Penny Harvey

GEOLOGY AS UNCONFORMING INFRASTRUCTURE FOR THE HOSTING OF NUCLEAR WASTE

As the dramatic consequences of climate change finally begin to motivate governments around the world to explore how to move away from a dependence on fossil fuels, nuclear power is back on the agenda in the UK as a potential energy source. However, this new-found enthusiasm confronts a fundamental challenge—namely, that the radioactive wastes, accumulating since the very first nuclear power stations were built in the 1950s, have yet to be made safe for the long-term future. At the governmental level, there is a clear international commitment to the view that the most secure option for the management of radioactive waste matter is burial deep underground in an engineered geological disposal facility (GDF).[1] Finland leads the international field, and the repository at Onkalo is expected to be fully operational by 2025. The Swedish government approved plans for the construction of an underground repository for spent nuclear fuel in 2022, with Canada, France, Japan, Switzerland, the UK, and the USA all actively engaged in siting and design initiatives. Strategies for generating public acceptance of geological disposal vary, as do the modes of engagement, the investments of time and money afforded, and the decision-making processes. These processes are conceptually and politically challenging. They require not only technical expertise and scientific understanding across an entire range of disciplines, but also the imaginative capacity to think across scales of time and space in what Ele Carpenter (2016: 14) has suggestively referred to as 'reverse mining'.

However, the return of radioactive matter to the deep underground is no simple reversal. It requires the elaboration of an infrastructural system of unique ambition in the history of modern engineering. Some of the high-level radioactive waste that GDFs are designed to accommodate will take hundreds of thousands of years to decay to levels equivalent to natural uranium ore. The safety cases for these facilities assume a far longer time frame, with models built to a million-year time horizon. These capital-intensive, state-led projects are justified as a cross-generational public good with jobs and investments underpinning the promise of social transformation for the most affected communities, and environmental remediation and long-term protection the goal for both contemporary and future generations. Congruent with this framing, the dominant narratives of government departments and delivery bodies focus on the balance of risks, costs, and benefits.

Government policy for siting a GDF in the UK rests on a voluntaristic process in which the delivery body is charged with identifying a site where there is both a 'willing community' and a 'suitable geology'.[2] As I watched and listened to discussions about how to achieve this initial crucial siting milestone, I was struck by the recurring references to potential 'host communities' and to possible 'host geologies'. Hosting is a key concept that mediates the discussions of high-level nuclear waste disposal I have followed over the past four years through my engagement with policymakers, government delivery bodies, and residents of current search areas.[3] The waste materials themselves are, of course, central to the story, but their movements are contingent upon the possibilities and the limitations of specific hosting relations. It is these relations, and, specifically, the geological hosting relations implied by a GDF, that are the focus of this article.[4]

Anthropology has long had a strong interest in the ambivalent relationships of hospitality and the specific modes of moral reciprocity that they imply.[5] The host/guest relation rests on a sense of alterity, categorical difference, and a potential imbalance of power, such that the transformational possibilities afforded by the presence of outsiders are also acknowledged as threatening or even destructive. In the face of such a possibility, hospitality signals a rather particular ethic of care, a sense of responsibility to the outsider, and even a mode of protection. The UK siting process, and the overarching national project to deliver a geological disposal facility to house all of the UK's most highly radioactive waste, involves a whole range of social actors including not only departments of state, the delivery body, the producers and current holders of waste, the supply chain for the construction process, and the potential host communities, but also the dynamic physical structures of the Earth and the material relations that compose the subsurface world. The agencies of these diverse bodies and forces are all implicated in the movement of waste from the surface to the subsurface. In the rhetoric and the everyday talk surrounding this project, there are only two entities explicitly depicted as entering into hosting relations: the host community and the host rock. In what follows, I argue that the hosting concept offers a powerful ethnographic analytic through which to approach the categorical impositions and disruptions that comprise this infrastructural form. Engineering projects rely on technical knowledge, probability studies, scenario planning, risk assessments, and the elaboration of generic forms. The hosting concept complicates these abstractions and directs attention to the multiple temporal and spatial scales invoked in the siting process. These include the intrinsic instabilities of the key relational categories of both 'community' and 'rock'; the ambivalent political, moral, and ethical values in play; and the transformations and unconformities of the material relations that the infrastructure ultimately seeks to contain.

THE DIVERSE TEMPORALITIES OF HOSTING

A brief review of the history of the UK siting process sets the scene for my observations of these contemporary hosting relations. The first siting initiative got underway in the 1980s but was abandoned due to public opposition (Blowers 2016), with more than 20 years passing before another attempt was made. This time, government agencies took the advice of the recently established Committee on Radioactive Waste Management and tried to implement a voluntary process.[6] There was significant support for the initiative in West Cumbria, the region where most of the UK's high-level waste was already held in temporary storage at the Sellafield Nuclear Facility. However, there was also committed opposition (Bickerstaff 2012; Gregson 2012). The Sellafield site adjoins the Lake District National Park, and proposals generated a passionate rejection from those who feared irreversible damage to this protected environmental area. Scientific opinion as to the suitability of the geology of West Cumbria was also divided (Lee 2012). In addition, a widespread sense existed that, as in the past, the opinions and concerns of local people were not really listened to nor taken seriously (Blowers 2016).

By 2013, the delivery body accepted that the siting framework continued to elicit more resistance than enthusiasm. Nevertheless, the need for a permanent subterranean facility remained a priority. Government bodies revisited the policy and made changes that included a solid commitment to exclude the possibilities of siting within the boundaries of a National Park. At the end of 2018, a new initiative was launched with the release of the current 'Working with Communities' policy.[7] Under the terms of this policy, any interested party, such as an individual landholder or community stakeholder, can approach the delivery body to discuss the possibilities of siting in their area. These conversations are confidential and only made public once the delivery body has made an initial assessment of the prospects for the site in terms of the geology, transport links, and the possibility of sustained interest and support from local government. If these criteria are met, then a Working Group is formed to identify the specific electoral ward that could provide the surface site, or point of entry, for a GDF. Working Groups are formalised as community partnerships with a contractual relationship to the delivery body if at least one local council commits to participate in the process, alongside other community leaders and employers. The delivery body is also represented on the Community Partnership whose primary task is to work with the local community to define a future vision, to assess the potential contribution of a GDF to that vision, and to build information on the geology, transport links, and any other economic, political or social factors deemed relevant. At this stage, funds of up to £1 million per year become available for community projects within the siting area (always a political ward or wards). This funding can be increased to £2.5 million per year if the delivery body assesses that there are sufficient possibilities for meeting the criteria of a 'willing community' and a 'suitable geology' to justify investment in more intrusive investigations, including borehole drillings, as part of the geological characterisation process.[8] Both the Partnerships and the delivery body have the right to withdraw from the process at any time. Ultimately, however, after a period of several years, the Partnership has to conduct a meaningful test of public support to definitively demonstrate 'willingness'.[9] Only then can the delivery body finalise the design and apply for the formal Development Consent Order that allows construction and investment to proceed in accordance with national planning regulations.[10]

However, while there appears to be general agreement between the delivery body and the Community Partnerships that 'the community' needs to learn what the siting process involves—just as the delivery body needs to learn about their understandings, expectations, and fears—there is far less clarity regarding how a community might ultimately emerge as a stable and singular collective with the capacity to act as 'host' over the 150-year period needed to build and run a facility until the point of ultimate closure. Thus far, there is very little exploration of what hosting might involve beyond a commitment to compliant ongoing cohabitation with the waste. The possibility that a GDF could be considered for their area provokes deep anger in some people, allied to a sense of invasion and destruction.

Many assume, and fear, that decisions are effectively made elsewhere, that the process is out of their hands, and that to actively seek to learn about it is already a show of willingness and must, therefore, be resisted.[11] The delivery body obviously wants to identify a site for a facility and people to trust that it will be safe. However, while the personnel of the delivery body might hold the conviction that a GDF will deliver an invaluable 'public good', both for local people and for the wider public (including the taxpayers supporting the growing costs of maintaining the waste securely in temporary storage), they must also confront people's direct experiences of a nuclear industry with a history of not being open and honest with local people or addressing local concerns in a sustained and serious way. In West Cumbria, many have felt ignored or discounted by industry experts over the years. Whether or not people are conversant with nuclear technologies (and many are), many more have a deep knowledge of how particular projects undertaken in the name of the 'public good' landed in their communities in the past, with little or no appreciation of local politics or local needs.[12] These represent social knowledge, which some within the development company know they must learn about if they want to engage people, but others more readily dismiss as the outcome of ignorance, ideology or 'politics'.

As yet, there is no identified site and, in many ways, a GDF remains an abstract, conceptual possibility. However, in other ways, a GDF has already materialised as a major state infrastructure project. There is a government policy and a parliamentary endorsement of the commitment to geological disposal and to a consent-based siting process; there is a long-term public financial commitment of approximately £45 billion from the Treasury; there is an organisational hierarchy of government bodies including the Nuclear Decommissioning Agency (a non-departmental public body), and its subsidiary, Nuclear Waste Services;[13] and there is considerable activity and investment in technical research and design and in programmes of community engagement.[14] In other words, the institutional, financial, epistemic, and engagement infrastructures underpinning the possibility of a GDF already exist and have already begun to shape what it is that a GDF can be, regardless of *where* and *how* a GDF is ultimately built. For now, the infrastructure thus exists both in formation (as a generic form) and in suspension (until the siting decision is made).

The commitment of the volunteer community at the heart of a national infrastructure of this scale is unusual and produces a paradoxical effect. Despite the centralisation of government control over financing, regulation, design, and delivery, the *specific* design, budget, and timeline cannot be decided upon until a 'volunteer community' has committed to hosting a facility. It is proving rather difficult to know how long it might take for a 'community' to emerge as a stable, positively committed social entity, or indeed how such a 'community' might take a decision on behalf of others in both the near and the very distant future. The delivery body finds itself under pressure to deliver a site. It is their job to limit costs and get the project properly underway, but they appreciate that 'willingness' is both elusive and fragile. They are anxious not to provoke a contagious refusal. They want to listen to local concerns, but they also have their own concerns to manage, including their anxieties that uninformed opinions and misinformation might easily foreclose potential avenues of acceptance. In this context, the identification of a 'suitable geology' becomes critical for the reassurance and consolidation of emergent publics (Chilvers and Kearnes 2015).

Here again, things become complicated as the voluntary siting process does not begin with the notion of an optimal geology but is committed to work instead with the possibilities afforded by the *specific* geological environment of a yet-to-volunteer host community. Both a 'willing community' and 'suitable geology', thus, exist as co-dependent, open categories that have yet to be brought into being.

Beyond the complications of the voluntaristic siting process, the radically divergent scales of time, space, and material power that a GDF has to encompass also pose major challenges. The functionality of a GDF is ultimately framed in relation to geological time. The engineering of the design and safety rest upon the assumption that the infrastructure will gradually move towards a point of closure from whence no further human input or engagement will take place. Once completed and closed, the infrastructure will become a fully passive system. This ideal of total detachment could be seen as the classic utopian vision of civil engineering, whereby technical automation channels and limits human action in the name of rationalisation. However, a GDF has a far more radical ambition, to definitively isolate the radioactive materials from the surface and close off the way back. This radical shift from managed facility to passive system is to be achieved through the alignment of geological forces with those of a highly technical engineered infrastructure. Industry professionals refer to this as a multibarrier system comprised of nested layers of containment designed to impede the movement of radioactive matter, but also to ensure that there is no single point of failure.[15]

These precautions demonstrate that GDF design is not conceived in ignorance of the ongoing material processes underground. On the contrary, engineers work with geologists who take it as axiomatic that below ground a GDF will become integral to an alternative environmental system than that experienced on the surface. That system, nevertheless, will remain open-ended and will continue to transform. The movement of rock and of radioactive matter is assumed and responded to in every aspect of the design. In addition, much of the current experimental work that the delivery body undertakes focuses on the many material interfaces that the infrastructure needs to anticipate and accommodate. The open-endedness of this time horizon unfolds beyond the realm of human engagement and poses the challenge of how to think beyond the human scale into spaces that, while not currently unknowable, *are* ultimately designed to become inaccessible to future human intervention. The engineering out of human agency, nevertheless, requires a whole range of human artefacts both material and conceptual. Amongst these, one of the most significant is the conceptual separation of categories of time and space, the 'deep time' of the subsurface, and the 'human time' of the surface world (Ialenti 2020).

Deep time is a geological and ultimately cosmological concept that scholars of nuclear technologies routinely deploy to draw attention to the exceptionally enduring vitality of radioactive matter (Hecht 2012, 2018; Ialenti 2020, 2022; Irvine 2014, 2020; Morton 2013). Geologists, astrophysicists, and cosmologists immerse themselves in the study of deep time as they explore both the origins and the demise of planets, stars, and universes. Their understandings of deep time are central to the conceptualisation of a geological disposal facility as an infrastructure of permanent disposal. Yet, the siting and construction of a GDF begins at the surface or near-surface of the Earth. The human host community must, first, receive the waste and facilitate its route to the deep underground, to the world of geological time, where the rocks will be supported to take over as hosts in a time–space that no longer relies on the continuity of human existence to oversee the containment of radioactivity.

The ongoing vitality of this anthropogenic and highly radioactive matter is of huge concern to many people. The materials are deeply political in the sense that their very existence indexes the power struggles, entrenched inequalities, and divergent values of a highly securitised industrial economy. In this context, and with the awareness that there can never be absolute certainty with respect to the impact of a GDF on future generations, there are those who question the ethics of geological disposal. Gregson (2012), for example, criticises the disposal of highly radioactive waste in a GDF as an act of abandonment. A GDF is, indeed, a proposal to deliberately remove these materials from the surface and to leave them deep underground, effectively forever. However, it is not an act of abandonment that ignores the ongoing vitality of these nuclear waste materials (as Gregson suggests), but rather rests on a calculation of the relative risks, costs, and benefits of deep geological disposal compared with surface storage options. Such calculations should, of course, be closely scrutinised. Debates about nuclear waste are also congruent with contemporary fears about the future habitability of the planet, provoked by a new-found awareness of limited resources, fragile environments, and the extreme vulnerability of many human and other-than-human lives (Chakrabarty 2021; Latour 2018; Latour and Weibel 2020). Much effort in the broad field of environmental humanities is now directed at fostering conversations about collaboration with the natural sciences, and about how to live well on and with the Earth.

Nigel Clark (2013: 2825) suggests that a growing awareness of the limits to human agency and the consequent sense of vulnerability might induce the industrialised world to think more deeply about what he refers to as a new 'geologic politics (…) a turn from issues hinging on territorial divisions of the earth's surface toward the strata that compose the deep temporal earth'. In this respect, he suggests that the discourses and imaginaries of geoengineering do not *necessarily* imply a retreat from politics (that is, from the human struggles over how best to configure our relationships to the earth at the surface). These could perhaps invite an extension to the scope of politics to include the other-than-human agencies of deep subterranean rock.[16] A GDF offers one example of how a future geological politics might be framed.

Anthropologists and social historians of nuclear matters have long been attentive to the beyond-human timescales of radioactive materials, many of which have half-lives that far outreach the horizons of human being.[17] Hecht (2018) recognises the need to think beyond the human scale, but not at its expense. Her determination is to find a way to 'hold the planet and a place on the planet on the same analytic plane' (Hecht 2018: 112). She pays attention to what is revealed and hidden by specific scaling practices, and she analyses the political and ethical work that scalar choices and claims accomplish. Using examples of what she refers to as 'interscalar vehicles' as diverse as the map, uranium, the atom bomb, and the international benchmarks used to calibrate and compare the bodily harm caused by exposure to radiation, Hecht looks not only at what each of these devices makes knowable or significant and what they hide or erase, but also at what they bring into dialogue and on what terms. To disappear the waste through the invocation of a geological scale might well deflect attention from the ongoing 'slow violence' (Nixon 2011) of nuclear waste in the here and now. At the same time, geological disposal could offer protection to both human beings and the wider environment from the lethal hazards of many legacy wastes. It is in recognition of this ambivalent possibility that I return to the multi-scalar relations of a GDF as an infrastructural system, and to the ways in which the hosting relation operates as an interscalar vehicle promising to enable the transfer of highly radioactive waste from the surface to the subsurface.

As noted previously, the transfer is not a simple return or reversal. Both mining and engineered disposal involve potentially damaging human intrusion, and too often hubris and the violence of neglect. Nevertheless, the stakes of geological disposal are not identical to those discussed by critics of industrial extraction. Indeed, while disposal is undoubtedly a corporate and state-led enterprise, with interests that connect to future investments and related extractive activities, it also carries the ethical dimension of the hosting relation as a moral gesture of care and protection in the face of an unknowable future.

GEOLOGY AND THE ANTHROPOCENE

The promoters of a GDF face a somewhat paradoxical situation as they argue for the responsible removal of radioactive waste from the surface of the planet at a time when previous human irresponsibility, with respect to both discards and extraction, might challenge the wisdom of a proposal to further penetrate the subsurface with the deliberate intrusion of radioactive wastes. Other disposal alternatives were considered in some detail (CoRWM 2006), including the possibility that the wastes could be launched into outer space. This solution was discounted not only in relation to cost, but also because it had never been attempted before and was, thus, unproven. In conversation with geologists, I also learned that the underground offered a huge advantage over outer space with respect to the rates of dispersal of highly radioactive matter. In space, the movement of particles accelerates. Deep burial produces an opposite effect. Underground, the process of dispersal will slow down, engaging a dimension of time external to the fluctuations of the surface and of the biosphere. The ultimate aim of the multibarrier approach to geological disposal is, thus, to embed the engineered structure in a specific geological environment. Here, human time and the time of radioactivity are collapsed into a single geological moment and, thus, rendered inconsequential: 100 000 years barely registers on the geological time scale.

At a geology conference organised by the delivery body, the chief geologist introduced a general audience to the three basic or generic rock types that could meet the requirement for the isolation and containment of waste, each chosen for their ability to slow down the movement of radioactive particles. The three categories of rock are hard rock, clays and mudstones, and evaporites, each with its own particular advantages and disadvantages. Hard rock is an obvious candidate for a GDF. In Sweden, as in Finland, the construction of a GDF is about to begin in granite rock that is more than a billion years old. The challenge with hard rock is that it is brittle and can sustain open fissures and networks that groundwater and gas can flow through. In these environments, geologists look for evidence of blocks of rock without fractures and, thus, with limited hydraulic connectivity.

Clays and mudstones have a certain advantage over granite, because the movement of this rock affords a self-sealing capacity. The rock also has a low permeability, and a permeability that further decreases over time. Its long-term behaviour is deemed highly reliable. At the same time, clay rocks are not as strong as hard rocks such as granite and would not as easily withstand the pressure of expansion caused by the heat of high-level radioactive waste. A GDF in clay rock would need more space across which to distribute waste containers. Evaporites such as salt rock are practically impermeable and, like clay, they 'creep' and, thus, operate their own self-healing mechanism. But they also throw up their own challenges, not least the exceptional difficulty of accurate mapping. Salt structures often remain transparent, and three-dimensional seismic data do not easily reveal the evidence of absence that geologists need to find. Boreholes, core sampling, and underground geophysical investigations are then needed, which risk compromising the integrity of the rock formation.

The work of geologists in search of evidence for stability connects to the eighteenth-century roots of the discipline, when the theory of uniformitarianism and consistent gradual change displaced previous biblical theories of catastrophe and abrupt change (which were pretty much erased from the agenda until relatively recent times). The work of James Hutton, Charles Lyell, and others established that the earth's history was one of slow geological transformation via processes unfolding over time at even, predictable rates. Their work led to a reappraisal of the age of the planet, and completely changed the time horizons of humanity. Furthermore, their approach was fundamental to Enlightenment as a way of thinking about human beings and human capacities and ushered in what we now look back on as the age of 'modernity' with its focus on planning and improvement (Gould 1988; Ghosh 2016). Then, as now, rocks were approached as semiotic repositories and sign systems, which held the secrets of the origins and evolution of life on Earth. What changed from previous eras, and what has continued to change since, are the methods of observation and interpretation. Only much more recently have the meanings of the geological traces of 'deep time' begun to be more systematically inferred through the deployment of ideas about probability and improbability grounded in statistical thinking, and projections both forward and back in time enabled by contemporary simulation and modelling techniques.

These techniques have, in turn, made visible the complexities of the geological record. The most spectacular are perhaps the missing years of rock from the Earth's geological record, referred to as unconformities. Geologists have calculated that the Great Unconformity of the Grand Canyon in the USA registers a missing 725 million years between what are now two adjacent strata. Questions regarding whether the causes of the discontinuity or gaps in the geological record are due to a series of gradual erosions or more sudden events are debated. Either way, geologists refer to these gaps as 'lost time'. Contemporary fascination with abrupt changes and with lost time continue to inflect human understanding of the history of the planet, as well as opening new sites of possibility for resource prospecting. These sites of intrinsic uncertainty and of possibility are what excite geologists. A Swiss geologist presenting at the conference explained the choice of a claystone site for a Swiss GDF in these terms: 'We have to make sure that the geology makes a good contribution. We need to maximise the contribution of the geology to the multibarrier system. We excluded the Alps for their rapid uplift rates, and other areas for tectonic complexity. We looked for host rock at the right depth and thickness. We discounted strongly faulted zones and came up with the three most boring sites of Swiss geology.' These are not sites with the best stories; they are sites where nothing had happened for millions of years. A GDF incites a search for rock that is otherwise unremarkable. Suitable geology implies stability and conformity, and geologists look for evidence of an absence of activity, a complex task given that the evidence gathering itself involves intrusion into the layers laid down in the deep past.

Geological research is also fundamental to assessments of how the rock will behave in the deep future. The deep past is accessed via a range of sampling and scanning techniques. The deep future, by contrast, is evidenced by analogy, a mode of reasoning that rests on the theory of uniformitarianism, whereby changes in the materiality of the Earth's subsurface are slow and gradual. Ialenti's (2000) ethnographic work with the Finnish GDF at Onkalo looks in detail at how experts connect the deep past and the deep future through analogical reasoning. He gives the example of Lake Lappajärvi, a crater lake in Finland that formed when a meteor crashed into Earth some 73 million years ago (Ialenti 2020). A detailed study of this rock formation allowed geologists to demonstrate the changes that have (and crucially have not) occurred over this time frame. On this basis, they can project forward with confidence on the likelihood of significant activity over the next 100 000 years, a very short period on the geological timescale.

Geologists do not ignore the possibility of a future dramatic change; they simply search for sites where there is a high probability that change will occur on an entirely different time horizon from life on the surface of the planet. Their models anticipate extreme climate change, continental glaciation, seismic activity, and human intervention. In public presentations, and in response to concerns frequently voiced over the effects of climate change, geologists reiterate that the temporal scales of change are quite different on the surface than they are underground. While the rise in sea levels will have devastating consequences in some places, in others changes will be negligible over the 100- to 150-year period of operation when the facility would be most vulnerable to water intrusion. Continental glaciation is a near certainty over the next 100 000 years, but the geological record provides an assurance (by analogy) of an absolute cut-off for glacial erosion at 200 metres, the minimum depth at which a facility would be constructed. The frequency of seismic activity must be assessed for any site, but the UK is not close to tectonic plate boundaries and, thus, major earthquakes are not assumed to pose significant risk.

Calculations of optimum depth for a GDF are, thus, drawn by analogy with previous events of ice-age erosion and changes in sea levels. Central to all these calculations by analogy is the recalibration of time. As stated above, one million years in geological time is but the blink of an eye, while 100 000 years barely registers on the scale of planetary time. Thus, despite the clear understanding of the perpetual fluidity of rock, the relative speed of change in the geological environment is such that waste is stabilised by time itself. Above ground, nuclear waste is out-of-time with life on the surface of the planet, where its enduring vitality poses a continual lethal threat to the biosphere. Below ground, its vitality is neither exceptional nor long-lasting. This arrangement leaves open the possibility of human intrusion and the unwelcome, and unpredictable, possibility of a future intersection of human and geological times. There are interesting experiments at all geological disposal sites, which consider how to communicate the existence of this underground hazard to future populations with the knowledge that we have no idea whatsoever what kinds of language or communicative processes might be significant or intelligible in future. These thought experiments in nuclear semiotics can only ever be speculative and rest upon an imaginary interpretation with no stable signifiers or points of reference. The exercise, nevertheless, offers a significant reminder of the fragility of the barrier between surface and depth. At the surface, all geologists can do is attempt to clarify whether or not the chosen geologies might become of interest for those looking to exploit natural resources. What cannot be avoided is the possibility that a GDF itself might become one such resource.

We, thus, reach the point where we return to the surface and to human time. However powerful the arguments about the ultimate stability of geology, this infrastructure of detachment must still be brought into being and its integrity maintained in human time. Here, the uncertainties and possible unconformities begin to multiply, even if we remain within the field of geology itself. Contemporary geology is primarily oriented towards resource prospecting, whether for minerals or in relation to the tracing of pollution plumes and the effect of mining and industry on water courses. From an anthropological perspective, there is important work emerging from these fields of practice as ethnographers follow the ways in which multiple data sources are brought together to produce 'reliable data' in specific times and places, following in detail how the criteria for reliability are assessed and by whom.

Gisa Weszkalnys (2015) described the speculative reasoning that prevails in the fields of oil and gas prospecting, drawing attention to how the search for a potentially valuable resource involves a continual balancing of the cost of the search in relation to the speculative value of what might be discovered. Geology becomes entangled with investment decisions, the different kinds of risks that must be managed, and the affective force of the resource potential. Thus, while such searches are data driven, they also involve many other kinds of embodied understandings including hunches, expectations, desires, aspirations, and negotiated possibilities. So, too, with a GDF.

Andrea Ballestero (2019, 2020) also draws attention to the subterranean interfaces where geology, the economy, and social concerns intersect. She analysed the geological detection techniques used to trace how a major oil spill affected a local water source in Costa Rica, and described how the geologists were working not simply on the rocks, but on the subterranean interfaces where nature, the economy, and social concerns intersected. She used the example of 'plumes' of hydrocarbon pollutants, learning from geologists how these were traced and described. Their focus was on the movements of the contaminating hydrocarbons within the movement of water courses. They worked to detect and trace the form, size, and speed of plumes, *and* the type of containment in which they were moving—that is, the solubility, density, and velocity of the groundwater movement. She observed that a plume 'is movement within movement and is scientifically studied under the rubric of fluid dynamics. In technical language, plumes of contamination in aquifers are described as migrant or stable (…) How expansive or contained a plume's contours are is also a matter of textural relations between the intruding substance and the substances in which it tries to move' (Ballestero 2020: 5). These tensions between conceptualisations of discrete (bordered) entities and the more fluid, situational textural relations are commensurate with what comes to the fore when we turn our attention to the hosting relations of a GDF. Ballestero's argument focuses on the way in which modes of description create a sense of reality, in this case a disputed reality. The legal case that she followed hinged on two very different hosting relations. In one, the aquifer was a discrete entity, the container of a plume; in the other, a more elastic or topological figure of oscillating concentration and movement, one that resisted 'being infrastructuralised' (Ballestero 2019: 22). This tension between the bordered and fluid figuration also pertains to a GDF, where hosting always involves encounters across difference and ambiguous shape-shifting processes in which distinctions between hosts and guests become difficult to maintain.

HOSTS AND GUESTS

If narratives of geological time remove the alarm from the subterranean post-closure life of radioactive waste, I want to pursue the idea that the 'hosting' relation might offer another layer of reassurance via the analogy between rocks and communities, which posits the hosting of waste as an ethical act. The Swiss geologist speaking at the conference referred to above wants to ensure that rock makes a good contribution to the process; he wants the rock to be effective. At times, it can seem as if the appropriate *community* contribution might simply involve not making a fuss, to comply and let engineering works proceed. But the community is called to go further, forming partnerships and acting as hosts. Although largely unacknowledged, the community is thus called into being through the invocation of an ethical and moral relationship. But, to whom or to what exactly? What are the desirable hosting capacities and how might these be cultivated and sustained over what is a very lengthy period in human time?

On the surface, the hosting relationships of a GDF are particularly ambiguous, given that the 'host community' itself is only drawn into being through the hosting process. Even if we suspend that complication, it is unclear at what point the community moves from hosting the state (in the guise of the developer who comes with incentives, criteria, science, policy, and financial resources) to hosting the construction process (where a whole swathe of private companies will arrive with machinery, materials, job contracts, supply chains, and the control of all kinds of movement and the circulation of materials, money, jobs, and information). At a much later stage, different organisations will arrive to begin the operational phase, when increased securitisation will accompany the radioactive waste materials on their journey underground. There is a possibility of protests and occupation at any stage. All these relationships suggest that the identity of a host might easily transform into that of the occupied or besieged. Many who were once guests are likely to stay and become residents, as well as hosts to the ongoing processes both above and below ground. Once the facility is closed, and the rock takes over the task of hosting the waste, future generations will no longer serve as hosts in an active sense.

What will the waste itself have become in the meantime? Ethnographers of hospitality have also pointed to the tension between transformation and domestication that hosting implies.[18] Antinuclear activists who oppose a GDF clearly fear its capacity to domesticate nuclear power by providing a solution to the waste. This concern echoes concerns about how waste in general is made to disappear using techniques of spatial and temporal distancing and/or by rhetoric and other calculative and distancing practices designed to reassure and remove blocks to consumption (a topic explored by Alexander and O'Hare 2020). These are clearly important issues, and the decision by the UK government to include the waste from new nuclear facilities challenges the previous narrative of the 'public good' that argued for a GDF in relation to the urgent need for environmental remediation of legacy wastes. There is a well-founded concern that a GDF will, in practice, enable future nuclear technologies and the generation of new, and as-yet-unspecified wastes.

Hosting relations above and below the surface are also not commensurate in ways that are themselves revealing of the unconformities of geological infrastructures and the central role that temporal discontinuity plays in the shaping of their imaginaries. For a start, a host community must assume the role of host voluntarily, but a willingness to host does not imply that a community exercises any kind of sovereign rights in the extension of an invitation to another. Hosting does not imply control over the process but is achieved through a dance of consensus and coercion. It emerges from an offer and from imposed conditions of subsequent compliant cohabitation, such that a GDF can appear as an ethical act and not a sacrificial act on the part of the community in question. In the projected timeframe for the construction of a GDF, the developer anticipates that full agreement to build a facility might take many years. During this time, the host/guest relation holds a specific kind of ambiguity. It remains unclear whether 'the guest' will decide to stay. The 'volunteer community' puts themselves forward as a candidate who may or may not be chosen. The 'volunteer community' can also decide to end the relationship right up until the test of public support. There is, thus, a lengthy period of exploration and negotiation around the terms of a potential co-habitation, while 'the community' lives with the construction phase and the ongoing negotiation of an 'offer' is concluded.

Once the radioactive waste materials begin to arrive for disposal below ground, a new phase begins. For a period of approximately 100 years, the hosting relationship will be shared between those above ground and the rock below. The community at the surface is not directly involved in the negotiations between rock, radioactivity, and nuclear expertise below the surface. Gradually, the rock will take over the hosting role, until ultimately it is presumed that the regulatory agencies of the future will end the phase of human hosting. Over time and below ground, the radioactive wastes will become incorporated and themselves become the guest that never leaves. From the perspective at the surface, incorporation is viewed as a highly undesirable possibility that sits alongside a fear that the transfer below ground will reduce their capacity to shape the relationship with the wastes going forward. In short, this imagined coming into being of a GDF reveals an ever-shifting sense of moral, political, and economic claims across social spaces and across generations, where insiders and outsiders can never be definitively defined and where both 'geos' and 'bios' are also constantly transforming internally and in relation to each other.

CONCLUSIONS

This article has focused on the relationship between two key hosting relations that sit at the heart of the UK government initiative to provide a geological disposal facility for the long-term management of highly radioactive nuclear wastes. This infrastructure of disposal requires the active participation of a willing host community and a suitable host rock. It also requires the navigation of radically different scales of space and time, and the management of intrinsically ambivalent hosting relations. This ambivalence appears not only in the shifting perceptions of ethics and morality that a GDF poses with respect to intergenerational, intragenerational, and future generational needs, or to the multiple needs and fragilities of the biosphere and the wider environmental ecologies, but also with respect to the granular specificity of the hosting relation itself. Hosts and guests are not always clearly bordered or discrete entities, but emerge as relational and dynamic forms, moving at different speeds above and below ground.

The level of empirical detail that Ann Kelly (2012) could draw on in her analysis of the hosting relations involved in the study of malarial transmission in Tanzania has yet to unfold for the case of a GDF. However, even at this very early stage in the process, the intrinsic instabilities of the fundamental host/guest relations at the heart of a GDF programme are visible and significant. It may still take many years to identify a 'willing community' and a suitable host rock. If the search fails, the policy might have to be revised. Nevertheless, the hosting idiom remains important because it makes the moral and ethical dimensions of the siting relation explicit, without negating the ambivalence and the powerful disconnections that are also in play. In this way, a focus on the cross-scalar temporalities of hosting, around which the UK's GDF programme is currently conceived, might open possibilities for a new awareness of 'geological politics'. The policy framing of a GDF could, perhaps surprisingly, encourage a new awareness of the interdependence of human life and rocks deep below the surface of the earth.

The anthropologist Jerry Zee has argued that anthropology and geology are compatible thought spaces in that they are both disciplines that are highly attuned to transformative potential (Zee 2020: 3).[19] The GDF project provoked me to think about such transformations at a time when environmental change appears almost unstoppable and potentially catastrophic. Nuclear power and its waste products are highly controversial figures in this space, deeply implicated in environmental pollution in the recent past, from weapons testing to the irresponsible dumping of waste. Furthermore, there is an ongoing tendency for governments to be more enchanted by the next technological possibility than by the need to ensure that the previous overflows have been securely contained. Nuclear waste management is a space of disputed sovereignty, at times unaccountable public investment, and an inward-looking securitised environment where there is little room for meaningful public engagement. However, the growing international consensus on the need for secure long-term isolation of the most hazardous waste opens a different arena in which it is acknowledged that *in practice* the technology cannot be abstracted from the site in which it will be built.

It is not currently possible to deliver a GDF until enduring alliances are forged with a specific human 'community' (above ground) and a specific rock formation (below ground). Even if a UK 'community' declared itself willing to host waste today, the delivery body still has to maintain that willingness for well over a century, until final consent is granted for the facility to close. It is perhaps in the spaces of such negotiations that a future Earth politics will take shape and demonstrate that the ambivalent sociality of hosting is more prevalent and more significant than a dichotomy of acceptance or refusal allows. For now, the hosting relation provides a conceptual language with which to think about engagement with the subsurface beyond the practices of violent extraction or the hubris of technical control. This brings the diverse temporalities, connections, and associations between the surface and subsurface into view in the context of a gesture of care and protection that is not simply imposed, but which also must accept the uncertainties and unconformities of material worlds beyond the horizons of the human imagination.

PENNY HARVEY
PROFESSOR
SOCIAL ANTHROPOLOGY
UNIVERSITY OF MANCHESTER
penny.harvey@manchester.ac.uk

ACKNOWLEDGEMENTS

This article was first presented as the Westermarck Lecture, sponsored by the Finnish Anthropological Society, and delivered online in October 2021. I am grateful to the Society for the invitation and for the questions and feedback from the virtual audience. I subsequently presented the work to members of the Beam Social and Nuclear Research Group at the Dalton Nuclear Institute, University of Manchester; to members of the Manchester Social Anthropology Writing Group; to participants at the anthropology seminar at University College London, and to the History of Science Technology and Medicine seminar at the University of Manchester. Timothy Choy and Marisol de la Cadena, at the University of California at Davis, were also very generous with their time and their feedback, as were the journal editors and two anonymous reviewers. I am very grateful for all the comments and questions that continue to keep me thinking.

NOTES

1 The advice to UK policymakers from the independent Committee on Radioactive Waste Management outlines the key arguments in support of this position (CoRWM 2006 and 2018).
2 In 2018, the delivery body was Radioactive Waste Management. In 2022, the organisation was restructured and renamed as Nuclear Waste Services.
3 I am deeply indebted to my anthropological colleagues in the Beam research group at the University of Manchester. Their in-depth ethnographic research on spaces of nuclear decommissioning in West Cumbria (Petra Tjitske Kalshoven, Ian Tellam), and in the USA (Basak Saraç-Lesavre) has been a constant source of inspiration and learning. See thebeam@manchester.ac.uk for details of projects and publications.
4 Since 2017 my research on nuclear decommissioning has been supported by the British Nuclear Fuels Endowment Fund. The fund has charitable status and is administered by the University of Manchester to support independent academic research on nuclear. In 2019 I was appointed to the Committee on Nuclear Waste Management (CORWM). CoRWM is sponsored by the UK governments (of England, Scotland, Wales, and Northern Ireland) to provide independent scrutiny and advice on the long-term management of radioactive wastes. Through my work on CoRWM I have had the opportunity to closely follow the UK siting process, and to learn both from my fellow committee members, and from the many different organisations, government and non-government agencies, communities and individuals involved in the process. I am grateful to all those who have spent time explaining things to me. All errors in interpretation are mine alone.
5 See the collection by Candea and da Col (2012) for a review of this field and for a recent set of essays.
6 In 2003, the Committee on Radioactive Waste Management (CoRWM) was asked to make recommendations for the long-term management of the UK's higher activity waste. Their 2006 report recommended geological disposal as the best available long-term solution, the need for safe and interim storage in the meantime, and the

need for ongoing research and development. They also recommended the importance of a consent-based process.

7 Department for Business, Energy & Industrial Strategy, 2018.

8 In spring 2024, the equivalent in euros—€1.13 million—was earmarked for the early stages of participation, increasing to €2.83 million if boreholes are drilled.

9 Community Partnerships are charged with devising this test of public support. Current discussions suggest that a referendum with a very low turnout or with a small majority voting in favour would not be taken as indicative of public acceptance. From the delivery body perspective, the ideal would be a situation in which local areas are actively competing to house a facility.

10 The first Community Partnerships were formed in West Cumbria in late 2021. By August 2023, there were four active partnerships. Three of these were in the region of West Cumbria, where most of the UK's high-level radioactive waste is held in temporary storage at the Sellafield Nuclear Facility, the fourth formed on the East coast of England in Lincolnshire, where people have little if any experience of the nuclear industry. In late 2023, one of these partnerships was terminated due to limited suitable geology.

11 A position discussed by Li (2015) in relation to consultations by mining companies in Peru, where local people refused to be drawn into the consultation process for fear that engagement would be used as evidence of a willingness to collaborate. See also Cooke and Kothari (2001).

12 Key examples from West Cumbria include Bickerstaff (2012), Bickerstaff et al. (2010), Wynne et. al. (1993) and Wynne (1998).

13 The Nuclear Decommissioning Agency (NDA) was formed by the Energy Act of 2004 to deliver the decommissioning and clean-up of the UK's civil nuclear legacy. NDA owns the UK's nuclear legacy sites and acts primarily as a strategic and governing body. The delivery bodies, subsidiaries of NDA, have changed several times since 2004. In 2022, Nuclear Waste Services replaced the previous organisation, Radioactive Waste Management. The delivery body in 2013 was NIREX. Given the frequency with which these organisations appear and transform, I refer to them simply as 'the delivery body' in this article. Furthermore, much of the work of the delivery body is subcontracted to large and small companies in an extensive and growing supply chain.

14 Department for Business, Energy & Industrial Strategy, 2019.

15 To this end, nuclear waste is first vitrified or otherwise solidified by processes of cementation. The solid waste forms are placed in stainless steel canisters, which are, in turn, further enclosed in a thick overpack of corrosion-resistant materials before being buried in a layer of low permeability clay, and then surrounded by 200–1000 metres of 'host rock'.

16 The anthropological record features numerous detailed accounts of the many ways in which diverse human societies have long paid close attention to their relationships to Earth, to rocks, and to the wider cosmos. For a specific focus on rock, see, for example, Cruickshank (2005), Harvey (2019), Povinelli (1995), and Raffles (2020).

17 See, for example, Gusterson (1998), Hecht (1998, 2012, 2018), Ialenti (2020, 2022), Irvine (2014, 2020), Masco (2006), McBrien (2016), and Saraç-Lesavre (2020).

18 Kelly (2012) offers a vivid example of the ambivalence of the hosting relation, which arose during her research on scientific experimentation on malaria in rural Tanzania. The scientists built an experimental hut that was designed to simulate the site of malaria transmission on a domestic scale. However, on the ground, she found that the relatively straightforward scenario that scientists had conceived was constantly destabilised by the changing dynamics of the relationships involved. The experimental hut produced multiple configurations of the host/guest relation that emerged from the cross-scalar juxtaposition of divergent knowledges and positionings of the scientists and villagers, domestic and experimental spaces, mosquitos and human beings, and mosquitos and pathogens.

19 For more detail see Zee (2022).

REFERENCES

Alexander, Catherine and Patrick O'Hare 2020. Waste and Its Disguises: Technologies of (Un) Knowing. *Ethnos* vol. 88(3): 419–443. https://doi.org/10.1080/00141844.2020.1796734.

Ballestero, Andrea 2019. The Underground as Infrastructure? Water, Figure/Ground Reversals, and Dissolution in Sardinal. In Kregg Hetherington (ed.) *Infrastructure, Environment, and Life in the*

Anthropocene. Duke University Press, pp. 17–44. https://doi.org/10.1215/9781478002567-003.

Ballestero, Andrea 2020. The Plume: Movement and Mixture in Subterranean Water Worlds. Theorizing the Contemporary, *Fieldsights*: 22. https://culanth.org/fieldsights/the-plume-movement-and-mixture-in-subterranean-water-worlds.

Bickerstaff, Karen, Irene Lorenzoni, Mavis Jones and **Nick Pidgeon** (eds.) 2010. Locating Scientific Citizenship: The Institutional Contexts and Cultures of Public Engagement. In *Science, Technology & Human Values* 35:4 474–500. https://doi.org/10.1177/0162243909345835.

Bickerstaff, Karen 2012. "Because we've got history here": Nuclear waste, cooperative siting, and the relational geography of a complex issue. *Environment and Planning A*, 44(11): 2611–2628. https://doi.org/10.1068/a44583.

Blowers, Andrew 2016. *The Legacy of Nuclear Power*. London: Routledge. https://doi.org/10.4324/9781315770048.

Candea, Matei and Giovanni da Col (eds) 2012. The Return to Hospitality: strangers, guests, and ambiguous encounters. *Journal of the Royal Anthropological Institute* 18 (s1). https://doi.org/10.1111/j.1467-9655.2012.01757.x.

Carpenter, Ele 2016. *The Nuclear Culture Source Book*. London: Black Dog Publishing.

Chakrabarty, Dipesh 2021. *The Climate of History in a Planetary Age*. Chicago, IL: University of Chicago Press.

Chilvers, Jason and Matthew Kearnes 2015. *Remaking Participation: Science, Environment and Emergent Publics*. London: Routledge. https://doi.org/10.4324/9780203797693.

Clark, Nigel 2013. Geoengineering and Geological Politics. *Environment and Planning A: Economy and Space* 45 (12): 2825–2832. https://doi.org/10.1068/a45646.

CoRWM, Committee on Radioactive Waste Management 2006. Doc. 700. Managing Our Radioactive Waste Safely.

CoRWM, Committee on Radioactive Waste Management 2018. Why Geological Disposal? CoRWM Position Paper.

Cooke, Bill and Uma Kothari (eds) 2001. *Participation. The New Tyranny?* London: Zed Books.

Cruickshank, Julie 2005. *Do Glaciers Listen? Local Knowledge, Colonial Encounters, and Social Imagination*. Vancouver: UBC Press.

Department for Business Energy & Industrial Strategy 2018. Implementing Geological Disposal. Working with Communities. UK Government

Department for Business Energy & Industrial Strategy 2019. National Policy Statement for Geological Disposal Infrastructure. UK Government.

Gould, Stephen Jay 1988. *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time.* The Jerusalem-Harvard Lectures. Cambridge, MA.: Harvard University Press.

Ghosh, Amitav 2016. *The Great Derangement: Climate Change and the Unthinkable*. Chicago: University of Chicago Press. https://doi.org/10.7208/chicago/9780226323176.001.0001.

Gregson, Nicky 2012. Projected Futures: The Political Matter of UK Higher Activity Radioactive Waste. *Environment and Planning A: Economy and Space* 44 (8): 2006–22. https://doi.org/10.1068/a44600.

Gusterson, Hugh 1998. *Nuclear Rites: A Weapons Laboratory at the End of the Cold War*. Berkeley: University of California Press. https://doi.org/10.1525/9780520353602.

Harvey, Penny 2019. Lithic Vitality: Human Entanglement with Nonorganic Matter. In Penny Harvey, Christian Krohn-Hansen and Knut Nustad (eds.) *Anthropos and the Material*. Durham, NC: Duke University Press, pp. 143–160. https://doi.org/10.1215/9781478003311-009.

Hecht, Gabrielle 1998. *The Radiance of France: Nuclear Power and National Identity after World War II*. Cambridge: MIT Press.

Hecht, Gabrielle 2012. *Being Nuclear: Africans and the Global Uranium Trade*. Cambridge, MA: MIT Press.

Hecht, Gabrielle 2018. Interscalar Vehicles for an African Anthropocene: On Waste, Temporality, and Violence. *Cultural Anthropology* 33 (1): 109–141. https://doi.org/10.14506/ca33.1.05.

Ialenti, Vincent 2020. *Deep Time Reckoning*. Cambridge MA: MIT Press. https://doi.org/10.7551/mitpress/12372.001.0001.

Ialenti, Vincent 2022. Boiling sand, metallic fire. Technopolitics and temporal form in an Idaho nuclear waste accident. *American Ethnologist* vol. 49(3): 387–400. https://doi.org/10.1111/amet.13089.

Irvine, Richard 2014. Deep Time: An Anthropological Problem. *Social Anthropology* 22 (2): 157–72. https://doi.org/10.1111/1469-8676.12067.

Irvine, Richard 2020. *An Anthropology of Deep Time. Geological Temporality and Social Life*. New Departures in Anthropology. Cambridge: Cambridge University Press. https://doi.org/10.1017/9781108867450.

Kelly, Ann 2012. The Experimental Hut: Hosting Vectors. *Journal of the Royal Anthropological Institute* 18: S145–S160. https://doi.org/10.1111/j.1467-9655.2012.01769.x.

Latour, Bruno 2018. *Down to Earth: Politics in the New Climate Regime*. Cambridge: Polity.

Latour, Bruno and Peter Weibel 2020. *Critical Zones: The Science and Politics of Landing on Earth*. Cambridge, MA: MIT Press.

Lee, Matilda 2012. Battlelines Drawn as Cumbrian Residents Square up over Nuclear Waste Site. *The Ecologist* 15.02.2012. https://theecologist.org/2012/feb/15/battlelines-drawn-cumbrian-residents-square-over-nuclear-waste-site. <accessed 10.04.2024>

Li, Fabiana 2015. Unearthing *Conflict: Corporate Mining, Activism, and Expertise in Peru*. Durham NC: Duke University Press. https://doi.org/10.1515/9780822375869.

Masco, Joseph 2006. *The Nuclear Borderlands: The Manhattan Project in Post–Cold War New Mexico*. Princeton: Princeton University Press. https://doi.org/10.1515/9781400849680.

McBrien, Justin 2016. Accumulating Extinction. Planetary Catastrophism in the Necrocene in Jason Moore (ed.) *Anthropocene or Capitalocene? Nature, History, and the Crisis of Capitalism*. Oakland CA: PM Press, pp. 116–137.

Morton, Timothy 2013. *Hyperobjects: Philosophy and Ecology after the End of the World*. University of Minnesota Press.

Nixon, Rob 2011. Slow *Violence and the Environmentalism of the Poor*. Cambridge, MA: Harvard University Press. https://doi.org/10.4159/harvard.9780674061194.

Povinelli, Elizabeth 1995. Do Rocks Listen? The Cultural Politics of Apprehending Australian Aboriginal Labor. *American Anthropologist* Vol. 97 (3): 505–518. https://doi.org/10.1525/aa.1995.97.3.02a00090.

Radioactive Waste Management 2017. The Multibarrier Approach. UK Government.

Raffles, Hugh 2020. *The Book of Unconformities: Speculations on Lost Time*. New York: Pantheon Books.

Saraç-Lesavre, Basak 2020. Desire for the 'worst': Extending nuclear attachments in Southeastern New Mexico. *Environment and Planning D: Society and Space 38*(4): 753–771. https://doi.org/10.1177/0263775819889969.

Weszkalnys, Gisa 2015. Geology, Potentiality, Speculation: On the Indeterminacy of First Oil. *Cultural Anthropology* 30 (4): 611–639. https://doi.org/10.14506/ca30.4.08.

Wynne, Brian, Claire Waterton and Robin Grove-White 1993. 'Public Perceptions of the Nuclear Industry in West Cumbria'. Bibliographic information available from INIS: http://inis.iaea.org/search/search.aspx?orig_q=RN:34004547. Available from British Library Document Supply Centre- DSC:02/41264.

Wynne, Brian 1998. May the Sheep Safely Graze? A Reflexive View of the Expert-Lay Knowledge Divide. In Scott Lash, Bronislaw Szerszynski and Brian Wine (eds). *Risk, Environment and Modernity: Towards a New Ecology*. London: Sage Publications, pp. 44–83.

Zee, Jerry 2020. The Dust Kaleidoscope. Theorizing the Contemporary. *Fieldsights*: 22 https://culanth.org/fieldsights/the-dust-kaleidoscope.

Zee, Jerry 2022. *Continent in Dust: Experiments in a Chinese Weather System*. Berkeley: University of California Press. https://doi.org/10.1525/9780520384101.