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A coalbed methane ‘stratum’ for a low-carbon future: a critical inquiry from the Lorraine basin (France)

Olivier Labussière

Researcher at PACTE Social Sciences Research Centre, Grenoble, France (CNRS, Université Grenoble Alpes, SciencePo Grenoble)

Corresponding author: olivier.labussiere@umrpacte.fr

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Summary

Coalbed methane exploration in Lorraine (France) is part of a rush to unconventional natural gas around the world. These resources are envisioned as a “transitional bridge” to a low-carbon economy dominated by renewable generation. This paper tackles the idea that such a “fuel bridge” could lead to a more sustainable transition. It studies the network of actors and interests involved in exploring a coalbed methane ‘volume’, its modelling and how it becomes public. Through this lens, it shows how a ‘volume’ endures in a ‘stratum’, as well as the political issues related to this reconfiguring of the underground in Lorraine.

The article contributes to three debates in relation with political geology. First, it proposes a renewed definition of ‘volume’ based on the work of Michel Serres. The ‘volume’ is not a property of the underground nor a geometric ideality but defined as a transitory ordering of the ‘multitude’ that encompasses material, knowledge and political issues. It enables to develop a more continuous analytical strategy to follow geological and political crossed influences, and contributes in this going beyond existing divides (e.g. vitalist/constructivist). Second, the paper provides the reader with a complementary perspective (from the field instead of a compilation of data at an international level) about what it means to assess an unconventional resource. The proposed definition of ‘volume’ does not reduce uncertainty to a matter of knowing but makes it constitutive of the making of a gas potential. This enables to follow the all chain of mediations through which uncertainty is framed and strategically managed to meet industrial, scientific and political interests, while taming local oppositions. Third, the paper analyses why this coalbed methane ‘stratum’ may be democratically contested and transitory instead of preparing the ground for a low-carbon transition. This case study looks at a unique situation in France, namely a private company receiving public support in the context of political tensions about unconventional gas, and shows the country’s internal contradictions and delays in updating its institutions and strategy concerning the use of underground resources for a low-carbon transition.

Keywords

Subsoil; coalbed methane; fuel bridge; Michel Serres; volume; stratum; France

Taking the “fuel bridge” to a low-carbon economy

In 2012, the International Energy Agency published a report entitled “*Golden rules for a golden age of gas*” (IEA, 2012). Among others works and scenarios (Weijermars et al., 2011; Shell, 2013), it calls for a large-scale development of unconventional natural gas to meet energy security and climate policy targets at affordable costs. This “golden age” refers to a transitory period during which natural gas could help to buy time in order to transition towards low-carbon energy services in a gradual way through coal-to-gas electricity generation and power-to-gas storage. Over the past few decades, natural gas has gained the controversial status of a “transitional bridge” to a low-carbon economy dominated by renewable generation (Howarth, 2014; Delborne et al., 2020).

This article analyses the entanglement of political, industrial and scientific interests on which this promise of a transition is built. It follows the exploration of coalbed methane in the Lorraine Basin (France) between 2000 and 2015. The distinction between shale, whose development slowed down after France placed a moratorium on hydraulic fracturing in 2011, and coalbed methane is key here. For *Kimberley Oil*,¹ the junior company committed to this development in France’s industrial northeast, exploration entails horizontal drilling in ‘naturally’ fractured coal seams that does not require the use of this banned technology. Strategically, this allowed the company to argue its commitment to developing a “clean-tech” that will reduce CO₂ emissions by substituting foreign gas imports with local production and by testing power-to-gas technologies.

This article provides the reader with a critical analysis of this “clean” coalbed methane’s potential. Following Clark (2016), it approaches the underground as a ‘stratum’ – that is, an interplay of actors, interests and socio-technical assemblages. The goal is to examine the shift from a coal mining ‘stratum’, which has a long history in Lorraine, to a coalbed methane ‘stratum’ by documenting emerging socio-technical assemblages. To this end, the research considers how various entities (such as gas molecules, knowledge and political passions) are redefined within a ‘volume’ to stabilise, calculate and market the potential of coalbed methane. In so doing, the ambiguities of this promise of a transition are revealed and help us to consider where such a “fuel bridge” may lead.

Material and methods

To explore these issues, the article uses concepts from critical literature on the underground. The notion of a ‘stratum’ is approached as a liminal principle of articulation between different groups of actors, instruments and interests; it is not a given. The paper deepens the notion of ‘volume’ to support a pragmatist inquiry into the changing articulations of a ‘stratum’. A ‘stratum’ does not precede a ‘volume’; the latter is the space in which relationships are configured and a ‘stratum’ gradually emerges. Thus, a ‘volume’ refers to a type of potential. Others types of potential exist that emphasise others qualities of the underground, such as habitability (to offer conditions for living underground, see Adey, 2013) or invisibility (to hide radioactive waste, see Hamblin, 2008).

To describe a ‘volume’ as a type of underground potential, the paper engages with two major fields of literature: One relates to the ‘voluminous’, which refers to the changing qualities of a

¹ Prior to 2006, the junior company had been called ‘Kimberley Oil’. It was renamed ‘European Gas Limited’ (EGL) in January 2006 and ‘Française de l’énergie’ (FDE) in June 2015. These changes demonstrate not only the adjustments in terms of shareholding but also the company’s increasing ambitions: from exploration to production. It also makes clear the company’s efforts to appear as an industry player contributing to the country’s national energy sovereignty.

medium in continual transformation (Steinberg & Peters, 2015; Adey, 2013; McCormack, 2015; Squire, 2017); the other relates to the ‘volumetric’, which refers to the knowledge, mediations and rules that provide groups with calculative capacities, as well as control over the materiality (Elden, 2013; Bridge, 2013). These heterogeneous realms are different dimensions of a “volume” in tension and are not hierarchised according to a hypothetical shape/substance divide. The paper builds on Michel Serres’s reading of Lucretius² by expressing a “volume” as a transitory ordering of the multitude (molecules, knowledge and political passions).

With this approach, the paper develops a pragmatist type of inquiry that focuses on the practices and mediations (to drill, to navigate, to calculate, to visualise, to finance, to market) that bring the “multitude” to successive stasis of gas potential (exploring, modelling, making public). In so doing, we shine a light on the political ambiguities of an emerging ‘volume’ of coalbed methane. Our pragmatist analysis acknowledges the kinds of uncertainty at work in the geological exploration and modelling and how they are strategically managed to fortify investors’ expectations, meet public policy targets and tame public concerns. On this point, the paper shows that the relationships between materiality, uncertainty and calculative practices makes it possible to trace the steady entanglement of industrial, political and scientific interests. This study offers a valuable understanding of how this transition with unconventional gas (“fuel bridge”) takes place and the kind of transitory ‘stratum’ that is developed for the near future.

• The “volume” as a type of underground potential

There is a wide-ranging, burgeoning literature on the underground (Kinchy, Phadke & Smith, 2018; Squire & Dodds, 2019; Bobbette & Donovan, 2019). For better clarity, the paper mentions two leading areas before discussing some of their writings in relation to our conceptual proposal grounded in the re-reading of Lucretius by Michel Serres. The two ways of thinking that dominate with regard to the notion of ‘volume’ are the ones mentioned above (‘voluminous’ and ‘volumetric’). This divide is challenged by more and more work – an effort to which this paper also intends to contribute.

Over the past few decades, there has been widespread interest in relational ontology among philosophers (e.g. Deleuze and Guattari, 1987; DeLanda, 2006). The main argument of relational thought is that things do not define themselves but come into existence because of their changing relation to their environment. This perspective has influenced geographical works (Thrift, 2000; Whatmore, 2002) committed to going beyond the idea of space as a container in which social life unfolds. Recently, works have increasingly highlighted the elementary and turbulent nature of space. The ocean is a critical case to grasp this shift in spatial thinking (Steinberg and Peters, 2015). Its ‘volume’ is an assemblage of molecules that constantly change their connections, speeds and shapes as different forces (sea currents, wind, sun etc.) move and shift them from one state to another (liquid, solid, gas). Thus, what a

² Lucretius’s life (98-56 B.C.) unfolded at a troubled time that preceeded the decline of the Roman Republic. It remains mostly unknown nowadays. After others philosophers like Democritus and Epicure, his work deepened the intellectual tradition of the antique atomism. For being introduced to it, the English reader may refer to Algra, K., Koenen, M., and Schrijvers, P.-H. (1996) *Lucretius and His Intellectual Background*. Proceedings of the Colloquium, Amsterdam, 26-27june 1996. Amsterdam : North-Holland ; and more recently to the historical essay of Greenblatt, S. (2011). *The Swerve. How the world became modern*. London : The Bodley Head. The French reader may fruitfully read the introduction of Alain Gigandet to the work of Lucretius (2002) and the reading of Michel Serres (2000).

‘volume’ is may be answered by studying the relations in which molecules are aggregated, mixed and dispersed. In some of these works, the body was highlighted as a means to characterise a ‘volume’ through its sensitive dimensions and affective atmospheres (Adey, 2013; McCormack, 2015). Prior to any calculation, being part of a ‘volume’ is an immersive experience that engages various (light and acoustic) qualities of space (McCormack, 2018). Squire (2017) goes further by showing that even in a highly controlled, calculable and safe environment, the bodily experience of a ‘volume’ (e.g. a “dive” in a hyperbaric chamber) undergoes uneven situations and affects. Our paper pays attention to the experience of drillers in the field and the development of their embodied knowledge regarding coal. Using the work of Serres, it intends to relate the experience of materiality to the advent of empirical geometrics and demonstrate their role in calculation tools.

Works in the field of geopolitics, as well as resource and energy geography, have also considered the notion of ‘volume’ along with issues of knowledge, power and property. The ‘vertical’ dimension of space has been studied in relation to historical connections between how geological science forms and how state power develops (Braun, 2000). More recent works have introduced the notion of ‘volume’ to revitalise the analysis of border control and security issues. Elden (2013) uses Israel’s border with Lebanon and draws attention to the different infrastructures (e.g. tunnels, bridges, hilltops, airspace) that make borders porous for flows of people, capital and commodities. In this case, the ‘volume’ results from calculative practices. This work inspired many others and contributed to increase the attention for the contemporary proliferation of new volumetrics to manage global environmental issues, such as global carbon dioxide emissions and the Arctic ice (Dalby, 2013). In resource geography, the notion of ‘volume’ has been introduced as *‘primarily a metric of anticipation and potential: calculations of what space contains’* (Bridge, 2013). Building on this, a ‘volume’ is *“a spatial form of property through which the circulation of resources and commodities is controlled”*. The vivid interest in these new geometrics tends to overemphasise humans’ ability to control the environment and in some cases might legitimise a large-scale political gesture such as geo-engineering (Lehman, 2013). Following other works (Forman, 2018), this paper argues that the politics of a ‘volume’ cannot be studied solely through calculative practices. It assumes that there is a range of scientific and non-scientific experiences of a ‘volume’. For instance, if we consider a local population that used to adapt its daily life to a seasonally fluctuating space (e.g. delta region), we can see others’ abilities to manage a ‘volume’ and its social and economic potentialities (Grundy-Warr, Sithirith and Li, 2014).

The paper proposes an original approach to the notion of ‘volume’ that focuses on how it forms and does not pit one dimension against another. It does so through Serres’s work, *The Birth of Physics* (2000). It is a re-reading of Lucretius’s *De natura rerum* (2002), a philosophical poem more than 7,000 lines long. According to Lucretius, nature is composed of atoms, and each atom follows a general movement of falling. But atoms may also have deviations (*clinamen*) that produce vortices and singular trajectories. The atom’s movement is not linear but marked by successive temporary states of equilibrium. In particular, the general falling of elements alternates between two types of swirl, namely a phase of disorder (“*turmoil*”) and a phase of order (“*vortices*”): *“The first designates a multitude, a large population, confusion and tumult. It is disorder [...] but the second is a round form in movement like a spinning top, a turning cone or a vertical spiral [...] The world in its globality may be modelled by vortices. The origin of things and the beginning of order consist simply in the narrow space between turba and turbo [...] The first is simply disorder, and the second is a particular form in movement”* (Serres 2000:28).

This excerpt introduces an alternative conception of ‘volume’. Serres brings attention to the fact that a ‘volume’ is not defined *ex ante* as a geometric ideality. It derives its meaning from

the spiralling race of elements. It is the progressive transformation of a “multitude” (molecules, knowledge, political passions) into “a particular form in movement”. This idea of a moving shape is extremely important as it does not subsume the elemental (the voluminous) into an abstract three-dimensional form (the volumetric); on the contrary, the moving shape is precarious. The voluminous and the volumetric co-evolve as two dimensions of a ‘volume’. It is both unstable and stable, fluctuating and in equilibrium, simultaneously order and disorder. The turbulent nature of a ‘volume’ is constitutive of its ‘potential’. This perspective compels us to study the invention of new geometrics in relation to the elemental (exploring, modelling, making public).

The paper proposes to look at the ‘volume’ as a way of endowing the underground with new potential. This potential is articulated and stabilised along with geological experiments, the development of knowledge and a market strategy and the rise in environmental controversies. It is fundamentally multi-dimensional and uncertain and requires a pragmatist inquiry to follow the range of human and non-human entities (such as methane molecules, geological knowledge, local oppositions) affected by these processes (Labussière & Nadaï, 2018). The ‘ontological trouble’ (Marres, 2012) induced by these mutations is not external to the definition of the potential but comprises it. Account has to be taken of how these entities are reconfigured within an emerging (coalbed methane) ‘volume’, along with its political effects.

• Inquiring into the emerging politics of a ‘volume’

The notion of what a ‘volume’ is offers a critical point of view of the development of unconventional natural gas as a solution for the transition. It enables an original inquiry into the changing status of geological uncertainty during the exploration and its strategic management in relation to political, market and local social forces. This inquiry complements two areas of debate, namely assessing unconventional gas resources and framing them as a low-carbon solution.

In the wake of the shale boom, some works have focused on the overall assessments of unconventional gas resources in Europe (Kuchler, 2017; Kama & Kuchler, 2019). Beyond the diversity of their methodologies, these works illuminate the geopolitical use of calculative practices. Some European countries suddenly benefit from huge ‘volumes’ of unconventional gas. These ‘volumes’ have sparked major controversy amid deep uncertainty over local geological conditions. Uncertainty refers to a widespread deficit of knowledge but also to the inadequacy of oil and gas standards. McGlade et al. (2013) stress that “*resource definitions are inconsistent, imprecise and in need of standardisation. While this problem applies to all hydrocarbon resources, it appears particularly acute in the case of unconventional gas*” (2013:1–2). Categories like ‘economically recoverable resources’ have been shown to be imprecise because of the sensitivity of what is economically producible through technical means, which are conditioned by the distribution of a diffuse materiality in place-specific undergrounds. More attention should be paid to calculative efforts regarding the technological feasibility of extraction (Kuchler, 2017). Consequently, it is necessary to have ethnographic inquiry into the making of unconventional ‘potential’, assuming that this ‘potential’ is neither pre-defined by standard economic and technical models of production nor the sole result of speculative practices in the face of uneven material events (Weszkalnys, 2015). Thus, as a complementary perspective to global assessment, the paper’s proposal is to question the notion of ‘volume’ at the scale of a project and its gradual up-scaling.

Following the making of a ‘potential’ from the field also changes the appraisal of uncertainty and how to study it. The paper uses the work of Serres to proceed in this direction. Uncertainty is *constitutive* of a ‘volume’ but also has a *transitive* character. Uncertainty exists

not *per se* but in relation to the conditions of a given experience (i.e. it is *constitutive*), and experience always appears uncertain regarding the potential it offers to reach a new desirable situation (i.e. it is *transitive*). This relational appraisal of uncertainty echoes pragmatist thinking (Dewey, 1929). The paper looks closely at the mediations (gestures and embodied knowledge, instruments, visualising tools, calculative practices and market devices) used to explore the gas potential and stabilise new visions of the underground. It is necessary to specify how uncertainty, which often relates to uneven material changes, is configured and (re-)distributed through these mediations. It is equally important to analyse how uncertainty is strategically managed to secure the confidence of private investors, gain public support and tame local opposition. From this perspective, the reduction of uncertainty is not only a matter of knowing more or less. It also refers to the political boundaries that progressively circumvent a coalbed methane ‘volume’. This offers a stimulating perspective to discuss the ambiguous promises of a “fuel bridge” to a low-carbon transition: Does it extend rather than end the use of fossil fuels? What kinds of industrial, political and scientific synergies support their building? And what is the democratic openness of this new ‘stratum’ ?

The paper draws on a three-year (2013–2015) interdisciplinary research project³ that was a collaboration between geologists and social scientists. Geological research was closely intertwined with the coalbed methane project steered by the private junior company, whose name was European Gas Limited at the time of the study. This situation afforded opportunities to observe the company in Lorraine, meet its different experts and learn more about the different issues that the exploration raised over the course of these three years. The inquiry was also expanded to include other voices from state administrative services, NGOs and inhabitants. This resulted in 20 face-to-face interviews divided into three parts: (i) *‘exploring’*: on several occasions, the driller and the geologist in charge of the test well at Tritteling, both at the office and in the field to visit the testing site; (ii) *‘modelling’*: the mining engineer hired by the junior company to gather mining archives, the geologist dedicated to the analysis of the paleo-geology of the Lorraine Basin, the chief of the modelling department, as well as many documents related to their respective works, such as archives, maps, reports and 3-D visualisations; (iii) *‘making public’*: a regional NGO for environmental protection, one NGO run by opponents of coalbed methane exploration, the regional authority for economic development, the regional authority for environmental protection, the regional authority for mine management, the local water management committee, a local mayor and researchers from a geological research centre. I also analysed reports from local public inquiries, as well as national parliamentary debates on unconventional gas that took place in 2011. These three parts do not refer to pre-defined analytical categories but focus on three practical trials observed in the field. They gradually illuminate the ways in which uncertainty has been managed (in relation to gas materiality, heterogeneous knowledge and political passions) in order to up-scale the coalbed methane potential in Lorraine.

³ The project named “Gazhouille” was funded by the French National Scientific Research Center (CNRS).

While authorisations are delivered according to a list of substances, it ignores the material specificity of their deposits and, thus, the technological means needed to investigate the underground. This approach led to massive local opposition to shale gas in 2011 when inhabitants discovered that hydraulic fracturing was inadequately regulated but used extensively. As a result, the French parliament prohibited the use of hydraulic fracturing. The case of coalbed methane in Lorraine fell between the cracks. *Kimberley Oil* was developing a “clean” technological approach based on horizontal drilling in “naturally” fractured coal seams. This case provides the reader with a very rare experience of unconventional gas still under development in France. The rush towards unconventional hydrocarbons also made clear that the administrative procedures to access underground resources had historically been centralised and were not open for public consultation (see Fig. 2 and Fig. 3). Some changes were adopted in the wake of this parliamentary debate: Since June 2012, a public inquiry has been mandated before exploration can start, and since August 2013, a constitutional change has allowed people to have a say about the issuing of mining permits.

Industrial (the ‘holder’)	Decision power (scale, progress of the procedure →)			
→ Submits a demand to get the “exclusive right to explore”, which includes: (i) maps specifying the search area (limits, surface, administrative areas), (ii) length of the permit (max. 5 years) and proposed name, (iii) description of technological means, (iv) list of mineral substances being sought, (v) financial commitment to the work programme and (vi) environmental impact statement	→ <i>National, centralised</i> Ministry for the Economy and Finance (Office of exploration-production of hydrocarbons – OEPH)	→ <i>Regional, centralised</i> Regional administration of the environment (RAE) determines whether or not the exploration is technically feasible; the regional state representative (prefect) and the RAE send advice to the OEPH	→ <i>National, centralised</i> The award plan is submitted for advice by the General Council of Economy and Industry, which is a consultative body on raw materials and energy	→ <i>National, centralised</i> The exploration permit is granted by a single ministerial decree and is published in the Official Journal Prior to August 2013, public participation was not required. Since 5 August 2013, following a constitutional change, “All persons have the right to participate in the elaboration of public decisions having an impact on the environment” for a period of 21 days

Fig. 2: Administrative procedure to be granted an exclusive exploration permit⁵

⁵ Most of the administrations are state services (‘centralised’) that fall directly under a ministry (‘national’) or designate the regional office of a ministry (‘regional’). At the ‘local’ level, the different administrations are coordinated by a local state representative, named a prefect (‘centralised’), who is in charge of implementing the policy of the French government. Finally, from among the (‘decentralised’) state apparatus, the citizens of each municipality elect a mayor tasked with addressing ‘local’ issues and interests.

Industrial <i>(the 'holder')</i>	Decision power <i>(scale, progress of the procedure →)</i>			
→ Submits a declaration for exploration works, which includes: (i) the work programme, (ii) safety and health documents, (iii) effects of the work on the water resource, (iv) environmental impact statement; if authorisation is required, additional documents are provided: (v) a description of the exploration methods considered, (vi) an estimate of the cost of ceasing the mining work	→ <i>Local, centralised</i> The local state prefect receives the declaration and determines whether the applicant may have to request an authorisation (if the depth of drilling exceeds 100 metres)	→ <i>Local, centralised</i> The prefect transmits the application to the relevant local state services <i>Local, decentralised</i> The application is transmitted to the mayors of the municipalities in which the works are planned; mayors can send remarks to the prefect	→ <i>Local, decentralised</i> The prefect refers the authorisation application for a month-long public inquiry (since 1 June 2012) <i>Regional, centralised</i> The RAE compiles the results of the public inquiry and the eventual special requirements delivered by the administrative services	→ <i>Local, centralised</i> The prefect informs the applicant whether authorisation has been given

Fig. 3: Administrative procedure to be granted authorisation for exploration works

• **A genealogy of test sites, exploring ‘more than a volume’**

The first line of inquiry follows the geologists and drillers hired by the Australian junior company at work in Lorraine. Their stories refer to successive geological experiments scattered across time (from the 1990s to 2015) and space (France, Canada). The paper looks at these experiments as a genealogy that gradually enabled the geologists and drillers to explore the underground in Lorraine. Each experiment is steered by a ‘geological concept’ that connects geological entities (e.g. methane molecules, fault, coal panel, conglomerates, water table) inside a net. No ‘volume’ had existed prior to this experimental activity. Its existence is conditioned on the drillers’ ability to generate new principles of connection underground (e.g. do geological faults foster gas desorption?). The good principles are the ones that allow methane molecules to circulate between the underground and the surface.

Serres’s work helps us to understand that the ‘volume’ is not a geometrical ideality but a moving form. In the field, drillers test successive wellbore designs that connect differently to the geological multitude. The ‘volume’ is like a spinning top. The wellbore designs change their axis, make them lean slightly, produce angles and explore beyond their regular body. More than variations in the molecules’ routes, their changes affect the way that molecules relate to each other and their medium (dry or wet coal, heavy or low pressure). In turn, these uneven molecular changes require changes to the socio-technical assemblage (men, gestures, techniques, instruments). The analysis follows the evolution of different wellbore designs and studies how each diagram fleshes out efforts to stabilise relationships with the geological materiality (voluminous), as well as the first geometric principles (volumetrics).

coalbed methane recovery,¹⁰ it was not possible to depressurise the fault and recover the gas. In 2008, drilling was suspended. The assumption was that the “natural” faults inside the anticlinal structures could act as the first aggregators of methane molecules and could make them accumulate faster. Instead, gas or water seemed to circulate at random along these faults, especially in the specific post-mine context marked by wet subsoil.

Testing sites	<i>Folschviller-1</i>	<i>Folschviller-2</i>	<i>Tritteling-1</i>
Geological concept (assumptions)	Coal seams are naturally faulted; faults are the first aggregators of methane molecules	To target the most promising coal seams, to drill the longest drains as possible, to avoid faults	To develop longer drains to get more gas in the same coal panel, to avoid faults
Geometry, connectivity	One horizontal well, with three drains (A, B, C) in three different coal seams, intersecting faults	From the same well, to develop the drains (B, C) in different coal seams	To separate the well to place the horizontal drains and the well to position the progressive capacity pump
Skills	Former HBL engineers – to mobilise know-how about where and how to drill in the Lorraine Basin	Engineers from Alberta – to benefit from their experience in steering horizontal wells	To improve the steering of the cutting head (collecting data, visualising logs in real-time)
Achievement	One horizontal well with the first drain (A) entered a fault; a lot of water entered the well; the drain cannot be dewatered	Two other drains (B, C), well-positioned but not long enough to have a significant production test	Six horizontal drains successfully positioned to reach a length of 1,500 metres
Materiality, circulation	Endless circulation of water through the faults	Limited circulation of gas	Unrecoverable mixture of water and gas, ‘bouncing effect’

Fig. 5: Evolution of the experiments of EGL at three of its testing sites (Folschviller-1, -2 and Tritteling-1)

EGL revised its strategy and hired a Canadian geologist and a driller who was a specialist in coalbed methane production in Alberta. The goal was to solve the problems of the inundated well F-2 and to develop a new technique to extract gas from wet coal. When they arrived in Lorraine in July 2008, the drilling team was unable to accurately locate the cutting head at the bottom of the well. “*We don’t really know where we are [...] their ability [former team] to steer the drill was limited by their lack of experience. They didn’t appreciate the importance of bringing together all the available information*”, said the Canadian geologist.¹¹ The Canadian engineers improved the steering of the drill in two ways. First, using software (Weatherford Compact XCD) helped them to compile all the data (e.g. gamma ray, drill speeds) necessary to produce consolidated well logs. Different curves were then represented on a single screen in real-time. “*In the field, you need something that you can update in five minutes or less*”, he noted.¹² Contrary to the difficult interpretation of stratigraphic data, this helped to finely steer the cutting head between the floor and the roof of the coal seam. Second, the survey system associated with the cutting head was placed behind it. “*None of the*

¹⁰ Coalbed methane (CBM) is methane gas liberated from unmined coal seams. CBM extraction requires the removal of groundwater to reduce the pressure in the coal seam, which allows gas to flow to the surface through the well.

¹¹ *Ibid.*

¹² *Ibid.*

current systems around the world will tell you where exactly the drill is now. It will tell you where the survey tools are, but the survey tools are always a little behind. So the effect is that you are flying a helicopter while moving in eight directions: left, right, back, up, down and a combination of all of them", he explained. As the two engineers were used to working together, their embodied experience in coal drilling allowed them to anticipate deviations and minimise unintended exits from the coal.

Despite these new means, the engineers failed to isolate the well from its first horizontal drain (A). They had to close the lower part of the well and create new exits for two other drains (B and C) in the upper part. *"The initial concept was three drains in three different seams ('Maurice Michel', 'Alpha Beta Y' and 'Z-Zi'). This concept was complicated by the company wanting to do many experiments at the same time"*, said the driller.¹³ Drilling continued in 2009 and 2010 before the drains were finally in place. Because these drains were too short (200 metres), the amount of recoverable gas was limited. Nevertheless, it was a first for France, and EGL made sure that this news was publicised. Important findings were also made about how to connect the geological entities (coal panel, fault, water table).

In 2014, a new testing site was opened at Tritteling, where the wellbore's geometry had been significantly revised. The horizontal drains had to be placed in the same coal panel to avoid entering faults at their edges. The goal was to have longer drains. Six drains had been successfully positioned for a total length of 1,500 metres, which confirmed the technical feasibility of the wellbore design. A pump had been placed where the six drains met, and it was expected to suck in water and then gas. However, problems arose during the production test. Because of the pressure underground, the gas was in a solution similar to a bottle of Champagne: When the gas surged, it generated bubbles inside the well, and because the pump moved very fast, the water and gas produced a mixture that could not easily escape. *"We've got a column of water and gas moving up and down! And when the bouncing is hard, it has serious effects on the pump"*,¹⁴ said the driller. The gas introduced a compressible 'volume' into a usually incompressible column of water. In his office, he has what he calls his "black museum" – a range of six broken rigs on a library shelf (Fig. 6). In October 2015, when this fieldwork ended, these rigs represented all the unsuccessful attempts to pump water and gas. The wellbore design was changed again.

¹³ *Ibid.*

¹⁴ *Ibid.*



Fig. 6: Rigs broken by untamed wet coals (picture of the author)

This first line of inquiry shows that the ‘volume’ is not pre-defined; its capacity to bring geological elements into a system gradually emerges from a socio-technical assemblage in which embodied knowledge play a central role. In this respect, the case study provides different illustrations. The first is the use of the mining archives. They call for a life-long experience of the mine in order to situate the coal layers and to know how to approach the old pits and where to drill to avoid hitting water. The bodies not attached to the former coal mining ‘stratum’ get lost in this multitude of mine galleries. Another example is the steering of the cutting head. Former mining engineers who lacked experience in horizontal drilling lost control over the first test site. The drillers from Alberta revealed themselves to be skilled at using this machinery, though not at the outset. In Alberta, they were used to drilling dry coal at a depth of 400 metres, while in Lorraine, they explored wet coal dipping at 25° at a depth of 1,500 metres. Their embodied knowledge was supposed to be re-attuned to these material specificities. The wellbore design provided the drillers with principles of connection, but the exploration itself sometimes sounds like dancing in the dark with unexpected others. These others are gradually discovered in their extension (coal seam), resistance and potentiality of deviation (conglomerate), connectivity (faults) or flow intensity (table water). As noted by Rolston (2013), instruments play a “*role in the bodily harms that emerge from years of operating the same machinery*” (Rolston, 2013). They help to acquire an “*embodied sense of the texture, composition and capacities of coal*” (Rolston quoted in Richardson & Weszkalnys, 2014). In our case, the geologist and the driller slowly embedded themselves in a coalbed methane ‘stratum’ while bringing formerly separate instruments (embedded monitoring, consolidated logs, real-time visualisation) to bear on a new approach to coal materiality, which enables them to drive the machinery and handle the unpredictability of the materials. From one experiment to the next, the wellbore’s geometry is refined, the number of horizontal drains in a seam increases and the distance between the drains is optimised. Gradually, the drillers come up empirical metrics and a geometrisation of the underground

that are place-specific. Nevertheless, the ‘volume’ does not have clear-cut boundaries. Beyond the expected connections and targeted material flows, they are still exploring ‘more than a volume’. This ‘stasis’ of potential produces the first speculative estimates of gas from samples.

• **Reserve and resource assessment, modelling ‘less than a volume’**

The second line of inquiry studies the ‘volume’ from a different perspective. While the first (*genealogical*) line of inquiry allowed us to discover a continuous process of change during which a ‘volume’ gradually increased as the wellbore design and the experience of its material connections improved, we now observe the engineers, archivists, modellers and certifying officers at work. Their contributions are oriented towards the extrapolation of initial gas estimates obtained from inherited mining knowledge and recent test sites. The analysis focuses on the calculative practices involved in scaling up the ‘potential’ and assessing the recoverable gas in the basin. Following Serres’s perspective, it has to be understood how a new industrial player succeeds in managing a ‘multitude’ of knowledge from different eras and uses this knowledge to estimate a marketable ‘volume’ of gas.

In the previous section, uncertainty was largely the product of uneven material connections underground in reaction to which the wellbore design had been adapted. The paper assumes that calculative practices contribute to internalising uncertainty, in the sense that it rationalises uneven relationships between the borehole and the elemental underground into a standardised and scalable vision of the ‘potential’ of gas. One device that is central to the process of calculation is the 3-D geological modelling: On the one hand, it aggregates a ‘multitude’ of heterogeneous kinds of knowledge from different ages into one coherent epistemic understanding of the underground; on the other hand, it allows for the addition of different (geological, technical, economic, geographical) constraints to assess ‘volumetric’ potentials. The analysis stresses that this modelling ends in “less than a volume”, meaning that it allows the application of rules to remove uncertain elements (e.g. faults, water table) from the ‘volume’.

Historically, the coal basin had been exploited by mining concessions (Petite-Rosselle, Sarret-Moselle, Faulquemont-Folschviller) that did not develop concurrently. Each site produced place-specific geological knowledge; from one site to the next, it was possible for the same coal seam to have different names and the sites not to have the same zero mark. Thus, the coal could sometimes not be located at the same depth as shown on a map. While located in the same coal basin, it was as if the mining sites did not belong to the same epistemic space. It was much more a collection of specific kinds of knowledge that were juxtaposed but not completely attached to each other. In 2005, Kimberley Oil “concluded an agreement with HBL to access [its] archives. Because it was a ‘mine’ of knowledge”,¹⁵ according to a former mine director. Within a few months, the vast amount of public data became a strategic asset for the ‘junior’ company without any financial compensation. A recently retired director of HBL was tasked with collecting the archives. His connections and friendships with the different offices helped him to gain access to crucial documents (mining maps, stratigraphic sections, seismic surveys, well logs and data on gas concentration in the coal seams). “For months, we copied and scanned every document in order to build as broad a database as possible.” In the rush, the documents were amassed without being sorted.

While the retired HBL director determined the first testing site in Folschviller intuitively (see the previous section), Kimberley Oil had to do a large-scale analysis of the basin to circumvent the existence of a gas field of coalbed methane. It was no longer possible to

¹⁵ Interview #3, FDE, 15 October 2015.

manage the ‘multitude’ through embodied experience; comprehensive geological modelling was required. This work started in the autumn of 2011 and consisted of reconstituting the formation of the coal seams and their evolution to specify their depth, slope, direction and (dis)continuity between scattered geographic points. In the solid substance of the subsoil, the ancient rivers where the biomass had accumulated and transformed into coal had to be located. “Here [the modeller shows the 3-D visualisation], we are in a sort of lake basin with wetlands. Sorts of ‘coal beaches’ formed in these wetlands. These beaches can vary with time, climate and tectonics. The coal seams are not linear over 200 metres. Here we see a seam that is divided into three smaller ones.”¹⁶ These variations may affect gas production. The modeller’s main goal was to correlate short sections of coal seams at different depths and thereby produce a coherent vision of the geological structure. In this respect, the mining archives, which mostly dated to the 1950s (mining maps, stratigraphic sections, well logs), had progressively detached from their former world (mines, infrastructures, miners) and been converted into standalone data. An extensive seismic and drilling database (on 600 drill holes, including seismic surveys from the 1980s and data from the exploratory works in Folschviller) had been built up and used with software (Petrel) linked to a digital terrain model. The modelling here is a transitory ordering of heterogeneous and uncertain data into a homogeneous representation of the subsoil. This offers a 3-D image of the different coal seams informed by statistical results about the characteristics of the coal (moisture, gas load, ashes). This provides the developer with a first estimate of the overall amount of gas in the basin. Estimating its probability of production is now the central question.

The work of a junior company is to prove that substantial gas reserves may be exploited at a high profit. Since the first results (modelling, exploratory wells) were encouraging, EGL asked an independent geological expert (the French Institute of Petroleum) to simulate the development of a gas field in accordance with the permits held in Lorraine and assess the quantities of recoverable coalbed methane. The auditor examined just 2.8% of the overall surface held by EGL. The company received its first certification of the commercial potential of the gas resources in April 2012 and an update in September 2015 (FPI, 2015). From the overall ‘volume’, the ‘volumetrics’ of the gas with the highest probability of production was calculated. In the words of Deleuze and Guattari (1987:487), this calculation is “*more than a surface, [but] less than a volume*”: more than a surface because it is a challenge to define a conceptual wellbore design (derived from field experiments) that optimises the drainage of the largest surface of a coal seam; less than a ‘volume’ because assessing gas reserves (volumetrics) involves reducing uncertainty by subtracting the influence of geological processes (voluminous) that may affect production.

The wellbore design used at Tritteling (Trit-1, see previous section) proved the capacity of EGL to place four horizontal drains 570 metres away for a total length of 900 metres. The auditor worked on optimising this architecture by calculating the best spacing between the drains. This resulted in four drains placed 340 metres away from the architecture and surrounded by a ‘no-flow boundary’ of 170 metres: The water table is supposed to have no impact beyond this buffer space. This method of optimisation translated the former wellbore design tried at Tritteling into a standalone geometric model. While informed by the first geometric principles acquired in the field, this model remains disconnected from the voluminous changes resulting from the interactions between water and coal. It is expected to be developed at a rate of two drains/km². In this perspective, the auditor also studied the potentially accessible lands (free of regulatory constraints regarding the environment and urbanisation) to develop a maximum number of well pads. In the project area, this resulted in 39 potential wells intersecting the 10 coal seams identified in the geological model.

¹⁶ Interview #4, FDE, 15 October 2015.

Every intersection of a well with a coal seam opens a productive area called a ‘block’. This operation divides the area under scrutiny into 390 ‘blocks’ considered as independent units. The exploitation of one ‘block’ is not supposed to affect nearby blocks either vertically or horizontally. This means that the principles of connectivity and circulation, which were so hard to manage in the field due to the entangled materialities of water and gas, are now developed within the boundaries of a ‘block’. This makes it possible to differentiate each of the 390 ‘blocks’ according to critical dimensions (thickness, porosity, pressure, gas and water content) and to assess the overall reserves and resources (volumetrics) by adding their probable individual productivity. As a result, the gas reserves in 2.8% of the land covered by the mining licenses for the next 20 years are about 5.3 Bcf (proven), 27.9 Bcf (probable) and 73.5 Bcf (possible).

With respect to the Petroleum Resources Management System (2011), unconventional resources are classified according to a scale of certainty along which the categories of the ‘potential’ are hierarchised. According to this scale, the development of a ‘potential’ involves the removal of successive (knowledge, technical, economic, recoverability) barriers.¹⁷ Contrary to this representation of uncertainty as a continuum (i.e. a continuity and a hierarchy of actions), the field shows that scales (test site, gas field) matter in the up-scaling of a gas ‘potential’. At a global scale, the assessment of gas resources is a matter of “extrapolation”, which means assuming the “continuity of nature” from one deposit to another to extend given values (Kuchler, 2017; Kama & Kuchler, 2019). At the scale of a project, practices of calculation are different because materiality matters. The process of up-scaling joins the limited scale of the wellbore with the broad scale of the basin. Up-scaling confronts two types (micro, macro) of swirls. A close reading of calculative practices (compilation of data to forge a common epistemic space, 3-D geological modelling, optimisation of the wellbore design, probabilistic assessment of the gas production) shows the influence of managing uncertainty in the integration of scales. Uncertainty, which was previously attached to specific material issues, has been standardised and distributed in a new representation of the underground organised by ‘blocks’ aligned vertically and horizontally. Uncertain spaces remain between the blocks. These interstices compile the materialities of the underground excluded from production (e.g. the geological faults through which water may propagate, such as the overburden and different layers like conglomerates and clay that are not targeted by the developer). In the end, what could be called a matrix of probability combines two regimes of uncertainty in relation to the small (material unevenness) and the large (probability of producing gas in a block) scales. This echoes Albena Yaneva’s observation on the process of architectural design (Yaneva, 2005): “‘scaling’ is not a way to fit into reality; rather, it is a conduit for its extraction.” Seeing in different scales through a variety of ‘stases’ enables experts to reformulate uncertainty (*voluminous*) and lay the path for assessing a large quantity of gas (*volumetric*). This ‘volume’ of coalbed methane now follows a public carrier, which is at the core of the next section.

¹⁷ From assessing the gas physically present in a given field (OGIP), the gas producible under current technological conditions (TRR), economic conditions (ERR), the gases that have specific probabilities of being produced (reserves) and of being effectively produced (production).

• Raising funds, making a ‘volume’ of coalbed methane public

The third line of inquiry concerns the way in which a ‘volume’ becomes public. By following the marketers, private investors, scientists, state administrative services, local NGOs and water management assembly, the focus is on how different stakeholders pave the way for a coalbed methane ‘volume’ to enable a low-carbon future. This section shows that not everyone goes onto a ‘fuel bridge’. A coalition of industrial, scientific and political interests lays the foundation for this new ‘stratum’ (e.g. by fundraising, setting up a technological pilot, developing the regional economy) because it meets strategic ends. However, these processes do not open the issues related to geological exploration up to public debate.

A major issue for the junior private company was to fundraise from private investors, including wealthy industrialists, and then develop its activity. Despite initial interest in the project, investors were wary of investing in a country whose government had halted shale gas exploration in 2011. *“Our response was to say that the region and the state want the project to advance, and they will help financially”*,¹⁸ said the company’s director in February 2013. The company received support from the Lorraine region, a public authority headed by local elected representatives. The region had struggled for decades to find new ways to boost economic development following successive crises in the mining and steel industries. It considered the shift from coal to gas a potential contributor to the energy transition and green growth strategy. However, the region could not invest directly in a risky private venture. The plan that was worked out was to support a research project on which EGL collaborated with scientists from the University of Lorraine, and a “CBM project” was developed in September 2012. It aimed to optimise the technologies dedicated to recovering methane from the specific subsoil of Lorraine and contributing to the re-industrialisation of the region. It was supposed to start in 2013 but was ultimately considered part of a broader comprehensive regional development plan (“Pacte Lorraine”)¹⁹ co-led by the French state and the Lorraine region. At the national level, EGL’s activity was viewed as a factor contributing to the emerging “European Valley for Materials and Energy”. The ‘CBM project’, later renamed REGALOR²⁰ (for gas resource in Lorraine), gained a European dimension (Lorraine, Luxembourg, Wallonia, Saar and Rhineland-Palatinate) between 2014 and 2015. It sought to quantify recoverable gas from technologies with a low impact on the environment and assess the conditions for developing an eco-industry based on coalbed methane. In July 2017, the Grand Est region (to which the Lorraine region had previously belonged) decided to support the REGALOR project with a public subsidy of about €1.75 million: €500,000 would go to FDE (former EGL) and €1.25 million to the University of Lorraine. Gaining public support allowed EGL to increase investor confidence in its development activity in France, which contributed to making the ‘volume’ public while strategically limiting the discussions about its uncertain assemblage to the scientists. Thanks to these public-private synergies, the scientists could access a European technological pilot to bring their research further into the field of low-carbon transition by means of the underground (hydrogen, carbon capture and storage, geothermal energy).²¹

Thanks to the initial positive assessments of gas reserves (see the previous section), FDE envisioned the development of a gas field rather than a limited exploration. As suggested by

¹⁸ Frederic Briens in “Politics hamper bid to unlock French coal mine gas riches”, at <https://www.reuters.com/article/us-france-gas-mines/politics-hamper-bid-to-unlock-french-coal-mine-gas-riches-idUSBRE91H0M320130218>

¹⁹ The Pacte Lorraine document: http://www.prefectures-regions.gouv.fr/content/download/14347/99771/file/PACTE_Lorraine_Document.pdf

²⁰ Interview with the director of a research centre participating in the REGALOR project, 21 May 2015.

²¹ <https://regalor.univ-lorraine.fr/folschviller/>

the development plan, this strategy involves starting about 14 well pads in the near future to support the massive production of gas. While a limited part of this coalbed methane ‘stratum’ is open to pioneering research for low-carbon processes, most of it is entangled in the usual carbon economy. FDE launched a national advertising campaign in March 2016 to raise private funds.²² The promotional picture showed traditional jars of local products full of unconventional gas labelled “Coalbed methane from Lorraine” or “Coal mine methane from the North”. These labels conveyed the idea that the gas was already a stable commodity, but this was not the case, as was clear out in the field. It also ambiguously played with the reference to ‘local’. The advertising conveyed the idea of a small-scale venture managed according to traditional know-how, while it was, in fact, an industrial development with minimal links to the ‘local territory’. This campaign was rolled out in the run-up to FDE’s initial public offering at Euronext Paris on 30 June 2016. The campaign depicted the ‘volume’ as a set of easily handled ‘containers’. Making the ‘volume’ divisible was crucial to convincing investors to buy shares. This is another illustration of a process that makes the ‘volume’ public but does not acknowledge its uncertainty.

At the regional level, there was limited politicisation of coalbed methane exploration. This issue was bypassed during the participatory process linked to the development of a regional framework for climate, air and energy in 2011–2012. There was also little discussion of the matter on the Water Management Committee. From 2008 to 2017, this committee steered the development of a water management and development plan (SAGE) for the coal basin, which led to a public regulation document. Water issues related to coalbed methane exploration had been discussed on only one occasion,²³ in May 2013, when the junior company asked the committee to endorse the ongoing work. According to a representative from an NGO on the committee, *“I said no. I said that we really needed external expertise. The committee can’t have a public stance based on elements produced by a private company [...] I remember a local representative who said: ‘No, we can’t take a stand; we have to wait for the public inquiry and the decision of the local state prefect [to grant or not new drilling works to EGL].’ As a result, it had been said that it was too exploratory a project to be officially taken into account in the drafting of the SAGE.”*²⁴ The state prefect approved four new drilling works (Tritteling, Freyhouse, Pontpierre and Louperhouse) in October 2013.²⁵ Because the prefect bypassed the public inquiry that had been mandatory since 1 June 2012,²⁶ a regional federation for the protection of the environment (Mirabel), which includes 85 associations, lodged an appeal against the decision. The association underlined that there was a risk of methane leaks polluting the groundwater table in the case of large-scale exploitation of coalbed methane. *“The stratum of the Lower Triassic sandstone is a huge stock of fresh water, an international stratum that runs under France, Belgium, Luxembourg. This is a strategic resource. EGL’s idea is to explore faults that do not affect the Permo-Triassic... while a majority of them do. There is a risk of hitting a fault that affects the impermeable Permo-Triassic stratum and generating a migration of methane molecules to the water table. This risk is hard to assess... EGL already hit a fault in which water was actively circulating”*, noted the NGO’s expert in charge of the case.²⁷ The association did not present itself as being

²² See the advertisement at <http://www.place-des-victoires.com/project/francaise-de-lenergie>.

²³ Sources: summaries of meetings, intermediary reports and final documents between 2008 and 2016. <http://www.gesteau.fr/documents/sage/SAGE02008>

²⁴ Interview with a representative of a national organisation for the protection of consumers, 19 June 2015.

²⁵ France Nature Environnement, 31 October 2013. <https://www.fne.asso.fr/communiqués/gaz-de-houille-en-lorraine-nouveau-qatar-ou-nouveau-traquenard>. The case has not yet been adjudicated.

²⁶ EGL submitted its demand in May 2012, just before this procedural turn. The submission was incomplete, and the regional administration asked for additional documents that were finally delivered on 29 June 2012.

²⁷ Interview with the director of the regional federation for the protection of the environment, 24 October 2013.

opposed to coalbed methane on principle. Its position was that public investments should no longer support hydrocarbons and nuclear energy.

In 2015, when FDE asked for new authorisations to drill in three municipalities (Longeville, Zimming and Lachambre), the different local authorities mentioned above joined their efforts. The regional federation decried the lack of information from EGL regarding its strategy (Why increase the number of wells? Are they exploratory, or are they preparing large-scale exploitation?).²⁸ Its contribution to the public inquiry demonstrated its increasing preoccupation with the decline of the landscape and agricultural lands, as well as the pollution of the water table and the risk of ground subsidence. In Longeville, the public inquiry gathered 73 pieces of advice from individuals and NGOs: 1 for and 72 against. According to the SAGE for the Houiller Basin, the measures to control the drilling works and those aimed at restoring the site were not detailed enough. It also asked FDE how to manage the water coming from the drilling works without re-injecting it into the water table. *“The members of the local water commission have reservations about EGL’s plan.”*²⁹ Nonetheless, the Longeville project had received a favourable opinion from the inquiry commissioner and then the local state prefect in November 2015. Regarding Zimming, the inquiry commissioner gave an unfavourable opinion in November 2015, following the negative stance of the local municipality and the majority of the participants from civil society. Nonetheless, the local state prefect decided to grant authorisation to FDE in March 2016. In December 2015, associations that had not previously joined together in protest organised collective action – first in Metz and then in St. Avold in April 2016. Locally, these NGOs and municipalities feared a proliferation of the wells, which is what EGL had envisioned in its road map.³⁰

These processes reveal the political boundaries of a ‘volume’ when it becomes public. Kama (2019) argues that the difficult assessment of emerging ‘potentials’ of unconventional energies generates controversy as non-specialists rush in to offer contradictory expertise and discuss the future of underground resources. The current case study illustrates the difficulty for NGOs, inhabitants and the local water management committee seeking to open a ‘volume’ of coalbed methane encapsulated in public-private synergies to emerging concerns. The dynamics at work show how making a ‘volume’ public is a multi-pronged strategy whose aim is to secure its development: Hybrid (public-private research project, cross-investments in green growth strategy), private (public offer to market) and public processes (inherited tradition of centralised administration, decision making strictly supervised by the local state representative) make it possible to trace the boundaries of a ‘volume’ and ultimately assess its low democratic potential. The ‘ontological trouble’ (Marres, 2012) induced by the different entities’ (e.g. underground, water table, land use, landscape) reconfiguration in a ‘volume’ did not receive any attention. In line with other works (Howarth, 2014; Delborne et al., 2020), this analysis empirically shows the kind of synergies on which the “fuel bridge” to a transition is built and why it may help to extend rather than end the use of fossil fuels. This also contributes to understanding why there is so little protest against unconventional gas, which is otherwise explained by the weakness of civic institutions (Eaton & Kinchy, 2016) or the historical reliance of regions and social identities on the extraction industry (Hudgins, 2013).

²⁸ Regional federation of NGOs for the protection of the environment, 14 October 2015.

²⁹ Letter from the SAGE of the Houiller Basin, 2 October 2016, attached to the report by the inquiry commissioner.

³⁰ A report from the EGL’s General Assembly mentions that, after 2018, the company intends to shift from a ‘phase of pre-development’ to a ‘phase of replication’.

Governing a coalbed methane ‘stratum’: multitude, boundaries and the democratic challenge

As defined by Clark (2013, 2016), following Deleuze and Guattari, a ‘stratum’ is an interplay, a double articulation. It is a socio-political formation constructed by humans in the earth’s geological realm. A ‘stratum’ is highly coded and embedded in historical power relationships but is still open to unbounded earth forces. This paper sheds some light on such contemporary experiments with earth. It questions the processes through which materialities, knowledge and socio/technical assemblage bed down into a ‘stratum’. While stimulating, Clark’s idea of a continuously stratifying–destratifying earth has to be confronted with empirical works and a finer-grained analysis of these transformations. A radical constructivist understanding of these changes and their political potentialities – as if the material and political forces could be re-arranged in a completely new way every time – may be too simplistic to understand the trajectory of contemporary unconventional experiments (Neyrat, 2016).

The paper’s core proposition is that the notion of ‘volume’ could help to gain a better understanding of the various interplays that influence a ‘stratum’. A ‘volume’ refers to an experimental process. It is the attempt to connect various geological entities into a net to guide them towards production.³¹ A ‘volume’ is fundamentally uncertain and always situated between order and disorder, like a spinning top. The stabilisation of a ‘volume’ progresses through practical trials and benefits from synergies between a constellation of interests to endure – in both meanings of acquiring a robustness and a duration – as a new ‘stratum’. The ‘stratum’ emerges while the ‘volume’ progressively up-scales from a single exploration to a new comprehensive view of the underground. This perspective regarding what the ‘volume’ is and how it endows the underground with new promises of production and/or transition is in dispute. A challenge for this research is to shed light on the political meaning of this emerging ‘stratum’ and its ambiguous promises.

The first contribution of this paper is that it proposes an alternative definition of the notion of ‘volume’ based on the work of Michel Serres. The ‘volume’ is not a property of the underground nor is it a geometric ideality. It is not equivalent to the quantification of a resource but is the space in which relations between a constellation of actors, as well as terrestrial forces, are explored, tested, hierarchised and privileged. This is a process of stabilising the ‘multitude’ by selecting the relations that, at a given scale, are relevant to achieving qualitative or quantitative operations. These are the operations thanks to which a ‘volume’ is ultimately reduced to a divisible entity (a ‘container’ in the case study) and can be shared and appropriated. This perspective brings fresh insight into the contemporary making of geometrics and their political uses. Many geographical works have previously used these geometrics to explain how the underground are partitioned and administered as a geopolitical ‘volume’ (Elden, 2013; Bridge, 2013), but the current paper develops a different analytical strategy. It argues that geometrics are best understood in relation to changes in the material substratum. In other words, materiality and power are not *a priori* hierarchised. A ‘volume’ is not equivalent to a metric. Following Serres, a ‘volume’ produces tension between two dimensions: the ‘*voluminous*’ (*vo*) (i.e. the materialities of the underground brought into a process of change/exploration) and the ‘*volumetric*’ (*vc*) (i.e. the geometrics used to translate the underground materialities and assess it as quantitative reserves/resources). These dimensions co-evolve and are reconfigured along with the progress of the geological exploration. A major assumption is that a ‘volumetric’ does not remove any reference to the

³¹ The paper assumes that the relationships between human groups and their undergrounds over time have given rise to different types of potential. Approaching the underground as a ‘volume’ has a lot to do with the productivist preoccupation of modern societies.

‘voluminous’ from the process but standardises the relationship between them and internalises part of the voluminous in the form of calculations of uncertainty. Managing uncertainty in relation to an ongoing experiment is a critical point that helps to illuminate the political implications of how a ‘volume’ is re-arranged.

The relationships between materiality, uncertainty and calculative practices have made it possible to specify how these two dimensions (i.e. voluminous and volumetric) interact with each other. The geological exploration re-arranged the underground in a coalbed methane ‘volume’ according to three ‘stases of potential’. Here, the singular ‘stasis’ is preferred to ‘phase’ because this evolution is not sequential. The different ‘stases’ may influence each other. This process is summed up in Figure 7, and described in more detail below.

	From ‘multitude’	To an emerging ‘volume’ of coalbed methane
<i>Stasis of potential</i>	Multiplicity, heterogeneity	Stabilising transitory orderings (‘volume’); the related (in)capacities of actors
1. Exploring more than a volume	<p><i>Diffuse materiality (vo)*</i> – methane molecules scattered in complex geological conditions (fractured coal seams, wet coal)</p> <p><i>Heterogeneity of knowledge and experiences (vo.vc)</i> – drilling works benefit from the skills of former mining engineers, and then geologists/drillers from Alberta</p>	<p><i>Uneven material connections underground (vo.vc)</i> – circulation of water, limited recovery of gas, unrecoverable mixture of water and gas</p> <p><i>Successive wellbore designs (vo.vc)</i> – elaboration of first geometrics (geometry of the well, number and length of the drains), stabilisation of a geological concept</p> <p><i>First estimate of gas in place (vc)</i> – Extrapolation of GIP from samplings, early strategy of communication to gain financial support from private investors</p>
2. Modelling less than a volume	<p><i>Accumulation of data from different ages (vc)</i> – 1. Capturing public archives from state mining company from the 1950s (mining maps, stratigraphic sections, seismic surveys, well logs and data on gas concentration), 2. Compiling seismic surveys from the 1980s, 3. Producing data from the exploratory works led by EGL in the 2000s</p> <p><i>Multiplicity of geometrics (vc)</i> – juxtaposition of different mining spaces, place-specific geological knowledge, necessity to correlate the data</p>	<p><i>3-D modelling of the Lorraine Basin (vo.vc)</i> – comprehensive visualisation of the basin (faults, coal seam), statistical distribution of the gas in place; erosion of public knowledge and expertise about the basin</p> <p><i>Standardisation of the wellbore design (vc)</i> – optimisation of a concept tested in the field, improvement of its geometry (number of drains, length, spacing), application of a ‘no-flow boundary’ to reduce random connections with the water table ground (vo)</p> <p><i>Assessment of reserves and resources (vc)</i> – division of the underground into 390 independent ‘blocks’ of production, aggregation of recoverable gas units into ‘reserves’, certification of commerciality, uncertain spaces remain between the blocks (vo)</p>
3. Making a volume public	<p><i>Raising funds from private investors (vc)</i> – preparation of FDE’s public offering on Euronext Paris to support coalbed methane exploration and production</p> <p><i>Increasing local oppositions</i> – from environmental NGOs, municipalities and water management assembly; public concerns about the land use, the landscape and the water table ground (vo.vc)</p>	<p><i>Green growth strategy (vc)</i> – gaining public support to give private investors confidence in a less favourable general context (French ban on fracking and shale gas); project uncertainty confined to the scientists (vc.vo)</p> <p><i>National advertising campaign (vc)</i> – presents a container for readily accessible ‘gas from Lorraine’ to encourage new shareholders; instrumental use of the reference to the ‘local’ specificity</p> <p><i>Centralised administrative procedures (vo.vc)</i> – deficit of democracy, company granted drilling rights by the state prefect, regardless of the outcome of the public inquiry, deficit of public knowledge on the underground resources</p>

* A ‘volume’ brings two dimensions into tension: the ‘voluminous’ (vo) (i.e. the materialities of the underground brought into a process of change/exploration) and the ‘volumetric’ (vc) (i.e. the geometrics used to translate the underground materialities and assess them as quantitative reserves/resources).

Figure 7: From ‘multitude’ to an emerging ‘volume’ of coalbed methane. Entanglements of voluminous and volumetric dimensions in the successive stasis of a potential of gas.

The first process (*exploring more than a volume*) opens the analysis to the elemental nature of coalbed methane and, more broadly, to geological entities in the Lorraine Basin. The ‘volume’ (as outlined by Serres) has a moving form. It is a space that makes it possible to bring the ‘multitude’ into an experimental process and to learn from its uneven associations. Serres’s image of the spinning top helps to grasp this point. While in motion, the top’s axis moves and explores a ‘volume’ beyond its regular body. The ‘volume’ is approached as a matter of stabilising the wellbore architecture – in other words, optimising the balance between the feasibility of its geometry and its connectivity (with the faults, water table, coal seams). From this changing diagram, the first geometrics were derived to make progress in assessing the reserves. Unevenness is not channelled by calculative practices prior to exploration but through a genealogy of test sites that help to attune embodied knowledge and adapt the socio-technical assemblage (skills, know-how and instruments) in relation to a place-specific underground. The endless production of water or the forming of an unrecoverable mixture of water and gas revealed that the ‘volume’ always has a surplus: connections with something more than the targeted materiality.

The second process (*modelling less than a volume*) deals with the up-scaling of the experiment to simulate the potential of a gas field. The ‘multitude’ is composed of a vast amount of geological data from different ages and embedded in multiple (coal and oil) geometrics. The capture of public archives from Charbonnages de France, the public/state company, stresses the input of a former (coal mining) ‘stratum’ to foster the calculation of an emerging (coalbed methane) ‘stratum’. The 3-D modelling is a new epistemic space in which geological data are put together in a coherent way to produce comprehensive, never-before-seen visualisations of the Lorraine Basin. The modelling aims to stabilise ‘volumetrics’ by refining uncertainty. Practically, this involves translating the ‘voluminous’ into manageable criteria and dimensions (e.g. application of a no-flow boundary to reduce random connections to the water table ground). In the end, the ‘volume’ is translated into a distribution of thousands of productive ‘blocks’ that exist independently, placing uncertainty in the space in-between. This volumetric operation is not equivalent to the ‘volume’ that made it possible.

The third process (*making a volume public*) questions the means through which a ‘volume’ is made shareable. This uncertain assemblage (*‘more than’, ‘less than’*) is unequally made visible and negotiable. A symmetric challenge is to organise the relationships between terrestrial forces, which are never fully controlled, as well as highly dispersed market actors, around a stabilised commodity. Here, the public offering is supported by an advertising campaign that goes beyond the materiality of coalbed methane: The representation of a ‘container’ eliminates the idea of uncertainty that surrounded the former ‘blocks’. The gas encapsulated in a clear-cut object can easily be divided to raise funds and thereby put the ‘multitude’ of eventual investors in a new ‘volume’ of shareholders. This growth strategy is supported by public authorities that legitimise the project and agree to confine uncertainty to a strategic and restricted area of public research. At the same time, centralised administrative procedures reduce local actors’ capacity to have a say while the assemblage of this coalbed methane ‘volume’ is questioned in relation to the landscape, the land use and the water table ground.

The second contribution of this paper is to develop a critical analysis of the promises of transition associated with unconventional natural gas resources. Instead of a “fuel bridge” to a low-carbon economy, our analysis describes the emerging coalbed methane ‘stratum’ as a joint infrastructure between a constellation of actors and interests that meet various ends – completing others critics (Howarth, 2014; Delborne et al., 2020). Even if they do not have the same vision of an energy transition, the opportunity to gain access to the underground (to produce gas, lead technological research and develop the regional economy) has led them to

make political compromises. In this regard, the ‘stratum’ is narrowed down to an infrastructure rather than a socio-political arrangement that would call for collective choices to ensure a sustainable transition.

This argument is based primarily on the relationships between the coalbed methane ‘stratum’ and the legacy of coal mining. This emerging ‘stratum’ should not be naturalised as if it was clearly distinguishable from the former coal mining ‘stratum’. Both ‘strata’ interact geologically and as socio-technical assemblages. Interestingly, the abandoned ‘stratum’ comprised by mine galleries is still active. It has ground subsidence, groundwater upwelling and contaminants in the long run. During the post-mining era, it has been re-embedded in a new socio-technical assemblage of former mining engineers, local mayors and public state services to monitor these changes. In a short time, aspects of this assemblage that are less considered return to the ‘multitude’, a process highlighted by Serres: “*Born on the clinamen, this place declines, drifts, it runs down the thalweg of degradation*” (Serres, 2000:173). This ‘stratum’ is de-stratifying. A vast amount of mining memories and archives have been forgotten or even destroyed. Through a minimal gesture, which I call a ‘swerve’, Kimberley Oil captured a vast amount of public knowledge and skills from this decomposing stratum. This gesture had a political effect. Contrary to expectations, this capture of knowledge was done with the agreement of the former state/public company, as well as the help of mining engineers who had steered the first test sites and drillings. Nevertheless, this swerve led to a major change in the status of knowledge and the distribution of capacities around the emerging coalbed methane ‘stratum’. Since the mines were shuttered, the erosion of public knowledge and expertise about the subsoil (including its seizure by private actors) has made it impossible for local people to discuss new assumptions about the exploitation of the ‘stratum’ and the collective benefits and impacts associated with it. Geological knowledge is increasing, but no one has access to it to produce critical expertise. The calculation capacities developed by EGL strengthened the market actors’ predominance to have a say in the development of a ‘stratum’.

The temporal frame (mainly the near future) in which this coalbed methane ‘stratum’ is embedded also has to be considered. I argue that it is a transitory infrastructure rather than a “transitional bridge”. This temporal frame is an outcome of an “hybrid neoliberalism” in which the neoliberal economy and state power intersect. Bridge, Özkaynak and Turnhan (2018) express the view of an ‘infrastructural moment’ in the context of a reassertion of state power. Their distinction between post-neoliberal states, populist forms of economic nationalism and liberal economies partly operates here. With regard to the energies of the underground, the French context lacks a national strategy to bring public and private forces altogether. Under the presidency of Nicolas Sarkozy, a fast-track legislative debate ended with a ban on hydraulic fracking in 2011. However, state authorities opened the door to the exploration of unconventional gas through other technical means (“*green technologies*”) – a situation that benefitted the geological concept of EGL, which official public reports mentioned as a model for development (INERIS & BRGM, 2013; Bataille & Lenoir, 2013). Under the presidency of François Hollande, the economic and environmental ministries were publicly at odds over the exploitation of unconventional gas. The current case study is unique in France in that a private company receives public support and procedural facilities despite political tensions over unconventional gas. This ‘hybrid neoliberalism’ fleshes out state efforts to support new industry players, especially in the post-industrialist context of Lorraine. It is, however, less a national strategy (a ‘reassertion of the state’) than a development resulting from a changing gas market at the global level. FDE was renamed ‘Française de l’énergie’ and opportunistically played with France’s growing political obsession to locate new industries in the country. However, this coalbed methane adventure on its own could

hardly support the myth of an industrial redevelopment in the country, nor does it reflect a national low-carbon strategy through the underground resources. The coalition of industrial, political and scientific interests relies on their common need to obtain breakthrough results in the near future from this underground infrastructure. In other words, a well's production curve slows down drastically after two or three years, even when it continues to produce gas for 20 years, and the operation of the Foschwiller well, which was used to demonstrate the development of "clean" technologies, is envisioned for four years. As such, the current experience ambiguously extends the use of fossil fuels while opportunistically engaging research for a low-carbon transition.

A third aspect involves the low democratic potential of this coalbed methane 'stratum'. Serres's work not only focuses attention on changes in the material environment, that is, how a 'volume' is formed from a 'multitude' of methane molecules, but also connects the notion of 'volume' to the 'multitude' of political passions. The article has shown that, although uncertain, the geological exploration is supported by private-public synergies that do not account for its uneven outcomes. There is no place where political passions may be channelled and a collective inquiry initiated. In terms of pragmatist thinking (Dewey, 1927; Marres, 2012), it is difficult for local people to become 'public' since the processes, instruments and scales that are at stake are not explicit. It is hard for people to share their concerns about this geological exploration and thereby have an impact on decisions and actions. Thus, public support from State administrative services and local authorities is unequally distributed : while it has largely supported the geological exploration, the NGOs and inhabitants have not benefitted from the same public and institutional support that would structure the emerging coalbed methane 'stratum' to be steered democratically. As shown before, these forces cannot draw on any resources either in the past (i.e. earlier geological expertise) or in the near future (industrial and scientific interests has shaped the underground as a restricted infrastructure) to configure the underground for the energy transition in Lorraine. The public regional authority could have brought together experts and non-experts already committed to managing regional underground issues (e.g. former coal mines, water table management) to form an advisory body tasked with setting rules for emerging geological exploration. This would entail a profound change at the national level, where the very slow work on revising the French Mining Code to meet the outcomes and rules developed by the French Environment Code has illustrated the difficulty that inhabitants and non-industry stakeholders face when seeking to open mining projects to debate.

Conclusion

Coalbed methane exploration in Lorraine (France) is part of a rush to unconventional natural gas around the world. These resources are envisioned as a "transitional bridge" to a low-carbon economy dominated by renewable generation. This paper tackled the idea that such a "fuel bridge" could lead to a more sustainable transition. It studied the network of actors and interests involved in exploring a coalbed methane 'volume', its modelling and how it becomes public. Through this lens, it showed how a 'volume' progressively endures – in both meanings of acquiring a robustness and a duration, as a new 'stratum', as well as the political issues related to this reconfiguring of the underground.

Through this analysis, the paper contributes to contemporary debate in political geology about what distinguishes the underground from the living but provides underground materialities with an agency and a capacity to influence political issues (Bobbette and Donovan, 2019). In contrast to classical science's predilection for governable and predictable materiality, Michel Serres's notion of 'volume' introduces us to a turbulent nature. Thinking in terms of a

‘volume’ means entering the spiralling race of elements with the hope of generating a new but transitory order from within. This definition is very different from other geopolitics approaches that underline the power of science to govern materiality with metrics. The notion of a ‘volume’ as proposed does not hide the need to build and adapt metrics but emphasises their place-specific nature and their political use in relation with material unevenness and uncertainty. As such, this definition of a ‘volume’ embraces material, knowledge and political issues. This opens an analytical space that contributes going beyond existing divides (voluminous/volumetrics, vitalist/constructivist). It offers a stimulating perspective to understand what is included or excluded from emerging promises of low-carbon future that bet on new underground resources.

From this perspective, another contribution of the paper is to enter the debate about the uncertain assessment of unconventional gas resources in Europe (Kama & Kuchler, 2019). Beyond reducing uncertainty to a deficit of knowledge (Dong, 2015), it argues that the relationships between materiality, uncertainty and calculative practices matter when characterising the forming of a ‘potential’. What the inquiry allows us to see is that uncertainty is not external to a ‘potential’ but *constitutive* of it and plays a *transactive* role (when configured at a stasis, uncertainty becomes a resource for the next experiment or calculus). Taming molecules has consisted of a chain of mediations through which uncertainty has been experienced (by test sites), geometrised (by successive wellbore designs), well demarcated (by a model of productive ‘block’), distributed in interstices (by a matrix of ‘blocks’), translated into probabilities (by the assessment of categories of resources) and neutralised over time (by a promotional container, public-private synergies and centralised procedures). This chain supports the up-scaling of a coalbed methane potential. It offers a critical perspective on its forming and how it fits with the notion of a low-carbon future.

Finally, the paper analyses why this ‘stratum’ may be democratically contested and transitory rather than laying the ground for a low-carbon transition (Delborne et al., 2020). What the inquiry highlights is that this uncertain assemblage is not equally visible to and negotiable by all the actors concerned (i.e. NGOs, municipalities and the local water management committee). France has dragged its feet in updating its institutions and strategy about the use of underground resources for a low-carbon transition. As a result, the case of Lorraine presents a mixed and ambiguous development of carbon exploitation and low-carbon experiments for the near future. The transitory nature of this ‘stratum’ hampers the emergence of new democratic forces and the discussion about what a ‘sustainable’ energy future may be. Française de l’énergie may assert that a methane molecule from the Lorraine underground is only 3.4g of CO₂/kWh compared with an average of 32 g from foreign gas suppliers, but this calculation does not account for all the relationships in which a methane molecule is embedded, which is what the current inquiry has helped to make explicit.

Acronyms

BRGM – French Bureau of Geological and Mining Research
CBM – Coalbed methane
EGL – European Gas Limited
FDE – Française de l'énergie
HBL – Houillères des bassins de Lorraine (French Public Coal Mining Company)
KO – Kimberley Oil
INERIS – French National Institute for Industrial Environment and Risks
OEPH – Office of exploration-production of hydrocarbons
OPECST – Parliamentary Office for Evaluation of Scientific Technological Options
SAGE – French name for the water management and development plan

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