Situated With Infrastructures: Interactivity and Entanglement in Sensor Data Interpretation

Abstract

This paper is based on studies of how petroleum engineers interpret subsurface data. It demonstrates how their interpretative work is profoundly entangled with the digital technologies that produce and handle sensor data. This entanglement arises through a history of interaction between humans, technology and the oil reservoir. It is central to the particular circumstances in which work is performed. We empirically elaborate how sensors produce data and how these are creatively "stretched" to represent subsurface phenomena and show how these processes results in a profound entanglement between interpretation practices and technology. We argue that the history of interaction with the sensors and software is an important aspect of situated work in this context. When groups of engineers collaborate remotely with colleagues to make sense of problematic data, entanglement with specific II's is an important aspect of situatedness. The situationally particular in these settings is not as much a matter of locations as of histories of interaction with specific technologies.

Highlighting the importance of the particular circumstances in which work is performed the notion of situatedness has throughout its history been a counterweight to rationalistic accounts of work and the focus on design of standardized work processes. Here we show that patterns of interaction with specific information infrastructures make up a crucial part of situated work and that these may have non-local dimensions.

1. Introduction

This paper elaborates on situatedness as an empirical phenomenon in highly computer-mediated settings. It is based on studies of petroleum engineers and how they work with digital sensor data to understand what is going on within petroleum reservoirs located thousands of meters beneath the seabed. We have studied their interpretation practices and how these are based on interaction with sensors and information infrastructures (IIs). The interpretive work is profoundly entangled[1] with specific sensors and the information infrastructures to which they are connected. Situated work, in this setting, is situated in relation to these systems.

The empirical analysis shows how making inferences about underground phenomena is central to work in subsurface departments. We elaborate the epistemological characteristics of sensors to explain the nature of these work practices; that is, how digital sensors produce mobile data points triggered by their interaction with the surroundings. In order for such data points to be meaningful, to say something about the surroundings from which they come, they must be stretched. They must be made to represent more than their immediate value. These practices illustrate that through multiple layers of aggregation and mediation, knowledge about the reservoir is always both social and material; it is produced in the relation between people and information systems.

The work practices we describe are born out of a history of constitutive entanglement with specific types of sensors, the data they produce, and the information systems that process them. The practices of interpretation, of stretching the data based on disciplinary and experiential knowledge, is contextually situated interpretation. The workers converge on the data and all information available and seek to understand

[1] It is important to stress how the practices and digital technologies we discuss are inextricably entwined and mutually constitutive. Though this is quite simple in principle, such relational arguments tend to produce quite complicated formulations. We hope the “jargon monoxide” (Kautz & Jensen, 2013, p. 15) is not too suffocating.

which phenomenon under the surface that might have triggered the data points they see. In this paper, we empirically elaborate how the situatedness of these interpretative situations depends on access to raw data with their yet-to-be-realized reference to underground phenomena and the experience, competence, and tools to collaborate in extrapolating it. As such, the extent of the situation depends on the entanglement with certain infrastructures of collective sensemaking.[2] Importantly, these infrastructures are both built to support, and have co-developed in support of, the extrapolation processes we describe. They are products of and enablers for the interactivity that is characteristic of situated interpretation. They are intrinsic elements of the situation in which extrapolation occurs; the infrastructures are entwined with the practice of interpretation. This can be contrasted to other information infrastructures in which stabilized, black-boxed data are produced to convey stable meaning out of the community of practice in which they are produced.

Theoretically, the paper answers recent calls in IS research for new approaches to situatedness (e.g., Monteiro et al., 2012a; Pollock et al., 2009). A central critique raised here has been the appropriateness of situatedness as an analytical term for understanding the nature of work with information infrastructures. Our concern here is with situatedness as an empirical phenomenon in the interpretative work practices in subsurface departments. Seeking to contribute to a more refined understanding of the connection of IIs and situatedness, we forward the somewhat overlooked yet central notion of interactivity in Suchman (1987) and Orr's (1996) studies of situatedness. By investigating the how subsurface professionals interact with sensor data and the connected IIs, we propose that these interactive patterns are keys to understand situated action in settings like these, and that they are present an empirical example of a situatedness that extends out of the local setting. Insights

[2] We employ the word sensemaking here quite loosely as making sense of data, i.e. establishing reference. Our understanding has parallels to Weick's (1995) discussions of sensemaking as a negotiation of clues, context and relations.

from research on sociomateriality (Orlikowski & Scott, 2008; Leonardi & Barley, 2008; Robey et al., 2013)[3] is particularly useful for studying this type of work that is constitutively entangled with IIs that stretch out of the local setting.

The paper is structured as follows: section 2 is a brief description of the research setting of petroleum production. In section 3, we present the theoretical background on which our analysis is based; this is structured as a discussion of the epistemology of sensor data and a discussion of situatedness in IS. We briefly present the research method and data our paper builds upon in section 4. Section 5 is the main empirical analysis; it is a description of how subsurface engineers use sensor data to support different operations, the importance of extrapolation, how interpretative work becomes entangled with technology, and how professionals contribute to the interpretation processes from different sites. Section 6 comprises our discussion; here, we elaborate on the entanglement of sensors and the knowledge practices of the subsurface workers, how sensor data are unstable representations, and the role of information infrastructures in extended situations. Finally, we conclude with section 7.

2. Research Setting

The Norwegian petroleum industry has become increasingly digitalized over the past decade or so (Østerlie, 2012). The strategic and technical changes related to such digitalization have been referred to as Integrated Operations (IO) (OLF, 2005). Empirically, our paper is centered on the work of particular types of teams that are typically attributed to IO. Our data is primarily based on a series of studies conducted within the Norwegian petroleum industry over the past decade. We have studied the

[3] We also draw on Actor-Network Theory (ANT) (Latour, 1999) and research on information infrastructures (Star & Ruhleder, 1996; Bowker & Star, 1999). The relational approach to technology also has similarities to other theoretical strands like distributed cognition (Hutchins, 1995).

subsurface departments of oil companies operating on the Norwegian Continental Shelf (NCS), a subsurface plateau in the North Sea off the Norwegian coastline. These onshore departments are responsible for the activities underneath the ocean floor, in the reservoir, and in the wells and pipelines accessing it. On the NCS, oil is produced from sedimentary formations buried deep beneath the ocean floor. The rock is composed of lithified[4] sediment dating back hundreds of millions years, when dinosaurs roamed the land and when huge rivers spilled sediment into the ocean off the coastal areas of present-day Norway. Over time, layer upon layer of sediment has been deposited upon these formations, increasing the pressure on the older layers. Through this process, hydrocarbons develop from organic materials in the sediments and are trapped in the pores of sandstone (lithified sand) that is sealed by layers of tight shale (lithified clay).

The geological structures containing hydrocarbon are called reservoirs and are typically found underneath an overburden of 1,500 to 3,000 meters of rock in the North Sea. Wells are drilled into these reservoirs from platforms or floating rigs, and the hydrocarbons contained within the cracks and pores of the reservoir streams out of these wells and through kilometers of pipelines toward offshore production facilities managing the production from individual wells and the field as a whole. Inaccessible to direct human inspection, any information petroleum professionals have about these deep geological structures and the contents of their pores is scant. What petroleum professionals do know about the subsurface reservoirs depends on vast sociotechnical projects, and their knowledge of it is indistinguishable from the knowledge machinery (Knorr-Cetina, 1999) by which they know it.

Over the past decade or so, digitalization of the petroleum industry has led to several new practices in onshore departments. In most petroleum companies, engineers are

[4] Lithification is the process through which sediments gradually become solid rock through pressure.

gathered in information-dense collaboration rooms, especially during critical operations like drilling, but also during regular production. These onshore centers are one of the hallmarks of IO. Work in an onshore subsurface department revolves around sensor data, and great efforts and investments are undertaken to improve data quality and to support the subsurface professionals' interpretation processes. The uncertainty is high, particularly when one goes into detail, but the engineers are pragmatic and are used to making do with imperfect representations of the underground (see Monteiro et al., 2012c).

Figure 1. A Picture from the Second-Line Support Center for Subsurface Operations. These rooms are technically similar to, though slightly bigger than, the onshore support centers that support operations on single fields.

While onshore engineers have always supported operations, thanks to the increased availability of real-time data combined with developments in bandwidth, instrumentation, software, and new strategic philosophies, onshore support from dedicated collaboration rooms is now the norm. Increased authority over ongoing operations has also been moved on shore, although this is a contentious issue with the unions, particularly when it comes to safety-critical work. During drilling operations, for example, the progression of the drilling process is now monitored by an onshore rig team (drilling engineers) in one room and an interdisciplinary team of reservoir engineers and geologists in another. After the well is completed and put in production, a group of production engineers monitors and controls the production individual wells and the whole field daily. All these teams of subsurface professionals rely on sensor data, and they work interactively with the data to understand and control subsurface phenomena.

Our discussion takes such onshore groups as a point of departure, centering on teams that support ongoing drilling operations and teams that monitor the production from wells that are already drilled. Our primary object of study is the field-specific operations centers and those subsurface professionals that support the operations on one single oil field. We also discuss how second-line expert centers are integrated in the interpretation processes. These expert centers are becoming a common part of the IO strategy. They have access to all of the data, keep an eye on operations on all fields, and provide support to the field-specific teams when necessary.

3. Theoretical Background

In this section, we theoretically situate our analysis of situatedness as an empirical phenomenon in the work of petroleum engineers. In section 3.1, we discuss the epistemology of sensor data, how they are produced, how they are made combinable, and the practices by which they gain meaning. In section 3.2, we discuss the notion of situatedness and how this relates to settings in which the entanglement with information infrastructures is central.

3.1 The Epistemology of Sensor Data

The authors' studies in different parts of onshore subsurface departments all focus on interpretation practices. We have observed that data are stretched, often very creatively, to say something about what is going on beneath the surface. These heuristic and often improvised inferences, what subsurface professionals refer to as "educated guesswork" (Almklov, 2008, p. 874), are based on disciplinary knowledge and a broad spectrum of experience. This is experience that individuals or groups of individuals have had with a particular type of sensor and its physical properties, a specific sensor, the reservoir or subsection of it, of similar reservoirs, of similar combinations or patterns of data, and so on (see also Østerlie et al., 2012). Data is the raw material for analogical reasoning; individuals and groups of workers stretch the scant data they have to obtain coherent understandings of the underground, to see what is “between and beyond” the data (Almklov & Hepsø, 2011).

In one sense, onshore engineers’ interpretation practices are similar to the activities in what Latour (1987: 215–57) refers to as “centers of calculation” in the sense that they rely on “immutable mobiles” **–** information formatted to be transported and combinable that is removed from its origins. With this concept, Latour captured a truly modern form of work based on decontextualizing information from diverse origins into mobile data. The IIs that provide mobility for decontextualized information should, on one hand, be understood as technical systems (ICT networks in our case), but also, more abstractly, as standards regulating communication[5]. They provide mobility to certain standardized types of data (Bowker & Star, 1999; Hanseth & Monteiro, 1997).

Subsurface departments are similar to centers of calculation in that the data onshore engineers rely on are data made mobile in a similar manner as immutable mobiles in order to be combinable elsewhere. There is, however, a distinct difference between work in a subsurface department and in a center of calculation. While subsurface engineers’ work practices hinge upon combinable, mobile data, their work relies more on creatively interpreting data rather than calculation. As such, understanding the characteristics of the data produced by sensors is essential for analyzing the interpretative work in subsurface departments. To explain the subsurface professionals’ work practices, we must summarize and illustrate our position on the epistemology of sensor data and how they are generated and transmitted.

[5] This dualism in the notion of information infrastructures as technology or rules is worthy of discussion. However, in our case, the abstract rules are usually inscribed in ICTs.

We base our position on the epistemology of sensor data and their production around Bateson's (1972; 1979) relational epistemology. Based on logical type theory[6], he argues that there is a fundamental logical step between the infinite variability of the external world and the differentiations that are data about it. The map is of a different logical type than the land it represents, and it only contains selected differentiations (boundaries) based on an infinite variability[7]. Though a boundary, like the ones drawn on a map, can be materially constituted with a fence or a signpost, it is also an infinitely thin ideal entity. Similarly, although signs may be materially constituted, they are still of a higher logical order than what is represented.

With this basis, we see sensors as devices that are constructed to let variation in the external world trigger the generation of differentiations. They are designed to let a selected "difference that makes a difference" generate data (Bateson, 1972, p. 459). The triggered data is of a higher logical type than the triggering surroundings, and it is a product of the relationship between the sensor and its surroundings[8]. The aspect of the surroundings that the sensor stands for, the one that triggers it, is inscribed in the sensor.

As sensors produce data in interaction with their surroundings, standardization is required to make data combinable across different sites of generation. This is best explained by beginning with a contrary example: a canary in a coal mine, where the canary is understood as a kind of analogue sensor. When conditions in the mine deteriorate, the canary stops singing or even dies. In contrast to digital sensors, and basically every sensor used in modern contexts, the canary lives or dies locally and is not connected to an II. A thermometer, on the other hand, is connected to an II because the mercury moves up or down a standardized axis, making its readings

[6] Whitehead and Russell's (1925) mathematical theory of logical types.
[7] See Korzybski (1994;1933) for the original discussion of the map-territory relation.
[8] Ilhde makes an excellent argument for why sensors are relational (1991, p. 98-114).

comparable across contexts as the mobile concept of temperature. Almost every sensor in modern contexts is of this kind; this is definitely true in petroleum production.

When a sensor responds to variations in its surroundings, it isolates a particular aspect of the world. The thermometer, for instance, moves up and down along its axis of temperature. It does not respond to the color, the taste, or the viscosity of the fluid it measures. It just moves up and down one single scale: temperature. We call this single-minded response to the surrounding world “aspectual punctuation”. A central facet of aspectual punctuation is that sensors report changes in their internal state regardless of what causes them. On a cold winter morning, a thermometer, to continue with this example, will not only measure air temperature when exposed to direct sunlight. It is no longer the only heat exchange with the surrounding air that triggers changes in the thermometer’s internal state, but also the heat generated with the sunlight. This facet of aspectual punctuation is central to subsurface professionals’ interpretation practices because they need to make inferences of what such changes in the sensor can tell them about the surroundings.

Along with aspectual punctuation, digital sensors also make samples at points in time, and most sensors – at least in petroleum production – register the spatial coordinates. We refer to this as “temporal” and “spatial” punctuation. Though they may be materially constituted, sensor data are abstractions without material or temporal extension.

Reference to the material reservoir is therefore a matter of stretching sensor data outward along the aspectual, temporal, and spatial dimensions. We refer to this stretching as “extrapolation”[9]. In order to represent space, time intervals, and the

[9] In some cases, when extrapolation is made in order to connect data points, this can be referred to as “interpolation”. We regard this as a subset of extrapolation as a more general procedure.

physical phenomenon of interest, punctuated data must be extrapolated. Like points in time or space, the axis of variation inscribed in the sensor is an abstraction that needs to be stretched to represent more than itself. Thus, reference to the material oil reservoir depends on spatial, temporal, and aspectual extrapolation. This might seem a theoretical point, but these inferences are pivotal practical necessities underlying almost all work in subsurface departments.

For example, lowering a sensor down into a well to measure electrical conductivity does not measure oil content, but it lets the surroundings produce variation in an electric parameter that is inscribed in the sensor. Competent engineers can then infer oil content from this reading, especially when it is combined with other sensors' measurements of single characteristics. Change in electrical conductivity is stretched to make inferences about what real-world phenomenon it may represent – about what triggered the sensor's reaction. Even though the sensor measures points along the well path, it is also made to represent volumes of oil. We describe this practice of inferring a referent from punctuated data more extensively with empirical examples in section 5. Our motivation for detailing with this is to show how meaning is constituted in the interaction with sensors and because an account of the situation in which data are interpreted should include the way data are produced.

Though it is quite clear that data must be extrapolated in this context of inaccessible reservoirs and scant data, this is generalizable beyond such situations. Inferring from data to reality is always an undetermined problem (Oreskes et al., 1994). There are many real-world solutions that can explain the constellations of data. Oreskes et al. (1994) discuss how earth models are underdetermined from a mathematical and logical standpoint. Whether or not they are represented in models, representations of the reservoir based on data are always underdetermined, and hence liable to be changed when new data arrive. Due to the sheer inaccessibility of the petroleum reservoir and the vast uncertainty in the representations produced by our informants, this philosophical problem is concretely felt in this context.

Interpretation of punctuated data is, as we will show, constitutively entangled with specific technologies. Meaning emerges in the relationship between sensors, ICTs, and people (Østerlie et al., 2012)[10]. As such, our understanding of the work practices in this context is a continuation of current research strands that highlight the entanglement and mutual constitutional relationship between the social and the material (Orlikowski, 2007; Orlikowski & Scott, 2008. See also Suchman, 2007; Barad, 2007; Leonardi & Barley, 2008). Although we employ the notion of entanglement, which is most commonly associated with the sociomaterial strand of research, our discussion is also inspired by other relational approaches to technology and the material such as actor network theory (Latour, 1999) and discussions of imbrication (Ciborra, 2006; Introna & Hayes, 2011, Leonardi, 2011).

3.2 Situatedness, Interaction, and Extended Situations

Subsurface engineers' work to understand subsurface phenomena and events is a form of situated interpretation practice. In studying this, we follow a long-standing tradition in practice-based studies where situated action is the pivotal object of study. Central references here are Suchman's (1987) study of plans and situated action, Lave and Wenger's (1991) study of situated learning, and Orr's (1996) study of situated repair work. The concept of situatedness in these studies draws attention to the relationship between action or activity and the social situations and concrete circumstances in which activity occurs. This line of research emphasizes the embeddness of activity and work in a situation rooted in a specific time and place.

[10] Here we stressed the duality of the material in this respect as the interpretative work we discuss explores a material reservoir by means of material artifacts (sensors and ICTs) (Østerlie et al., 2012).

The situated nature of computer use has been central to practice-based studies of computing. This has, within IS research, been a central component for understanding how users appropriate technology by fitting it with local organizational and situational contingencies through improvisations (Ciborra, 1999), tailoring (Greenbaum & Kyng, 1991), or workarounds (Gasser, 1986). More generally, Walsham (2001) makes the argument that computing technologies are beneficial when supporting situated action and meaning-making.

Recently, the idea of situatedness has come under critique within IS (Pollock et al., 2009; Kalinikos, 2004) and IS-related computing disciplines (Monteiro et al., 2012a; Karasti et al., 2010). This critique centers on how to understand situatedness in the face of the increasingly trans-local character of much computer-based work. Pollock et al. (2009: 79) observe that what they label "localist forms of analysis" tend to focus on work as rooted within a specific time and place. Monteiro et al. (2012a) argue that such localist conceptions of work tend to conflate situatedness with co-localization, forwarding the view of computing use as inherently embedded in local situations. Yet, with networked digital technologies, conflating situatedness and co-localization becomes problematic.

We appreciate the call to theorize situatedness in the ever-more-common settings dominated by interaction with digital data. Suchman (2007) defines situated action as "actions taken in the context of particular, concrete circumstances" (p. 26). This definition primarily serves to stress the particularity of these situations; it does not directly stress that they are local. Still, as particular, concrete circumstances are perhaps most easily studied locally, research on situated action has often focused on localized situations. Orr's (1996) work on copying machine repair technicians serves to illustrate how situatedness is not the same as co-location. A central issue Orr addresses is the very real limitations of the corporate machine repair manuals. The crux of his argument is that repair manuals, which are very detailed, are disembedded from the particulars of a situation. Repairing a copy machine is not simply a matter of following a set of disembedded steps, but a question of knowing the particulars of individual machines, their prior history of problems and use, as well as common issues with that particular model. Copy machine repair, contends Orr, is therefore situated within a particular context from which it is cannot be disembedded.

Yet, this does not mean that only the local here and now matters. Orr emphasizes the importance of the distributed network of copy machine repair technicians and the possibilities of tapping into the joint experience of the whole community of practice. He also emphasizes how experience with a particular machine or model of machines is not rooted in a single situation, but is historical in that it spans across both time and place. As such, saying that Orr offers a localist conception of action that is limited to a particular time and location is to oversimplify. At the same time, however, Orr devotes most of his analysis to particular situations rooted in a specific time and place.

For the purpose of our analysis of interpretation work in subsurface departments, we instead highlight the centrality of interactivity for Orr's understanding of situatedness. Through what he calls the “repair triangle”, he forwards that an understanding of how to fix a broken copy machine emerges through the interaction between the machine, the customer, and the repair technician. More generally, as in Lave and Wenger’s (1991) theory of situated learning, we also see the focus on interaction with a social and physical environment more than (in their context) learning as the reception of knowledge. In many ways, the interest in situated action can be seen as insistence of human activity and creativity and as a counterweight to more rationalistic or deterministic accounts (Suchman, 2007).

In a recent study of operational work in the energy and water supply, Almklov and Antonsen (in press) discuss the tension between standardized accounts of work and the embedded practices of operating an aging complex water or electricity infrastructure. Over time, the situated practices involved in keeping the system up and running co-developed and became entangled with the heterogeneous aging infrastructures. This history of interaction makes standardizing efforts required to implement new regimes of governance very cumbersome. In this study, entanglement and interactivity between the system and blue collar workers is mainly a matter of physical interaction, of people interacting with power lines, transformers, pipes, and pumps. In the present paper, we describe a history of entanglement that is similar, but that is less dependent on physical whereabouts. We will show that the discussions of sociotechnical embeddedness and the importance of the particular circumstances and relations in which work is performed are also relevant for empirical situations where interaction with the system is not dependent on spatial proximity to it.

Knorr-Cetina and Bruegger (2002) contend that the highly networked work of financial traders needs to be understood in terms of the situated action on individual trading floors while at the same time being able to encompass the underlying technology and how it facilitates interaction between traders situated on different trading floors. Knorr-Cetina (2009) calls for studies of situations in which on-screen projections are central to what is going on. These “synthetic situations” not only mimic physical interaction, but they involve new forms of interaction that are less constrained in time and space. Similarly, this paper addresses situations that extend out of the local. In particular, we discuss how specific information infrastructures facilitate interactivity and recursive meaning construction. Work in a subsurface department is entangled with these technologies, and this entanglement is a key characteristic of the situations we discuss.

4. Methods and Data

This paper builds on combined reflections from the three authors' individual empirical investigations. Each author has, by means of ethnographically oriented methods combined with interviews, studied work in the subsurface disciplines in the Norwegian petroleum industry. Moreover, we have done so with the intent of studying the industry's transition into IO and the associated implementation of new ICTs. As such, our cases can be seen as individual samples of how this development affects different disciplines, though this is not the result of a deliberate design. The difference in timing of our empirical investigations provides the combined analysis presented here with a longitudinal dimension. Though we have all interacted with the subsurface community as a whole, our individual projects have more specific foci. Haavik has studied drilling engineers (2010; 2011; 2013), Østerlie (2012, Østerlie et al., 2012) has particularly focused on production engineers, whereas Almklov (2008; Almklov & Hepsø, 2011) has had a slight affinity to geologists and reservoir engineers, though his work has considered interdisciplinary cooperation in subsurface departments in general.

The ideas and insights reported in this paper are analytical conceptualizations of observed commonalities with relevance for the IS field, like the importance of punctuation and extrapolation as sensor data are employed to understand the underground. The tendency in IS and CSCW studies to theorize on confined settings, single sites, and typically situated contexts with a community of practice in action may partly be explained by the relative methodological ease with which such settings may be approached compared to more comprehensive studies (see Monteiro et al., 2012a; Harris, 1998). More opportunistic composite studies like our own are probably one of the relatively few realistic ways of moving beyond local settings, particularly in companies that have priorities beyond facilitating research (Pollock & Williams, 2011)[11]. Also, since our field data cover several disciplines and sites, we are able to say something more generally about integrated operations than we can with our individual studies. Table 1 summarizes the combined body of empirical data we base this paper on.

As we address issues that are very close to the disciplinary knowledge of our informants, it has been particularly valuable for our analysis that the first and third authors are both trained in engineering geology (as well as social sciences). The third author has also worked with an offshore drilling rig crew as a mud-logging geologist. Though the years in social sciences have taken their toll on our engineering competence, it gives us the ability to address the substance of data and models in greater detail and to reflect upon the relationship between the data and the phenomena they are used to represent.

Table 1. Summary of Observations and Interviews

	Period	**Main Discipline Studied**	**Type of Study and Data**
Almklov	2001-2004	Interdisciplinary subsurface department.	7+3 months of ethnographic study. Observation data, informal discussions.
Almklov	2006-2012	Reservoir engineers, geoscientists, modeling specialists.	~30 interviews supplemented with visits. Applied projects on reservoir modeling.
Østerlie	2008-2011	Production engineers.	Participant observation as part of a grounded theory study over a period of 11 months.
Østerlie	2011-2012	Subsurface professionals and software developers.	~20 Interviews with subsurface professionals, and software and hardware vendors.
Haavik	2008-2012	Drilling engineers and colleagues.	Participant observation and visits over a period of five months. 50 interviews.
Haavik	1997-2000	Offshore drilling rig crews	Worked as an offshore mud logging geologist on twelve different drilling rigs for four different oil and gas companies.

[11] Ribes (forthcoming) proposes “ethnography of scaling”, studies of the devices and techniques the informants use to handle the extended nature of their work as an interesting methodological approach that might be useful in contexts like this.

For readability, some detail when it comes to technical issues and the organizational structure in the subsurface department has been sacrificed.

5. Empirical Analysis: Entanglement and Situatedness

Onshore engineers study data to understand the geology, control the drilling process, and locate and produce oil. In this section, we give some examples of how deeply entangled their work is with sensors and information infrastructures and what that means for our understanding of the situations in which interpretations occur.

Section5.1 discusses how meaning about the reservoir emerges in interpretation processes where punctuated data are extrapolated. By going into some detail in this, we illustrate how this is not just a matter of technology on the one hand, and the cognitive and social processes on the other, but also that it emerges in their relationship. In section 5.2, we argue that this entanglement is mutually constitutive – that particular constellations of technology and interpretation practices co-develop over time. In section 5.3, we demonstrate how this interaction with the sensors and data occurs from different sites and how personnel at different locations partake actively in interpreting the data.

5.1 Interpretation During Drilling: Extrapolating Punctuated Data

The interpretation practices in subsurface departments are inextricably entwined with the ways in which data are collected and mobilized. Meaning –in this case understanding of subsurface structures – emerges through the twin processes of generating punctuated sensor data and extrapolating from these data. We illustrate this by showing how geologists and engineers interpret sensor data in support of ongoing drilling operations. Their task is to determine which geological formation the drill bit is penetrating and where the drill bit is located in the expected sequence of layers of sedimentary rock in order to support optimal placement of the well within oilfilled sections of the reservoir. Drilling is also a cherished opportunity to get up close to the reservoir; the data obtained from the sensors accompanying the drill string are valuable resources for further work.

Data is generally quite accurate and detailed along the drilled well trajectory. Beyond this trajectory, however, subsurface professionals' knowledge of the reservoir is indirect at best. When the drill bit penetrates the reservoir, an assembly of sensors attached to it registers data along its path. These data are presented as point readings along the well trajectory in figure 2. The generated data are spatially punctuated in the sense that they only represent points along the well path – they only represent the reservoir when extrapolated outward. With several sensors combined, the readings in a well log usually give a robust image of the situation in the immediate proximity of the well. Wells are normally, however, hundreds of meters apart. The point readings along their trajectories must by inference be stretched outward to represent space. As such, knowledge about the reservoir (which is these people's core business) is based on spatial extrapolation.

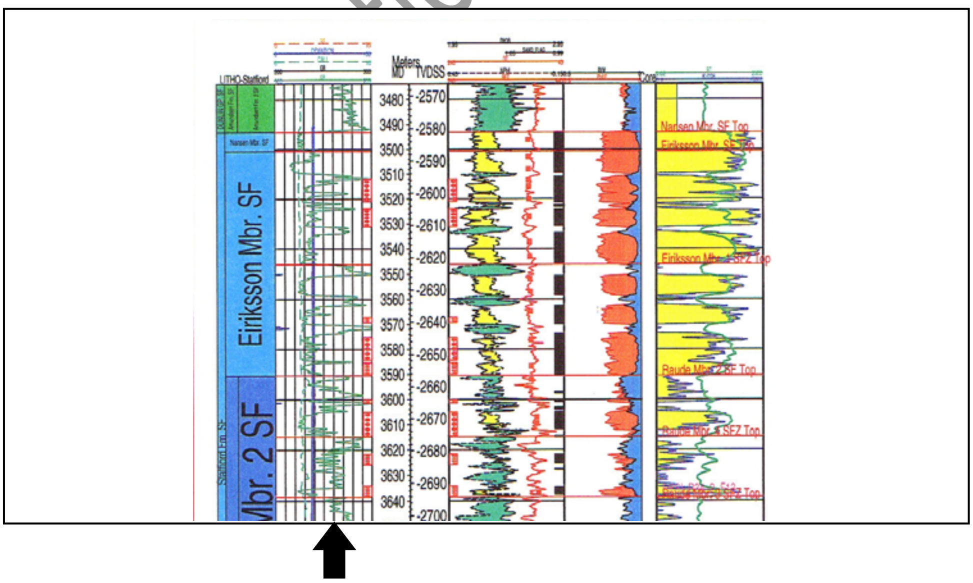

Figure 2. Section of a Well Log Various sensors are plotted on a downward axis. The Gamma Ray (GR) reading is the thin green line indicated with a black arrow. The axes denote well length (MD) and depth (TVDSS).

To produce oil, it is essential to know not only the geology around the well, but also the surrounding rock. Spatial extrapolation is not pure conjecture; rather, it is, as the geologists themselves sometimes say, educated guesswork. Their speculation is informed by geological theory, field analogies on dry land or other oil fields, as well as operational experience. In addition, the rather coarse patterns seen in remote sources like the seismics provide crucial support for spatial extrapolation. The seismics are 3D “echograms”: recorded reflections from explosions on the surface. These coarse images respond to density differences in the rock that makes sound waves bounce back. When the data are properly processed, these reflections can be seen as blurry patterns on a seismic chart (figure 3). To the trained eye, the seismics indicate the general structural patterns in the area, and these are valuable input when extrapolating well data outward. Though the resolution of the seismic is poor, the patterns seen in the seismic are useful inspirations when creatively stretching even detailed variations in the well logs outward.

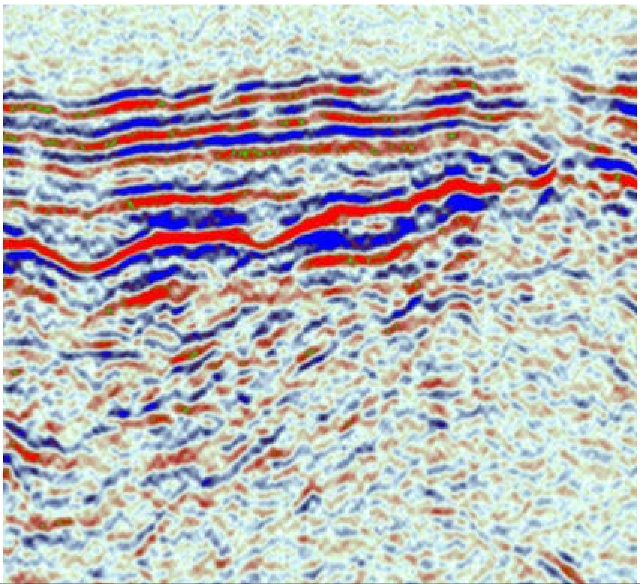

Figure 3. Seismic Chart: Vertical Cross-Section. The colored lines indicate structures that reflect sound waves.

The gamma ray (GR) reading, seen in figure 2, represents the sensor's response to gamma radiation. Gamma radiation in itself is not interesting for oil production purposes. It is, however, commonly associated with shale. Thus, combined with the geologists' knowledge, this isolated aspect is stretched to represent a type of rock. This is aspectual extrapolation. The reading is seen as indicative of shale in the well bore, and when it is spatially extrapolated, it regarded as a indication of a body of shale with some extension around the well. Aspectual extrapolation is thus a matter of stretching the single variability of sensors to represent phenomena that might have caused them. Since there are several sensors at the same point, this inference can be supported (or contradicted) by readings provided by other sensors. Shales are not only emitting gamma radiation, but they are impervious as well, and will register low on measurements of porosity, for example. The visual layout of the log itself is designed to facilitate inferences based on combinations of data points.

In a similar manner the measured aspect on the seismic, acoustic properties, are typically interpreted to represent geological boundaries, when they are supported with well observations of changes at the same depth. They are really measurements of sound reflections, but seen in combination with well data, they are made to represent geological boundaries. A common way to interpret seismics is to look at logs that penetrate the same area. If, for example, a log (as in figure 2) indicates sandstone at a depth corresponding with the red or black reflections on the seismic chart (figure 3), then it is a common assumption that the whole reflection represents the type of rock observed in the well. The above account shows that the data with which the subsurface workers work, do not represent the object they are interested in, but that they are extrapolated to do so.

It is not really the digital data that the subsurface professionals try to make sense of through these interpretation processes; their concern is to understand the geological structures the drill bit is penetrating. Digital data are, without a doubt, a central piece of the sensemaking process. At the same time, the data is of limited value in isolation. Meaning emerges through the extrapolation processes described above, and the punctuated data are close to self-referential without these processes. On the other hand, these practices have developed in a relationship with specific forms of punctuation.

5.2 Entanglement: Interpretation Practices and IIs Co-Develop

The discussion above shows how subsurface professionals' interpretation practices are entwined with the information infrastructure generating punctuated data. In this section, we elaborate upon this argument by showing how work practices and technology over time become interwoven. We elaborate upon the argument in two steps. First, we show a shift of emphasis from work practices to technological solutions. Second, we show how changes in technology give existing work practices new significance for making sense of down-hole developments. We illustrate this with empirical observations from another activity unfolding within the subsurface department: monitoring and mitigating sand in the fluids streaming out of individual wells, what is commonly referred to as the "well flow" by petroleum professionals. We start by looking at a central extrapolation process to explain how automation shifts emphasis between human activity and technology.

Sand in the well flow is a significant safety risk. The well flow streams out of wells and along thousands of meters of metal pipelines toward the topside platform. Sand in this fluid can erode the metal piping, threatening to puncture it. Sand detection sensors mounted at fixed positions within individual wells generate data about sand content in the well flow. One of the sand detection technologies currently in use draws on changes in ohmic resistance across a metal probe as a measure of sand content. Sand streaming across this probe erodes the metal; this increases the electrical resistance across this conductor. The sensor controller measures electrical resistance once every second, and a vendor-specific algorithm transforms the measured change in electrical resistance between two measuring points into a measure of sand content.

This indirect way of measuring sand content as a change in the sensor's internal state has uncertainties and frequently leads to false alarms. Measured changes in electrical resistance may have been caused by increased sand content in the well flow, but other phenomena may also cause electric resistance to change. This particular sand monitoring technology is particularly vulnerable to temperature changes in the well flow because temperature also influences electrical resistance. Subsurface engineers are aware of this; they will open the sand monitoring software to investigate an alarm triggered by measured changes in sand content. This software application plots sand content data along the same time axis as temperature data from a sensor mounted at the same position in the well. This correlation is based on the way this particular sensor technology generates data. Since the subsurface engineers know the principles of the sensor’s design, they seek to understand whether the alarm is really caused by increasing amounts of sand in the well flow. A simple juxtaposition of time-seried sand data with temperature data from the same points in the production systems is a typical starting point. If they co-vary, the sand alarm may be false. As in the well log, the phenomenon causing the sensor to vary along its axis is inferred, here by combining readings of different sensors.

The first version of the sand monitoring software did not integrate sand sensor and temperature data this way; it was originally designed for a wholly different purpose. With the convergence of real-time communication capabilities between platforms and onshore-based subsurface departments on the one hand, and increasing problems with sand in the well flow as oil fields aged on the other, subsurface engineers started looking at the possibilities of making use of the real-time sand data to monitor individual wells. The original software, however, displayed the sand data as a gauge with an arrow indicating the sand content value. Individual readings were of limited value to the subsurface engineers. A makeshift solution was found using the functionality in software to visually extrapolate between single data points of sand measurement readings into a graph.

The original use of sand sensor data had been to measure accumulated sand passing across the sand sensor over several months. These measurements were by no means as vulnerable to the vagaries of individual measurements as the real-time measurements are. To determine whether or not there is sand in the well flow, the subsurface engineers started manually correlating the plotted sand data with a graph visualizing the temperature measured by a sensor mounted at the same position in the well. This combination of data sources, however, was done manually because temperature data was visualized in another application. Upon a rewrite of the sand monitoring software, the temperature reading came to be visualized in the same plot as the sand sensor data, automating existing manual practices.

In addition to shifting the emphasis between humans and technology in the sensemaking process, this change in use of sand sensor data also brought existing work practices into relief. Again, the vagaries of aspectual punctuation are at stake. Other phenomena, apart from temperature changes, may influence individual sand measurements. One phenomenon in particular, changes in the well flow velocity, is of particular relevance. Changes or activities in one well may influence the well flow velocity of other wells in the vicinity. The problem, however, is that the well needs to be hooked up to a dedicated calibration device to measure the well flow velocity. There is only one such device aboard the platform, and consequently, the subsurface engineers know little about the velocity of individual wells in real time. The subsurface engineers attend a series of status meetings every weekday morning where representatives from different onshore and offshore departments report on their planned activities for the day. The subsurface engineers often use this information to determine whether or not sand alarms have been caused by changes in well flow velocity.

Knowledge about the history and characteristics of individual sensors is also crucial when interpreting the data they report. Down-hole sensors are subject to harsh conditions, and they deteriorate over time. Knowing when a sensor has been placed in the well, if it has sounded false alarms in the past, and whether or not it is broken is central for the subsurface engineers to understand it. What we see, then, is that even though the available data is basically the same, the sociotechnical arrangements whereby this variation in conductivity is combined with other data and other types of information made it possible to understand much more about sand in the well. As described above, the common correlation of the sand reading against temperature is now inscribed in the software application used to interpret the data. Other juxtapositions, other choices of how to display different data sets together and choices of time resolutions are not inscribed in dedicated software, but typically in worksheet templates.

The data points, still just conveying the resistance across a metal probe, were refined and developed in connection with the knowledge of production engineers. Successful combinations of data, done to extract the underlying phenomenon (sand) from the data, are inscribed in various ways and to various degrees of permanence into the information infrastructures. As mentioned, a vendor-specific black-box algorithm transfers the changes in conductivity to sand. As this sand reading is particularly sensitive to temperature variation, the software they use to analyze it juxtaposes the time series of nearby temperature readings with sand. Other practices, when sufficiently successful, are inscribed in worksheets, others in local or company-wide procedures, and some are shared experiences that are just talked about. We have also observed cases where experiential knowledge leads to changes in sensor hardware and software. To talk about the knowledge of these engineers as something separate from the technology makes little sense. The knowledge of monitoring sand content has co-evolved with technology from the time that the first gauge was placed off shore.

The sensemaking practice outlined above is related to determining whether or not there is sand in the well flow. Having visualized sand data as a graph, subsurface engineers could extrapolate along the temporal dimension to determine the cause of sand in the well flow, and consequently, what measures are needed to mitigate the situation. When time-seried sand sensor data is plotted as graphs, the engineers use the shape of the graph to establish the cause of the sand. The shape of these data visualizations take on meaning in relation to the production engineers' domain knowledge. Based on analyses of the time patterns of the sand data, but also pressure and temperature data, they look for patterns that are indicative of typical "text book" phenomena like gradual normal sand production, sand avalanches (a sudden collapse of the surrounding rock), or "slugging" (that the well is coughing rhythmically like shown in figure 4). Again, their episteme depends on the sensors, but also on the software. New practices co-develop with technological change. With the old sand gauge off shore, knowledge of the temporal patterns indicative of sand avalanche would be hard to operationalize. Just by presenting sand data in time series and allowing for combinations with other data types, new practices and knowledge developed themselves became inscribed in technology.

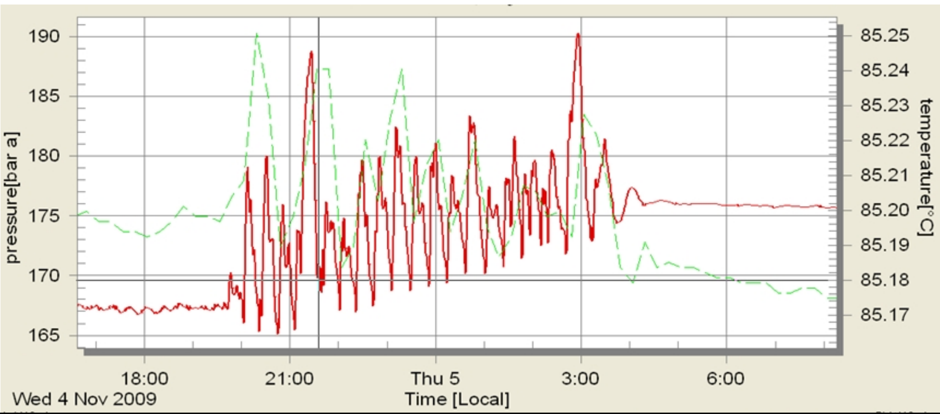

Figure 4. A Temporal Pattern of Temperature and Pressure Variation Typically Indicating "Slugging" in a Production Well. Seeing this pattern requires choosing a proper resolution for the display.

5.3 Joint Interpretation as Extended Situations

The onshore groups that work with a single oil field are usually co-located for at least part of their workday. The way they creatively make sense of data carries all the hallmarks of a situated practice. Their knowledge is developed via a history of interacting with specific technologies and seeking to understand specific subsurface phenomena. In this section, we illustrate how the interpretation practices involve personnel located elsewhere, but who are interacting with the same technologies and infrastructures. The underlying argument of this is not that location is irrelevant, but rather to stress the importance of the entanglement with information infrastructures as a characteristic of the situations in which interpretation occur. We see that engineers sitting in other locations contribute to the creative extrapolation processes in which meaning is made out of the data.

Colleagues that do not share access to the infrastructures by which meaning is constructed, nor competence to interpret the data, may sit physically close but still be remote to the sensemaking processes in question.

Some oil companies have implemented second-line onshore support centers to support drilling operations. The expert support center relates real-time data streams not only to the current ongoing operation, as the offshore rig crew does, not only to the history of the current and previous wells on the same field and on adjacent fields as the onshore rig team, but to the whole array of ongoing and historical operations the company undertakes[12]. The center is supported by an II that gives them continuous access to information from all the operations and allows them to communicate easily with the all the onshore rig teams.

One such center we studied monitors the operations on all wells drilled by the company on the NCS (not all in detail, though). When problems occur, they collaborate with the onshore rig team and offshore rig crew in interpreting the data and assist their decision making. The process of interpreting from sets of sensors involves combined sensemaking based on the same data, but against different backgrounds, as summarized in table 2.

Table 2. Overlapping Yet Different Contexts of Sensemaking of Real-Time Drilling Data

Rig Crew (Offshore)	**Onshore Rig Team (Onshore, the Fields' Operational Department)**	**Support Center (Onshore, Company Main Office)**
Real-time sensor data from ongoing drilling. Physical proximity to equipment and operative work. Smells, vibrations, sound from the drilling process. Operational experience.	Real-time sensor data from ongoing drilling. Historical data from other wells. Experience with other wells on the field. Have planned the well.	Real-time sensor data from ongoing well. They monitor all wells on the NCS. Broad aggregated experience and data from other wells. Generic and theoretical knowledge.

[12] See also Monteiro's (et al., 2012b) description of the well intervention group. These specialists also need to navigate data from several wells and develop techniques of seeing resemblances and differences in their "biographies".

An example of this collaboration and the different perspectives is illustrated by the following case observed during the study of an onshore rig team:

In a morning meeting between the onshore rig team and offshore rig crew, a formation integrity test (FIT) that had been undertaken during the night shift was discussed. This test is done by increasing the pressure of the drilling fluid and then inspecting the temporal pattern in pressure readings because this will indicate how tight the surrounding rock is. In this case, three FITs had been undertaken. The onshore rig team had discussed the pressure versus time plots produced during the test and found that the plots matched their experience from other wells in the same field and in a nearby field in which one of the drilling engineers had worked before. The reason they repeated the test is that well integrity experts in the support center had been involved during the night to give a second opinion on the test. The experts could not approve the shape of the curve because, according to the theoretical models, it indicated that the formation was not sufficiently strong to withstand (within required margins) the pressure to be exerted from the planned hydraulic regime in the well. Therefore, they recommended another test. Eventually, all three tests showed the same result, and the experts from the subsurface center recommended that the planned hydraulic regime be reconsidered[13]. The offshore rig crew's limited commensurable experience was from one previous well in the same field, but based on that well, they agreed with the judgment of the onshore rig team that the result was as expected.

The case circles around a controversy involving a series of FITs undertaken in connection with drilling a new well section. The crux is how the results of the FITs should be interpreted. Although the tests were taken in a normal manner and the results were considered trustworthy, the different communities involved did not

[13] Wells are drilled with overpressure to prevent blow outs. If this pressure is too high, however, the rock may fracture and cause other issues. A hydraulic regime is planned to balance these considerations.

manage to agree on how the results should be interpreted – on what phenomenon they were indicative of. More precisely, they disagreed on whether the interpretation of the test results should draw support from theoretical models of strength calculations or from empirical patterns of previous operations.

The general requirements for FITs are defined by certain marginal values for the pressure curve produced in the tests. However, the onshore rig team and the rig crew give the fact that pressure/time plots similar to those of this case have previously proven acceptable in a comparable context a high status. The rig team also anticipated this pattern due to their experience, and they documented it in their plan. Consider this statement by the drilling superintendent:

> *I am disappointed that the FIT is not interpreted as ok. The curve is in accordance with the template in the drilling program[14]. Also, I have never actually seen a curve that flattens out completely*.

The discussion on how to interpret the curves involved several perspectives, reflecting the different experience backgrounds of the involved actors. Eventually, they chose the rig team's interpretation (supported by the offshore crew) based on the fact that they had seen similar patterns in nearby wells. Since this interpretation was problematic in light of more generic models of FIT tests, experts meticulously reviewed this conclusion.

This rather brief case description[15] illustrates how the process of giving meaning to sensor data follows a process fluctuating along an axis of knowledge practices that involves different practices of extrapolation in different epistemic fields. Extrapolation is undertaken in all locales to make sense of data: the offshore rig crew, the onshore rig team, and the experts in the support center. The information travelling between

[14] The drilling program is a plan produced in accordance with governing documentation and that has been authorized by a range of persons at different levels in the organization.
[15] The case and its interpretation are supported by several similar observations during the authors' fieldwork.

the locales, the bits and pieces in the resulting body of new knowledge, may be both original, unaltered sensor data as well as juxtaposed constellations of such data[16].

Drilling engineers are in more retired positions than the offshore crew, and able, like the production engineers monitoring sand data, to develop new ways of making sense of data. This is in one sense a local practice, but its locality is defined more by their interactions with the data they are entangled with than their proximity to the platform. Where their office is located does not matter; it is their entanglement with sensor data and the knowledge practices borne of it that constitute their sensemaking. As we see in the discussion between the offshore crew, the onshore rig team, and the expert center, there is a local dimension of their knowledge in the sense that the different groups also interpret data via their different backgrounds when entering a collective sensemaking process. Again, this depends as much on the fact that these departments have different histories of entanglement with data as it does on more traditional notions of location.

This does not mean that we want to ignore the effects of local socialization in the teams. We could certainly have told stories about how different rig teams nurture different practices and how important their experiential knowledge on this particular field is; however, this must be supplemented with an understanding of their situatedness in an extended situation.

The experts were not present on the rig and did not get the sensory experience and knowledge of operations that the rig crew had. Neither did they, as the onshore rig team did, work immersed in a social environment of people interested in this particular field, this platform, and these specific wells for the entire work day. They interpreted the data based on another background. The II giving them access to both raw data and aggregates combined with experience with the interpretation practices

[16] For example, previously produced graphs that are used as a benchmark.

made it possible for the experts to collaborate across distance in making sense of the data.

6. Discussion

The above section empirically elaborates how intimately and interactively subsurface workers' interpretation processes are connected to the ways sensors produce and mobilize data. We have shown how data is only meaningful in relation to the knowledge, software tools, and practices of subsurface workers. Meaning about underground phenomena is not transported from sensors to humans on shore nor is it constructed by them, but emerges through the continued interaction between knowledgeable workers, digital sensors, and ICTs. The history of interaction with these information infrastructures produces unique, particular circumstances in which data are interpreted. In this section, we discuss the theoretical implications of this observation for the notion of situatedness.

6.1 Entanglement

We have shown how sensors, though reacting to only one aspect of their surroundings, one pre-inscribed axis of variation, are used to make inferences about an oil reservoir. In section 5.2, we described how technologies and practices co-evolve, how extrapolations that are seen as robust are inscribed in technology, and how new technologies become inextricably entwined with human practices. The sediments of this interaction constitute a form of sociotechnical knowledge in which the technological and human components are inseparable. We have seen the production engineers place curves next to each other on screens to sort out combined patterns. Such practices, when they prove useful, are rapidly disseminated in the immediate group of engineers. They are, as such, social, but they also become inscribed in formalized routines, programmed into the ubiquitous spreadsheets or aggregation and visualization software. In some cases, they can even influence sensor placement and design. Conversely, we have shown how work practices are shaped by the sensors and technological inscriptions. As such, technology and knowledge are not just inseparable, but they are mutually constitutive.

When subsurface workers inscribe their knowledge into software and hardware, it is a form of delegation (Latour, 1992). Similar to Ribes et al.'s (2013) observation, these actions are best understood as reconfiguration of work rather than as a transfer of human knowledge to the system. When inscribed, they immediately inspire new practices and new innovations. These inscriptions are not always robust, and an important part of the engineers' work is to be able to back-track to previous steps if necessary, to question the extrapolations done by others, and to recognize possible errors due to the sensor type or condition. An example of this is the display for juxtaposing temperature and the sensor software's sand reading. Knowledge of the possible sources of error in the sensor and its computed result led the engineers to institute and instrument a practice of checking readings of sand against temperature measurements. Representations are not stable signs presented by the system to the humans, but rather they are temporary stabilizations of meaning to be investigated further.

6.2 Sensor Data and Reference

There is a fundamental epistemological uncertainty in the work we have described. As all reference to the reservoir is based on extrapolations of punctuated data, they are subject to subsequent modification and contradiction. A fundamental aspect of the interpretation processes we have studied and the infrastructures involved is that they keep interpretations open to further investigation.

A glance at a couple of parameters in a well log makes it quite easy for a geologist to infer (based on his knowledge) what type of rock causes these readings at a certain depth. He will say that there is an object down there, a body of shale for example, triggering the data. He infers from the consequences that shale is assumed to have on the sensor that there is such a body of shale. Based on the model that one has of this type of rock, one can then expect this object to have other properties than those actually measured. The inference he makes is underdetermined (see Oreskes et al., 1994), and new data or new analyses can challenge the object he constructs. Extrapolations can always be challenged. New data can give new meanings to the old. The interpretation practices we have discussed, and the information infrastructures with which they are interwoven, are open to new meanings. This openness is not restricted to one local community of practice, nor to one department, but may involve external experts or others that interact with the same infrastructure.

Other IIs are built to convey more stable black-boxed objects. The organization in general needs to make decisions, prioritizations, and delegate work. Actually, much of the work in subsurface departments is concerned with translating situated knowledge to such objects (see also Almklov, 2008): production volumes for economic calculations, geological boundaries with fixed coordinates, simplified models in which to run simulations, and so on. It sometimes serves the organization well not to remember the extrapolation processes stabilized data rest upon. Organizations need to forget them to go on with their business (see Bowker, 1997 on organizational forgetting). Monteiro et al. (2012c) argue a similar point within the context of petroleum production, demonstrating that there are several incentives to close discussions and to construct “stable” representations in a subsurface department. These incentives are so strong that workers choose to live with errors and inaccuracies. For the interpretation processes we have studied, these black-boxing processes represent the clearest boundary between the situationally particular and the organizational activities surrounding them. The black-boxed interpretations are the objects that those who do not interact with the sensors and the sensor software, see. As such, stabilization of meaning is maybe the clearest boundary of the uniquely situated interpretation processes.

The teams we studied also communicate with other departments not involved in the interpretation processes, but then their knowledge is packaged, decontextualized, and black-boxed. Geologists may send off highly simplified descriptions of the geology to reservoir engineers or drilling engineers. Production volumes may be sent off to the economists at the office for budgeting and billing. Similarly, complex evaluations of risks and uncertainties are, in the organizational discourse, conveyed as standardized numbers. In these IIs, data are produced for use in other situations outside the community that produced them.

One cannot employ the same strategies for building infrastructures for data with stabilized meaning as when designing infrastructures for meaning in the making, like the ones we have described here. This point may seem theoretical, but it actually manifests itself as ongoing controversies in the industry, particularly with regard to IO. For outsiders to the subsurface groups, production data are trivial volumes and pressures, sand data represent sand, and the readings on a well log or seismics represent geological objects. Meaning, that we have shown is produced in interaction with the data, is by outsiders to this interpretative work attributed to the data itself as representations. The assumption that the meaning of sensor data is stable and transportable has led to several derailed efforts of data integration across disciplines and sites based on the Integrated Operations philosophy.

6.3 Infrastructures for Extended Situatedness

Integrated Operations challenge, like many other developments today, the notion of situatedness (Monteiro et al., 2012a). Increased data mobility makes it possible to move activities on shore and for new practices to emerge. The experience-based extrapolation processes we have discussed carry all the hallmarks of situated interpretation. It occurs in “synthetic situations” (Knorr-Cetina, 2009) in the sense that screens and representations saturate the rooms in which people are located. It is not the presence of computers and screens that make the difference however, it is the shared interactivity they mediate. Being part of the situated work here, contributing to the contextually particular sensemaking in which meaning about the reservoir is wrestled out of the data is not first and foremost dependent on spatial (co-)location. More relevant is the history of interaction with the sensors and sensor data. This again depends on flexible, open infrastructures that give the possibility to retrace extrapolation processes and use the data as tools for one’s own inspection and to challenge established meaning. The workers in the onshore collaboration rooms and their second-line support teams converge on the same data in sensemaking processes that transcend the walls of the office building.

Pollock et al. (2009) challenge the notion of situated as a “small place” and call for studies that investigate extended situations and how these are handled. In contrast to ours, their study empirically illustrates mainly the organization of work in extended situations. In particular, they elaborate the secondary coordinative work in extended situations, such as the distribution of tasks among technicians and prioritization of tasks. Our study addresses interpretation and sensemaking and illustrates the mechanisms by which this primary work also extends out of the local setting[17]. We see that the entanglement with specific infrastructures and technologies makes new forms of situatedness possible. Crucial in this respect is that the IIs are built to support interpretation rather than to convey stabilized interpretations. It is not mainly a matter of which computers or which protocols are used, but the entanglement of IIs and the interpretative work practices.

[17] See Schmidt and Bannon (1992) for a discussion of CSCW’s role in supporting “articulation work” (Strauss, 1985), a secondary supportive coordinative work that supports the “primary work”. In this respect, our contribution is primarily focused on how IIs contribute to extending the primary work.

When arguing for the extended nature of the interpretation processes, there is a risk of underplaying the importance of local context. We have elsewhere (e.g., Almklov, 2008; Østerlie et al., 2012) gone into detail in describing how knowledge of contextual particularities pertaining to individual wells, types of equipment, people's competence, and so on weigh heavily on interpretative processes. This knowledge is largely grown out of presence at the operational department. In the case where three different groups interpreted well data, their extrapolation practices are both joint and rooted in experience gained at different departments. However, situated knowledge in this setting is also dependent on a history of interacting with sensor data and infrastructures.

This paper is not considering "how much" the local matters, or to what extent technology can alleviate the problems of not being present in face-to-face interaction; rather, we have demonstrated that being involved in the interpretation of such data is dependent on entanglement with specific IIs. Work is reconfigured by the tight interaction with IIs. In our cases, new forms of interaction with technology arise, forms in which the relationship to physical location is less important.

The support centers, for example, are much "closer" contextually to the situated work of production and drilling engineers than most of their colleagues in their office building. These colleagues do not share their experience interacting with sensor data and have to rely on reports or accounts that are stabilized and simplified according to the organizational discourse. The difference, then, is whether they collaborate in interacting with data or whether they just receive black-boxed results.

When responding to the critique of *Plans and Situated Action*, Suchman (2007) states that one of her interests when writing the book was to "to take the idea of human-computer interaction seriously *as interaction*" (p.18, emphasis in original). Our informants interact with infrastructures, and their work is profoundly situated in these interactions. The information infrastructures allow interaction from several sites. Taking this interpretative work, seen in several disciplines in the petroleum industry, seriously as interaction presents us with situations that are extended by means of specific IIs. When we trace the relations that make up the context of their work, we find situations that transcend the local settings of interaction.

For researchers interested in situated work, tracing interaction with information infrastructures also has methodological consequences: Beaulieu (2010) argues that in field-sites where distributed work and mediated action is important, ethnographers should look for ways to be co-present as much as co-located with the informants:

> *Co-presence is a very active form of 'field-making'. The field is constituted in the interaction. The field is not a container or background in which interaction takes place* (Beaulieu, 2010, p. 463, emphasis in original).

Field-making is, among other things, a matter of interacting with the same information systems as the informants. Though her discussion is mainly methodological, it also recognizes that interaction in the situation (that she would like to study) also consists of technologies that transcend the local context. They are both artifacts (locally) and infrastructures (Monteiro et al., 2012a).

Taking interaction seriously means recognizing that in some settings, sensemaking is not a purely cognitive venture performed on or with technology, but rather a relational phenomenon in which technology is an intrinsic part. The object of study: are hybrid ensembles of technologies, material phenomena, and human actions.

7. Conclusion

We elaborated the concept of situatedness as an empirical phenomenon through an analysis of how subsurface professionals interact with sensors and information infrastructures as they collectively make sense of the oil reservoir and what is going on in the production system. Through this analysis, we demonstrated the profound entanglement between technology and work practices in this kind of work. It is the history of interaction with these information infrastructures that produces unique, particular circumstances in which data are interpreted. Being present in the situation in which interpretation occurs, therefore, depends on this constitutive entanglement between the interpretative work practices and IIs.

The situated knowledge of the petroleum engineers grows mainly out of interaction with data and the epistemic machinery for handling data about subsurface phenomena. Understanding the oil reservoir depends on extrapolation of sensor data. As such, it depends on infrastructures that facilitate the recursive movements necessary to draw inferences based on combinations of sensor data. These infrastructures have co-developed with extrapolation practices. Being part of the situation in which these data are interpreted depends on the tools and abilities to search for new extrapolations, new meaning, and to question existing ones.

IS researchers have recently questioned the appropriateness of the notion of situatedness for analyses of computer-based work in the face of the increasingly trans-local character of such work. This is an appropriate question because much empirical research on situated computer-based work tends to focus on single groups of people using a single application in a particular location. We contend, however, that the problem is not with the notion of situatedness as such, but that the empirical investigations should trace interactive patterns that go beyond the local setting. Our contribution to the discussion of extended situations is that we show how interactive entanglements that may (or may not) extend beyond local settings are parts of the particular concrete circumstances, the situations, in which sensor data interpretation occurs.

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