel liquid elements within such rigid structures as conduits, pipes and embankments, it can do so only thanks to the very power of hydraulics it seeks to subordinate, to wrest islands of solidity from the matrix of the fluid.[14] Hydraulics, placing dynamics ahead of statics, derives solid from fluid; the state, placing statics before dynamics, extracts liquid from solid. Caught between state science and hydraulic science are technicians – builders and engineers – tasked with the application of designs and plans, ruled from on high, in a fickle and inconstant world comprised of fluid materials that are no more predisposed to fall into their designated structures than they are to remain in them (Gruppuso, this issue). As the environmental pundit Stewart Brand (1994: 2) puts it, 'the idea is crystalline, the fact fluid'. There is a mismatch, a kink, between the two. Builders and engineers inhabit this kink (Ingold and Hallam, 2007: 4). For example, in excavating the foundations for large buildings such as tower blocks, engineers struggle to protect the excavated void from flooding or its sides from caving in under pressure of forces of turbulence distributed throughout the ground mass (Meulemans, this issue). No amount of prior calculation or theoretical modelling can prepare for all eventualities, and every builder knows that the work will necessarily involve a measure of practical improvisation on site. Builders and engineers, it seems, are fated to face both ways, to look back and to feel forward at one and the same time.

Explorations at the Boundary

The articles gathered in this issue were originally prepared as part of a wider project. Entitled 'Solid Fluids in the Anthropocene', the project responded to calls to rethink the relationship between human and earth sciences, in an epoch in which humans have become the leading force in shaping the earth's history. We do not claim that the convergence of geological and social phenomena is unique to the present epoch; on the contrary, we believe there has never been a time when they could truly be separated. But the onset of the Anthropocene compels us to attend to this inseparability as never before. With rapid anthropogenic changes to earth system dynamics, the illusion that the planetary surface affords a solid platform for the enactment of human affairs, or that these affairs are carried on in a domain that floats above the fixities of the physical world, can no longer be sustained. Traditional divisions between 'hard' and 'soft', or 'long-term' and 'short-term' phenomena, need to be revised. To focus our discussions, we resolved to concentrate on things and materials that, in their histories and properties, have defied any strict opposition between solidity and fluidity. With this focus, however, it soon became evident that the solid-fluid conundrum is by no means tied to the specifics of the Anthropocene. It rather belongs to a much deeper history of relations between matter and meaning both within and beyond the Western intellectual tradition. For this reason, we chose not to confine our reflections to the horizon of the Anthropocene, but to open them to more extensive historical terrains. This approach is also adopted by the authors of the articles assembled here. In the following paragraphs we introduce each in turn.

There can be few environments in which solid and fluid elements are more comprehensively imbricated than the deltas of major rivers. In the first article of our collection we find the anthropologist Franz Krause engaged in fieldwork in the delta of the Mackenzie river, in the northwest Canadian Arctic, as part of a wider comparative study of delta life from regions around the world.[15] In every region, these 'hydrosocial' environments are subject to pronounced oscillations between more or less solidly grounded or amphibious lifeways, which have only intensified and been rendered more uncertain through the effects of climate change. Particular to the Arctic region, however, is that these oscillations include seasonal cycles of freezing and thawing, which can alternately solidify water and liquefy mud. Here, too, rhythms are becoming out of joint. Yet the idea of 'climate change' misleads, in so far as it presupposes a preceding epoch of stability. Building on the thinking of theorists and philosophers indigenous to the region, Krause shows that in the experience of its inhabitants, the Arctic environment has never been stable or predictable. It is, rather, vital and dynamic, and the task of life has always been to respond to this dynamism, not passively but through pragmatic interventions that are as ingenious as they are inventive, yet always respectful. Key to these interventions, especially relating to travel and construction, are judgements of time. Solidity and fluidity in the Arctic, as Krause demonstrates, are fundamentally dependent on the tempo of seasonal oscillations and their rhythmic interrelations.

With Paolo Gruppuso, in our second contribution, we turn to a very different site of anthropological fieldwork, the Pontine Marshes (*Agro Pontino*), around 40 miles south of Rome. Once a place of woodland and swamp, occupied for some nine months of every year by a transhumant population engaged in hunting, animal husbandry, fishing, and the production of charcoal, the Marshes also had a fearsome reputation among city dwellers as a place of bad air (whence the term *malaria*) and fever, smelly and squelchy, virtually uninhabited and uninhabitable. During the 1930s, in a massive campaign of environmental engineering directed by the fascist regime under Benito Mussolini, the entire region was drained. Presented as a war against nature, and undertaken with heavy machinery and explosives more suited to the battlefield, the landscape was levelled for cultivation on an industrial scale and for paving in readiness for urban development, while a network of channels and ditches took away the aqueous effluent. With the solidification of the marsh, then, went the liquefaction of its originally fluid medium. Solid and liquid were separated out. Yet looking back on this transformed landscape, with eyes more sympathetic to the subtle ways in which, over the centuries, human lives had both shaped and been shaped by the rich and heterogeneous ecology of the Marshes, Gruppuso reveals how the dream behind the reclamation project, of establishing human mastery over nature once and for all, has crumbled. Solid grounds soon revert to an earlier fluidity once their upkeep is neglected, leaving a legacy of rusting machinery, abandoned quarries and encroaching swamp.

Our third contributor, Germain Meulemans, takes us from the solidification of the land to the art of foundation building. The majority of modern urbanites, as they go about their business in the city, pay scant regard to the foundations upon which its architecture rests. Save on a construction site, they are normally invisible, fostering the impression that the ground already offers a solid stage upon which real buildings have only to be placed – much as models, in an architectural studio, stand on a baseboard. For the most part, we are confident that the ground will not cave in. Yet as Meulemans shows, this confidence is misplaced, as we find to our cost when buildings suffer subsidence or sinkholes suddenly open up beneath our feet. For in reality, the solidity of the ground is not given. It has to be engineered, and it is here that the work of foundation builders comes into its own. Beneath the hard surfacing of the city, the earth is only contingently solid, and its unruly behaviour defies prediction and control. Compelled to negotiate with materials that will insist on going their own way, foundation builders require a knowledge of the ground that is both local and intimate. Below the city of Paris, where Meulemans carried out his fieldwork, lies the basin of the River Seine, whose innumerable tributaries and side channels continue to meander through semi-saturated soils, while the river itself seeks ever to return to its original bed. The challenges of wresting solidity from this turbulent, semi-fluid mass are formidable. Overcoming them calls for relentless effort.

The instability of the soil is a problem not only for foundation builders, however. It is also faced by archaeologists, as Gavin Lucas shows us in the fourth contribution to this collection. The problem is in part a practical one: working the vertical face of an excavated trench, Lucas recalls his worry that at any moment, the face could cave in, burying him alive. Fortunately, the soil deposit was of thick clay, which was actually stiffened and made more compact by the heavy rain falling at the time. However, the propensity of soils to flow disturbs any idea that archaeological deposits fall neatly into discrete strata. Water, seeping through the layers, can redistribute the substances it encounters through leaching, while tree-roots or earthworms can mix them up to the point where they are no longer distinguishable at all. Deposits, then, are mutually permeable, combining properties of solidity and fluidity in their colloidal composition. As Lucas shows, they might be better characterised on the axes of durability and permeability, both of which redirect our attention to the possibility of movement: whether of a stratum itself in bending or buckling, or of materials seeping through from one layer to another. Yet far from resolving the problem of solid fluidity, the focus on movement recasts it in another form. Do we understand movement disjointedly, as the successive displacement and re-attachment of solid bodies, or as a process of fluid deformation? Here we rediscover in archaeology the same controversy that we have already encountered in glaciology and in the astronomical study of nebulae.

These questions, as Lucas shows, can be traced back to the celebrated paradox of motion originally set forth by Zeno in the 5th century BCE. If the trajectory of a solid body, like an arrow in flight, can be resolved into an infinite series of fixed points, then how can it move at all? In our fifth contribution, Cris Simonetti returns to Zeno's paradox, and to the alternative view of movement – attributed to Heraclitus – as the fluid deformation of a continuous and heterogeneous material. Central to Simonetti's discussion is the concept of viscosity. From John Locke's understanding that solidity underpins our very sense of what is real in the world, through William Wordsworth's appeal to 'the solid ground of Nature', to contemporary appeals to hard science, the default assumption of the solidity of matter is a deep-rooted and persistent theme of modern thought. From this perspective, the condition of viscosity shows up as an anomaly. Stickiness offends the alleged human propensity to order the material world into discrete categories. Focusing on the case of glacial ice, Simonetti shows that ice's viscosity, already an issue in the aforementioned dispute between Forbes and Tyndall, continues to trouble our understandings of glaciers and how they move. Time and again, ice has been opposed to soil: the former inert, homogeneous and barren; the latter active, heterogeneous and fertile. But we now know that ice is as heterogeneous as soil, and that it is packed with micro-organisms. Could viscous ice be a reservoir of life itself? And is organic life only possible thanks to the fundamental viscosity of all matter?

For some answers to these questions, we turn to our next contribution, from environmental sociologist Bronislaw Szerszynski. Szerszynski's focus is on colloids, and his approach is fundamentally rheological. Starting from the assumption that all matter is continuous, Szerszynski argues that colloids are intermediate in scale: neither macroscopic nor microscopic but mesoscopic, on the mezzanine floor of matter, so to speak. But they are intermediate in the other sense as well, for in them, continuous matter folds in on itself so as to form an intricate topology of surfaces by which particles appear separated from the medium of their suspension. Colloidal materials, then, are constitutionally in the midst, formed of the interior crumpling and knotting of their own medium. No grain, droplet or pore can ever be alone, since it exists only thanks to a cascade of repetitions that rebound throughout the entire mass. Thus the very condition of existence of particles in colloidal suspension is to be *with* one another. For that reason, Szerszynski argues, colloids provide a powerful model for thinking about the social. It is not that social life is a condition only reached on approach to humanity; on the contrary – in this view – sociality is a constitutive quality of *all* matter in its colloidal condition. As much as bubbles of air in a liquid foam, we humans, too, are formed through the iterative infolding of the medium; only for us, the medium is an atmosphere. This is to understand social phenomena neither as compound effects of individual interactions, nor as their subsumption under a totalising, solidary whole, but in terms of the rheological dynamics of colloidal substance.

One way to distinguish relative solidity from relative fluidity is by materials' capacity to remember or forget. Elastic materials, under stress, preserve the memory of their initial configuration in the tension of their molecular bonds, which allows them to revert to form once the tension is relaxed. Plastic materials, by contrast, release the energy of deformation as heat, remembering nothing of their previous shape. But colloids – as Szerszynski shows – neither fully remember nor fully forget, confounding the distinction between the two. Material memories, however, can inhere not only in inter-molecular bonds but also in the nuclear core of matter itself. In our penultimate contribution, geohumanities scholar Sasha Engelmann explores the mnemonic capacities of materials in greater depth through a focus on the detritus of thermonuclear explosions. Every such explosion involves a phase transition so rapid that to our human senses it appears over in a few seconds. In the composition of radioactive glasses and minerals the moment of transition is, as it were, frozen in time. Yet these substances remain unstable, caught in a process of decay over earthly timescales vastly in excess of human lifespans. In what Engelmann calls their 'elemental memory', radioactive materials both register the singularity of atomic events and problematise the constructs of time on which our usual distinctions between solid and fluid – and correspondingly between remembering and forgetting – are based. To investigate this tension, between the virtual instantaneity of the atomic event and the long-drawn-out process of radioactive decay, Engelmann introduces us to the work of artists Mari Keto and Erich Berger, who have made it their practice to forge jewellery from radioactive minerals.

Now if, with Engelmann, we take memory to be a constituent property of the material world, brought to a focus in human minds yet not contained in them, might we argue, more generally, that the achievements of humanity – its civilisations and industries – likewise bring to a focus geophysical forces and processes operating on a planetary scale? This, in essence, is what critical geographer Nigel Clark argues in the final contribution of this collection. Throughout the history of our planet, oceanic and riverine sediment has settled and compacted to form solid strata, while volcanic eruptions, and the seepage of magma into cracks and crevices, have left us with expanses and intrusions of hard, igneous rock. But the irrigation works that supported the growth of ancient, urban civilisations did no more than continue age-old sedimentary process under new management, while the pyrotechnic arts of pottery, brickmaking and metallurgy likewise concentrated igneous processes of earth-formation in the heart of the city, made safe within the protective shell of the kiln. Where pottery and brickmaking replicated the heat-induced formation of metamorphic rock from sediment, the metallurgist would reproduce in the furnace the very conditions of the magma chamber whence metal-bearing, igneous rocks were once born. In short, the city, far from being walled off as an island of civilisation against the rest of the globe, can be better understood as a place of intensification, where planetary geopower is concentrated and reproduced in the human domain. But with our cities inundated by floodwater and forests ablaze, have the same hydrological and igneous forces that once fuelled the growth of civilisation now turned against us?

We are certainly faced today with formidable challenges. If these explorations on the boundary between solidity and fluidity have taught us anything, it is that we will have to find ways to live with planetary forces, not against them. But we have also learned that in the long run of history, this is what human beings have always done. The Anthropocene is popularly presented as the epoch in which humans finally became the dominant force in shaping the conditions of the planet. But if this really is a new epoch, it is only just beginning. We have no idea how it will turn out. Perhaps, after all, it will prove to be a period of rediscovery, in which we eventually develop the necessary skills for living with a solid fluid planet much altered by millennia of previous activity.

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Notes

1. From an interview with Michel Serres, conducted in 2009 by Roberto Leo Butinof, Adrián Cangi and Ariel Pennisi.
2. A handbook by the 15th-century painter Piero della Francesca instructs merchants in the art of gauging the volume of a barrel. As the art historian Michael Baxandall shows, Piero's mercantile public, observing his *Madonna del Parto* of c.1460, depicting the pregnant Madonna in a pavilion shaped like a half-barrel, would have immediately set about estimating its volume (Baxandall, 1972: 87–8).
3. Precisely because he imagines an environment furnished with solids, psychologist James Gibson – in his ecological approach to visual perception – ends up depicting gaps in the tree canopy as holes: 'it is into these holes that the birds fly' (Gibson, 1986: 106). But birds cannot fly in holes. They fly in the air, setting it in motion with the beating of their wings (Ingold, 2011: 127).
4. See Kenneth Change, 'The nature of glass remains anything but clear', *New York Times*, 29 July 2008, https://www.nytimes.com/2008/07/29/science/29glass.html.
5. Art historian Barbara Baert (2020: 42) notes that the word 'marble' is derived from the Sanskrit root *mar*, connoting movement, as of the waves of the sea, 'and may have contributed to the idea that marble is water metamorphosed into stone'.

6. Starch in water (or 'corn-starch') is an example of what is known technically as a 'non-Newtonian fluid', in that it does not conform to Newton's law, according to which viscosity is a constant, independent of the rate of flow. In non-Newtonian liquids the amplification of flow, such as by stirring, can either reduce or increase viscosity. With corn-starch, viscosity in increased. Shaking ketchup in a bottle, however, makes it runnier (Szerszynski, this issue).
7. Landscape architects Anuradha Madha and Dilip da Cunha (2014), for example, argue that instead of blaming floods on inadequate drainage, we should take what they call the 'wealth of wetness', of land ubiquitously saturated by rainfall, as an invitation to build differently.
8. From the *Book of Judges*, Chapter 5, verse 5.
9. These lines are taken from the new English translation of Lévi-Strauss's *La pensée sauvage*, first published in French in 1962. An earlier translation appeared in 1966 under the title *The Savage Mind*.
10. Whitehead set out his views on science in his Lowell lectures of 1925, *Science and the Modern World*. A year later, in a series of lectures entitled *Religion in the Making*, he attempted to apply the same ideas to religion that he had previously applied to science (Whitehead, 1926, 1929).
11. Though Bergson and Whitehead both adhered to a philosophy of process, Whitehead (1929) would not have agreed with Bergson's view that the tendency to solidify is intrinsic to all human intellection. For Whitehead, it was rather specific to a culture of the intellect that emerged in the 17th century and went on to dominate science.
12. Elsewhere, one of us (Simonetti, 2019b) has aligned this distinction with a contrast, respectively, between *imaginative* and *chronographic* attitudes, specifically in the discipline of geology. To adopt the former is to enter, in the imagination, into the processes of earth formation and to go along with them; to adopt the latter is to cast a retrospective eye over the stages of this history, already petrified in strata of rock, and to order them in chronological sequence. For an equivalent contrast in archaeology, see Lucas (this issue).
13. It is possible that in writing these lines Blake was influenced by the vortex theory of planetary motion advanced by René Descartes, according to which the planets ride the rings of an immense cosmic vortex whirling around the sun. The theory remained popular and influential until the mid-18th century, when it eventually fell to the Newtonian theory of gravitational attraction.
14. This is to paraphrase the rather more longwinded formulation of the same point by Deleuze and Guattari (2004: 400–1).
15. See https://delta.phil-fak.uni-koeln.de/.

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