[CN] 8 [/CN]

[CT] Geosocial Polar Futures and the Material Geopolitics of Frozen Soils [/CT]

[CA] Juan Francisco Salazar and Klaus Dodds [/CA]

[A] Introduction [/A]

[TXF] In the last 150 years, the world has lost half of its topsoil due to erosion, intensive agriculture, and the industrialization and urbanization of the planet (Pimentel 2006). The scale of this impact becomes even more significant when considering that topsoil acts as an interface in the regulation of the flows and transfer of key elements between the atmosphere, biosphere, hydrosphere, and lithosphere. As David Pimentel concluded:

[EXT]

Careful management of these vital resources [i.e., soils] deserve high priority to ensure the effective protection of our agricultural and natural ecosystems. If conservation is ignored, the 3.7 billion malnourished people in the world will grow and per capita food production will decline further. (2006: 132)

[/EXT]

[TXT] As María Puig de la Bellacasa has made clear, historically, “the predominant drive underlying human–soil relations has been to pace their fertility with demands for food production and other needs, such as fiber or construction grounds” (2017: 169). In this chapter, we look at soils that are often considered marginal to conversations about topsoil and soil erosion, namely polar soils, as opposed to temperate and tropical soils or urban soils. Puig de la Bellacasa notes: “[A]t the turn of the twenty-first century, Earth soils regained consideration in public perception and culture due to global antiecological disturbances”, and “[h]uman–soil relations are a captivating terrain to engage with the intricate entanglements of material necessities, affective intensities, and ethico-political troubles of caring obligations in the more than human worlds marked by technoscience” (2017: 169). These are precisely some of the questions that animate this chapter, which we use to develop a different approach from the perspective of geological politics and geosocial futures.

[TXT] Rather than deem frozen soils as simply inert and infertile, we address a generative terrain where these soils service human and nonhuman communities, store carbon-rich resources, suspend past life in frozen animation, and, when thawed, reveal the contested politics of settler colonialism, resource capitalism, and anthropogenic change. Permafrost, a giant cold-storage compost heap stuffed full of frozen carbon, is ground that remains frozen for two or more consecutive years. It is the bedrock of Arctic terrestrial environments, containing rock, soil, sediments, bacteria, and varying volumes of ice that bind these materials together through a range of what Karen Barad has termed “intra-actions”: a dynamism of elements and forces in which all the “stuff” of permafrost soil is constantly caught up in an “open process of mattering through which mattering itself acquires meaning and form through the realization of different agential possibilities” (2007: 141). Often found under a thin layer of topsoil, permafrost can range from less than one meter thick, like in the Antarctic, to 1,500 meters, as in many parts of Siberia or North America. It stores the carbon-based remains of plants and animals that froze before they could decompose. Permafrost can be frozen for tens or hundreds of thousands of years and is in a permanent process of geological becoming. However, as recent studies in the Canadian Arctic indicate, permafrost is now thawing at levels not previously expected until 2090, more than 70 years early because of climate change (Farquharson et al. 2019). Drawing on Tim Ingold’s illustration of the temporality of materials (2012: 41), we argue that permafrost, like ice, not only exists in time but also is the “stuff of time” itself in the polar regions (Salazar 2018).

[TXT] The Arctic and parts of the Antarctic Peninsula are warming at twice the rate of the rest of the planet. In both instances, they have become sources of evocative imagery and amplified sentiment concerning environmental change (Nilsson and Christensen 2019). They have also turned into a spatial setting for climate crisis discourses (Paglia 2016) and—in the case of the Arctic—an opportunity to expand economic exploitation and generate new controversies around militarization and securitization. The polar regions are no longer peripheral frontiers. Over the past century, polar landscapes have been subjected to extraordinary endeavors designed to probe their subterranean interiors and submarine environments (Dodds and Nuttall 2016: 64). At issue today are “scrambles” over resources, control over shipping routes, and increasing securitization (Dodds and Nuttall 2016: 14). Polar soils are not inert backdrops to these geopolitical and geo-economic dramas; they are active mediators in their expression. The extreme, as opposed to normal and seasonal thawing of permafrost, is overwhelming existing social-political practices and infrastructures. If the ground being frozen is no longer reliable, then travel becomes more dangerous and costly and infrastructure such as pipelines, roads, and housing is destabilized. Life in Arctic communities is infinitely more livable if things are kept perma-frozen (Dodds and Nuttall 2019). This is most significant, for instance, in the case of Shishmaref, Alaska, which has been home for millennia to a tightly knit Iñpuiat community and which observers have often called “ground zero for climate change in the Arctic” (Martin 2018). Drowning islands and the resistance of Indigenous communities is one facet of this predicament. In a recent study, Crate and colleagues (2017) show how Indigenous Sakha (Yakuts) in northeast Siberia have used thermokarst areas for animal husbandry for at least the last half millennium. This practice is encountering serious difficulties due to permafrost thawing. Thermokarst is a landscape characterized by topographic depressions because of thawing ground ice; these are today being transformed at an unprecedented rate due to climate change. Similarly, across the western Arctic (Canada and Alaska), the thawing of ice-rich permafrost is also significantly disturbing thermokarst landscapes, which is detrimentally affecting cultural resources, for instance, as recorded for the Gwich’in nation in the northern Yukon (Andrews et al. 2016). These are only two cases among dozens of profound instances of climate injustices against Indigenous peoples of the Arctic. As Kyle Powys Whyte (2017) would ask, is this a case of colonial déjà vu? Most certainly. Climate injustices associated with ice melt and permafrost soils thawing are the most recent episode of “a cyclical history of colonialism inflicting anthropogenic (human-caused) environmental change on Indigenous peoples” in the Arctic, who are facing climate risks “largely because of how colonialism, in conjunction with capitalist economics, shapes the geographic spaces they live in and their socio-economic conditions” (Whyte 2017: 88).

[TXT] While topsoil in the polar regions was always too thin to cultivate under standard settler colonialism, colonialism has happened by other means. The Arctic is also tantalizingly rich in terms of what it is capable of incubating and revealing in terms of past life and future exploitation and microbial biodiversity. With melting and thawing, different worlds are being revealed—sunken, flooded, shifted, muddied, and displaced. Permafrost thaw is providing not only ample evidence of the past reborn (materials being exposed that were previously hidden) but also disruption with fears that native communities might “vanish.” In the polar regions, it is clear that the planetary system is transitioning toward a different, and partly unpredictable, state, or what in paleoecology and ecological forecasting is sometimes referred to as “no-analogue climates” (Williams and Jackson 2007). The global climate emergency is being felt profoundly in the polar regions, and these changes indeed are also taking place below ground, fostering changes in “the climate of soil” (Granjou and Salazar 2019).

[TXT] Polar soils are sites of and for promissory investment and speculative intent. To reappraise the ways in which we “think-with” soils in the polar regions, both materially and conceptually, we link our efforts to calls to think “beyond existing dependencies of social worlds upon particular geological strata and to imagine alternative ‘geosocial’ futures” (Clark and Yusoff 2017: 3). This has implications for thinking about a novel “geo-logic” of the polar regions (Salazar 2019). Drawing on the notion of “geosocialities,” which Palsson and Swanson define as “the commingling of the geologic and the social and the sensibilities involved” (2016: 151), we also wish to picture the intricacies of geology in its relation to social life. In the case of the Arctic region, as Michael Bravo has shown, dominant discourses of Arctic geopolitics and geosocialities are often too blind to the realities of life in the Arctic as peoples and ecosystems are persistently trivialized or where an alternative arrangement of imaginings of a habitable Arctic interwoven with densely linked networks of Inuit routes, rich and deep in cultural meanings, is often rendered invisible (Bravo and Sörlin 2002; Bravo 2018).

[TXT] Geosocial politics in the polar regions often unfold through a logic of abduction, an anticipatory politics of preemption, precaution, and preparedness (Anderson 2010) wherein a material event, such as permafrost thaw and melting sea ice, can quickly turn into an index or a proxy for a wider assemblage of geopolitical entanglements (Dittmer et al. 2011). This is much less the case in the Antarctic than it is in the Arctic, where the dynamic instability of ice sheets, for instance, or the thawing of permafrost, become a code through which the political instability of the Arctic region can be grasped. As Bravo attests through his long-term work in the Arctic, “the melting of sea ice and other frozen states such as permafrost adds another dimension to the accelerated warming of the atmosphere caused by greenhouse gases” (2017: 27). However, as Bravo adds, “what hasn’t yet been adequately explained are the politics of frozen ecologies, and why they matter for the majority of citizens of the globe living in cities with no special interest in visiting the polar regions. Cryopolitics is the story of how the earth’s frozen states have come to matter in the age of the Anthropocene” (ibid.).

[TXT] We use the term “thermal geopolitics” as a framing device to examine how permafrost surfaces as a figure of both concern and hope in the northern polar region. Our discussion of frozen soils is attentive to what we call the everyday volumetrics of life and how it is being altered by thaw and melt. Sea ice and permafrost undergo seasonal thawing, which in many cases enables life forms to thrive and take advantage of summer light, open water, and additional moisture. Human and nonhuman communities, over millennia, have learned to work with what might be considered “normal” thermal regimes. Frozen soils are integral to “thermal geopolitics,” because the state of permafrost has shaped the scope and potential of settler colonial states such as Canada to “land” the northern fringes of the North American Arctic. Abnormal thawing poses existential challenges to not only smaller Indigenous/native settlements but also settler colonial infrastructures. In the Arctic, thawing permafrost is generative of disaster imaginaries, a new and unwelcome world where the effects of contemporary global warming are felt first. Thereafter, we turn to Antarctica, which lacks the extensive landscapes of permafrost soils whose changing dynamics cause so much fascination and trouble in the northern hemisphere, but which is, however, abundant in microbes, as well as being actively reimagined as a frontier for biological prospecting. Polar soils prove to be anything but inert companions in our interrogation of a polar geopolitics, which is being animated by thawing and warming, or what we call might call, drawing on Puig de la Bellacasa (2019), a reanimating of polar soils through science, culture, and community.

[Insert Fig. 8.1 here]

[A] Frozen soils and thermal geopolitics [/A]

[TXF] In many other parts of the world, soil enhancement and management are increasingly being enrolled in a range of social and political projects in response to concerns over climate change, environmental degradation, biodiversity loss, food security, and rural livelihoods (for an influential study, see Blaikie 1985). The capacity of humans to disrupt soil systems on an unprecedented scale has become apparent, at the same time as social life continues to be intensely underwritten by the biogeologic agency of the planet’s soils. As Mark Whitehead (2014) reminds us in his geographical interrogation of the Anthropocene, the Dust Bowl storms of the 1930s provided a disturbing example of what is at stake when vast amounts of earth and topsoil are blown away by severe winds. Made worse by extreme drought compounded by inappropriate farming methods, the result was devastating to millions of American and Canadian families and communities. It remains one of the most serious environmental disasters in modern North American history.

[TXT] When we turn to the colder parts of the world, the relationship between soils and human communities is less well appreciated. In the recent past, our temperate framings such as “dust bowl” would have made little sense in the Arctic region. Polar soils were considered “reliably frozen.” The permafrost found in Alaska was different to the soils and ground that America novelist John Steinbeck narrated in *The Grapes of Wrath* (1939). Nowadays, however, dust storms are not uncommon in Arctic regions. When snow cover retreats earlier than it used to, glacial flour, river silt, and soil are suddenly a lot more exposed to late winter storms. Ice and snow cover used to hold things in place, in other words. Drier summers also allow for more material to be picked up by strong wind flows and then deposited elsewhere. These storms disrupt air and road transportation and, in the most severe cases, cost lives.

[TXT] Unseasonal early snow cover retreat in combination with warmer and drier summers in the Arctic is inverting our geographical framings of polar soils and the subsurface. The implications are profound given the soils concerned. Scientists estimate that the world’s permafrost holds 1,500 billion tons of carbon, almost double the amount of carbon that is currently in the atmosphere (Cho 2018). As permafrost thaws, the scope and diversity of change is mind-boggling. Rising temperatures cause frozen ground to thaw, and thus accelerate and facilitate decomposition of organic material. The conversion of soil organic carbon into methane and other greenhouse gases is not just restricted to the underground. Subsea permafrost located off the continental shelves of Russia and the North American Arctic is also adversely affected by rising temperatures.

[TXT] The largest submarine permafrost stores are found in the 2 million km2 of the East Siberian Arctic Shelf (ESAS). The ESAS was submerged around 12,000 years ago as the world entered the warming period known as the Holocene. The ESAS is so large that it has been calculated as holding 80% of the world’s known subsea permafrost hydrate deposits. The ESAS is thought to be highly vulnerable to thawing and methane release because of ongoing warming trends.

[TXT] The interaction of soils with humans is demanding ever greater attention because the evidence is mounting that anthropogenic change is leading not only to soil loss but also to a fundamental change of state; the Arctic ice is melting and warming in unprecedented ways. Forest fires in the summer are at an all-time high and permafrost thawing is destabilizing previously frozen ground. For thousands of years, the subterranean and submarine Arctic has captured a vast amount of carbon as plant life (roots and other organic matter which was not fully decomposed) was covered by ice and water. As the Arctic warms, subsurface permafrost (permanently frozen soil) is thawing and being broken down by microbial activity. As thawing continues, methane and carbon dioxide are being released. In short, Arctic soils are likely to be shifting from a net carbon reservoir to a net source. The thawing of the Arctic is one of the key stories of the present time. As we have described elsewhere (Salazar and O’Reilly, forthcoming), microbes awakening in the muddy permafrost thaw spew large amounts of methane as they chew and decompose organic matter. These processes are more than passive objects of human concern or regulation. The “thawing” of the Arctic is often being cited as productive of new geopolitical imaginaries, with wide-ranging implications for northern communities, Arctic states, and extraterritorial parties.

[TXT] The release of carbon dioxide into the shallow waters of the continental shelf and thereafter the atmosphere exemplifies what Isabelle Stengers terms “Gaia’s intrusion into collective historicity.” The challenge for these “catastrophic times,” as Stengers puts it, is to develop a more sustained engagement with the politics of varied matters (2015: 54, 117). As subsea permafrost thaws, it releases methane bursts. This has consequences beyond atmospheric change. The pressurized release of gas creates underground instability on the continental shelf. Scientists are able to use hydroacoustic technologies to monitor, measure, and represent methane release, which takes the shape of bubble clouds. As they breach the surface, these bubble clouds release further methane. Thawing subsea permafrost sets in motion a biophysical and geochemical pattern of change above and below the water surface.

[TXT] A great number of human settlements in the Arctic are rooted in and structured by permafrost dynamics; thawing permafrost brings with it physical disruption and financial cost. Much of the Arctic’s landmass is covered by permafrost, with vast and continuous areas found in Siberia and the North American Arctic. Permafrost is often termed “permanently frozen ground,” but this description may not be the most accurate because permafrost is not necessarily “frozen,” and, as recent studies have shown—and as Inuit have been experiencing first hand—it may not always be permanent. Several northern communities have incorporated research on changing permafrost conditions into their coastal adaptation planning. There are reports that thinning sea ice jeopardizes modes of transportation and that thawing permafrost destabilizes community infrastructure (Mustonen 2005; Sakakibara 2008). Thawing wreaks havoc when ice loses volume as it turns to slush and water. Thawing permafrost underneath or at the edge of a lake can cause it to drain like a leaky bathtub, with disruptive consequences for human and nonhuman communities. Landslides are common, and erosion exacerbates an already precarious situation.

[TXT] Environmental writer Renée Cho (2018) vividly recounts how, in her time reporting in the Alaskan Arctic, thawing permafrost becomes a matter of concern for northern settler and Indigenous communities:

[EXT]

In Bethel, Alaska, walls are splitting, houses are collapsing, and the main road looks like a kiddy rollercoaster. In the coastal town of Kongiganak, sinking cemeteries prevent Alaskans from burying their dead in the ground. The village of Shishmaref, located on an island five miles from the western Alaska mainland, has eroded so much that it is contemplating total relocation. These communities are being plagued by permafrost that is thawing.

[/EXT]

[TXT] Permafrost invokes, embodies, and animates a particular relational ethics that, as Puig de la Bellacasa would argue, becomes “a lively *beingness*” that manifests “a world of ‘companions’ sharing the trouble” (2014: 33). The great “awakening” of the Arctic is one where frozen and inert elements are reanimated by warmth and moisture. Thawing permafrost releases methane fumes and restores life to bacteria and microbes preserved by low temperatures and lack of oxygen and sunlight. Thawing carcasses have enabled new bacterial and zoological possibilities to emerge, as reports of infections take hold of humans and animals. New pathogens are being discovered in ancient permafrost. New and old life forms commingle and co-produce one another. Arctic soils, long frozen, are incubators of microbial life, a reservoir of gases, and a crucible for past animal and plant life. Permafrost thaw is the textbook definition of positive feedback, where warming generates further thaw, microbial activity, and methane release.

[TXT] All of this, we believe, needs to be understood as integral to a “thermal geopolitics.” Permafrost shaped the scope and potential of settler colonial states like Canada to settle the northern fringes of the North American Arctic. Incapable of supporting agriculture and “land improvement,” the boundary between sporadic and permanent permafrost necessitated a different form of colonial occupation. In Canada, Greenland, and Alaska, Indigenous peoples were displaced, dispossessed, and sent “south” to residential schools. Indigenous communities were also deployed in the occupational strategies of settler states. Notably, in Cold War Canada, an Indigenous community of 87 in northern Québec was relocated in 1953 to the Northwest Territories in a deliberate attempt to artificially populate remote spaces. This relocation, seen as an experiment, was designed to bolster Canadian sovereignty in the High North—prompting characterization of the community as “human flagpoles”—while providing new opportunities for communities affected by poor hunting in the north of Québec. The relocation proved disastrous. Indigenous peoples were in effect dumped on freezing permafrost and given insufficient support in terms of food and shelter. The end result was a heartbreaking tale of suffering and extraordinary courage in the face of elemental extremes and food shortages (McGrath 2006).

[TXT] While Indigenous ontologies have long recognized land, ice, and water as living actors entangled with human lives and other communities, the 1953 High Arctic relocation was a telling example of a settler colonial conceit: that Indigenous peoples are well adapted and resilient and thus well able to cope with “Arctic” environments. No allowance was made for the fact that the human and physical geographies of the Arctic are diverse. The Canadian North was considered to be a “frozen desert.” What mattered was that northern territories be populated and studied. Permafrost was a topic of considerable academic and political attention (Farish 2006). Attracting substantial government funding, universities across Canada focused their intellectual energies on cold-weather frontier engineering. Making sense of permafrost was integral for Canada’s resource sector, government scientists, and armed forces.

[TXT] What changed between the 1950s and the 2000s was a fundamental reframing of frozen soils in the North American Arctic. Permafrost used to be thought of as a problem that cold-weather engineers would study, advise upon, and find a solution for. The challenge for the communities of people in the military and the mining/petroleum industries working and living in the North was to anticipate and manage the active top layer of permafrost. Over time, however, more extensive experiences of permafrost thawing have unleashed a different imaginary: permafrost now evokes a vulnerable and disappearing archive of Arctic pasts rather than a problem space for cold-weather civil engineering. Thawing has become, in the contemporary Arctic, indicative of rapid and unwanted change, and complicit with new anxieties that the Arctic is distressed.

[TXT] Scientists have not only recorded milder winters in the Arctic but also detected thick and slushy mud where frozen earth would have been expected. Higher snowfall in the polar winter has been credited with inadvertently trapping heat on the surface of the frozen ground. The stored heat then further contributes to the warming of the active layer and is capable of provoking new spatial forms such as sinkholes, craters, and ravines. Ground is hollowed out. Ice is stripped away. Air is altered by methane release. Fires in the Arctic summer season contribute further to the degradation of frozen ground. This lends credence to the claims by Peter Adey (2010) that we need to be attentive to “vertical reciprocity” of the subterranean, the surface, and the aerial, as volatile forces move and transform organic matter into mud and gas. Frozen territory becomes in part gaseous, as ice and soil are brought to the surface and exposed to the elements of wind and water.

[TXT] Stuart Elden was among the first to argue that the volumetric can be mobilized as an expedient analytic within geopolitical (and also, in this case, geosocial) theorization, taking into consideration “the dimensionality implied by ‘volume’ and the calculability implied by ‘metric’” (2013: 49). In the polar regions, the everyday volumetrics of life is being altered by thaw and melt, shifting the conjoined relations of what Peter Adey calls “vertical reciprocity” (2010: 2) that dwell between subterranean, subglacial, surficial, and aerial spaces (Bonilla 2017; Hemmings 2019; McNeill 2019). Geological strata emerge as “provocations for political issue formation” (Clark 2017). Interior and littoral landscapes change. Communities are disrupted as frozen ground no longer provides a reliable foundation for travel and inhabitation. Polar permafrost soils create a volumetrics of life that assembles through belowground, surface, and atmospheric conditions and forces.

[EXT]

On his presidential visit to Alaska in 2015 US President Barack Obama admitted that:

Thawing permafrost destabilizes the earth on which 100,000 Alaskans live, threatening homes, damaging transportation and energy infrastructure, which could cost billions of dollars to fix … Consider, as well, that many of the fires burning today are actually burning through the permafrost in the Arctic. So, this permafrost stores massive amounts of carbon. When the permafrost is no longer permanent, when it thaws or burns, these gases are released into our atmosphere over time, and that could mean that the Arctic may become a new source of emissions that further accelerates global warming. (Obama 2015)

[/EXT]

[TXT] The spatial reach and depth of life is complicated and disrupted. The state of frozen soil is intimately linked to matters of local, national, and international governance. Housing shortages are common in Arctic communities, and property, when it can be found, is expensive. In 2018, the Alaskan community of Newtok received federal funding to begin a relocation plan for its 350 residents. The town is becoming uninhabitable due to coastal erosion, landslides, and flooding. The US Army Corps of Engineers estimates that the final bill for the relocation will be around $130 million; so far $15 million has been allocated. Throughout Alaska, up to 30 villages have been identified as vulnerable due to excessive and accelerating thawing and melting (Mandel 2017). Relocation will be a resolutely geopolitical matter. Meanwhile, the Trump administration has been accused of delaying a federal response to climate change and the consequences of permafrost thaw, sea ice melting, and low-lying flooding. These changing states are only going to become more dramatic, more disruptive. The latest research from northern Canada and Alaska reveals that permafrost is extremely sensitive to climate change, and this is set to continue to degrade landscapes via retrogressive thaw slumps (Petley 2019).

[TXT] As Isabel Stengers (2015) reminds us, there is no future where “nature” can be safely imagined as returning to a passive backdrop of human life. We are living in the ruins of the Holocene. And yet, the Arctic faces a situation where environmental imaginaries of a melting and thawing place don’t produce the political outcomes that native communities might have hoped for. Instead, affected communities are expected to be resilient and adaptable, and wait for their time. During his visit to Alaska in February 2019, President Trump spoke about the state’s strategic importance and the desire to license energy prospecting in the Arctic National Wildlife Refuge. He mentioned his grandfather’s interest in gold prospecting. Permafrost thaw was not mentioned in his speech; nor was climate change (Trump 2019). The speech could be thought of as exemplifying what Laurent Berlant (2011) describes as impasse: a moment when ecological and political crisis does not produce expected outcomes.

[A] Antarctic soils: A new frontier of genetic material [/A]

[TXF] Antarctica lacks the extensive permafrost soils whose changing dynamics spark so much fascination and trouble in the northern hemisphere. The Antarctic’s soils arguably posit a different set of futures where warming nourishes a framing of the continent’s marine and terrestrial environments as an exploitable form of biodiversity. The polar regions, particularly the Antarctic, are being actively reimagined as a frontier for biological prospecting (Salazar 2017), with Antarctic biodiversity being identified as a great deal richer than previously thought, including in terms of diversity of soil biota (Chown et al. 2015). Biotechnology based on polar genetic resources ranges from enzymes (including in both life sciences research and industrial applications), anti-freeze proteins, and bioremediation to pharmaceuticals, nutraceuticals and dietary supplements, cosmetics, and other health and personal care uses (Leary 2008).

[TXT] In Antarctica, climate change, in combination with human activities such as fishing, tourism, and scientific research expeditions, has been recognized as impactful. In terrestrial Antarctica, factors such as energy, shelter, and water have contributed to distinct patterns of soil and plant-life diversity. Comparative isolation and long periods of cold and darkness are pivotal to the biogeographies of Antarctica. Rising temperatures, accidental species introductions, and human mobility are changing Antarctica’s biodiversity, and soil development is facilitated as ice-free areas expand. For much of Antarctica’s history of human contact, the ice-free areas of the Antarctic Peninsula and McMurdo Valleys have attracted considerable interest from scientists eager either to understand their paleoclimates or, more lately, to work with NASA to develop and plan for Moon and Mars landings (Salazar 2017). Now other areas such as Signy Island are hotspots for research as scientists discover new species such as the flightless midge, which feeds on organic matter and has been responsible for affecting peat decomposition and soil structure (Bartlett et al. 2019).

[TXT] The microbial communities in Antarctic soils have generated considerable interest because of their ability to survive in extreme environments such as polar deserts. Only about 0.4% of Antarctica’s surface is permanently free of ice, and the soils concerned have very low levels of carbon and nutrients. These ice-free environments are more dynamic than previously thought. Drivers of change are found to include alien species introductions, the movement of microorganisms, meltwater runoff, rotting animal carcasses, and cumulative human impact including pollution (Cowan et al. 2014). Scientists have, over the last 30 years, invested ever more energy into analyzing and processing these soils and their compositional matter. While polar scientists warn about the absence of baseline knowledge of polar biota and non-native species management, others are racing ahead to capitalize on polar soils and biota (O’Neill 2017). The ice-free regions, of which about 90% are soil-forming, are located mainly on the coastline of the Antarctic continent, mostly on the Antarctic Peninsula and also in the McMurdo Dry Valleys within the Ross Sea region. Antarctic soils are characterized by extremely low soil temperatures, with an average mean annual temperature ranging between –15°C and –40°C, and low soil moisture (Manaaki Whenua Landcare Research, n.d.). Terrestrial ecosystems on the western side of the Antarctic Peninsula have patches of continuous vegetation that include not only mosses, lichens, microbiota, and algae but also two grasses (*Deschampsia antarctica* and *Colobanthus quitensis*), the latter the only vascular plant reported in Antarctica (Fretwell et al. 2011).

[TXT] Antarctic soils are being conceptualized as genetic material to be studied, extracted, and commodified. In international law, where Antarctica is recognized as a global commons while at the same time governed by the 1959 Antarctic Treaty System, biological prospecting and extraction raises substantial issues regarding the freedom of knowledge exchange, benefit sharing, and intellectual property rights in a part of the world that has often been framed as exceptional for its levels of scientific and political cooperation. Antarctic biological prospecting is ongoing and attracting an ever greater diversity of scientific stakeholders. In February 2019, for example, Indian scientists working in a consortium of government, industry, and universities revealed that they were experimenting with Antarctic fungi in the hope that it might offer insights into the development of new chemotherapeutic methods for cancer treatment (*India Today Web Desk* 2019).

[TXT] This biological imaginary of technoscientific optimism and potential was revealed in ethnographic interviews carried out between 2012 and 2014 in the Antarctic Peninsula. These interviews, carried out with a range of scientists while at sea meandering around the South Shetland Islands as well as in several research stations in the Antarctic Peninsula, were regarded as “agential conversations” (Müller and Kenney 2014). For Müller and Kenney, reframing research interviews as “agential conversations” that interfere with the contexts they seek to understand is key to creating “situated moments of reflection, connection, and disruption” (2014: 539), which in this particular case serve as a basis for discussing the problematic conditions of bioprospecting in the Southern Ocean and on Antarctic soils.

[TXT] The prospect of discovering new organisms offers biotechnology the great promise of finding new geochemical and genetic properties that might be developed for scientific and commercial activities. This offers a profound contrast with the imaginaries of doom and disaster that frame public engagement with climate change science in the Arctic. As Helmreich’s (2009) anthropological work on “microbial seas” attests, microbes can be thought as “embodied bits of vitality” that define a new resource frontier in marine microbiology and ecology, where genomics and bioinformatics afford new multiscalar associations “linking genomes to biomes.” Unlike commercial mining, which threatened to undermine the Antarctic Treaty System in the 1980s, biological prospecting does not generate anywhere near the same level of political and public passion. The Antarctic is routinely considered the “last wilderness on Earth” and a “continent for peace and science.” These framings and narratives are, one would think, incompatible with resource extraction. The Antarctic Treaty System, especially the Protocol on Environmental Protection, bans any form of mineral prospecting and mining and values Antarctica for its wilderness qualities, which need to be protected. Political value is attributed to the containment of mineral extraction while recognizing that other forms of activity such as fishing have to be carefully managed.

[TXT] The framing of Antarctica as an emerging pharmacopeia is narrating and legitimizing new forms of extraction that do not appear to conflict with the framing of a “continent for peace and science.” Ratified in 1991, the Environmental Protocol to the Antarctic Treaty has been, Alan Hemmings suggests, “largely driven by the success of Antarctic science, which has been given an entrenched and privileged role in the international Antarctic governance regime provided by the Antarctic Treaty System over the past half century” (2010: 6). As reported by the Antarctic Treaty Consultative Meetings held every year in Antarctic Treaty states, more than 200 research organizations and companies from at least 27 states are undertaking research for commercial purposes in the Antarctic. The greatest concentration of genetic resources in Antarctica comes from the research by pharmaceutical and medical technology industries (20%), followed by molecular biology and biotechnology (18%), industrial applications (12%), chemical processing (11%), cosmetics and personal care (6%), aquaculture and agriculture (6%), culture collection or databasing (3%), and environmental remediation (1%) (Joyner 2012).

[TXT] As the hunt for new medicines and biotechnological applications turns to the Antarctic and the deep seabed, Antarctica is being reframed as a space of opportunity, as a biotech cornucopia of discoverable genetic riches. Drawing on Veronica Davidov’s (2013) analysis of the commonly deployed imaginary of the Amazon as a pharmacopeia, we argue that a similar metaphor could be used in the Antarctic, notwithstanding that the rich biodiversity of the Amazon is not directly comparable to that of the Antarctic. As Davidov reminds us, it was not so long ago that the Amazon was being framed as “the lungs of the earth,” a vital organism for a “healthy” planet. As “pharmacopeia,” however, the Amazon is reimagined as an inviting biological resource that can be safely prospected and sustainably exploited. Moreover, the politics of bioprospecting in the Amazon is facilitated by its co-option of Indigenous traditional knowledge of plants and other bioresources.

[TXT] Bioprospecting also raises particular and distinctive geopolitical issues in Antarctica by virtue of its peculiar historical and legal arrangements (Jabour-Green and Nicol 2003; Hemmings 2010; Jabour 2010; Joyner 2012; Rogan-Finnemore 2017). The Antarctic Treaty System does not directly regulate bioprospecting activities in the Antarctic. To the extent that rules for bioprospecting now exist, they stem from the host government under which the researching company or group of scientists is carrying out the bioprospecting. Nonetheless, certain provisions of the Antarctic Treaty, the Protocol for Environmental Protection, and the Commission on the Conservation of Antarctic and Marine Living Resources (CCAMLR) have relevance for bioprospecting, and these may provide the genesis for a future regulatory regime. As many voices claim, the extraction and use of any resources from the Antarctic Treaty area is highly controversial because such extraction “has the potential to impact the Antarctic environment, and the use of Antarctic resources always awakens the dormant argument on Antarctic sovereignty and sovereign rights” (Meduna 2015). Without some institutional separation of science as actor from science as independent advisor, bioprospecting may “risk moral hazard for science in the Antarctic Treaty System” (Hemmings 2010).

[TXT] A number of unresolved bioprospecting issues could pose serious challenges for the Antarctic Treaty Consultative Parties as a group, particularly, though not exclusively, between claimant and non-claimant states. One fundamental issue is the lack of a consensus definition of biological prospecting as a research activity. The geopolitics and ethics of earthly bioprospecting certainly speak to current modes of thinking about terraforming and planetary ecosynthesis. During visits to sub-Antarctic islands and follow-up visits to the biologists and ecologists working on sampling trips, and in laboratory work on King George Island, descriptions of how extremophilic microbes present raw material for innovative science loomed large (Salazar 2017). This is similar to Stefan Helmreich’s observations on the work of marine biologists, where the ocean microbes were seen, on the one hand, as “potential ancestors of all life, helpful monitors of climate control, raw material for new life-saving drugs, and, on the other, beings always erasing the trace of their own origins, entities indifferent and adaptable to human ecological disaster, vehicles of seaborne disease” (2009: xi).

[TXT] In contrast to this depoliticized vision of bioprospecting, the Antarctic and Southern Ocean Coalition has warned:

[EXT]

One of the biggest controversies is whether companies and governments should be able to profit from Antarctic species. Antarctica is set aside under the Environment Protocol to the Antarctic Treaty as a protected area dedicated to open science and environmental protection. Allowing a free-for-all on biological prospecting is inconsistent with those values and would allow some countries and companies with an unfair advantage to profit off of Antarctica’s fragile ecosystem. (ASOC 2019)

[/EXT]

[A] Conclusion [/A]

[TXF] As we invert Cymene Howe’s focus on “vitalities, materials, and movements that are skyward, spacey, and atmospheric” (2015: 203), we ask how a new generation of researchers in the human sciences can write on what she terms “climate inhabitants living within weather-weathered political economies” (2015: 207) and what it means to analytically inhabit life below earth’s surface in ways that provoke seeking out forms of porous mutuality (Howe 2015; Granjou and Salazar 2019). Polar soils provide entrées into very different sociopolitical worlds. We might ask in this context: What do polar soils promise? What do polar soils do? And what do polar soils reveal? In the Arctic, the thawing of permafrost has informed and escalated an imaginary of ecological breakdown and potential disaster. For some Arctic coastal communities, thawing permafrost in combination with melting and retreating sea ice has contributed to repeated vulnerabilities from coastal storms, landslides, and flooding. As Sheila Watt-Cloutier, in *The Right to Be Cold* (2016: 3), noted:

[EXT]

We are all accustomed to the dire metaphors used to evoke the havoc of climate change, but in many parts of the Arctic the metaphors have already become a very literal reality. For a number of reasons, the planet warms several times faster at the poles. While climate experts warn that an increase of two degrees in the global average temperature is the threshold of disaster, in the Arctic we have already seen nearly *double* that. As the permafrost thaws, roads and airport runways buckle. Homes and buildings along the coast sink into the ground and fall into the sea.

[/EXT]

[TXT] The “buckling of infrastructure” reveals evidence of a social and material terrain that is riddled with uneven geographies of inequalities and vulnerabilities. Infrastructure is integral to northern communities and often extraordinarily important because communities are small, scattered, and often dependent on frozen ground and ice for mobility. Roads are often absent or sparse, and air transport is expensive and irregular. An unstable Arctic is an expensive Arctic, and a thawing subterranean Arctic generates a landscape akin to Swiss cheese—full of holes and cracks, and prone to subsidence. Melting and thawing is disruptive, and its effects are felt disproportionately by Indigenous and northern communities who have borne the brunt of power plays, security projects, and community relocation for much of the Cold War and since. When soils and ground thaw and flood, it more often than not reveals the precariousness of northern communities, the limits of distributional justice, and the aspirations of political elites in the southern part of national territories. Thawing and melting have been regarded by many as providing opportunities for further resource extraction and cargo transportation.

[TXT] Indigenous peoples have dwelled on and inhabited northern frozen soils for millennia. These spaces today continue to be contested, fossil-resource rich, and thawing, which makes their political economies very different to the geologic politics of Antarctic soils. In this chapter, we further trouble the imaginary of soils as “inert.” Frozen soils are lively assemblages that both depend on and develop with this inertness and participate in its animation. This very inertness turns out to be agentic—by “keeping things in,” the permafrost makes life livable.

[TXT] As geosocial formations, polar soils offer up rich possibilities for thinking about the intersection of social and political life and the geological and ecological processes and spaces that make up the proverbial “ends of the earth.” Within ancient Arctic permafrost and the low-carbon soils of ice-free Antarctica, we find evidence for multiple imaginaries and geosocial formations. Thinking with and through polar soils and frozen ground enables us to ask new questions about warming, the organic, and the mutual interconnectedness of ice, water, and air (Clark and Yusoff 2017). The polar subterranean and submarine is revealing itself to be highly stratified, home to multiple species and thermal energy regimes. There is now a growing recognition that the remotest parts of the earth such as the deep oceans and poles are anything but inert and incapable of hosting life.

[A] Acknowledgments [/A]

[TXF] Klaus Dodds acknowledges the Leverhulme Trust for the award of a Major Research Fellowship (2017-2020).

[A] References [/A]

Adey, P. (2010), *Aerial Life: Spaces, Mobilities, Affects*, Oxford: Blackwell.

Anderson, B. (2010), “Preemption, Precaution, Preparedness: Anticipatory Action and Future Geographies,” *Progress in Human Geography*, 34 (6): 777–98.

Andrews, T. D., S. V. Kokelj, G. MacKay, J. Buysse, I. Kritsch, A. Andre et al. (2016), “Permafrost Thaw and Aboriginal Cultural Landscapes in the Gwich’in Region, Canada,” *APT Bulletin: The Journal of Preservation Technology*, 47(1): 15–22.

Atlantic and Southern Ocean Coalition (ASOC) (2019), “Biological Prospecting” [<https://www.asoc.org/advocacy/antarctic-environmental-protection/biological-prospecting>].

Barad, K. (2007), *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, Durham, NC: Duke University Press.

Bartlett, J. C., P. Convey, and S. A. L. Hayward (2019), “Life Cycle and Phenology of an Antarctic Invader: The Flightless Chironomid Midge, *Eretmoptera murphyi*,” *Polar Biology*, 42 (1): 115–30.

Berlant, L. (2011), *Cruel Optimism*, Durham, NC: Duke University Press.

Blaikie, P. (1985), *The Political Economy of Soil Erosion in Developing Countries*, London: Longman.

Bonilla, L. (2017), “Voluminous,” Theorizing the Contemporary: Speaking Volumes series, *Society for Cultural Anthropology*, October 24 [<https://staging.culanth.org/fieldsights/voluminous>].

Bravo, M. (2017), “A Cryopolitics to Reclaim our Frozen Material States,” in J. Radin and E. Kowal (eds.), Cryopolitics: Frozen Life in a Melting World, 27–57, Cambridge, MA: MIT Press.

Bravo, M. (2018), *North Pole: Nature and Culture*, London: Reaktion.

**Bravo, M.** and S. Sörlin, eds. (2002), Narrating the Arctic: A Cultural History of Nordic Scientific Practices, Canton, MA: Science History Publications.

Cho, R. (2018), “Why Thawing Permafrost Matters,” State of the Planet, Earth Institute, Columbia University, January 11 [<https://blogs.ei.columbia.edu/2018/01/11/thawing-permafrost-matters/>].

Chown, S. L., A. Clarke, C. I. Fraser, S. C. Cary, K. L. Moon, and M. A. McGeoch (2015), “The Changing Form of Antarctic Biodiversity,” *Nature*, 522 (7557): 431–38.

Clark, N. (2017), “Politics of Strata,” *Theory, Culture & Society*, 34 (2/3): 211–31.

Clark, N. and K. Yusoff (2017), “Geosocial Formations and the Anthropocene,” *Theory, Culture & Society*, 34 (2/3): 3–23.

Cowan, D. A., T. P. Makhalanyane, P. G. Dennis, and D. W. Hopkins (2014), “Microbial Ecology and Biogeochemistry of Continental Antarctic Soils,” *Frontiers in Microbiology*,5: 154 [https://doi.org/10.3389/fmicb.2014.00154].

Crate, S., M. Ulrich, J. O. Habeck, A. R. Desyatkin, R. V. Desyatkin, A. N. Fedorov et al. (2017), “Permafrost Livelihoods: A Transdisciplinary Review and Analysis of Thermokarst-Based Systems of Indigenous Land Use,” *Anthropocene*, 18: 89–104.

Davidov, V. (2013), “Amazonia as Pharmacopia,” *Critique of Anthropology*, 33 (3): 243–62.

Dittmer, J., S. Moisio, A. Ingram, and K. Dodds (2011), “Have You Heard the One about the Disappearing Ice? Recasting Arctic Geopolitics,” *Political Geography*, 30 (4): 202–14.

Dodds, K. and M. Nuttall (2016), *The Scramble for the Poles: The Geopolitics of the Arctic and Antarctic*, Cambridge: Polity Press.

Dodds, K. and M. Nuttall (2019), *The Arctic: What Everyone Needs to Know*, New York: Oxford University Press.

Elden, S. (2013), “Secure the Volume: Vertical Geopolitics and the Depths of Power,” *Political Geography*, 34 (1): 35–51.

Farish, M. (2006), “Frontier Engineering: From the Globe to the Body in the Cold War Arctic,” *Canadian Geographer*, 50 (2): 177–96.

Farquharson, L. M., V. E. Romanovsky, W. L. Cable, D. A. Walker, S. V. Kokelj, and D. Nicolsky (2019), “Climate Change Drives Widespread and Rapid Thermokarst Development in Very Cold Permafrost in the Canadian High Arctic,” *Geophysical Research Letters*,46 (12): 6681–89.

Fretwell, P. T., P. Convey, A. H. Fleming, H. J. Peat, and K. A. Hughes (2011), “Detecting and Mapping Vegetation Distribution on the Antarctic Peninsula from Remote Sensing Data,” *Polar Biology*,34 (2): 273–81.

Granjou, C. and J. F. Salazar (2019), “The Stuff of Soil: Belowground Agency in the Making of Future Climates,” *Nature and Culture*, 14 (1): 39–60.

Helmreich, S. (2009), *Alien Ocean: Anthropological Voyages in Microbial Seas*, Berkeley, CA: University of California Press.

Hemmings, A. D. (2010), “Does Bioprospecting Risk Moral Hazard for Science in the Antarctic Treaty System?,” *Ethics in Science and Environmental Politics*, 10 (1): 5–12.

Hemmings, A. D. (2019), “Subglacial Nationalisms,” in E. Leane and J. McGee (eds.), *Anthropocene Antarctica: Perspectives from the Humanities, Law and Social Sciences*,33–56,Abingdon: Routledge.

Howe, C. (2015), “Life Above Earth: An Introduction,” *Cultural Anthropology*, 30 (2): 203–9.

*India Today Web Desk* (2019), “IIT Hyderabad Researchers Find Antarctic Fungi that Could Make Childhood Cancer Treatment Cheaper, with Fewer Side Effects,” *India Today Web Desk*, February 19 [https://www.indiatoday.in/education-today/news/story/iit-hyderabad-researchers-find-antarctic-fungi-that-could-make-childhood-cancer-treatment-cheaper-with-fewer-side-effects-1459708-2019-02-19].

Ingold, T. (2012), “Toward an Ecology of Materials,” *Annual Review of Anthropology*, 41: 427–42.

Jabour, J. (2010), “Biological Prospecting: The Ethics of Exclusive Reward from Antarctic Activity,” *Ethics in Science and Environmental Politics*, 10 (1): 19–29.

Jabour-Green, J. and D. Nicol (2003), “Bioprospecting in Areas Outside National Jurisdiction: Antarctica and the Southern Ocean,” *Melbourne Journal of International Law*, 4 (1): 76–111.

Joyner, C. C. (2012), “Bioprospecting as a Challenge to the Antarctic Treaty,” in A. D. Hemmings, D. R. Rothwell, and K. N. Scott (eds.), *Antarctic Security in the Twenty-First Century: Legal and Policy Perspectives*, 197–214, London: Routledge.

Leary, D. (2008), “Bi‐polar Disorder? Is Bioprospecting an Emerging Issue for the Arctic as well as for Antarctica?,” *Review of European, Comparative and International Environmental Law*,17 (1): 41–55.

Manaaki Whenua Landcare Research (n.d.), “Antarctic Soils” [https://www.landcareresearch.co.nz/science/soils-and-landscapes/antarctic-soils].

Mandel, K. (2017), “America’s Climate Refugees Have Been Abandoned by Trump,” *Mother Jones*, October 17 [<https://www.motherjones.com/environment/2017/10/climate-refugees-trump-hud/>].

Martin, A. (2018), “An Alaskan Village Is Falling into the Sea. Washington Is Looking the Other Way,” *PRI*, October 22 [https://www.pri.org/stories/2018-10-22/alaskan-village-falling-sea-washington-looking-other-way].

McGrath, M. (2006), *The Long Exile: A Tale of Inuit Betrayal and Survival in the High Arctic*,London: Vintage.

McNeill, D. (2019), “The Volumetric City,” *Progress in Human Geography* [https://doi.org/10.1177/0309132519863486].

Meduna, V. (2015), “The Search for Extremophiles: Antarctic Biological Prospecting,” in D. Liggett, B. Storey, Y. Cook, and V. Meduna (eds.), *Exploring the Last Continent: An Introduction to Antarctica*, 463–76, Dordrecht: Springer.

Müller, R. and M. Kenney (2014), “Agential Conversations: Interviewing Postdoctoral Life Scientists and the Politics of Mundane Research Practices,” *Science as Culture*, 23 (4): 537–59.

Mustonen, T., ed. (2005), *Stories of the Raven—Snowchange 2005 Conference Report, Anchorage, Alaska, USA*,Snowchange Cooperative, Alaska Native Science Commission, Inuit Circumpolar Conference Alaska.

Nilsson, A. E. and M. Christensen (2019), *Arctic Geopolitics, Media and Power*, London: Routledge.

Obama, B. (2015), “Remarks by the President at the GLACIER Conference—Anchorage, AK,” speech delivered at Dena’ina Civic and Convention Center, Anchorage, Alaska, August 31 [<https://obamawhitehouse.archives.gov/the-press-office/2015/09/01/remarks-president-glacier-conference-anchorage-ak>].

O’Neill, T. A. (2017), “Protection of Antarctic Soil Environments: A Review of the Current Issues and Future Challenges for the Environmental Protocol,” *Environmental Science and Policy*, 76: 153–64.

Paglia, E. (2016), “The Northward Course of the Anthropocene: Transformation, Temporality and Telecoupling in a Time of Environmental Crisis,” PhD thesis, KTH Royal Institute of Technology, Stockholm.

Palsson, G. and H. A. Swanson (2016), “Down to Earth: Geosocialities and Geopolitics,” *Environmental Humanities*,8 (2): 149–71.

Petley, D. (2019), “Thawing Permafrost Is Triggering Thousands of Landslides Across the Arctic,” *The Conversation*, April 3 [<https://theconversation.com/thawing-permafrost-is-triggering-thousands-of-landslides-across-the-arctic-114702>].

Pimentel, D. (2006), “Soil Erosion: A Food and Environmental Threat,” *Environment, Development and Sustainability*, 8 (1): 119–37.

Puig de la Bellacasa, M. (2014), “Encountering Bioinfrastructure: Ecological Struggles and the Sciences of Soil,” *Social Epistemology*, 28 (1): 26–40.

Puig de la Bellacasa, M. (2017), *Matters of Care: Speculative Ethics in More than Human Worlds*, Minneapolis, MN: University of Minnesota Press.

Puig de la Bellacasa, M. (2019), “Re-animating Soils: Transforming Human–Soil Affections through Science, Culture and Community,” *Sociological Review*, 67 (2): 391–407.

Rogan-Finnemore, M. (2017), “What Bioprospecting Means for Antarctica and the Southern Ocean,” in G. Leane and B. von Tigerstrom (eds.), *International Law Issues in the South Pacific*, 211–40, Abingdon: Routledge.

Sakakibara, C. (2008), “‘Our Home Is Drowning’: Iñupiat Storytelling and Climate Change in Point Hope, Alaska,” *Geographical Review*, 98 (4): 456–75.

Salazar, J. F. (2017), “Microbial Geographies at the Extremes of Life,” *Environmental Humanities*, 9 (2): 398–417.

Salazar, J. F. (2018), “Ice Cores as Temporal Probes,” *Journal of Contemporary Archaeology*, 5 (1): 32–43.

Salazar, J. F. (2019), “The Anthropocene Melt: Antarctica’s Geologic Politics,” in E. Leane and J. McGee (eds.), *Anthropocene Antarctica: Perspectives from the Humanities, Law and Social Sciences*,73–84,Abingdon: Routledge.

Salazar, J. F. and J. O’Reilly (forthcoming), “Materials after Ice Thaw: Methane, Microbes, Mud,” in R. Ruiz, P. Schönach, and Rob Shields (eds.), *After Ice: Cold Humanities for a Warming Planet*, Durham, NC: Duke University Press.

Stengers, I. (2015), *In Catastrophic Times: Resisting the Coming Barbarism*, London: Open Humanities Press.

Trump, D. (2019), “Remarks by President Trump to U.S. Service Members, Anchorage, Alaska,” Joint Base Elmendorf-Richardson, Anchorage, Alaska, February 28 [<https://www.whitehouse.gov/briefings-statements/remarks-president-trump-u-s-service-members-anchorage-alaska>].

Watt-Cloutier, S. (2016), *The Right to Be Cold*, Harmondsworth: Penguin.

Whitehead, M. (2014), *Environmental Transformations: A Geography of the Anthropocene*, London: Routledge.

Whyte, K. P. (2017), “Is it Colonial Déjà Vu? Indigenous Peoples and Climate Injustice,” in J. Adamson and M. Davis (eds.), *Humanities for the Environment: Integrating Knowledge, Forging New Constellations of Practice*, 88–105, New York: Routledge.

Williams, J. and S. Jackson (2007), “Novel Climates, No-Analog Communities, and Ecological Surprises,” *Frontiers in Ecology and the Environment*, 5 (9): 475–82.

**Figure legend**

**Figure 8.1:** Permafrost in the National Petroleum Reserve-Alaska, 2017. Credit: David Houseknecht, USGS. Public domain.