The Anthropocene and the memory of the Earth1

Bronislaw Szerszynski

DRAFT – please do not circulate, cite or quote without permission

Natural scientists sometimes us the word 'memory' to describe biological or even geophysical process: they talk of 'climate memory', or 'ecological memory', or materials as having 'shape memory'. But what would happen if we took such usages seriously, and applied the idea of memory to a complex entity like a planet? How could the Earth be said to remember and to forget? What memory systems has the Earth evolved in its 4.5 billion-year 'geostory'? And if the Earth is indeed entering 'the Anthropocene', a new geological epoch in which humans are the determining geological force (Crutzen and Stoermer 2000), how might the Anthropocene be inserting itself into the memory of the Earth? Is the Anthropocene to be thought of as just another layer, inserted into the 'rock memory' of the Earth? Or does it actually change the Earth's powers of remembering and forgetting? And might thinking of the Earth as something that remembers and forgets change the way that we think about this thing we call the Anthropocene, what it is and what it means?

Memory

Thinking sensibly about 'memory' is very difficult – it's a slippery topic that can quickly run away with you. But let me clarify what I think this project requires – seven necessary characteristics of a concept of memory that might be adequate to the task of embracing Earth processes.

1 I would like to thank Nigel Clark, Piers Foster, Andy Jarvis and Wolfgang Lucht for conversations which have greatly helped me in the ideas in this paper – though I have to take full responsibility for the way that I have brought them together.

First, we need to think memory in a way that happily crosses any imagined boundary between the ideational (semiotic) and the material (physical), the living and the non-living etc. We must not simply use memory metaphorically, extending by analogy from what we understand about human and more generally animal memory to the wider material world. Instead, let us try to think of human memory as just a specific example of a wider phenomenon. Saying that something exhibits memory need not commit us to regarding it as a subject, as having mind or consciousness, or even as being a unified, bounded entity; it may be that bounded, sentient, living things that are aware of themselves as a subject are merely one kind of thing that can remember and forget.

Secondly, any general account of memory has to engage with *thermodynamics*. This is not just to reduce memory to being a thermodynamic phenomenon – if anything, and in the same spirit as the previous comment, it is more like treating thermodynamic processes as a subclass of a larger category. But thermodynamics certainly allows us to draw an improbable line between Claude Shannon's mathematical theory of information (Shannon 1948) on the on hand, and the continental philosophy of Georges Bataille, Michel Serres, Gilbert Simondon and Gilles Deleuze on the other, who in different ways argued that the semiotic extends way beyond the human world. Also because memory in some sense *is* time, a particular kind of internal time of things, so we have to think about how memory relates to the 'arrow of time' that the second law of thermodynamics describes. But memory in any interesting sense also has to be understood as a phenomenon that occurs on the borderline between chaos and order (Kauffman 1993). The limit cases of memory are on the one hand white noise, random motion, with no memory or correlation between one event and the next, and on the other black noise, effective silence, duration without event, a total memory where future states totally correspond to previous events. Memory is something that can only happen somewhere in the middle of these two extremes.

Thirdly, memory is in some sense an autorelation. As Gilles Deleuze puts it, following Kant, '[m]emory is the real name of … the affect on self by self' (Deleuze 1988: 107). So memory is something topological, about the shape, in some sense, of the entity or assemblage that is said to have memory, how it is folded, made to affect itself, through time.

Fourthly, there are different kinds of memory. When we talk about memory in human beings we typically talk about different kinds of memory – long-term and short-term memory, for example, or episodic memory, which is memory of something that happened at a particular place and time, or semantic memory, which is memory of the concepts and rules that underpin memory, thought and language. If we generalise memory beyond the human, and beyond the living, then it is likely that these categories of memory will have to be wildly modified; but we can be pretty sure that some similar set of distinctions will persist.

Fifthly, if memory is time, it can however be converted into space and back again. Think of the 'memory palace' used by classical and renaissance orators, in which memories were placed in different places in an imaginary building (Yates 1966), or think of writing. Or think about placing things at the bottom of the stairs, not just to 're-mind' you to take them upstairs, but as a form of memory itself – an act of delegation, in Latour's language (1992), of distributed memory. We can call all of these 'mnemotechnics', or 'hypomnesia', and can follow Bernard Stiegler (1998) into seeing this not just as referring to techniques of memory, but the way that artefactuality and technicity in general is an exteriorisation of memory, a hypomnesis – that the equipmental assemblage of cups, stairs and pencils with which we are surrounded is part of how we remember who we are and what we know. We will have occasion to ask if hypomnesis occurs beyond the human.

Sixthly, memory also includes forgetting. Forgetting is not just privative, the lack of memory. Just like death presupposes life, forgetting presupposes memory: only things which can remember can forget in any interesting sense. Forgetting is an active process,[2] a capacity, a skill. And specific kinds of memory can *require* forgetting, selection, erasure. When later I talk about the atmosphere having memory, about the air 'affecting' itself over time, when for example a hurricane forms, the capacity of the hurricane to have 'working memory' depends on parcels of air forgetting their origins before they were taken up into the hurricane. If the carbon recycled into our bodies remembered too much about its origins in the animals and vegetables we eat, or in the organisms whose matter they absorbed, this would affect our capacity to remember ourselves and what we know.

[2] (Klein 1998) is useful here.

Seventhly and finally, if memory is about autoaffection, as Deleuze puts it, it has to be active and constitutive, affecting how something reacts to its environment. Thermodynamic ideas can help us think about memory not just as a supplement to being but as constitutive of being itself, as part of how a certain kind of entity 'goes on', the specific way that it endures through time as the kind of being that it is. And here again forgetting may be as important as remembering for the ability of an entity to act. As well as hypomnesia there is *hypermnesia*, over-remembering, of which Nietzsche accused the ancient Greeks. In order to act, the individual has to overcome the stifling nature of history by recovering the powers of the pre-historical animal to forget – to develop a 'memory of the future' (Nietzsche 2006). We will have to ask whether the Earth can have a 'memory of the future' that enables it to act in surprising ways.

Thermodynamics and memory

So let's turn to thermodynamics and systems (though the word 'system' might imply too rigid and formalised an arrangement of things for what we're talking about here). As I hinted above, memory in the sense that I'm using it emerges in systems that are far from equilibrium, on that generative boundary between order and chaos expored by Ilya Prigogine and Isabelle Stengers and others (Prigogine and Stengers 1984). The arrow of time which thermodynamics says points in one direction, to equilibrium, entropy and disorder, does funny things on that boundary. Many complex systems have a tendency evolve not to simple equilibrium but to their most challenging ("minimally stable") state. They organise themselves into what Per Bak called a state of self-organized criticality (SOC), on the edge of a phase transition (Bak et al. 1987).

Andrew Watson and James Lovelock devised their 'Daisy World' model to explore how systems with very simple components and interactions can in fact self-organise in very sophisticated ways (Watson and Lovelock 1983). But instead, let's go down to Copacabana beach and play 'Sand World'. Let's stay above the high tide mark, and fill up a bucket with nice dry sand. (This is a nice example of sympoiesis, of borderless self-organisation (Dempster 2000).) If we pour the sand slowly out, a pile will start to form, getting steeper until it reaches a *critical angle*. Beyond this point, the sand pile will "organise itself" so that any further addition of sand will cause cascades of avalanches to flow, maintaining the pile at the critical angle.[3]

Using the language that Isabelle and Prigogine developed (1984) the sand particles in a 'flat pile', in state of equilibrium, are "hypnones", unaware of each other. But once the pile has built up to the critical angle, the whole pile becomes self-organising, with a kind of resonance throughout it – the sand particles have "woken up" to each other.

You know when a system has woken up if it starts to exhibit pink noise. **White noise** is fully random, with each frequency contributing equally. It is the result of what are known as Markov processes, processes where the system has no memory at all; the next state of the system depends solely on the current state. In **pink noise** – aka flicker noise, 1/f noise – low frequencies dominate, and the system has memory of past events (Csermely 2006: 57-8). It develops scale-invariant, fractal behaviours. So the repeated avalanches on the pile which maintain it at the critical angle are not the random white noise of relaxation to equilibrium, but a form of pink noise where the probability of any size of avalanche is inversely proportional to its size.

There have been huge debates about how to understand self-organisation. But the general point is that even very simple matter can self-organise; and once it starts to do so it develops new and interesting kinds of memory and forgetting, without thereby having become a 'whole' in any strong sense.

So self-organising systems or couplings **can remember what they are**: a grain of sand falls on the pile, and is 'woken up' by the rest of the pile, exhibits a kind of anamnesis, and joins the dynamic. But it also in some sense forgets its origin and past behaviour as it swept up into the crowd of grains. (Though Copacobana sand grains are very old, ground down from continental rock, so are very rounded, which means that our sand pile will never get very steep.)4

[3] http://www.timeshighereducation.co.uk/books/the-world-in-a-grain-of-sand/156168.article

[4] I haven't decided whether that counts as having a memory of past states or not.

A self-organising system also has a kind of **working-memory,** which is how it organises the scale-invariant behaviour and power laws.

It can also have an **episodic memory,** a memory of specific events, since at the point of phase transition from one dynamic to another the boundary conditions can be 'frozen' into its emerging dynamic from then on (this will become relevant later when we talk about 'geotrauma').

So, how do ideas of thermodynamics and self-organising criticality apply to the Earth? The Earth has an applied energy gradient. As Bataille pointed out in *The Accursed Share* (1988), the Earth receives a huge excess of energy from the sun, and has to deal with it. Thanks to the curvature of the earth it also receives it unevenly, creating a further gradient in the solar forcing between equator and poles. This creates a kind of thermodynamic compulsion for the Earth to evolve toward states that give the maximum degradation of available energy (Paltridge 1979; Schneider and Kay 1994). And it is this that drives the gift economy of Gaia.

But then there are phase changes; metaphorically speaking, the Earth doesn't remain a pile of sand, on the edge of a phase transition. It has what Bruno Latour calls a 'geostory' (Latour 2014). It has evolved in complexity through a progressive unfolding of singularities, a cascade of symmetry-breaking bifurcations (DeLanda 2002: 17, 20). So, rather like an egg, the Earth started as undifferentiated but became progressively more anatomical or geometrical. It did this through processes of *migrating* (where constituent materials move within the body of the Earth) but also *folding* (where it creates new topological relations with and within itself) (DeLanda 2002: 52). So, for example (and allowing ourselves to talk about the Earth as 'doing' things):

- in the process of accretion from the solar nebular, it created the surface between *inside and outside*;
- in heating up, melting the rocks so they can sort themselves out according to density, it created the relation between *iron core and rock mantle*;
- in cooling and allowing oceans and atmosphere to form – so we get *shorelines* like Copacabana with their complex dynamics, but also the wider water cycle;

- development of *lateral tectonics* about 3.0 Ga (billion years ago) or earlier (Hazen et al. 2013: 85), creating stable continents about 2.5 Ga;

- developing life, and thus the relation between organism and environment, predator and prey, parent and progeny, symbiont and symbiont, and so on.

So from a shapeless body dominated by the *intensive* – by gradients of temperature, pressure, density concentration and so on – it develops extensive structures, form – what Deleuze calls strata. But the emergence of this extensivity, this internal structure, also creates new intensivities, new gradients to generate new subsystems, new forms of becoming and so on and so on. So the Earth has progressively developed the hydrological cycle, atmospheric circulation, plate tectonics, biological evolution – and now technology (because I do think that that is a key development in the Earth) (Haff 2013). Each builds on the achievements of the former; each introduces new forms of criticality – but each also introduces new forms of memory and forgetting.

The Memory of the Earth

So, finally we can get to our central question. How does the Earth remember? Because of lack of space I'm not going to say much about biological or ecological or social memory – even though these are so important. Instead I'll just focus on air and rock, and then talk about interactions between the different memory systems.

Air memory[5]

Although the atmosphere is self-organising, its memory time is so tiny, compared to that of ocean, rocks or ecosystem. Our very concept of 'weather' points to our awareness that the memory of the air, especially in the troposphere, is very short. This is partly due to the **gaseous and vaporous** character of the atmosphere, which limits the sort of structures it can form, the amount of heat it can store, and generally its capacity to limit or control the propagation of change through itself. Later on I will want to suggest that this means that the characteristic memory of air is a kind of living, or 'oral' memory –

---

[5] Many thanks to Piers Foster for help on this section.

a memory of motion and intensivity, that has to be continually maintained in action or it almost literally evaporates. For example, in some latitudes, air sometimes forms itself into dissipative systems (Prigogine and Glansdorff 1971) such as cyclones and anti-cyclones, that maintain their identity and shape over time over a number of days by exporting entropy to their surroundings. In these situations the atmosphere can be said to have developed working memory.

But at other times atmosphere does not seem to have any memory, and forecasting is impossible. Why does the air forget? This is partly due to the topography of the Earth below it: the very active system of tectonics which as we will see helps the rocks *remember* also produces features on the Earth's which make the atmosphere *forget*. Other planets, such as the gas giants in the outer solar system, Jupiter, Saturn, Uranus and Neptune, have atmospheres with a much longer memory, with vortices that can last for hundreds of years or longer – Jupiter's red spot, for example, or the hexagonal cloud over Saturn's north pole. But on Earth the mountain ranges wipe the memory of the air as it moves over them, rather like the erase head on an old-fashioned tape recorder.

But the forgetfulness of the air on the Earth is also partly due to the clouds. The one part of the atmosphere with a longer memory is the stratosphere, because here there are no clouds to make the atmosphere forget. So for example there is a water vapour memory in the stratosphere, whereby seasonal high levels of water vapour at 15km altitude in the tropics slowly rise, five years later reaching 40km altitude. In the troposphere by contrast, clouds wipe memory.

But of course the atmosphere is not completely chaotic. The air could be said to rely on its own mnemotechnics, its own hypomnesia. Its largest features, the overturning Hadley, Ferrell and Polar cells that determine the direction of trade winds and westerlies, are themselves huge dissipative systems that therefore have their own internal self-organisation and memory. But their internal memory is very short; if the sun went out, for example, the cells would lose their form over a few days. However, the atmosphere is reminded every minute 'who' it is and how it behaves by the Earth's placement 93 million miles from the Sun, its shape, tilt and spin (Paltridge 1979).

Rock memory

What about the rock? The rocks of the earth seem to have longer and more complex forms of memory.

First of all, there are traces of the past in the rocks, as interpreted by geologists – the Earth shares this power with other rocky bodies, as evidenced by the long memory of early periods of the solar system recorded by Luna and Mars. Yet the memory of the Earth is different from that of other bodies, since the Earth is an extremely effective machine for making strata (Zalasiewicz 2008). The earth developed new forms of memory by its power to make strata through the combination of lateral tectonics, a buoyant continental crust and the water cycle. In particular, there are zones of *erosion* in the uplands pushed up by tectonic collisions and 'tectonic escalator' effects, and zones of *sedimentation* around the coast; the forgetting of erosion is necessary for the memory-forming of sedimentation (Zalasiewicz 2008). Rocks like sandstone are clastic, made of fragments of older rock. If Copacabana beach became sandstone, it would be a 'society of rock', not having totally lost the rock-being of the grains that made it up; the granite of Sugarloaf mountain by contrast is a crystalline rock whose grains (which give it its name) form from the molten rock as it cools.

But the memory of the Earth is more than just the passive capturing of traces, like Freud's mystic writing pad. For a start, **minerals themselves have evolved**; in the solar nebula and planetesimals there were just a few 'ur-minerals', but the symmetry-breakings of planetary accretion, tectonics, sub-aerial continents, life, the Great Oxygenation Event and so on have created the huge variety of minerals we see today (Hazen et al. 2013). And strata are more than a record to be read by disinterested geologists – **the strata system is part of how the planet remembers what it itself has done and what it is able to do**. The rocks of the Earth record not just solar system history (such as bombardments) but also the Earth's own internally generated geostory. The internal topology of sedimentary rocks – like the imagined future sandstone made in Copacabana – are not snapshots but infinite numbers of different landscapes made by wind and wave (Zalasiewicz 2008).

The interaction between memory systems

Although there are good reasons to talk of relative closure of the different memory systems, there are also crucial points of transduction between them (Mackenzie 2002).

For example, the **atmosphere's** memory is improved by being in contact with the **ocean and land**. It practices its own mnemotechnics, exchanging moisture and heat with them and thereby increasing the length of its memory to the length of years. **Ice sheets** gives the atmosphere even longer memories, to be measured in thousands of years – the ice sheets are still detectably recovering from the last ice age.

But the interaction between **rock and water** is really complex too. Firstly, as well as water having its own memory dynamics (which I won't say much about here), water's properties are 'borrowed' by rock memory. The water plays a crucial role in **keeping the tectonics going** (Venus's stopped partly due to it heating up and losing its water). But also it is crucial in the **creation of new strata** – strata formation is best at or around sea level (Zalasiewicz 2008: 60). Water also plays a crucial role in **preserving** strata(by overlaying them with new strata) – but also in **destroying** them – by keeping lateral tectonics going, which pulls the mudstones of the deep ocean down into the mantle and breaks it up; through the slow destruction of coasts at the pounding surfline; and through upland erosion. So in relation to rock memory, we might call Earth's waters are waters of memory *and* forgetfulness.

But also rock helps the water's memory; let me give two examples. The first involves the movement of water. Let's go back to the beach. Note how, as each wave rushes up the shore and then drains back down again, it reorganises the sand into forms which then affects the ability of the next wave to drain back. The water can learn, remember what it did last time. But this is crude compared to the dynamics of river basins, which over centuries and millennia self-organise themselves into complex fractal networks that drain in optimal ways (Rodríguez-Iturbe and Rinaldo 1997). It is striking to compare the complex fractal patterns of earth valleys with those on Mars, which are typically created by one-off flood events.

The second is geochemical. The rock-water system evolves. Once free water emerges on the Earth, it develops a water-rock system which is always in an 'equilibriumnonequilibrium state'; that is, water is always in equilibrium with some minerals in which it is in contact but simultaneously in noneqilibrium with others. The rock-water system thus 'behaves as a single coherent structure, which over eons persistently transforms, rearranges, form new minerals and diverse chemical types of water' and develops new, 'higher-organized dissipative systems' (Shvartsev 2009: 262, 266).

Summary so far

To summarise what I've said so far:

- the earth in its symmetry-breaking transitions has developed interlinked subsystems (rock, water, air, life, and so on), each with their own multiple forms of memory;
- the earth has working memory, sustained in dissipative systems of different time scales;
- the different subsystems also have long term memory, especially in the subsystems which have evolved massively greater complexity over the age of the earth – e.g. rock strata; mineral species; biota – all of which bear the traces of their complex history;
- each system of memory has its own forms of forgetting which are crucial to their operation; and
- memory systems interact in complex ways – sometimes in ways that the memory of one system depends on increasing the amnesia of another system; sometimes in forms of hypomnesis, in which the memory of one system is increased by placing memory outside of itself, in another system.

We might also enquire how the great phase shifts and symmetry-breakings of the Earth have left echoes and suppressed memories. Here we are in the vicinity of Nick Land's 'geotrauma' – the idea that all personal, human trauma is a recapitulation of the traumas undergone by the Earth during its evolution. During the Archean aeon, the symmetry breaking that was the burial of molten core (Cthell) under a crustal shell is, as Land puts it through his fictional Baxter, 'the anorganic metal-body trauma-howl of the earth' (Land 2012: 498).

Then the Great Oxygenation Event, when the atmosphere started to accumulate free oxygen about 2.3 billion years ago and become toxic to the very living organisms that were producing it. Baxter cites Lyn Margulis' argument that this led to some prokaryotes taking shelter inside other ones, resulting in the nucleated eukaryotic cells out of which all plants and animals are assembled. Whatever the later advantages of nucleated cells, Land argues that the command-control model of genomic read-only memory of cells – 'locked-up … more-or-Iess obedient to Darwinian selection mechanics … suppressive' – is the result of this trauma (Land 2012: 498).

And what about the beautiful granite inselbergs or bornhardts around Rio, like Sugarloaf Mountain, or Corcovado mountain where Christ the Redeemer stands? These were formed by erosion along exfoliation joints parallel to the surface of granitic intrusions, making the steep sides and flat tops. But the dramatic shape of the Rio bornhardts are a memory of the violent creation of this beautiful coastline by the splitting of South America from Africa about 120 Mya, and the crustal stresses this produced.

Anthropocene and memory

How does the set of developments we call the Anthropocene relate to this complex system of systems through which the Earth remembers and forgets? Will the Anthropocene simply insert itself into the memory of the Earth as a new stage of its development, or will it change the way the Earth remembers? Let me close with some tentative remarks.

Firstly, the Anthropocene is potentially a **scrambling of the memory systems of the Earth**, not just for observers but for the Earth itself, so that it forgets what it knows. Imagine the Anthropocene as a transient, a huge wave that washes across a catchment area. We need to distinguish at least three forms of forgetting that such a transient can cause.

- Firstly, a transient can degrade memory in self-organising systems (Rodríguez-Iturbe and Rinaldo 1997: 373). So, for example, as the Anthropocene washes across the planet it causes a loss of rock memory by the mixing up of strata, but also a loss of cultural memory and ecological memory, as the semiotic systems through which humans and non-humans remember how to interact with each other are degraded (Harries-Jones 2009).

- Secondly, a transient can activate new singularities, tipping systems into new basins of attraction which completely wipe the memory of the previous metastable state and push the system to build new memories (e.g. if the thermohaline circulation of the oceans altered its pattern). Invasive species also bring new memories into ecological systems.

- Thirdly, a transient can also actually push a system away from criticality, thus destroying a particular mode of self-organisation and thus a whole mode of memory (e.g. if there were no humans to read an archive, or if life itself died out).

Secondly, the Anthropocene also of course involves the **laying down of new forms of memory**; this is the focus of the Jan Zalasiewicz's Anthropocene Working Group, which has to see even forgetting as the laying down of a trace, in terms of lithostratigraphic, chemostratigraphic and biostratigraphic signals in future rocks (Zalasiewicz et al. 2011a; Zalasiewicz et al. 2011b; Zalasiewicz et al. 2008). When Rio joins the geological archive will it be submerged, sedimented, and preserved; or will it be pounded to destruction? The great storm that you had in 2010 suggests it will be a bit of both.

And in the shorter term the Anthropocene spreads unevenly across the Earth (agriculture, industry, markets), the explosive reorganisation of fossil fuels and minerals, and power and social life, leaves its traces on any Anthropocene future and in itself is a combination of memory and forgetting – of uneven power relations and uneven development, of low and high entropy, that will imprint themselves into the possible course of society, whether human or posthuman.

But thirdly we should also consider whether what we are struggling to name at the moment is in fact **the Earth adding a new memory system**. How would we name this? Technosphere? Capitalosphere? Metrosphere? Cybersphere? Chthulhusphere? Probably some combination. And we have seen how in symmetry breaking, in the evolution of new forms of memory, typically the new forms depend on the old continuing but also depend on degrading the energy and information being used and generated by the old. But we have also seen that memory systems can in a sense help each other – water and rock, rock and water. And Nick Land's notion of 'geotrauma', and Elizabeth Grosz's 'geopower' (2008), suggest that new memory systems carry things over from the old, that memories can lie repressed or become reactivated. In the Anthropocene, is the Earth forgetting its old way of remembering, in order to develop new forms of memory? Are the new, Anthropocenic memory systems of the Earth wiping the memory from the old, like the mountains wipe the memory from the air? Or are they bringing to light, opening the archive of the Earth from its incarceration? Are the archives of extinct species and lost ecosystems a form of mnemotechnics as the biosphere loses its internal capacity to remember what is being lost?

But we must remember what Derrida said about archives in 'Archive fever'. In contrast to live or spontaneous memory (mneme or anamnesis), the archive tries to protect memory from destruction by incarcerating it in a memory prosthetic (Derrida 1995: 22). Spontaneous, living memory, *mneme*, is vulnerable – we have seen that with the air, how quickly it can forget, as it tries to pass on its oral history from molecule to molecule. But of course the hypomnesia of the archive contains within itself a vulnerability. The archive repeats, and repetition is an aspect of the death drive, of the very destruction which the archive is trying to resist. The archive works against itself – this is the *mal d'archive*, (Derrida 1995: 14). Whether it is the very strata of the rock, or an archive created by humans in order to record Earth's memories and what it knows, the archive's very form of resistance to forgetting makes a more final forgetting possible – the hiding or destruction of the archive. The closed archive of the solid body of the Earth is now being opened but at the same time ransacked.

So to simplify I'll end with a choice – not rock, paper or scissors, but rock, water, air, life? Which kind of memory is strongest? Which will last the longest? Will the different forms of memory undermine or reinforce each other? When we remember the Earth, and remember for the Earth, do we remember as a storm, a vortex, as living memory? Or as a mountain, as a great archive? Which kind of memory will enable the Earth to act in the way in which it needs to act at this time?

References

Bak, Per, Chao Tang and Kurt Wiesenfeld (1987) 'Self-organized criticality: an explanation of 1/f noise,' *Physical Review Letters*, 59(4), pp. 381-4.

Bataille, Georges (1988) *The Accursed Share: An Essay on General Economy*, Vol. 1-3, New York: Zone Books.

Crutzen, P.J. and E.F. Stoermer (2000) 'The "Anthropocene",' *IGBP Newsletter*, 41, pp. 17-8.

Csermely, Peter (2006) *Weak Links. The Universal Key to the Stability of Networks and Complex Systems*, Heidelberg: Springer.

DeLanda, Manuel (2002) *Intensive Science and Virtual Philosophy*, London: Continuum.

Deleuze, Gilles (1988) *Foucault*, tr. Seán Hand, Minneapolis: University of Minnesota Press.

Dempster, Beth (2000) 'Sympoietic and autopoietic systems: a new distinction for self-organizing systems,' paper presented to *International Society for Systems Studies Annual Conference*, Toronto, Canada, July 2000.

Derrida, Jacques (1995) 'Archive fever: a Freudian impression,' *Diacritics*, 25(2), pp. 9-63.

Grosz, Elizabeth A. (2008) *Chaos, Territory, Art: Deleuze and the Framing of the earth*, New York: Columbia University Press.

Haff, Peter K. (2013) 'Technology as a geological phenomenon: implications for human well-being,' *Geological Society, London, Special Publications*, 395.

Harries-Jones, Peter (2009) 'Honeybees, Communicative Order, and the Collapse of Ecosystems,' *Biosemiotics*, 2(2), pp. 193–204.

Hazen, Robert M., Robert T. Downs, Linda Kah and Dimitri Sverjensky (2013) 'Carbon mineral evolution,' *Reviews in Mineralogy and Geochemistry*, 75(1), pp. 79-107.

Kauffman, Stuart A. (1993) *The Origins of Order: Self-Organization and Selection in Evolution*, Oxford: Oxford University Press.

Klein, Norman M. (1998) *The History of Forgetting: Los Angeles and the Erasure of Memory*, London: Verso.

Land, Nick (2012) 'Barker speaks: the CCRU interview with Professor D.C. Barker,' in *Fanged Noumena: Collected Writings 1987- 2007*, Falmouth: Urbanomic, pp. 493-505.

Latour, Bruno (1992) 'Where are the missing masses? The sociology of a few mundane artifacts,' in *Shaping Technology/Building Society: Studies in Sociotechnical Change*, ed. Wiebe E. Bijker and John Law, Cambridge, MA: MIT Press, pp. 225-58.

Latour, Bruno (2014) 'Agency at the time of the Anthropocene,' *New Literary History*, 45, pp. 1-18.

Mackenzie, Adrian (2002) *Transductions: Bodies and Machines at Speed*, London: Continuum.

Nietzsche, Friedrich (2006) 'On the utility and liability of history for life,' in *The Nietzsche Reader*, ed. Keith Ansell Pearson and Duncan Large, Oxford: Blackwell, pp. 124-41.

Paltridge, Garth W. (1979) 'Climate and thermodynamic systems of maximum dissipation,' *Nature*, 279(5714), pp. 630-1.

Prigogine, Ilya and Paul Glansdorff (1971) *Thermodynamic theory of structure, stability and fluctuations*, New York: Wiley.

Prigogine, Ilya and Isabelle Stengers (1984) *Order Out of Chaos: Man's New Dialogue with Nature*, Toronto: Bantam Books.

Rodríguez-Iturbe, Ignacio and Andrea Rinaldo (1997) *Fractal River Basins: Chance and Self-Organization*, Cambridge: Cambridge University Press.

Schneider, Eric D. and James J. Kay (1994) 'Life as a manifestation of the second law of thermodynamics,' *Mathematical and Computer Modelling*, 19(6–8), pp. 25-48.

Shannon, Claude E. (1948) 'A mathematical theory of communication,' *Bell System Technical Journal*, 27, pp. 379-423 & 623-56.

Shvartsev, S. L. (2009) 'Self-organizing abiogenic dissipative structures in the geologic history of the Earth,' *Earth Science Frontiers*, 16(6), pp. 257-75

Stiegler, Bernard (1998) *Technics and Time, 1: The Fault of Epimetheus*, Stanford, CA: Stanford University Press.

Watson, Andrew J. and James E. Lovelock (1983) 'Biological homeostasis of the global environment: the parable of Daisyworld,' *Tellus B*, 35(4), pp. 286-9.

Yates, Frances Amelia (1966) *The Art of Memory*, London,: Routledge & Kegan Paul.

Zalasiewicz, Jan (2008) *The Earth after Us: What Legacy will Humans Leave in the Rocks?*, Oxford: Oxford University Press.

Zalasiewicz, Jan, Mark Williams, Richard Fortey, Alan Smith, Tiffany L. Barry, Angela L. Coe, Paul R. Bown, Peter F. Rawson, Andrew Gale, Philip Gibbard, F. John Gregory, Mark W. Hounslow, Andrew C. Kerr, Paul Pearson, Robert Knox, John Powell, Colin Water, John Marshall, Michael Oates and Philip Stone (2011a) 'Stratigraphy of the anthropocene,' *Philosophical Transactions of the Royal Society A*, 369(1938), pp. 1036-55.

Zalasiewicz, Jan, Mark Williams, Alan Haywood and Michael Ellis (2011b) 'The Anthropocene: a new epoch of geological time?,' *Philosophical Transactions of the Royal Society A*, 369(1938), pp. 835-41.

Zalasiewicz, Jan, Mark Williams, Alan Smith, Tiffany L. Barry, Paul R. Bown, Peter Rawson, Patrick Brenchley, David Cantrill, Angela L. Coe, Andrew Gale, Philip L. Gibbard, F.John Gregory, Mark W. Hounslow, Andrew C. Kerr, Paul Pearson, Robert Knox, John Powell, Colin

Waters, John Marshall, Michael Oates and Philip Stone (2008) 'Are we now living in the Anthropocene?,' *GSA Today*, 18(2), pp. 4-8.