Speculative Volcanology

Time, Becoming, and Violence in Encounters with Magma

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Abstract In 2009, exploratory drilling of geothermal wells in Iceland's Krafla volcanic caldera unexpectedly struck magma. The fact that the encounter did not have catastrophic consequences has excited considerable interest—and an international research facility is now being set up to explore energy generation and other possibilities of closer engagement with magma. We take this event as an incitement to explore how the Earth-changing "violence" of volcanic or igneous processes might be seen not simply as happening *in* time but as both generative and destructive *of time itself*. We approach volcanism through the construct of a "speculative geology" that draws on a recent return to metaphysical themes in philosophy as well as a growing interest in geologic processes in the arts, humanities, and popular culture. In this way, alongside cause-effect relations, we explore the more enigmatic processes through which subterranean geologic forces offer an excessive potentiality from which humans and other life forms select and actualize a narrower range of creative or generative possibilities. The article explores three significant volcanic episodes: a series of massive magma extrusions about 1.9 billion years ago linked to the ascendance of multicellular life; volcanism present in the East African Rift during pivotal phases of human evolution; and the volcanic activity of the early-mid Holocene viewed as a contextual factor in the emergence of ancient practices of artisanal pyrotechnology. Our reading of the dynamic and violent interchange between the inner and outer Earth in these examples points to a non–self-identical planetary condition, on which the very structure of temporality emerges through a play of destruction and generativity. In this light, we circle back on the Krafla project to consider questions of risk, uncertainty, and responsibility that attend the potential new interface with the underworld of magma.

Keywords time, volcanism, geology, speculative theory, catastrophe, evolution, Anthropocene, planetary futures

Environmental Humanities 10:1 (May 2018)
DOI 10.1215/22011919-4385571

Eruptions of Time

Rather than conceiving of time as a continuous flow sutured or punctuated by events, we might think of events as generative of time. What happens or takes place opens a future that is other than the past or present. Events, we might say, are *temporizing*: they provide or give the experience of passing time. As Jacques Derrida intones: "What there is to give, uniquely, *would be called time*."[1] In this way, time—and the processes of becoming that are inherent to temporization—also involve a kind of violation: a rupture with preexisting states of affairs, pathways whose opening precludes other trajectories.

If this intrinsic violence is constantly enacted in the minor but consequential durations of daily life, it can be truly cataclysmic once we scale up to the times and spaces of the Earth. Such upheavals leave their mark. Even when time appears to us as modulated and smoothly flowing, it bears traces of its violent inaugurations. The sand in an hourglass and most of the glass itself are of igneous origin, materials that have at some point burst forth from the inner Earth. Likewise, the crystal in a digital clock is a gift of subterranean forces. And we too, the living beings who deploy such devices to impose order on the passage of time, carry within ourselves traces of violent extrusions of matter from the Earth's interior.

That we experience eventful time as *erupting, irrupting, interrupting* suggests memories of those ruptures that our planet delivers now and again. "Earthquakes, floods, hurricanes, and droughts," notes geologist Robert Frodeman, "are places where deep time erupts into our more familiar rhythms":[2] a list crying out for the addition of volcanoes. Engaging with artist Nelly Ben Hayoun's installations of pocket-sized "working" volcanoes in domestic spaces, Gísli Pálsson and Heather Anne Swanson remind us how the "lively and unpredictable geologic being" of volcanic processes can entwine with everyday lives. And as they go on to show, episodes in living memory open onto a much deeper history of life-changing volcanic encounters.[3]

Such life changes can of course be fatal, with eruptions such as Tambora (1815), Krakatau (1883), and Mount Pelée (1902) claiming tens of thousands of human lives. Dig deeper and we come to events of such magnitude that their impacts are of evolutionary significance: the Lake Toba eruption seventy thousand years ago with its much-debated winnowing effect on the genus *Homo*, the Deccan Traps eruptions implicated in the mass extinction event at the boundary of the Cretaceous and Paleogene periods, and the Siberian Traps eruptive events at the Permian-Triassic boundary that contributed to the die-off of an estimated 90 percent of Earth's species.

More than brute death tolls, what interests us is the way volcanic processes mediate between the Earth's forbidding interior and the lively envelope around the planet's surface, how they bring the slow, churning temporalities of the inner Earth into the

1. Derrida, *Given Time*, 29.
2. Frodeman, *Geo-logic*, 125.
3. Palsson and Swanson, "Down to Earth," 150.

more familiar rhythms and durations of the outer Earth. Such breachings, we suggest, are both exorbitantly generative and profoundly destructive, at once a giving and a taking away of time.

As we will see, the upwelling of matter from the subterranean domain into the crustal strata—predominantly in the form of magma—is a constitutive aspect of earthly existence. In the geoscience lexicon, "magma" refers generically to molten rock, "lava" to molten rock that reaches Earth's surface. Magma comes from the mantle—the layer of rocky material between the Earth's core and crust that comprises some two-thirds of the planet's mass. Mantle rock is predominantly solid but also slow moving—circulating in vast currents driven by heat radiating from the Earth's core. This convection drives the movement of the tectonic plates that make up the planet's crust, in the process causing a small proportion of mantle rock to melt—by a reduction in pressure as it moves upward.[4] There are other ways of generating magma, however, such as when crustal rock is partially melted by being infiltrated by seawater and then dragged down as one tectonic plate is pushed beneath another. More buoyant than the rock from which it is formed, magma tends to rise where it stalls in fractures, collects in subsurface magma chambers, or—sometimes—bursts through the surface in volcanic eruptions.[5]

The trigger for this article, however, is not simply the surprises that rising molten rock periodically send our way. It is a stranger and more enigmatic set of events, goings-on that are in the process of complicating the dynamic relationship between inner and outer Earth that has reigned since early in our planet's history. While the formation and ascent of magma will continue unabated, recent years have seen the first real contact between a terrestrial life-form and magma in its subterranean "natural" habitat.

In 2009, enterprising members of our own species who were engaged in exploratory drilling of geothermal wells in Iceland's Krafla volcanic caldera unexpectedly struck magma.[6] At zones of rifting and extension in the crust—as we have touched on—magma regularly intrudes into the Earth's upper crust, where it collects in chambers. When groundwater is present or added to such sites, the resultant steam or hot water can be tapped as an energy source—as already occurs in Iceland and other geothermal regions.[7] But the chamber at Krafla was far shallower than anticipated. The fact that the magma strike did not trigger an eruption has excited considerable interest in the possibility of extraction—from wells that could be up to ten times as productive as standard geothermal bores. Only twice before—in the active volcanic chain of Hawai'i and at the Menengai caldera in Kenya—have engineers encountered magma in situ. As researchers propose: "Krafla could one day become the site of the world's first enhanced

4. White and McKenzie, "Magmatism."
5. Rothery, *Volcanoes*, 21–31.
6. Elders et al., "Drilling into Magma."
7. Ibid.

geothermal system operating at, or near, magmatic temperatures."[8] More than this, Krafla offers what has been described as "the first direct access to the magmatic environment of Earth."[9]

The accidental encounter has inspired geoscientists and engineers to set up a unique international research facility—the Krafla Magma Testbed. An impetus for the project is awareness of the urgent need to substitute renewable energy for hydrocarbon combustion.[10] Alongside energetic opportunities, researchers are exploring the possibility of placing sensors directly into magma and even deliberately cooling molten rock—with implications for reducing volcanic hazards from magma chambers. At the same time, they are rigorously assessing risks involved in working with magma, which include mobilizing toxic chemical species such as mercury or arsenic and triggering volcanic eruptions.

"In spite of studies of the magma, well testing and modelling," geologists S. Scott, T. Driesner, and P. Weis observe, "the thermo-hydraulic nature of the reservoir at Krafla has remained enigmatic."[11] But what is the nature of this "enigma" in relation to our questions about the temporization of the Earth? What does it mean, not only for a select group of scientists and engineers but for human and terrestrial life more generally, to be contemplating new turns in the temporal relationship between the Earth's surface and its interior? That members of our species have deliberately inaugurated traffic with the domain of magmatic processes, we suggest, is so unprecedented that the contours and implications of this event cannot yet be anything but opaque and enigmatic.

The mode of inquiry we propose is intentionally *speculative*. By this we mean that we are at least as concerned with creative, explorative, and conjectural probings as we are with establishing causal relations or all-encompassing interpretive frameworks. Rather than the tallying of risks against gains, what interests us most about Krafla as an unfolding event is the radicalness of its rupture with existing times of the Earth—its possible reconfiguring of the temporization of inner-outer Earth relations. At risk of sounding grandiose, we suggest that such eventualities potentially shift the very conditions of possibility through which new forms, structures, entities come in and out of existence on our planet.

Rather than confront Krafla directly, we take a more oblique and extended approach. We explore three earlier volcanic episodes that might be considered turning points in Earth or social history. After setting out what we mean by a speculative geology, we turn to our first example: magma extrusions occurring about 1.9 billion years ago that have been linked to the ascendance of multicellular life. Our second example

8. Ibid., 116.

9. International Continental Scientific Drilling Program, Krafla Magma Drilling Project Workshop, October, 2017, www.bgs.ac.uk/icdp/blogs.html.

10. Elders et al., "Drilling into Magma," 117; Scott, Driesner, and Weis, "Geologic Controls," 5.

11. Scott, Driesner, and Weis, "Geologic Controls," 2.

concerns volcanism present in the East African Rift during pivotal phases of human evolution and its possible connections with early hominid fire use. Third, we advance to a more conventionally human history to explore volcanic activity in the ancient world as a contextual factor in the emergence of artisanal practices using high heat to transform inorganic matter. While differing greatly in spatial and temporal scale, each of these encounters with magma opens up questions of rupture and becoming: issues in which shifting inner-outer Earth relations might be seen to function as at once giving and taking away time. These are themes with which we engage more explicitly as we circle back on the Krafla project and consider questions of responsibility attendant on making contact with magma.

Toward Speculative Geology

Art theorist Geoffrey Batchen observes that several decades before the actual invention of photography around 1840, there was a surge of desire to capture and fix images that emerges simultaneously at numerous global locations and across a range of scientific, artistic, and philosophical milieus.[12] Perhaps in our own era we can glimpse something similar regarding penetration of the Earth's crust and sustained contact with the molten underworld.

In recent months, NASA scientists have gone public about their research into quelling the eruptive potential of supervolcanoes by drilling into magma chambers and pumping in water to cool the magma body—a scheme conceivably stretching over tens of thousands of years.[13] Apparently unrelated to developments at Krafla, the NASA research also envisions combining volcanic risk reduction with geothermal power generation.

Popular culture, meanwhile, runs ahead. The *Superpower Wiki* catalogues some forty superheroes and villains—from Lava Girl to Molten Man—with magma-manipulating capabilities, while forums dedicated to the video game Minecraft feature comprehensive discussion about what can be done with magma in the digitally generated world.[14] In the last two years, science fiction author N. K. Jemisin has won consecutive Hugo awards for the first two instalments of the *Broken Earth* trilogy, which is set on a geologically hyperactive supercontinent and centers on mutant humans with capacities to willfully intervene—for better and worse—in seismic and volcanic processes.[15]

With popularization of scientific claims that human environmental impacts are now reaching geophysical levels—shorthanded as the Anthropocene thesis—it is not especially surprising that there is growing interest in both human geologic agency and

12. Batchen, *Burning with Desire*.

13. Cox, "NASA's Ambitious Plans."

14. Superpower Wiki, "Magma Manipulation," powerlisting.wikia.com/wiki/Magma_Manipulation (accessed September 1, 2017); "Powering Magma Crucible without Magmatic Engines?" FTB Forum, May 7, 2013, forum.feed-the-beast.com/threads/powering-magma-crucible-without-magmatic-engines.20606/.

15. Jemisin, *Fifth Season*; Jemisin, *Obelisk Gate*.

the changeability of the Earth itself. As Earth system and geologic science generate ever more authoritative data sets about significant events in Earth history, anthropologists and other social scientists are increasingly willing to consider the influence of changing Earth processes on human sociohistorical development. Across the arts and humanities, commentators have noted how a generalized interest in materiality is now morphing into a more explicit "geologic turn" in which theorists and practitioners "*direct sensory, linguistic, and imaginary attention toward the material vitality of the earth itself.*"[16] Concurrently, philosophers have identified a "speculative turn" in their discipline—characterized by new inclinations to think beyond human experience.[17] Also construed as a return to metaphysics—recently defined as "speculative theory on the nature of ultimate reality"[18]—philosophy's (re)discovery of realities that precede or exceed human presence frequently takes the geologic as a kind of test case.

When Graham Harman directs philosophy's attention to "the volcanic core of objects," he is making a case that all manner of objects have a hidden or "molten" interiority.[19] The reference point here seems to be not only the relative paucity of scientific knowledge about the inner Earth but the fact that the very process of bringing hot, viscous rock to the surface inevitably changes its properties. "We never gain a direct view of these underground functions," observes Harman of his generic philosophical objects; "as soon as we do, they have already been converted into something else."[20] Or as geologist Bruce Marsh speaks of his own objects of interest: "Once magma erupts, it begins cooling unusually quickly and it loses any gases that it may contain, so it really is a different animal."[21]

There is more at stake in the conjuncture of geology and speculative thought, however, than shared questions of how reclusive, more-than-human realities resist our ability to access them. It is also a matter of how reality exceeds *its own* manifest or actual forms. The "metaphysical" dimension of speculative philosophical thinking connotes a concern not just with what currently exists but with the conditions or processes through which not-yet-existent things might come into being—or what has been described as "a reality exceeding all of the particular facts of any given situation."[22] This is not, in itself, a novel philosophical issue. In the early twentieth century, for example, Henri Bergson extrapolated on Darwin's evolutionary theory to draw out the more general implications of life's inherent capacity to explore new forms. But the current generation of speculative philosophers draw attention to the overemphasis on biology and the relative paucity of "geologic" thinking among their predecessors. Revisiting the eighteenth century, Iain Hamilton Grant proposes that "the metaphysical dissymmetry

16. Ellsworth and Kruse, introduction, 25.
17. See Bryant, Srnicek, and Harman, *Speculative Turn*.
18. Harman, *Towards Speculative Realism*, 49.
19. Ibid., 131.
20. Harman, *Tool-Being*, 133.
21. Quoted in Johns Hopkins, "Magma Discovered," n.p.
22. Harman, *Guerilla Metaphysics*, 66.

that retains biology as a philosophical science while ejecting geology or chemistry from its remit has haunted the philosophy of nature ever since."[23] And in this regard, philosophical inquiry that hews to the biological while eschewing inorganic, mineral, or geologic processes is seen to be foreclosing far too soon on the imperative to truly think beyond human experience.[24]

It is Gilles Deleuze and Félix Guattari, in their collaborative work from the 1970s, who are most often credited with bringing the speculative or metaphysical dimensions of geology onto contemporary intellectual agendas. In *A Thousand Plateaus*, they not only identify the inorganic or geologic as a distinctive level of reality with its own properties and dynamics, they view this stratum as the condition of possibility of subsequent planetary developments.[25] In this way, Deleuze and Guattari salvage the "geo" from earlier, disparaging philosophical associations with foundationalism and stasis—reworking it into an unstable, excessive ground from which biological and social processes draw much of their potentiality. Influenced by their approach, Elizabeth Grosz explores how living organisms—including human beings—draw out and elaborate on creative possibilities that inhere in geologic processes,[26] while Manuel De Landa explicitly develops the theme of the generative qualities of subterranean molten rock on a planetary scale.[27]

What we refer to as speculative geologic thought has strong connections with the ways that aesthetic traditions and practices explore the permutations of media, materials, and bodies. It also takes a keen interest in science, though with a tendency to extrapolate from scientific development in "collateral" directions that are not necessarily a priority of scientists themselves.[28] In important ways, speculative approaches to geology overlap with the critical and interpretive impulses of the social sciences and humanities. Here we would point to such shared concerns as the uneven impact of Earth system changes on global populations, unequal distribution of access to geoscientific research and experimental opportunities, and the importance of "speculation" on mineral and energetic resources to the current global economic order.[29] But whereas critical social thought privileges active, deliberative encounters with worldly matters, speculative approaches to geology and other inhuman processes acknowledge and probe the limits of human intentionality. For if geologic processes are understood, to some degree, as subtending and conditioning human life, then these forces are likely to act on or through our social and individual bodies in ways that inherently exceed our capacity for control or knowledge.[30]

23. Grant, *Philosophies*, 10.
24. Ibid., 81.
25. Deleuze and Guattari, *Thousand Plateaus*, 40–49.
26. Grosz, *Chaos*.
27. De Landa, "Geology of Morals."
28. Grosz, *Nick of Time*, 157.
29. Weszkalnys, "Geology, Potentiality, Speculation."
30. Colebrook, "Queer Vitalism."

In the sense that it explores the open-endedness of change, speculative thought is bound up with time. Because potential for transformation "always threatens to destabilise or de-actualise" those beings or structures that are already existent,[31] the temporal logic in question is inherently as destructive as it is generative—as intimated above. In a related sense, Derrida explores the interplay of threat and chance that comes from the way that all living beings are caught up in movements between an unrecoverable past and an unknowable future.[32] Derrida's sense of a constitutive contamination of life by its outside, we suggest, invites more explicit consideration of how the integrity of "the living" is both violated and animated by its openness to geologic forces.

The significance of breaching the space between the inner and outer Earth, we propose, lends volcanism an especially pronounced speculative dimension. In the "speculative volcanology" that we work up over the next three sections, we are interested in both scientific and social scientific causality. But we have selected our three examples expressly because each one also admits of a kind of exorbitance: they involve moments when extrusion of magma generates far more possibilities than can be taken up or actualized in specific forms of human or nonhuman life. In this way, we seek to move between inquiry into causal relations and a more aesthetic or metaphysical reflection on the potentiality inherent in the molten interiority of our planet—setting out from a moment of life's *becoming with* volcanic processes that long precedes the emergence of our own species.

Magma, Metals, Metazoa: *Becoming Multicellular*

Life scientists, understandably, have long been curious about the ascendance of relatively complex multicellular beings—the *Metazoa*. As evolutionary biologist Lynn Margulis quips, there is no necessity for creatures "big like us,"[33] no inevitability about their eventual appearance on Earth. We metazoan beings, she insists, came to pass in a biosphere that microscopic, mostly single-celled organisms had successfully shaped and run for two billion years without our help.[34] In short, organisms of the archaea and bacteria domains (collectively known as prokaryotes) evolved all the major forms of metabolism that characterize terrestrial life and still play the predominant part in maintaining our planet as a place conducive to life. Why more complex creatures finally burgeoned is a question that brings together research in the earth and life sciences. And a key consideration is massive extrusion of mantle-derived magma.

The time is the Proterozoic—an eon characterized as prior to the proliferation of complex life—stretching from about 2,500 to 540 million years ago. The place is the landmass of Columbia, the supercontinent assembled from a convergent drift of crustal

31. Ibid., 80.
32. Derrida, *Dissemination*; Derrida, *Spectres*.
33. Quoted in Hird, *Origins*, 21.
34. Margulis and Sagan, *What Is Life?*, 68–72.

slabs some 1.8 billion years ago.[35] Super in quantity more than quality, to our eyes it would have seemed an interminable, barren expanse, largely devoid of visible life. For while land at this stage had been colonized by single-celled and colony-forming bacteria, multicellular life was still ocean-bound—and even there a marginal presence.

Evidence suggests that organisms with more complex cellular structures—including a membrane-enclosed nucleus and other distinct "organelles"—emerged in marine environments around 2.3 billion years ago. They were to form a new domain of life: the Eukarya—some of which would become multicellular and eventually metazoan. Like most living systems, eukaryotes require metals in minute quantities to perform respiration, digestion, photosynthesis, or any of hundreds of other metabolic processes. These trace metals are especially important for the catalytic activity of enzymes, which both accelerates and improves the accuracy of metabolic reactions.[36] For many millions of years, eukaryotic newcomers—inexperienced at foraging and hampered by less-pervious cell walls—had difficulty competing with their more permeable and better-practiced prokaryotic counterparts for "bioessential" metals such as copper, zinc, and molybdenum. But as researchers suggest, what tilted circumstances in favor of eukaryotes was a significant shift in the availability of key trace metals.

Around 1.9 billion years ago, according to geologist John Parnell and his colleagues, a huge volume of molten crust-forming material was pumped out of the mantle, an extrusion that helped consolidate the Columbia supercontinent.[37] Magma continued to well up through fractures in the continental plate. As well as reworking minerals already present in the supercontinental crust, this hyperactive plume delivered new material from the mantle to the surface—enriched with metals as it stalled and formed magma chambers.

Hardening into great expanses of metal-rich granite, the extruded rock gradually eroded over the next few hundred million years, releasing exceptional quantities of copper, zinc, and molybdenum. As Parnell explains: "We . . . believe that the metalliferous upper crust delivered a substantial flux of metals into terrestrial and shallow sedimentary environments in the Mesoproterozoic."[38] While useful for archaea and bacteria, these trace metals were especially conducive to the proliferation and diversification of eukaryotes. Parnell teases out the evolutionary implications of this surging availability of bioessential metals: "It was the introduction of the metals into these single-celled organisms that changed their chemistry and allowed them to evolve into the complex multi-celled organisms which were the first step towards more diverse life on Earth—and one of the new functions of the complex multi-celled organisms which developed at this time, was sexual reproduction."[39]

35. Parnell et al., "Heavy Metal," 751.
36. Andreini et al., "Metal Ions."
37. Parnell et al., "Heavy Metal."
38. Ibid., 753.
39. Quoted in University of Aberdeen, "Heavy Metal," n.p.

Care is needed here, for although bacteria and archaea reproduce in a variety of nonsexual ways, mostly involving budding or fission, they also exchange genetic material—which many researchers refer to as sexual activity.[40] What is new about eurkaryote sex is the way nuclei split into separate sex cells capable of fusing with those of another parent organism. While bacterial gene transfer and reproduction are also profoundly generative of diversity, the constant recombinance of parental genetic material characteristic of eukaryotic sex provides a new kind of "engine" of biological differentiation. So too, however, is sexual reproduction bound up with a new kind of termination. For the price of relying on reproduction involving transfer of half one's genetic material to offspring, Margulis reminds us, is the dawning of inevitable, preprogrammed death.[41]

And so, when we concern ourselves today with volcanoes threatening human communities or consider the impact of supereruptions on evolutionary pathways, we are generally thinking in terms of multicellular organisms—the inheritors of the eukaryotic lineage. These—especially our fellow metazoans—are the creatures whose individual lives or biological diversity matter most to us, but they are also the bodies that we know to have limited lifespans. In this regard, the very life and death with which we empathize may itself be as much the *product* of magmatic processes as it is *threatened by* volcanic activity.

In another sense, however, the life "big like us" that we find so precious is a kind of planetary luxury, by no means essential to the maintenance or flourishing of the biosphere. After all, the burst of eukaryotic diversification that signaled the end of the Proterozoic and the start of the Cambrian began some 540 million years ago—rather late in a tenure of terrestrial life that may exceed 4 billion years. Then again, necessity may not be life or the Earth's last word—for the many creative and exuberant ways that living things "contact and cross-fertilize the earth," as Grosz insists, are nothing to look down on.[42]

The rise of multicellular life did not need to happen, and the causal link with magma extrusions strung out over many millions of years remains contentious. But read speculatively, hypotheses about the role of volcanically derived bioessential elements in an evolutionary leap invite us to consider the "monstrous" subtending role of the inner Earth, the inseparability of geologic violence from biological becoming, and the implication of catastrophic and more gradual or linear temporalities. In the next section, we leap forward to another series of extrusive events whose ramifications are no less contentious or hypothetical: upsurges of magma that may have lured or provoked our more recognizable ancestors onto novel pathways.

40. Margulis and Sagan, *What Is Life?* 73–76.

41. Ibid., 114.

42. Grosz, *Chaos*, 20.

Continental Rifting, Fiery Extrusion: *Becoming Human*

Following fossil finds in the 1960s and 1970s, the East African Rift has been the hub of research on early development of hominins—a category comprising the multiple species of the genus *Homo* and its immediate predecessors.[43] While studies of human origin have taken physical forces into account, attention has most often focused on changing climate. Only recently has there been sustained interest in the tectonic forces at work in East Africa and their implications for an unspecialized, ground-dwelling primate.

The rifting of Africa's Ethiopian plateau is currently the largest-scale example of the extensional tectonics that occurs when a landmass overlies a major upwelling or "plume" of molten rock from the mantle—a more recent, scaled down version of the rifting of the Columbia supercontinent that featured in the previous section. As rising magma pushes the crust upward, fault lines open in the stretched rock—resulting in subsidence between rising flanks—with the melting of rock as it rises frequently generating volcanic activity.[44] The extensional tectonics that have been shaping the East African Rift for some twelve million years saw forested plains give way to more variegated topography of valleys, escarpments, and river terraces. This is a landscape where fertile sediment accumulates, surface water collects, a mosaic of vegetation flourishes, and foraging animals gather. But for geophysicist Geoffrey King and archaeologist Geoff Bailey, it is the affordances of a subset of this topographical diversity—volcanism and its distinctive traces—that are of most interest.

Volcanic effusions have featured in paleoanthropological accounts, notably through their discussion of the various kinds of volcanic rocks—basalt, granite, rhyolite, obsidian—that have been used to fashion tools. What King and Bailey do is to conceptualize volcanic rock not only as object but as milieu. Focusing on the pervasive presence of lava flows, they consider how extruded lava hardens into jagged, winding, braided ridges of rock. Coupled with shelter offered by scarps and canyons, King and Bailey contend, fields of lava would have provided natural stockades in which an agile, bipedal omnivore could seek refuge between forays into nutrient-rich environments.[45]

The importance of landform shaped by volcanic and tectonic activity, however, may stretch well beyond the primordial sites of *Homo*. King and Bailey propose that major pathways of human migration across and out of Africa follow tectonically active zones—which, like the "original" rift valley, provided sheltering rock formations, pockets of fertility, and buffering from climate change. Some of the earliest sites of human occupation beyond the African Rift—including parts of northwest Africa, the Jordan Rift, the southern Caucasus, and Indonesia—King and Bailey demonstrate, are zones shaped by "complex tectonics and intense volcanism."[46]

43. King and Bailey, "Tectonics."
44. Ibid.
45. Ibid., 269–70.
46. Ibid., 277.

Further possibilities arise out of this volcanic milieu story. Alongside language, tool using, and various forms of sociability, the capture of fire by hominins has long been considered axial in the "ascent" of the genus *Homo*.[47] Given the difficulty in distinguishing between "naturally occurring" fire and that ignited or proliferated by humans, the time and place of earliest hominin use of fire remains elusive. Though it is not central to their narrative, Bailey, King, and I. Manighetti hint at Rift Valley volcanic connections: "Very early evidence for the use of fire remains controversial, but the association of early hominid activity with volcanically active areas would certainly have enhanced the possibilities for observing and making use of the benefits and effects of fire and heat."[48]

In a hypothesis explicitly couched as "speculative," geographer Michael Medler extrapolates on King and Bailey's thesis to propose that lava flows were the most likely origin of the first fire captured by hominins. While lightning would have sparked wildfire in the African savannah and forest, Medler suggests that lava oozing from active volcanoes would have provided a more constant and approachable source of flame. There is evidence, he notes, that some Rift Valley volcanoes extruded lava over thousands of years: "During that time, sources of warmth and flame would have been available almost continuously as the flows would radiate considerable warmth and often ignite vegetation. Hominins may have learned quite early to stay near these fires and add fuel to the fires. Perhaps they even learned to move burning materials.[49]

Medler, we note, assumes that fire was, from the outset, *useful* to those who hazarded its handling. Likewise, more widely discussed theories of emergent hominin fire use, such as Richard Wrangham's claims about the evolutionary significance of the increased caloric content of cooked food, prioritize the quantifiable utility of fire over the more obscure circumstances of its capture.[50] However valuable such approaches may be for understanding the subsequent trajectory of "our" genus, their intentions are somewhat different from our own concern with speculating about how a living creature may have originally been lured or captivated by the "exorbitant" presence of Earth processes.

Without singling out fire, Grosz has considered how humans and other living things play variations on the colors, shapes, sounds, and rhythms they encounter in the elemental worlds around them. Beyond dictates of survival, she suggests, we and other beings respond to "provocations posed by the forces of the earth."[51] For Grosz, this nonutilitarian encounter with a vibrant, powerful, and often threatening cosmos is what characterizes, in the broadest sense, art. "Art," she professes, "takes what it needs—the excess of colors, forms, materials—to produce its own excesses, sensations with a life of their own."[52]

Perhaps—for a creature dwelling in the shadow of towering, effusive, and intermittently explosive volcanoes—the original brandishing of a flaming branch was less

47. See Pyne, *Vestal Fire*, 9–18; Medler, "Speculations"; and Clark, "Rock, Life, Fire."

48. Bailey, King, and Manighetti, "Tectonics, Volcanism," 43.

49. Medler, "Speculations," 20.

50. Wrangham, "Control of Fire."

51. Grosz, *Chaos*, 2–3.

52. Ibid., 9.

an act of utility than a symbolic gesture: an exuberant and expressive response to the sheer power of volcanism, which perhaps only later found an application.

Recent archaeological evidence zeroes in on a remarkable moment in the human exploration of such elemental potentiality. As early as seventy thousand years ago, researchers demonstrate, humans in coastal South Africa were using fire to change the properties of stone: heat treatment rendering raw stone into a form more amenable to flaking into tools.[53] Or perhaps into ornaments, we would add. As research team leader Kyle Brown sums up: "Here are the beginnings of fire and engineering, the origins of pyrotechnology, and the bridge to more recent ceramic and metal technology."[54]

Following this lead, the next section develops the theme of human agents playing variations on matter's expressiveness. Returning in a very different context to the role of magma-derived metallic elements broached in the "Becoming Multicellular" section, we look at some of the uses "our" ancestors made of high heat and ask what role volcanism may have played in the incitement to experiment with "colors, forms, materials."

Vulcan's Forge: *Becoming Industrial*

As historian Theodore Wertime expounds of the metallic elements: "They became catalysts of social life for men even as they had been catalysts of energy exchanges for cells in the biological organism."[55] Resonating with their impact on biological metabolism in the mid-Proterozoic, the introduction of metals seems to have enriched and accelerated the social metabolism of the early urban societies of the ancient world.

It was in the semiarid plateaus of the Middle East, archaeologists suggest, that artisans first learned to smelt ores and work metals.[56] Here, at the lively juncture of the Eurasian and Arabian tectonic plates, "cracks and faults in the earth's crust . . . allowed metal-rich magmas and fluids to ooze up from deep within the Earth towards the surface."[57] Mountain building pushed rock layers upward, and ongoing erosion stripped away overlying strata, exposing rich seams of metallic ore beneath the footfall of sharp-eyed nomadic peoples.

However, while some metallic ores in their "raw" state have a certain visual allure, the chemical changes undergone in the smelting process are dramatic. "The conversion of crystalline or powdery green or blue ores into tough red copper is a veritable transubstantiation," observes archaeologist V. Gordon Childe.[58] Archaeometallurgists have long puzzled over how the early metalworkers discovered and learned to reproduce the chemical pathways involved in converting crumbly ore into lustrous, durable metal.

The key to smelting seems to lie in seeing it as part of a broader suite of "pyrotechnolgies" that collectively built on the much longer human experience of manipulating

53. Brown et al., "Fire as Engineering Tool."
54. Quoted in "Early Modern Humans," n.p.
55. Wertime, "Pyrotechnology," 680.
56. Yener, *Domestication of Metals*, 1–2.
57. Stewart, *Journeys*, 112.
58. Childe, *What Happened*, 85.

fire—but pushed these skills in new directions through containment or chambering of flame.[59] Excavations of the Neolithic town of Çatalhöyük on the Anatolian plateau have uncovered some of the earliest known pottery works—dated at about nine thousand years old.[60] So too is the settlement one of the oldest sites with evidence of artifacts made from copper—most likely the first metal to be smelted. With their robust walls, built-in covers, and flues to regulate air supply, Çatalhöyük's pottery kilns, it is argued, would have been capable of reaching the 1100°C temperature required to separate copper from its ores. The fact that the same oxygen-poor atmosphere required to fire the red or black clay used by the potters of Çatalhöyük would have produced the conditions required to melt copper ores—together with evidence that copper ores were used as ceramic glazes—fuels speculation that the Anatolian settlement was a site where artisans "stumbled upon" smelting in the course of pottery making.[61]

While recent research raises pertinent questions about whether copper unearthed from Çatalhöyük was heated "native" copper or smelted ore, it also considers the intriguing possibility that deliberate burning of buildings may have converted entire houses into kilns capable of transforming ore to metal.[62] What is known with more confidence is that, as kiln and furnace technology developed, artisans across the ancient world regularly attained thermal levels in excess of 1200–1300°C. As metallurgist J. E. Rehder reminds us, these temperatures approximate the maximum heat of lava.[63] With this in mind, we might extend Pálsson and Swanson's sense of a "domestic" entanglement with volcanoes to take in the multitude of pyrotechnic artisans who, over several continents and many millennia, routinely introduced volcanic-scale temperatures and a molten transmutation of matter into the heart of village and urban life.[64]

The proximity of Çatalhöyük to a historically active volcano prompts further ruminations. Excavations of the Neolithic town have uncovered a wall painting featuring a "spouting" twin-peaked orange mound behind a black and white grid-like pattern. While interpretations vary, this is most often viewed as a volcanic eruption close to a townscape—a reading that has gained weight from recent evidence that the double-coned stratovolcano Hasan Dağı—some seventy miles northeast of Çatalhöyük—erupted about nine thousand years ago, a date very close to that of the mural's estimated execution.[65]

59. Wertime, "Pyrotechnology."

60. Rehder, *Mastery and Uses of Fire*, 9; Joseph, *Copper*, 1–2.

61. Joseph, *Copper*, 1.

62. Birch et al., "Metallic Finds," 315.

63. Rehder, *Mastery and Uses of Fire*, 54.

64. See Clark and Yusoff, "Combustion and Society"; and Clark, "Earth, Fire, Art."

65. Schmitt et al., "Identifying the Volcanic Eruption." See also the intriguing evidence of the depiction of volcanic activity in thirty-six-thousand-year-old cave art in Southern France, in Nomade et al., "Thirty-Six-Thousand-Year-Old Volcanic Eruption."

Heeding John Grattan and Robin Torrence's advice,[66] we are cautious about hitching significant sociomaterial transformations to a single volcanic event. But it is worth considering that the timing of Çatalhöyük's wall painting, kiln construction, and copperwork—and the more general takeoff of a range of pyrotechnologies—occurs in the early Holocene, a period characterized by rapid postglacial sea level rise. There is related evidence that crustal stress resulting from shifting ice volumes was implicated in intensified volcanic activity—enhancing the frequency of explosive volcanism in the eastern Mediterranean.[67]

Ancient peoples themselves certainly made clear links between volcanoes and artisanal fire, as evidenced by the frequency of deities who preside over both realms. Vulcan is the Roman god of fire, forges, metalworking, and volcanoes; his Greek counterpart Hephaestus the deity of fire, potters, blacksmiths, metals, and volcanism.[68] Etruscan fire god Sethlans is also associated with metalworking and volcanoes, while Egyptian demiurge Ptah, god of metalworkers, embodies underground fire and triggers earthquakes.[69]

The perceived continuity in ancient imaginations between inhuman physical forces and artisanal work with fire resonates with Grosz's vision of art as an extrapolation on the potentialities of the Earth. If we are not to be overwhelmed by the power of the cosmos, she adds, we must find some way to scale down and enframe its forces: to construct for ourselves "a small space . . . where chaos can be elaborated, felt, thought."[70] And it is in this conjectural sense that we might conceive of the kiln as a kind of corralling of igneous force, an enclosed arena in which fiery energy can be applied to earthly materials.

Even with the firewall of the furnace between the artisan and the molten transmutation of matter, it helped to have gods on one's side. "If the fire was too hot, or not hot enough," observes Alison Burford, "dire things could happen to both the pots in the kiln and the metal in the crucible, or to the object being annealed and worked with tongs and hammer."[71] Dire things could happen to artisans too, who risked burns, blindness, or worse each time they cranked volcanic temperatures from homemade heat chambers.[72] And when fire escaped, whole towns could be consumed by flame—a regular occurrence in the ancient world.

Although they may have had experimental or accidental origins, "the pyrotechnic crafts in the years between 10000 BC and 2000 BC became formidable industrial "disciplines."[73] Archaeologists who have identified high-output factory systems and

66. John and Torrence, *Living under the Shadow*, 1.

67. McGuire et al., "Correlation."

68. Pyne, *Vestal Fire*, 60–61.

69. Forbes, *Studies in Ancient Technology*, 83–85.

70. Grosz, *Chaos*, 24.

71. Quoted in Goudsblom, *Fire and Civilization*, 111.

72. Ibid., 110.

73. Wertime, "Pyrotechnology," 670.

far-reaching exchange networks have no hesitation in referring to "complex metal industries" that precede the so-called Industrial Revolution by five to six thousand years. By six thousand years ago, observes Aslihan K. Yener, the Anatolian successors of Çatalhöyük are running extensive metalworking workshops, having decisively made "the transition from trinket metallurgy to the production of large-scale tools and weapons."[74]

Pyrotechnic products transformed the ancient world: the bricks, plasters, concrete, ceramics, metals, and glass that issued from the kiln provided the very fabric of the built environment. Metallurgy in particular, returning to Wertime's point, had a *catalytic* role in the early city-states: "Metals . . . established the norms of weight and value and monetary trust for urban life as well as standards of utility for cutting, thrusting, digging, and killing."[75]

Perhaps only now, in the light of the Anthropocene thesis, are the geologic implications of Europe's perhaps not-so-singular eighteenth- and nineteenth-century Industrial Revolution gaining a full appreciation. But from a pyrotechnical perspective, the relatively recent arrival of fossil hydrocarbon-combusting heat engines builds on a lineage of chambered fire that reaches back at least as far as the early Holocene.[76] Just as the mineral products of magmatic extrusion were fed into the fiery furnaces of the ancient artisans, so too, we have been suggesting, might the kiln itself be construed as a kind of volcanic microcosm: a scaling down but also a focusing and directing of the Earth's own igneous forces.

As in our previous examples, if on smaller scale, the volcanic activity we refer to has a broad temporal distribution—as do the metallurgical sites in question. Again, rather than seeking causal relations between specific volcanic episodes and social or evolutionary developments, our concern is with the way geologic processes provide materials that creative and experimental actors are able to channel into new forms or expressions. Indeed, as recent "speculative" interventions have suggested, when theorizing deep, formative forces, we can find ourselves in domains or zones in which it is difficult to discern the kinds of objects or forms to which causal analysis conventionally orients itself. Thus McKenzie Wark speaks of "a time (out of time) before objects and subjects became distinct,"[77] while Bruno Latour depicts a "'metamorphic zone' . . . where 'metamorphosis' is taken as a phenomenon that is antecedent to all the shapes that will be given to agents."[78] Or, as we might say, an "igneous zone."

As we return to contemporary engagements with magma, it is worth considering that we may once more be entering a time or zone prior to subjects' and objects' assuming clear outlines, a realm where geophysics begins to blur into metaphysics, and mythical thinking becomes harder to distinguish from practical or scientific thought.

74. Yener, *Domestication*, 12.
75. Ibid., 680.
76. See Clark and Yusoff, "Combustion and Society."
77. Wark, "Viveiros de Castro," n.p.
78. Latour, "Agency," 13.

Igneous Futures and "the Magma of the Other"

Origin stories intrigue and enthrall, but as Derrida points out, they are also troubling and dangerous—especially when used to adjudicate what is "natural" for us to do or to be. The important thing, he counsels, is to try to imagine something other than a pure and stable origin, to allow for messier beginnings, the coming into being at breaches, ruptures, rifts. For any fantasy of "primitive mythical unity," Derrida cautions, ". . . is always reconstituted retrospectively in the aftermath of the break."[79]

The fissures and vents through which molten matter from the inner Earth finds its way to the surface are a potent and literal instantiation of Derrida's originary rifting. If major magma extrusions are one of the most life-threatening events in our planet's repertoire, as we have been suggesting, so too are they among the most generative processes in social and geohistory. It is unlikely that there is a living being, micro or macro, whose trajectory has not at some stage been swayed or rebooted by igneous processes. But this should not be seen as a simple determination. Above all, to work with and through volcanism or other geologic process, we stress, is to engage with an excess of possibility. To think in terms of *becoming with* volcanic and magmatic processes is to recognize that "we" and other organisms have actualized only a fraction of the potentiality that inheres in the geologic domain. Which is also to imagine that, however much damage our species has done to the Earth—or the Earth to us—there remain a great many biogeophysical avenues as yet unexplored or incompletely realized.

We need to consider all this and more, our speculative inquiry suggests, if we are to probe the potential of a new interface with magma. While no previous or inherited practices should in themselves legitimate a novel procedure, it is worth considering how test-drilling at Krafla is already borrowing both techniques and products from the long lineage of pyrotechnology. For just as the concrete and metal used to stabilize boreholes are ultimately products of ancient high-heat technology, so too is the very idea of installing a "firewall" around an intense heat source the crux of the pyrotechnic enterprise. If the early artisanal kiln functioned like a scaled-down volcano or magma chamber, then it could be said that something of this enframing and containment is now being returned to the originary site of active igneous processes: a shift from the furnace as volcano to the volcano as furnace. A move, we might hope, that the old gods look well upon.

For Deleuze and Guattari, this process of enfolding a fraction of the "outside" is one of the primary ways that humans and other living things carry out a transformative trafficking with the forces of the Earth.[80] Or as Derrida would have it, it is the inevitable and ongoing contamination of the "inside" by its "outside" that propels life along new, unforeseeable trajectories.[81] How best to perform such an enfolding, how to

79. Derrida, *Dissemination*, 304.

80. Deleuze and Guattari, *Thousand Plateaus*, 238–39; see also Clark, "Earth, Fire, Art."

81. Derrida, *Dissemination*, 101.

welcome or moderate the opening to exteriority being among the most profound ontological, political, and practical questions we confront. While human agents, acting collectively, might well choose to avoid excessive danger, certain strands of philosophical and cultural thought have long stressed that any significant change involves a degree of risk: "fire and games being always . . . a play of luck with necessity, of contingency with law," as Derrida puts it.[82] Or as Maurice Blanchot speaks of our constitutive exposure to forces that might overwhelm us, we come face to face with "the magma of the other."[83]

Accordingly, however much we undertake the most rigorous risk assessments, ultimately any intervention takes place in a context of uncertainty or undecidability. For, with any significant innovation—and especially one involving a novel interchange with a new and "enigmatic" stratum—there is no existing solid base—no "un-molten" ground—from which to secure a decision. To break through the Earth's crust and make contact with the vast, churning forces beneath is surely a kind of violence. But it must also be seen as an engagement with an Earth that is, in its own way, non–self-identical—an astronomical body that constantly, sometimes catastrophically, breaks with its own integrity.[84] That is, in Derrida's terms, we need to consider the essential "*non-contemporaneity with itself of the living present*."[85] For if indeed Krafla risks triggering eruptions or releasing toxic elements, we should also heed Derrida's counsel that the very structure of time is violent, that there is no futurity without a violation of that which we inherit from the past.

While the Anthropocene thesis has sparked a certain apocalypticism in some quarters, a focus on deep geologic time helps us appreciate just how often the Earth has interrupted—and rebooted—its own temporal flows. A crucial aspect of this temporal disjointing and rehinging, we have been suggesting, is the episodic "magmatic" interchange between the great subterranean forces of the Earth and the more "familiar" planetary surface.

A new, deliberate, and deliberated exchange with magma offers possible paths away from the reliance on carbon-emitting hydrocarbons that currently risks triggering an epochal, life-extinguishing rupture in Earth history—or what we might see as one more in a long series of catastrophic unhingings of time. We have no way of telling whether the Krafla Magma Testbed—and the possible rise of intentional interchange with the magmatic subsurface—might set our species or even our planet on some wholly novel trajectory. The ability to study magma in situ, before it has cooled and degassed, promises unique new insights on the physical and chemical state of subsurface magma bodies.[86] Moreover, extrapolation from this information opens new windows on

82. Ibid., 277.
83. Blanchot, "Indestructible," 240.
84. See Clark, "Rock, Life, Fire."
85. Derrida, *Spectres*, xix.
86. Elders et al., "Origin of Rhyolite," 231.

subsurface geophysical processes, with potential for improved understanding of tectonic processes, oceanic crust formation, and even seawater chemistry.[87]

It is when we try to imagine what other as yet unthinkable possibilities might arise from novel capacities to traffic with and manipulate magma that analysis slides into speculation, and the geophysical morphs into the metaphysical. In spite of or because of its hazardousness, an emergent intimacy with the igneous offers the chance of temporal opening, of a giving or inaugurating of time. Such becoming with magma, we speculate, would likely be as much aesthetic as scientific, as mythic as it is modern, a matter of imagination and play as well as technological innovation. Or rather, as a deep history of chance magmatic encounters suggests, art and technics constantly comingle in the bringing forth of geologic potentiality. For, in the words of Blanchot, "Art is tied to all that puts man in danger, to everything that puts him violently outside the world."[88] Or should that be *violently inside the world?*

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Acknowledgments

We are grateful to two anonymous referees for their exceptionally insightful comments. Thanks also to the participants at Unexpected Encounters with Deep Time: Violence, University of Edinburgh, 2016, where an earlier version of the paper was presented.

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87. Elders et al., "Drilling into Magma," 117.
88. Blanchot, *Friendship*, 33.

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