Settler Geology: Earth's Deep History and the Governance of *In Situ* Oil Spills in Alberta

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ABSTRACT

Alberta's bitumen industry is frequently identified as a key site of environmental politics in the Anthropocene owing to the scale of its fossil fuel extraction operations. While popular images of surface mining activities often focus these discussions, approximately 80% of the bitumen reserves in the Canadian province lie too deep for surface mining and are extracted through in situ technologies, including processes that inject high-temperature, high-pressure steam to mobilize geologic formations of the tar-like fossil fuel. This article examines how in situ extraction was governed in response to four flow-to-surface (FTS) events in which bitumen unexpectedly migrated to Earth's surface as the result of in situ operations. The governance response to these events is of particular interest because it counters the assertion that existing governance institutions operate on time scales that are incommensurate with those relevant to the Anthropocene. The Alberta case shows the opposite owing to how Earth's deep history was used to provide temporal syntax for a geotechnical debate that ensued over what caused the FTS events. By detailing the controversy over what caused the FTS events, and the search for "enabling conditions" that would link causal explanations to the spatial distribution of the four bitumen seeps, Earth's deep history was made commensurate with the political geography of settler colonialism in Alberta. The article introduces and develops the notion of 'settler geology' in order to capture the naturalization of geologic forms of reasoning about Earth's deep history, the geologic force of anthropogenic in situ operations, and the temporal framework of settler colonial governance in Alberta.

1 INTRODUCTION

On 20 May 2013, workers on a seismic crew happened upon bitumen seeping to Earth's surface in northeastern Alberta, Canada. Officially, geotechnical explanations of what caused the bitumen seeps today remain indeterminate. In an Aristotelian sense, however, the prime mover of the geological formation was a technology known as High Pressure Cyclic Steam Stimulation (HPCSS), a form of *in situ* extraction that mobilizes bitumen deep underground by battering it with cycles of high-pressure, high-temperature steam over a period of weeks and months. Pulsing cycles of steam injection make it economically feasible to extract bitumen from the 80% of Alberta's 170 billion barrels of oil that lie too deep for surface mining. It also allows for extraction without the significant disturbances to surface ecology that characterize popular images of Alberta's northern fossil fuel industry—the oil sands or tar sands (cf. Remillard, 2011). Among the largest industrial sites on Earth, the massive scale of bitumen extraction in Alberta make it a frequently critiqued example of human impacts on the planet as well as a site for rethinking geopolitics in the Anthropocene (e.g. Adkin, 2016; Dalby, 2019). Even in scientific publications, images of, and references to Alberta's oil sands circulate as emblems of the Anthropocene alongside explanations of how human forces are so significantly altering how the Earth system functions as to warrant a new epoch of geologic time (e.g. Carey, 2016).

The bitumen seep discovered that spring proved only the beginning. Before the day was out, a second leak was discovered in what is known as the Primrose area, a bitumen play operated by Canadian Natural Resources Limited (CNRL) on military land within Canadian Forces Base, Cold Lake. Classified not as oil spills, but as Flow-to-Surface (FTS) events, two more FTS events were soon discovered in the Primrose area on the 8th and 24th of June. Three of the FTS events were terrestrial. The fourth occurred beneath a 55-hectare lake where two cracks totaling more than 120 meters in length opened up the bed of the lake. Too heavy to float, globules of bitumen bobbed below the surface of the water. Filmy deposits on reeds indicated that the bitumen had reached up to two feet above the water line, heights likely facilitated by the winter snowpack and indicative of the FTS events having been underway for some time. Observed under the high June sun of summer solstice, however, a sheen of oil glinted its telltale prism across the water—a multi-season event in a site significant for understandings of geologic time.

The four FTS events triggered environmental enforcement orders from the Alberta government while the Alberta Energy Regulator, which oversees provincial oil and gas operations, issued orders to cease operations and to develop remediation plans for the FTS sites, which included damming and draining a third of the lake. In an attempt to depressurize the geologic formation, gas was flared from nearby wells at rates of up to 23 000 cubic meters (m^3) per hour and over 500 000m^3 per day. It took months, however, before the geologic pressure subsided and bitumen stopped flowing to the surface. During this period and after, a massive mobilization took place to determine the extent of the FTS events, clean them up, and determine their cause. Effective governance was critical for CNRL, the Alberta government, and the regulator. The previous year (2012), the Canadian government exempted *in situ* projects from federal environmental assessments, and environmentalists were now keen to assess how the FTS events were responded to (Timoney and Lee 2014; cf. Urquhart 2018). Equally significant was the pressure on Alberta's economy from slumping oil prices. Primrose is an important site for capital inputs that exceeded $200 billion in Alberta's oil sands from 1999-2013 (Urquhart, 2018). As the private sector searched for signals, *The Wall Street Journal* reported on the FTS events and the Primrose area's 109 000 barrels of daily oil production as generating "returns amongst the highest in the company's [CNRL's] portfolio" (Dawson, 2013). Three years later, in March 2016, at a time when Alberta's economy teetered on recession, Imperial Oil announced it would invest $2 billion in an *in situ* project near Primrose (Lewis, 2016). The timing of Imperial Oil's announcement was telling. Ten days later, the Alberta Energy Regulator released its final report on what caused the Primrose FTS events.

The empirical aspects of this article examine a controversy over the unresolved geotechnical explanations of what caused the four FTS events. Summarized in the regulator's report, different causal explanations were held by the Alberta Energy Regulator (AER), CNRL, and an independent expert panel. Understanding the controversy, however, requires situating different interpretations of causal relationships amid the governance structure that organized competing views, and which stabilized many uncertainties involved. Two issues became critical in the governance process. The first was the role of Earth's deep history in geotechnical explanations of causal relationships; geologic processes from times past were mobilized to understand causal uncertainties in the present. The second linked geologic time to the spatial distribution of the four FTS events. This involved establishing agreement on what were termed "enabling conditions." These enabling conditions provided multiple working hypotheses through which Earth's deep history, previous human interventions (i.e. previous extractive operations), and *in situ* forcing might explain the spatial distribution of FTS events at the surface. To investigate the FTS events, the article draws on 5500 records acquired from the AER. This data was combined with public reports from the AER, press releases, and media accounts. Process-tracing methods were used to examine how causal relationships were configured within the governance structure regulating *in situ* extraction in Alberta (see Collier 2011).

The controversy over what caused the FTS events in Alberta also provides reasons to rethink theoretical claims about environmental politics in the Anthropocene. Two concerns are taken up in the literature review that precedes the empirical case. The first targets an assertion of several scholars, notably Chakrabarty (2009, 2017), that there is an incommensurability of Holocene institutions and Anthropocene realities owing to the (purported) fact that human temporal scales cannot countenance Earth's deep history. In the Alberta case, however, the opposite is the case: Earth's deep history was integral to governing an extractive site often identified as an Anthropocene exemplar. This raises a question that drives the second theoretical concern: what temporal imagination makes possible the commensurability of *in situ* technologies, Earth's deep history, and Alberta's governance structure? Following Fagan (2019), I argue that Anthropocene politics must attend to the temporal imagination from which geological accounts issue. To this end, I situate resource governance in Alberta with respect to Canada as a settler colonial state. Pivoting from Wolfe's (1999, pp. 45) trenchant analysis of how settler colonialism explains the causes of cultural difference through naturalized explanations of social evolution, the article argues that a similar "temporal syntax" also affects how settler colonial institutions govern geological resources. Empirical evidence shows how this is the case in Section 3, and Section 4 links the governance of causal explanations themselves to Alberta's regulatory structure. This frames the conclusion, which examines the political geography at work in making commensurate the temporal scales of Earth history and the geologic agency of human activity in ways consistent with the Indigenous dispossession upon which settler colonialism is premised.

2 RETHINKING INCOMMENSURABILITY IN THE ANTHROPOCENE

Anthropocene scholarship frequently takes evidence of human impacts on the Earth system as warrant to reject modern categories of thought owing to a claimed incommensurability of those categories with existing or anticipated states of affairs. For example, the scale of fossil fuel projects like Alberta's oil sands seem to demand new modes of thought to fully reckon with their planetary effects. Biemann (2016), for instance, characterizes Alberta's oil sands as a hyperobject—the term Morton (2013) invented to describe phenomena so vastly distributed in space and time that they defy the very idea of a 'thing' commensurate with human experience. Considerations of time are central to such claims because establishing an anthropogenic departure from the Holocene requires that Earth and human histories intersect rather than the latter playing out in the theatre of the former (McNeill and Engelke 2016). Determining criteria to mark this intersection, such as stratigraphic signals, is both scientific and political owing to the fact that these criteria are not socially weightless (Waters et al. 2016). Rather, these markers of geologic time also index social phenomena. Critical scholars consequently engage with the entanglement of the Anthropocene with colonialism, capitalism, industrialism, race, gender, and the role of science in conceptualizing the 'human' now affecting planetary functions (e.g. Lövbrand et al., 2015; Moore 2015; Ghosh 2016; Malm 2016; Castree 2017; Davis and Todd 2017; Grusin 2017; Simon and Maslin 2018; Yusoff 2019).

In this context, environmental politics are likewise critiqued for remaining beholden to society/nature dualisms or for harboring temporal horizons incommensurate with the scale of Anthropocene (e.g. Wapner 2014; Purdy 2015; Dryzek 2016). Among the most frequently cited accounts of temporal incommensurability are those of Chakrabarty (2009, 2014), who stakes his arguments on the insurmountable differences of 'human' time versus the Earth history disclosed by geologic and planetary sciences. Chakarabarty (2014) argues that reducing explanations of the Anthropocene to outcomes of globalized and accelerating forces of industrial capitalism are unsatisfactory because they reduce geologic or planetary explanations to outcomes of economic activity. These counterposing temporal scales, he argues, produce 'rifts' that must be navigated but cannot be bridged. According to Chakrabarty (2016), this is because ideas central to western political economy, such as Kant's influential account of human freedom, are deeply entangled with the inadequate categories of modernity. Like other scholars asserting that Earth system science is incommensurable with categories of modern thought (e.g. Morton, 2013; Hamilton 2017), Chakrabarty holds that the very bases upon which the conditions of possibility for politics are rethought operate on terms incommensurate with new geological realities. Chakrabarty (2017) later concludes that the Anthropocene is more than "the politics of capitalism" owing to how it is entangled with time scales irreducible to the human scale alone. Drawing on Clark's (2014: pp. 28) argument that the Anthropocene has "the capacity to undo the political," Chakrabarty (2018) notes incommensurate temporal scales admit an unresolved tension because they require avoiding the reduction of geologic time to human time, or vice-versa, and searching for ways of living in two respective times—human experience and Earth history—at once.

Assertions of temporal incommensurability have themselves been subject to critique. Coen (2016) trenchantly argues that Chakrabarty reduces socially and culturally diverse notions of time to singular accounts of what constitutes the 'human scale' in order to juxtapose them against geological or planetary time. Indigenous scholars, such as Whyte (2017), argue that the Anthropocene is not a qualitatively new time, but an intensification of colonialism. Davis and Todd (2017) likewise argue that Indigenous worlds face a double erasure to the extent that debates regarding Anthropocene time reproduce the elision of alternate histories and temporalities. Critiques from geographers, such as Schmidt (2019), point out that Chakrabarty also ignores notions of human time at work in Earth system science itself. Yusoff (2019: pp. 4, original emphasis) goes further, arguing that geology itself is racialized in ways that entangle it with colonial extraction and dispossession through a semiotic disposition that "creates *a*temporal materiality dislocated from place and time." An adjacent concern worries Fagan (2019), who argues that the temporal frameworks that stabilize debates over the Anthropocene themselves have critical effects on notions of political subjectivity (cf. de la Cadena and Blaser 2018). Given unease over assertions of incommensurability, Fagan's (2019) work raises a central question: if assertions of incommensurability do not sufficiently capture the political stakes of the Anthropocene, what temporal imaginations make possible the commensurability of human history and geologic time?

Alberta's response to the four FTS events provides an empirical entry point for response. It provides evidence for how the temporal framework of settler colonialism makes political institutions commensurate with Earth's history. A province of Canadian federalism, Alberta's governance structure is settler-colonial owing to several factors: colonists came and stayed, they created institutions focused on extracting value from land (rather than primarily from labor), and they established techniques of rule that keep state claims to legitimacy separate from the original and on-going violence of Indigenous dispossession (Byrd, 2011; Asch 2014; Pasternak, 2017). These techniques and their violent spatial expressions have been well documented: forced territorial removals, dispossession from land and resources, property surveys, border creation, family separation and detention, starvation, gender and racial discrimination, and environmental pollution (Harris 2002; Blomley 2003; Daschuk, 2013; Coulthard, 2014; Simpson, 2014; Hogue 2015). These techniques are neither ahistorical nor atemporal. They issue from on-going processes through which states sequence the temporal and spatial aspects of settler colonialism. This included standardizing time, such as for railroads hauling commodities between hinterlands and metropoles (Karuka 2019; cf. Mawani 2018). It also included efforts to assimilate Indigenous peoples into settler agrarianism, such as when administrators timed the maintenance of irrigation infrastructure in Alberta to interrupt the Sun Dance ceremony of First Nations (Matsui 2009). Such efforts coincided with the imposition of colonial time to determine what constitutes Indigenous occupation of, and title to, lands and resources (Povinelli 2011; Asch 2014; Coulthard 2014; Stevenson, 2014).

Wolfe (1999) argued that time is key to understanding settler colonialism owing to how evolutionary explanations function within the colonial categories used to establish cultural difference. The "temporal syntax" of settler colonialism, Wolfe (1999, pp. 45) argued, is evident in how states arranged cultural differences through appeals to directional, evolutionary vernaculars. In addition to biological and physiological claims, colonists ordered societies in a narrative sequence in which social evolution progressed through stages of savagery and barbarism that culminated in western civilization. In application, the 19th century establishment of liberal institutions of private property in Canada similarly excluded Indigenous peoples through racialized, evolutionary claims (Bhandar, 2018). This structure continues today. The Canadian government's recent private property agenda for Indigenous lands does not recognize Indigenous institutions, but instead naturalizes evolutionary explanations of human territoriality and sociobiology to align Indigenous lands with Canadian institutions of private property (Schmidt, 2018). Even in cases where Aboriginal title is recognized in Canada, it is done so in a way that leaves intact notions of *terra nullius* that erase Indigenous uses of, and claims to, territory in order to justify state territorial claims (Borrows, 2015).

The "temporal syntax" that Wolfe (1999) identified in evolutionary explanations of cultural difference had close connections to geology in projects of British colonialism. In India, for instance, geology was used to mark cultural spaces in the colonial imagination of "Gondwana Land" and to claim the forced labor of Indigenous peoples in coal mines was appropriate owing to their 'natural' affinity to the earth as living fossils of earlier geological times (Chakrabarti, 2019). British colonialism also used to geology extract value from land. In 1842, a quarter century before the Dominion of Canada was created by an act of British Parliament in 1867, the Geological Survey of Canada was created to unite geology with state formation, territorial expansion, and value extraction. In 1883, the Geologic Survey of Canada recommended developing Alberta's bitumen deposits for infrastructure projects (Hoffman, 1883). And by 1888, a Select Committee of the Canadian Senate working with geological advice estimated Alberta's oil sands were "the most extensive petroleum field in America, if not the world" and recommended 40 000 square miles be reserved owing to the probability that "this great petroleum field will assume enormous value in the near future and will rank among the chief assets comprised in the Crown domain of the Dominion" (Schultz, 1888: pp. 163). Together, geological reconnaissance and territorial claims precipitated a treaty between Canada and Indigenous peoples covering what is now northern Alberta. Agreed to in 1899, Treaty 8 was negotiated under pressures from a northern gold rush, and in a context where Indigenous peoples had observed the colonial economy for decades (McCormack 2010). Nevertheless, it laid the groundwork for what Huseman and Short (2012) describe as a "slow industrial genocide" that ensued as bitumen production expanded in contravention to the terms upon which the respective, sovereign nations entered into treaty (see also Asch, 2014).

The history of industrial oil expansion in Alberta is not the primary concern here (see Chastko 2004). Rather, what is of special interest is that, like evolutionary appeals made to establish cultural difference, geology also provides a temporal syntax—rules for arranging phenomena to be explained—that directly affected, and continues to affect, settler colonialism. Braun (2000) identifies early deployments of this syntax in the late 19th century use of geology to render islands off of the west coast of Canada governable through the production of what he terms "vertical territory." Critically, after jurisdiction over subsurface resources passed from the federal government to Alberta in 1930, the province moved quickly to set up regulations for hydrocarbon extraction. By 1938, established the practice of collecting geologic core samples as part of governing surface and mineral rights—with the aim of ensuring economic stability through managed production rates and resource conservation (Breen, 1993). The geological production of knowledge for purposes of political economy evolved alongside new extractive technologies, including those facilitating bitumen extraction (see Gow 2005; cf. Breen 1993). In this context, the FTS events in Alberta provide an opportunity to examine how geology continues to provide temporal syntax for resource governance. It also allows the FTS events to be engaged for how *in situ* technologies are governed in ways consistent with Indigenous dispossession, which has previously been studied with respect to how mineral claims are staked and developed within and beyond surface mining for bitumen in Alberta (Preston, 2013, 2017; Hoogeveen, 2015; Stanley, 2016). Indigenous peoples both contest and engage Alberta's energy economy in ways that reflect the challenges faced by Indigenous peoples and economies elsewhere in North America (compare Black et al. (2014) with Urquhart (2018); cf. Cattelino 2008; Powell 2018). In this context, the elimination of federal environmental assessments for *in situ* bitumen extraction in 2012 strategically curtailed opportunities for Indigenous peoples engaging those governance processes to assert Indigenous sovereignty (cf. Baker and Westman 2018; Joly et al. 2018).

Engaging the "temporal syntax" of settler colonialism in the context of Indigenous dispossession requires examining how geology is used to naturalize extractive projects to particular temporal and spatial frameworks. The capacity for geology to be used in this way is due, in part, to its semiotic function as both a body of knowledge about the Earth and a way of thinking (Baker, 1996, 1999). As a semiotic science accounting for both what is (ontology) and how phenomena are known (epistemology), geology can be a formidable naturalizing force owing to how it orders both time and meaning (Szerszynski, 2012). When used for extractive ends, geology's naturalizing force is deeply political owing to how it sequences causal relationships. Methodologically, for instance, geology has a long history of using hypothetical reasoning to connect past and present, dating at least to Chamberlin's (1890) notion that, contra positivism, geologic explanations require deploying "multiple working hypotheses." In the United States, forms of hypothetical reasoning proceeding in reference to analogy and surprise were developed by key scientists, such as Grove Karl Gilbert and Charles S. Peirce, as one outcome of their work for the United States Geological Survey (see Pyne 1978; Baker 2009). Peirce (1998: pp. 231), a key founder of semiotics, formalized the logic of hypothetical reasoning as abductive: "The surprising fact, *C*, is observed. But if *A* were true, *C* would be a matter of course. Hence there is reason to suspect that *A* is true." As recent geographic and historical work on the United States Geological Survey shows, this key institution also brokered a union of geological agency, liberal institutions, and settler colonial approaches to resource conservation (see Schmidt 2017; Black 2018). This American approach to resource conservation directly influenced federal and provincial approaches to hydrocarbon development in Alberta (see Breen 1993). Further, its methodological approaches to geologic reasoning continue to be relevant to Anthropocene sciences (see Baker, 2014). As the case below also makes evident, establishing the 'enabling conditions' for FTS events involved similar hypothetical reasoning: oil was surprisingly found at the surface and multiple hypotheses were generated to work out how this could be so in ways consistent with settler colonial institutions of resource governance.

In settler colonial contexts, the temporal syntax of geology orders the subsurface in a manner that allows presumptions of *terra nullius* to extend underground—a *geo nullius* to be configured according to governance structures congruent with those at the surface. Like the Indigenous erasures of *terra nullius* generally, these extractive techniques operate through an on-going exclusion and policing of 'risks' that Indigenous refusals pose to both infrastructure and capital circulation (see Pasternak and Dafnos, 2018). On the other hand, the underground extension of surficial institutions is not straightforward. Yet, what are sometimes interpreted as categorical misalignments, errors, or gaps between three-dimensional realities and areal accounts of territory are not oversights. They are part of the technological repertoire at work in the production of territory. Bridge (2013) argues that understanding the articulation of state territory with extractive practices requires examining the political, legal, and technical edifice that renders subsurface resources tractable to commodity flows and capital circulation. Critical engagements with the production of territory have recently focused on the categories, techniques, and contests that render volumes of heterogenous materials and spaces governable, whether terrestrial, atmospheric, or oceanic (Elden, 2013; Steinberg and Peters, 2015; Clark, 2017; Peters et al., 2018). Additionally, the material dimensions of claiming, extracting, transporting, refining, and selling geological products co-produce what Barry (2013) described as material politics (cf. Mitchell, 2011; Appel et al., 2015). Recently, Barry has called for research that connects political geography more clearly with the geological aspects of such politics (see Powell et al., 2017). The spatial distribution of the four FTS events offers such an engagement by opening a window into how *in situ* technologies articulate with the temporal syntax of geology, and the governing network of a settler colonial state.

In situ technologies of fossil fuel extraction connect the 'temporal syntax' of settler colonialism to the naturalizing force of geologic claims to territory. The role of extractive technologies in this process opens up the production of geologic knowledge in ways relevant to geographical engagements with science and technology studies (cf. Furlong 2011). Bowker's (1994) classic study of seismic technologies presented an early engagement with controversies now frequently studied by social scientists regarding adjacent technologies used in hydraulic fracturing for natural gas. In the latter, competing spatial claims regarding the nature and extent of inputs at the surface, such as the appropriation of sand and water, combine with subsurface geologic formations, technology, and the knowledge held by competing political actors and networks to co-produce contested spaces at and below Earth's surface (Bosworth, 2017; Pearson, 2017; Wylie, 2018). So too in Alberta, where contests over hydraulic fracturing entangle science, technology, and governing agencies such as the Alberta Energy Regulator (Nikiforuk 2015). These operations, like other sites of 'tight oil' extraction in Alberta, are increasingly understood as a complex intersection where technological productions of geologic knowledge and resource governance are operationally affected by concerns of capital circulation (Wood, 2016).

The FTS events in Alberta go one step further. They show how the extraction of value from one of Alberta's most profitable geologic deposits also makes Earth's deep history intrinsic to the 'temporal syntax' of settler-colonial institutions that govern the province's massive *in situ* bitumen industry. It is within this temporal framework that Earth history and human time are made commensurate. Here, the co-production of geologic knowledge augments Jasanoff's (2004: pp.2) claim that "the ways we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it." Rather than treating nature and society as respective domains of representation or knowledge, the controversy over what caused the FTS events takes place in a context where humans wield geologic force that is both locally specific and, owing to the scale of Alberta's extractive industry, globally relevant to the commensuration of human time and Earth history in the Anthropocene.

3 CAUSAL CONTROVERSY OVER FTS EVENTS

Explaining bitumen out of place at Primrose required distinguishing the causes of FTS events from normal operations. In 2007, 80 HPCSS operations were approved for the Primrose area, with an additional 120 approved in 2011. Each *in situ* operation works by setting up a phalanx of wells spaced 60-80m apart on a single well pad. Wells are bored down to bitumen deposits before the drill stem bends horizontally for anywhere from 800-1700m. Once the array of wells is in place, high-temperature, high-pressure steam is injected at rates of 1800-2200m^3 per day in either a 'block' pattern that steams all wells at the same time or a 'wave' pattern that pressurizes them in sequence. Each well uses approximately 130 000m^3 of water, while the geologic formation expands and uplifts to accommodate added volume and pressure (Alberta Energy Regulator, 2016). When everything works as planned, overlying caprock provides hydraulic isolation so that, as the formation is stressed through added volume and pressure, bitumen flows to areas of lower pressure made available once the wells are used to reverse flows for extraction. In the case of an FTS event, things go awry. Geological stress finds relief elsewhere as bitumen emulsion—the term for steamed bitumen—flows towards areas of lower pressure, including to Earth's surface. At Primrose, explaining FTS events involved interactions among Earth's deep history and what were termed the "enabling conditions" for FTS events.

3.1 Earth's Deep History

Determining causality for the four FTS events required understanding the geology of what Earth is and this entailed thinking geologically. Although, strictly speaking, geotechnical explanations only require analyzing the state of affairs in the vicinity of *in situ* operations, such as by calculating differential stress rates in different formations, geologic explanations were made by invoking temporal registers of Earth history. This produced both an account of what is, and a way of thinking about the relationships of past and present. As Figure 1 shows, local geologic formations in the Primrose area were presented in horizontal layers and mapped against the vertical, temporal eras of geology from the Paleozoic to the Cenozoic. The figure, reproduced in the AER's publications, was first produced by CNRL in the context of a previous FTS event several years prior known as Pad-74 (which returns below as a complicating factor). This mapping of local geology in terms of both depositional columns and Earth history is constitutive of a temporal syntax that orders explanations of subsurface dynamics. In operation, it provides a basis for different interpretations of FTS events and, potentially, for agreement on the geophysical processes of the deep past that might frustrate attempts to provide causal accounts in the present. Some of the geotechnical differences were straightforward: CNRL held that the Colorado Group provided the caprock (the boundary providing hydraulic isolation) for *in situ* steaming operations in the Mannville reservoirs "whereas the AER considers the Clearwater capping shale to be the caprock for CSS operations in the Clearwater reservoir at Primrose" (Alberta Energy Regulator, 2016: pp. 6). But, put in the context of Earth's deep history, these geotechnical differences played out against the need for a broader understanding of how all causal accounts were beholden to how geologic uncertainty regarding cause-effect relationships from the deep past inflected explanations of *in situ* operations that forced bitumen to flow into the present.

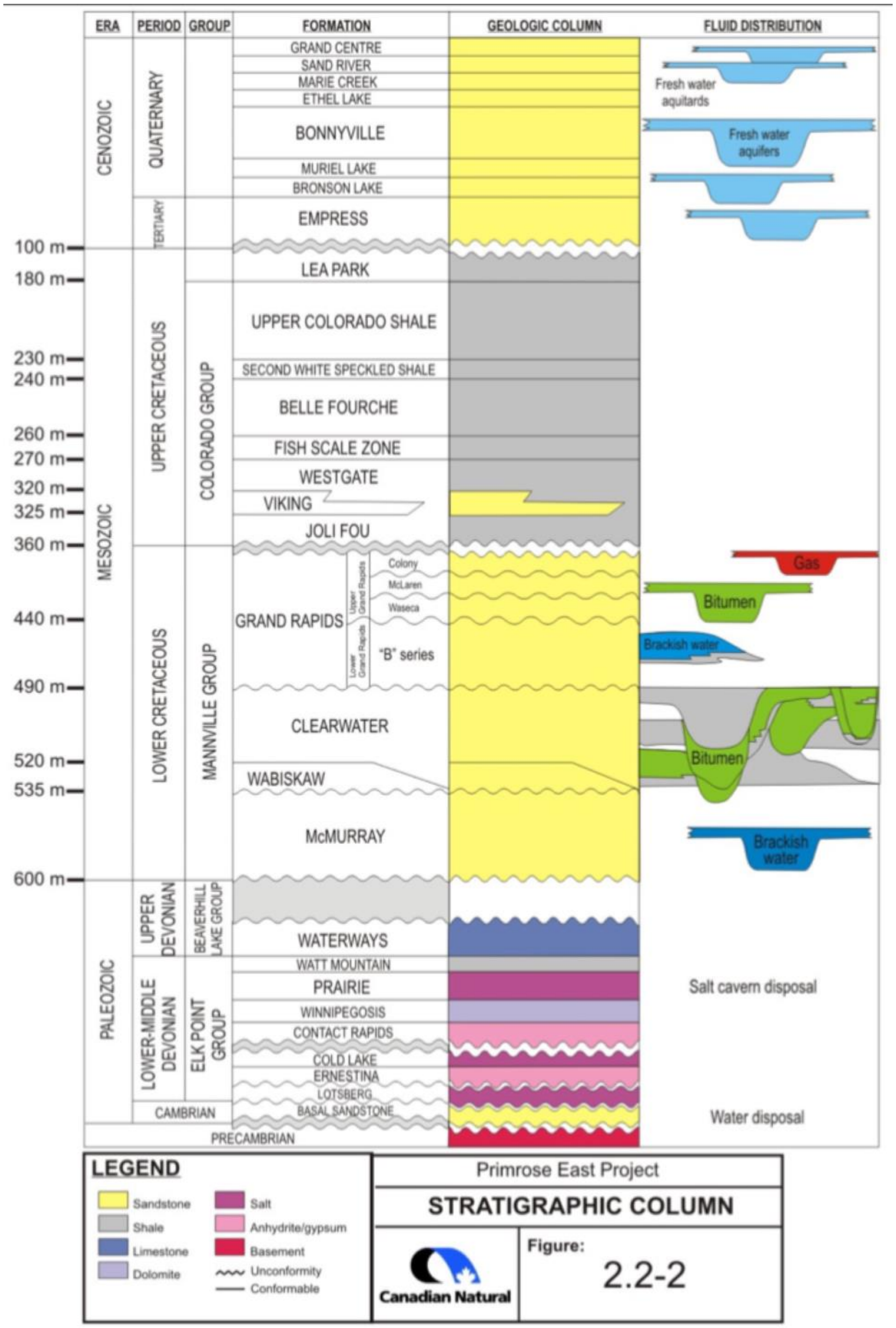

Figure 1. The stratigraphy at Primrose (CNRL 2011: pp. 15). The figure was also reproduced and slightly modified by the AER (without the depths marked in meters) in reports for the Primrose FTS events.

As Figure 1 shows, geotechnical differences were placed within a broader context in which Earth's deep history arranges the pursuit of causal explanations. Beyond the figure itself, Alberta's geologic history was consistently referenced for the context it provided to the FTS events, for the potential impact of geologic history on causal relationships, and for gauging satisfactory causal explanations. For instance, geological phenomena from past eras were identified as generating uncertainty regarding contemporary cause-effect relationships, including earlier processes of mountain building, glacial loading and unloading, and the deposition and dissolution of salts (Alberta Energy Regulator, 2016). Moreover, as the controversy took shape, the importance of Earth's history became an increasingly important factor in stabilizing legitimate differences over causal explanations. For instance, CNRL's (2014, section 6-5) causation report in June of 2014 references factors of mountain building and glacier action and adds to them "sediment erosional and depositional history," and the variations in stress arising from differences in the thickness of overburden owing to deposition and topography. Critically, in the formation that CNRL (2014: sec. 6-5) asserted as the caprock for *in situ* operations, Earth's deep history materialized as a "marine depositional environment [that] likely produces greater variations of rock properties vertically than horizontally." By reaching into Earth's deep history not only to describe a body of geological knowledge, but also to establish a way of thinking, these ancient marine environments, mountain spaces, and glacial cycles were configured alongside the suite of human and non-human geologic processes relevant to explaining the FTS events. This amalgamation connected geologic phenomena with ways to think about different causal possibilities using a temporal syntax that arranged geologic timescales, the variable effects of previous processes, and the uncertainty that Earth's deep history presents for contemporary explanations.

A month after CNRL submitted its causation report, the Independent Panel agreed that Earth's deep history required making a "thorough assessment" of the possible ways in which geologic stress states may be affected by "valley incision, glacial loading and salt dissolution in this part of the [Primrose] field" (McLellan et al., 2014: pp. 11). The following March, when CNRL (2015: pp. 21) presented its final report on the FTS events to the regulator, its introduction to local geology amplified the account to include a larger set of factors from Earth's history, including: "tidally influenced distributary channels near the top of the [Clearwater] formation" as well as "shoreface sandstones…separated by shales that correspond to marine flooding surfaces," and "incised valleys" that characterize the overlying Grand Rapids formation. These deposits, CNRL argued, must themselves be interpreted against later glacial actions of the tertiary and quaternary periods, in which "glacial melt waters eroded deep valleys into the Lea Park Formation and Colorado Group bedrock units" that were then subsequently filled with "glacial tills and freshwater aquifers" (CNRL 2015: pp. 22). To think about causation in this context, then, it was critical that Earth's deep history—mountain building, valley erosion, ancient oceans, glaciation, and the continent shaping floods of glacial retreat—be arranged in ways that situated the bitumen currently flowing to the surface within geologic time.

Earth's deep history provided evidence for a dynamic, multi-causal environment, a point on which CNRL, the AER, and the independent panel all agreed. The historical contingency of where bitumen deposits now lie, sunk well below what surface mining can get to, provided the parameters for any calculus of getting it out—for "liberating" bitumen as the local idiom in Alberta's oil patch describes it (Turner, 2017)—and for accidental flows to the surface. Here, both geologic complexity and the contingency of Earth's history have epistemological implications as causal knowledge moves from expectations of linear relationships to an assessment of plausible explanations in a multi-causal environment. In this context, the rather straightforward disagreement between CNRL and AER about what formed the caprock for *in situ* operations must be situated within the multiple available hypotheses that could explain geologic responses to anthropogenic forcing. The temporal syntax of geology that explained both what Earth's deep history is, and uncertainties around how it is known, was critical to establishing the parameters for plausible hypotheses of FTS events, where were termed 'enabling conditions.' More than this, however, this temporal syntax stabilized competing hypotheses among political actors over how bitumen finds its way from time immemorial into the regulatory present.

3.2 'Enabling Conditions' of FTS events

Explaining what caused the four FTS events required connecting geology to the geography of four bitumen seeps that were miles apart in some cases. As CNRL began drilling test wells to map the route(s) bitumen took to the surface, it reported that bitumen found in different formations was assumed "assumed native until finger printing analysis shows otherwise." The vertical and horizontal space between steaming operations at Primrose and the bitumen seeping up under lake beds and forest floors, however, was also punctured by previous extractive operations. CNRL was especially alert to the potential for the cement that cased old oil and gas wells to present a man-made way through caprock. But this was only one of four potential pathways, or 'enabling conditions' for an FTS event. This section shows how the enabling conditions used to account for FTS events linked the temporal syntax of geology to the spatial distribution of bitumen at the surface. Critically, this also produced a political geography that linked causal conditions of Earth history, the four FTS events, and Alberta's governance institutions.

The AER, CNRL, and the independent expert panel agreed on four 'enabling conditions' that could explain FTS events: (1) there could have been an excessive release of bitumen from one subsurface reservoir into an overlying, permeable formation; (2) there could have been a hydraulically induced vertical fracture from *in situ* operations; (3) there may have been a vertical pathway (like an old well casing) that facilitated transfer through impermeable shales that usually have *in situ* stress rates that favor horizontal fracturing; or, (4) it is possible that an uplift of the geological overburden changed the stress in the overlying formation sufficiently to allow horizontal and vertical *in situ* stresses to approach each other (see McLellan et al. 2014). Independently, if any one of these four conditions were met it could be hypothetically possible to explain the FTS events, but none of them is strictly necessary (Alberta Energy Regulator, 2016). The question arises: what condition, or combination of conditions, enabled the FTS events? The multifaceted nature of the question arose out of the geographic peculiarity of the problem—bitumen flowing to four different surface locations needn't all share a common causal explanation. Further, even a single FTS event could at different points be facilitated by different enabling conditions. To make an adequate determination, CNRL drilled a number of test wells and conducted seismic testing and imaging in the vicinity of all four FTS events. In the area near the bitumen seeping up under the lake, for instance, over 200 seismic shot holes were made. As it mapped out the area and submitted progress on these tests in reports that were part of an environmental enforcement order, CNRL began to collate data for its submission of a causal findings report to the AER. There, as Figure 2 shows, CNRL (2014, 2015) provided technical and representational schematics of how the different enabling conditions present paths to the surface.

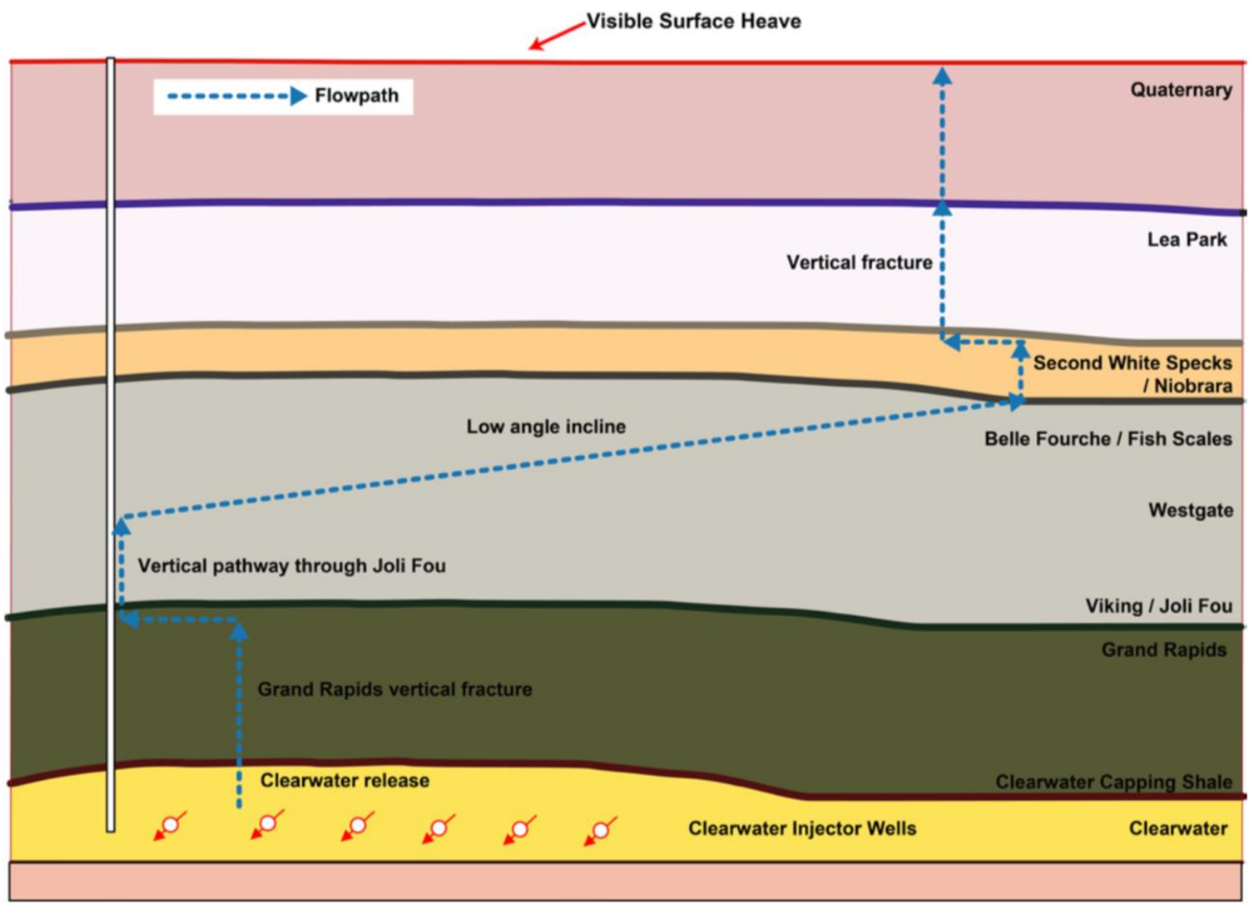

Figure 2: A non-technical schematic representing the four enabling conditions for FTS events: release from excessive pressure from reservoir into a permeable layer, vertical fracture, vertical pathway, or geologic uplift (CNRL 2015: pp. 4).

Determining the role that each enabling condition may have played in the FTS events turned on several factors, the most significant being that the Primrose area is not a blank slate. Geologically, Earth's deep history scoped a range of causal factors, but there were also industrial considerations. CNRL (2014) held that problems with old wells, whether failed casings or inadequate plugs designed to seal them off, were a significant explanatory factor for the FTS events. In all but one instance, the AER (2016) disagreed that old wells were a plausible pathway, and it used a combination of geography, time, and the materiality of bitumen to do so. Here, the earlier FTS event alluded to above—Pad 74—was used not only for the data and geological representations produced in response to it, but also with respect to the regulatory response and material consequences it had prompted for the four recent FTS events.

The FTS event at Pad 74 happened in similar circumstances to the four FTS events in 2013. On 3 January 2009, sometime between 05:30 and 08:00, HPCSS operations led to bitumen coming to the surface on a well on CNRL's Pad 74 operation. CNRL's (2011: pp. 2) final report on the Pad 74 incident noted it was not a "geographically widespread phenomena" but occurred from "a single point, or possibly through a number of points located in close proximity to one another." In response, CNRL conducted a series of diagnostic steaming exercises to test for possible routes of bitumen to the surface, such as caprock failure or other routes for bitumen migration. In the Pad 74 case, CNRL could not reach any confident conclusions about the precise cause of the FTS event. Nevertheless, Pad 74 did not go away, but reappeared in responses to the four FTS events in 2013. In particular, the Pad 74 event had resulted in numerous pressure tests and well maintenance activities in the vicinity of the four FTS events. AER cited the results of these tests as evidence of well casing integrity. But this was not its only rebuttal. The AER (2016) also argued that one result of possible casing failures in the Pad 74 case was that, once bitumen emulsion moved through weakened old wells, it would have become geologically trapped because not all of it would have flowed to the surface. As that trapped bitumen cooled, its increased viscosity would itself reduce potential pathways to Earth's surface. Effectively, cooled bitumen from previous FTS events now formed a geologic plug that bolstered AER's position that old wells were not the most likely culprit for the four FTS events. If tests of well casing integrity and the materiality of old bitumen flows were not sufficient reason to discount CNRL's preferred locus of blame on old wells, AER argued further, the distance of one kilometer between HPCSS operations and at least one event—the one under the lake—made casing failure a less likely cause. Something more geologically forceful, such as uplift caused by injected steam, had to connect 'enabling conditions' to actual events. Satellite observations by Natural Resources Canada added cogency to AER's position. These indicated high rates of ground deformation and 10-30cm uplift in local geology in the Primrose area from 2009-2013 (Fekete, 2014).

Further complicating causal explanations, the enabling conditions for FTS events could also be stratified geographically, meaning that different conditions could be at work in different places and across different strata. For its part, the Independent Panel view was that three of the enabling conditions were controllable, but the "propensity for hydraulic fractures to be vertical" as the result of "natural fracture and fault distributions" was not—although risks needed to be assessed and understood (McLellan et al., 2014: pp. 3). The panel tended towards explanations offered by CNRL faulting old well casings or plugs. But it did not wholly endorse this explanation and questioned whether the space available in old wells would be sufficient to allow the volume of flows involved in the FTS events (McLellan et al., 2014). The panel also considered the previous FTS event at Pad 74 as a fifth, analogous case as it clarified that the *in situ* stress rates of geological formations can deform under excessive pressure and volumes from HPCSS operations. Here, the panel noted that the stress rates calculated prior to steam injection can change under excessive pressure of *in situ* operations. In short, human activity is a geologic force. Additionally, the panel remarked that seismic tests were "in locations with no throughgoing wellbores" likely to facilitate flow to the surface (McLellan et al., 2014: pp. 5). Further, even though the independent panel acknowledged that CNRL had "collected an impressive amount of data" through test wells and seismic readings, there were two constraining factors on them. First, tests were performed after *in situ* operations had ceased and when local geology was no longer being uplifted by steam injection. Second, "the volume of the formation sampled" by CNRL's sample wells was "small compared to the total area being investigated" and this meant it was not likely representative of average natural fractures (McLellan et al., 2014: pp. 6). It also meant that it was precisely the relationship between human geology and geography—between volumes of injected steam and areal distributions of the four FTS events—that affected the veracity of CNRL's causal account.

4 SETTLER GEOLOGY AND CAUSAL EXPLANATIONS

Enabling conditions provided the governance category for hypothetical explanations that linked Earth's deep history to the geography of the four FTS events. But this is not all that they did. Enabling conditions also gave spatial form to a particular use of geologic reasoning in which multiple hypotheses for linking geologic signs to observed effects (e.g. bitumen at the surface) were made commensurate with the boundary of what is governable. In principle, one does not need to know *when* a geologic formation came into being to assess what exists—the temporal dimension is instead a feature of using the temporal syntax of geology to arrange possible epistemic explanations of cause and effect. By evoking processes of Earth history to situate the enabling conditions of FTS events, multiple working hypotheses structured causal relationships in ways consistent with governance institutions themselves. Subtly, causal explanations become oriented away from observed effects (i.e. the bitumen at the surface) and toward the conditions that enable particular geographies of leaking bitumen. The upshot is that explanations of what caused the four FTS events serve to identify, explain, and ultimately naturalize the boundary conditions of what can be governed to the structure of settler-colonial institutions. This shift is evident in the fact that even indeterminate causal conclusions do not signal governance failure: indeterminacy is not evidence of a lack of sufficient explanations for observations but instead reflects the natural range of hypotheses available to explain the causal relationships linking *in situ* forcing to Earth's history.

Explanations of Alberta's FTS events connect causal explanations to Earth's deep history, to the spatial and material conditions produced by geology and *in situ* operations themselves, and also to governance institutions. I refer to this process of commensuration as settler geology. Settler geology uses the temporal syntax of geology to reason through governance extraction challenges, such as the generation of "multiple working hypotheses" (i.e. enabling conditions) that organize causal explanations in ways consistent with governance institutions premised on extracting value from land. There is, of course, a well-known logical gap between "hunting causes and using them" in public policy (Cartwright, 2007). This is especially so in cases where multiple causal forces interact, such as is characteristic of complex social and biophysical environments. In such cases, as Cartwright (2007) argues, identifying causal relationships—the hunt—does not logically warrant particular uses of those explanations in subsequent interventions owing to complex, non-linear causal relationships. Settler geology deploys the temporal syntax of geology to structure the hunt for causes in ways that translate into delimited set of possible social uses of causal explanations themselves. Like the use of evolution to naturalize causal explanations of cultural differences, geology is used to naturalize the political space of colonial extraction. In this sense, settler geology employs the temporal syntax of geology to naturalize the range of ‘enabling conditions’ available for linking subsurface forces—human and non-human—to institutions governing the extraction of value from land. In so doing, the temporal framework of settler colonialism is made commensurate with that of Earth’s history in Alberta, itself a site frequently identified as emblematic of human impacts on the Earth system.

The AER (2016) eventually summarized the different causal accounts succinctly: CNRL viewed old wells as the most likely culprit even if local geological paths couldn’t be discounted entirely. The independent panel didn’t think CNRL had given sufficient treatment to geologic variability, notably because methods of testing took place under conditions different than those that caused the FTS events. The AER’s (2016: pp. v) view was that “all of the FTS events were caused by excessive steam volumes” in combination with “natural fractures or faults and hydraulically induced fractures.” In only one case did AER hold that an old well bore was a likely factor. As the AER (2016) subsequently explained the different interpretations of what caused bitumen to arrive at the surface, it moved across geologic time and geographic expression, from the Cretaceous and the Devonian to local geological formations and to legal land descriptions of the spills at the surface. Here, the hunt for causation was arranged through the temporal syntax of geology while the causal conditions of FTS events incorporated the geographic peculiarities of each of the four FTS events into the AER’s own governance structure. After careful technical presentation, the AER summarized similarities and differences between its own interpretations and those of CNRL and the independent panel in a table that compared probable explanations. The AER (2016: pp. 47) then reiterated that although “the exact pathways that allowed the bitumen to flow to surface were not definitively determined” that a number of proactive and reactive measures could be put in place to prevent similar incidents and to respond to them. In short, it outlined how indeterminate findings did not undermine legitimacy for the agency regulating *in situ* extraction. Rather, causal indeterminacy found place within Alberta's governance structure and the commensuration of Earth history and human geological forces.

Accelerating techniques of extracting value from land, such as *in situ* technologies, produce novel causal relationships where human geology breaks Earth open and makes new geographies. In the FTS cases, the geology upon which different causal factors act is also affected by different geographic pathways through which bitumen could flow to the surface. Those pathways themselves can be further segmented owing to how differential stress rates may vary spatially through the geologic column in ways that only exist during the application of geologic force by *in situ* technologies. So, causal relationships are not fixed by geology or geography. Instead, causal explanations require the joint tools of the temporal syntax provided by geology, hypothetical reasoning, and the temporal framework of settler colonialism to make commensurate Earth's deep history and the spatial distribution FTS events. In this process, settler geology legitimizes institutions for governing extraction in ways congruent with cultural claims to territory.

4 ALBERTA IN THE ANTHROPOCENE

Bitumen extraction in Alberta is a potentially planetary shaping force, a dynamic often in play as its fossil fuel industry is situated with respect to the Anthropocene (e.g. Boschman and Trono 2014; Bonneuil, 2015; Rosa et al. 2017). Rather than exhibiting the incommensurability of human history and geologic time touted as characteristic of this new epoch, however, the four FTS events in Alberta provide evidence for how a particular temporal framework was used to organize relationships of human geological forces and Earth's deep history. The temporal framework at work in the response to the FTS events is that of settler colonialism. By pivoting from evolutionary explanations of cultural differences to the role of geology in settler colonialism, Wolfe's (1999) dictum that settler colonialism is a 'structure, not an event' gains a further register in which the generation of multiple working hypotheses (i.e. enabling conditions) provides a way to identify where and how Earth's deep history is connected to, and governed by, settler-colonial institutions in Alberta.

Dalby (2019) has recently argued that understanding geopolitics in Alberta must be placed amid Canada's national and international fossil fuel economy, climate policy, and its role in the Anthropocene. In this context, settler geology offers a shorthand—a neologism—through which to identify the temporal framework that renders Earth's deep history commensurate with human geological forces. Contra Yusoff's (2019: 4) claim that geology creates "*a*temporal materiality dislocated from place and time," something quite different is at work. It is precisely through the temporal syntax of geology that both extraction and dispossession are structured by settler colonial governance institutions. These institutions are grounded in evolutionary tenets of racial superiority and they deploy geologic forms of reasoning—surprise observations, hypothesis generation, and probable explanations—to bypass issues of dispossession in causal explanations. By examining the current commensuration of human time with Earth's deep history it is possible to begin connecting geology to the political geography of the Earth—oceans, strata, and species of times past—that also figured centrally within the material configuration of colonial time itself, and anti-colonial responses to it, within and beyond settler colonial territories (Fabian 1983; Ogle 2015; Powell 2016; Mawani 2018). As in earlier iterations of settler colonial time-making, Indigenous presence in Alberta was erased by explanations of FTS events focused on the causal conditions for events—maritime, glacial, and mountain environments—rather than the forms of dispossession entailed by *in situ* technologies that push bitumen into new ecological, social, and political relationships.

Alberta's fossil fuel economy is an epicenter of settler colonial extraction in which the temporal syntax of geology arranges causal relations and discrete events—from mineral claim to commodity form to capitalized asset—in ways that naturalize institutions of liberal governance. As in other places where oil is embedded in everyday life, tracing the depth of these entanglements requires attending to forces of production, culture, and infrastructure (Huber, 2013; Appel et al., 2015; Wilson et al., 2017). It also requires attention to the accidental moments of non-accumulation, such as oil spills, of which Alberta averaged two per day from 1975-2013: 28 666 in total plus an additional 31 453 spills of related pipeline products (Young, 2013). Like regular oil spills that each receive their own causal infrastructure that structures explanations of what went wrong and why, the bitumen seeps crews stumbled upon in 2013 also had to become discrete events. In these cases, however, a single causal force produced a geographic problem—four spatially distant FTS events—that opened an illuminating window onto how causal explanations are produced in ways that align geology to settler colonial institutions. It is from within the temporal politics of settler geology that cases like Alberta's must be configured with respect to environmental politics in the Anthropocene. Indeed, it is striking to note that the existing representation of geologic time in Figure 1 employs a temporal syntax easily modified to accommodate the representation of shorter epochs—Holocene or Anthropocene—without needing any fundamental alteration. This is because geologic time units are already commensurate with the regulatory network governing *in situ* extraction. From within this temporal framework and its political use in governing extraction, the Anthropocene (as a unit of geologic time) does not require any significant departure from the geopolitical commensuration of Earth history and the geological force of *in situ* technology.

While the controversy over what caused the four FTS events proceeded through the regulatory process, laborers in northern Alberta mopped up bitumen along with thousands of tonnes of oil-soaked vegetation and peat. Eventually, geologic pressure subsided, and the FTS events ended. The lake was allowed to fill, *in situ* operations resumed, and capital investments stayed secure. One year after the AER released its final report, Canada's Prime Minister Justin Trudeau received a standing ovation in a Houston speech when he remarked that, "No country would find 173 billion barrels of oil in the ground and just leave them" (Berke, 2017). In this context, settler geology orients attention to the temporal syntax that orders and arranges geologic phenomena within settler colonial structures of resource governance. It also provides a way to explain how accounts of causality that link subsurface volumes to areal claims operate through geologic reasoning to commensurate Earth's deep history, human geological forces, and settler colonial time.

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