Engaging Anthropocene Science:

Perspectives on the role of geoscientific practices on Anthropocene debates

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i. Zusammenfassung

Die vorliegende Dissertation umfasst fünf Publikationen, welche die theoretische Perspektive der „Science and Technology Studies“ (STS) auf das Anthropozän beziehen. Sie untersuchen, welche wissenschaftliche Repräsentationen des Anthropozäns existieren, wie diese produziert worden und mit welchen Auswirkungen. Die Analyse nimmt die Geowissenschaften, und insbesondere die Stratigrafie, in den Fokus, da diese eine zentrale Rolle in der Entwicklung des Anthropozän-Diskurses gespielt haben.

Eine solche STS-Perspektive ist unabdingbar, um das Anthropozän zu verstehen. Denn sie zeigt auf, welchen Einfluss die Art und Weise wie wissenschaftliches Wissen produziert wird auf Konzeptionen des Anthropozäns und auf die darauffolgenden Maßnahmen zum Umgang mit dem Erdsystemwandel hat. Der essentielle Beitrag der STS zu Umwelt-Debatten besteht in der methodischen Annahme, dass Natur, besonders die globale, nicht direkt wahrnehmbar und als solche darstellbar ist, sondern einer Repräsentation durch andere bedarf; diese Rolle wird zumeist von Wissenschaftler*innen übernommen. STS untersuchen die wissenschaftlichen Praktiken, die solche Repräsentationen produzieren, kritisch. STS zeigen dadurch, dass wissenschaftliche Fakten nicht universell gültig sind, sondern unausweichlich abhängig von sozialen, historischen und geografischen Kontexten. Die vorliegende Dissertation wendet diese Perspektive an, um die Produktion geowissenschaftlich valider Aussagen über das Anthropozän zu verstehen, und um deren konzeptuellen und politischen Konsequenzen zu analysieren.

Die vorliegende Dissertation bringt im Gesamtüberblick drei zentrale Erkenntnisse hervor, welche über die Ergebnisse der einzelnen Publikationen hinausreichen. Erstens, sie zeigt, dass geowissenschaftliches Wissen über das Anthropozän aus verschieden sozialen Prozessen resultiert. Diese umfassen a) die Beilegung wissenschaftlicher Kontroversen zwischen Geowissenschaftler*innen, besonders um die Grenzen und den Charakter der Gesteinsschichten des Anthropzäns; b) die Verhandlung dessen, was innerhalb der geowissenschaftlichen Forschungsgemeinde als glaubwürdiges Wissen gilt, vor allem durch das Angleichen von neuen Forschungsergebnissen und etablierten Forschungspraktiken; und c) Grenzziehungen

zwischen Kompetenz-Bereichen, durch welche geowissenschaftliches Wissen für das Verstehen des Anthropozäns relevant wird. Dazu zählt insbesondere, zu bestimmen ob die Fähigkeit und der Willen, das Anthropozän zu erforschen, vorhanden sind. Zweitens, die Arbeit verdeutlicht, dass geowissenschaftliche Repräsentationen des Anthropozäns a) die Konzepte vom Erdsystemwandel beeinflussen; und b) normative Logiken beinhalten, die politische Konsequenzen haben, nämlich anthropogenen Erdsystemwandel möglichst einzugrenzen oder ihn zu akzeptieren und bewusst zu steuern. Drittens, die Dissertation legt offen, dass weder die neuartigen geologischen Eigenschaften des Anthropozän noch dessen breite gesellschaftliche Popularität Veränderungen in der geowissenschaftlichen Forschungspraxis hervorruft. Etablierte Vorgehensweisen überwiegen innovative interdisziplinäre Forschungsansätze und die gesellschaftlichen Folgen geowissenschaftlicher Forschung bleiben größtenteils unberücksichtigt.

Insgesamt bildet diese Forschung eine Grundlage dafür, mögliche Veränderungen der (geo-)wissenschaftlichen Forschungspraxis zu reflektieren und diese in Einklang zu bringen mit der gesellschaftlichen Reichweite der Anthropozän Forschung.

ii. Summary

This cumulative thesis encompasses five papers that apply the theoretical perspective of Science and Technology Studies (STS) to the Anthropocene, investigating what scientific representations of the phenomenon exist, how they were created and with what effect. The analysis focuses on the geosciences and particularly stratigraphy, which have played a central role in the development of the Anthropocene discourse.

The STS perspective offered by the thesis is indispensable for understanding the Anthropocene because it shows how the very activity of producing scientific knowledge on the Anthropocene shapes conceptions and societal responses to Earth system change. The fundamental contribution of STS to environmental debates is the notion that environments, especially of the global variant, require representation and that science has predominantly provided the latter. STS critically investigates the representational practices of science: it thus demonstrates that resulting scientific facts are inevitably contingent on social, historical and geographical contexts, and, therefore, always ambiguous. Applying this perspective, will help to understand the production of geoscientifically valid claims about the Anthropocene, and to analyse their conceptual and political consequences.

Beyond the contributions of the individual papers, the thesis yields three main overarching results. Firstly, it highlights that geoscientific knowledge about the Anthropocene is the result of social process including a) particular settlements of scientific controversies through geoscientists, especially disagreement about the boundary and character of Anthropocene strata, b) processes of aligning novel research results and existing research practices through which new facts gain credibility within the research community, and c) the drawing of boundaries between areas of authority, including the ability and willingness to study the Anthropocene, which render geoscientific knowledge relevant to Anthropocene discourses. Secondly, the analysis shows that geoscientific representations of the Anthropocene a) affect wider concepts of Earth system change, and b) engender normative logics that have socio-political implications, i.e. either to limit anthropogenic Earth system change or to accept and intentionally manage it. Thirdly, this thesis reveals that the novel character and the wide societal popularity of the Anthropocene do not induce changes in

geoscience scholarship. Established research practices prevail over innovative interdisciplinary approaches and the societal implications of geoscientific research are externalised.

This research provides the basis for reflecting possible changes in (geo-)scientific practice so to reconcile the societal reach of geoscientific knowledge with the agency of geoscientists to influence the knowledge that they produce.

iii. List of Publications

No	Title	Source of publication	Status
1	Parameters of the Anthropocene	In: Meisch S, Lundershausen J, Bossert L and Rockoff M (2015) 'Ethics of Science in the Research for Sustainable Development'. Baden-Baden: Nomos, pp. 301-322.	Published
2	(Dis)entangling descriptions of and responses to the Anthropocene: Norms & implications of scientific representations of the Earth system	In: Hickmann T, Partzsch L, Pattberg P and Weiland S (2018) 'The Anthropocene Debate and Political Science'. Abingdon, Routledge, pp. 31-47	Published
3	Marking the boundaries of stratigraphy: Is stratigraphy able and willing to define, describe and explain the Anthropocene?	*Geo: Geography and Environment* 5(1): e00055. https://onlinelibrary.wiley.com/doi/abs/10.1002/geo2.55 (first published 1 June 2018).	Published
4	The Anthropocene Working Group and its (inter-)disciplinarity	*Sustainability: Science, Policy & Practice*: 14(1), pp. 31-45 (published online 7. January 2019)	Published
5	Anthropocene: Be wary of social impact	Holmes G, Barber J and Lundershausen J (2017) Anthropocene: be wary of social impact. *Nature* 540: 464	Published

iv. Acknowledgements

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Early stages of higher education provide the basis for my academic work that cumulates in this thesis. I am thankful to Dr. Maxine David (Leiden University), Dr. Sam Randalls (University College London) and Prof. Peter Barta (Texas Tech University) for committed guidance during these stages.

Last but not least, I am fortunate to thank my friends and family for the continuous support and good humor. Without their companionship, I could not succeed.

v. Declaration on own contribution

Four publications included in this thesis are single-authored and were produced by me alone.

The empirical study upon which Paper (4) is based was initially prepared together with Jacob Barber (formerly University of Edinburgh, UK) and George Holmes (University of Leeds, UK) to maximize access to members of the Anthropocene Working Group and increase the variety and quality of questions posed to them. The result of this collaboration was a pool of data that was subsequently used for the separate research projects of the different researchers. While the survey and interview questions were prepared collaboratively, the interviews, which lasted between 38 minutes and 126 minutes, were conducted individually by different researchers of the team. The analysis and publication of the data in form of Paper (4) is my own responsibility.

Paper (5), a comment published in Nature, is a collaborative piece co-authored with Jacob Barber (formerly University of Edinburgh, UK) and George Holmes (University of Leeds, UK) at one third of the work share each.

For more information please refer to the ‘Declaration on the share in publications done in team work’ according to § 5 Abs. 2 No. 8 of the PromO of the Faculty of Science.

1. Introduction

Promising a comprehensive approach to complex socio-ecological systems, the concept of the Anthropocene[1] has become an important framework for thinking about contemporary changes of those systems, and the Earth system a whole. It is a proposed geological epoch that indicates an era in which 'humankind has become a global geological force in its own right […][being] largely responsible for moving the earth out of the Holocene' (Steffen et al., 2011: 843). Fundamentally, the Anthropocene encases the idea that cumulative actions of humans induce environmental changes of unprecedented spatial and temporal scale.

This thesis applies the theoretical perspective of Science and Technology Studies (STS) to the Anthropocene, investigating what scientific representations of the phenomenon exist, how they were created and with what effect. Chapter 1 introduces the rationale for an STS study of the Anthropocene and, more specifically, for an STS study of Anthropocene geoscience. Specifically, it outlines my understanding of debates about the Anthropocene, of the role of the geosciences in these debates and of the contributions that Science and Technology Studies can make to comprehend that role. The resulting framework lays the ground for briefly outlining the goals of the thesis (Chapter 2) and for presenting and discussing the results of the five papers (Chapter 3), starting with summary of the papers' individual results (Chapter 3.1), followed by general findings and synergies of the papers (Chapter 3.2). Finally a conclusion (Chapter 3.3.) summarizes the findings of this thesis.

1.1. From geoscientific to interdisciplinary debates about the Anthropocene

Although the Anthropocene has conceptual predecessors (Palsson et al., 2013) and was originally termed by Eugene Stoermer in the mid-1980s, its resurrection is attributed to Nobel laureate in chemistry Paul Crutzen. Somewhat unconscious of its conceptual history, Crutzen renewed attention to the term after a scientific committee meeting of the International Geosphere-Biosphere Programme (IGBP) in the year

[1] In the remainder of this text, I do not distinguish between the concept and the physical reality of the Anthropocene. In doing so, I would like to highlight the epistemological notion that socially embedded frameworks shape our conceptions of reality while retaining the ontological proposition that a reality exists independently of our theories (Proctor, 1998).

2000. After becoming agitated by his colleagues' repeated reference to the Holocene as the Earth's current geological era, he suggested that the Holocene should be replaced with the Anthropocene (Steffen, 2013). Following this meeting, Crutzen and Stoermer wrote a short commentary in the IGBP's Global Change Newsletter (2000) on the meaning and importance of the Anthropocene, which was restated a year and a half later in the journal Nature (Crutzen, 2002). The IGBP extensively commented on the Anthropocene in 2004 (Steffen et al., 2004) and, in 2012, organised a major international conference, entitled Planet under Pressure, at which the Anthropocene was presented as the new geological epoch and state of the Earth system.

Subsequently, stratigraphy, the branch of geology concerned with the study of rock layers (strata) and their layering (stratification), accepted the Anthropocene as a hypothesis meriting closer assessment. Both the original usage of the Anthropocene as the 'geology of mankind' (Crutzen and Stoermer, 2000) and its stratigraphic etymology, which indicates a new anthropogenic epoch ending the Holocene, render stratigraphy a discipline of fundamental relevance to judging the validity of the Anthropocene. Indeed, the number of scientific publications referring to the Anthropocene spiked in 2007, following a decision by the Stratigraphic Commission of the Geological Society of London to seriously debate the geological claim underpinning the Anthropocene (Castree, 2014b). The official stratigraphic status of the Anthropocene remains subject to debate (Zalasiewicz et al., 2017b). But the decision to establish an Anthropocene Working Group within the International Commission on Stratigraphy, which oversees changes of the Geological Time Scale, corroborates Crutzen's idea of a 'geology of mankind' (2002). Another key event in this regard was a workshop organised by the Geological Society of London in May 2011, which shifted the empirical focus from Earth system science to geology (Steffen, 2013: 487–488).

Ever since, many other fields of studying socio-ecological systems have embraced the Anthropocene. They include other natural sciences like biology (e.g. Kidwell, 2015) as well as many social sciences and humanities such as anthropology (e.g. Gibson and Venkateswar, 2015), history (e.g. Chakrabarty, 2009), literary studies (e.g. Clark, 2015), law (e.g. Vidas, 2011), social theory (e.g. Delanty and Mota, 2017) and political science (e.g. Pattberg and Zelli, 2016).

The discussions in different communities have diversified the meaning of the Anthropocene, creating a heterogeneous discursive space that has been called the 'anthropo(s)cene' (Castree, 2015). Reviewers of this space have grouped different interpretations. Whitney Autin (2016), for example, argues that scientific, philosophical, political and artistic debates about the Anthropocene are constructed around dichotomies such as a good or dystopian Anthropocene. Jamie Lorimer (2017) identifies four different ways in which the Anthropocene has been mobilised in addition to the geoscientific discourse. He contends that the Anthropocene may indicate a) an 'intellectual Zeitgeist' concerned with the 'end of nature'; b) an 'ideological provocation' in environmental politics; c) 'new ontologies' reshuffling the place of nature and humans in the world; or d) a 'science fiction' that mobilises different visions of the future.

One distinction necessary to understand the 'anthropo(s)cene' is between scholars who simply use the term and those who reflect it critically. Many authors writing on socio-ecological systems refer to the Anthropocene casually (Gren and Huijbens, 2014; Bennett and et al., 2016; Caoili, 2018; Ellis, 2018; Lamborg et al., 2014), simultaneously boosting the legitimacy of the term and borrowing legitimacy from the term for their own research endeavours. Other scholars have criticised such adoptions of the Anthropocene and their effects on scientific and societal discourses. They have cautioned that dominant interpretations reinforce an (inappropriate species-egoistic) anthropocentric world view (Crist, 2013), limit understanding of social processes to scientific analysis of Earth system change (Malm and Hornborg, 2014) or naturalise existing trajectories of socio-ecological systems and hence ignore the underlying social dynamics (Luke, 2013). Following this critical strain of analysis, this thesis questions conventional understandings of nature and society represented by the Anthropocene.

1.2. The theoretical perspective of Science and Technology Studies

In the vein of a social constructivism (Hess, 1997b), this thesis understands interpretations of the Anthropocene as inevitably contingent on social, historical and geographical contexts, and thus as always ambiguous.[2] However, I do not utilise the

[2] For purpose of this dissertation, it is unnecessary to decide whether realism or constructivism is 'true' in a propositional or ontological sense; it suffices to highlight the important insights that constructivist

idea of social constructedness as an overarching metaphysical notion, claiming that 'any object whatsoever [...] is in some non-trivial sense socially constructed', but as a more local position that takes the production and validation of scientific knowledge to be socially constructed (Hacking, 2001: 24). By taking this position, I do not aim to refute existing geoscientific knowledge about the Anthropocene (as other critical inquiries have done) but to arrive at a philosophical critique of the practices that have produced that knowledge (c.f. Demeritt, 2002). As such, I complement existing critical analyses of the Anthropocene by applying the constructivist paradigm to Anthropocene geoscience: I explain the production of geoscientifically valid claims about the Anthropocene by way of social dynamics, and I highlight their conceptual and political consequences. This investigation is crucial because the geosciences, as outlined above, have played a central role in the evolution of the Anthropocene discourse, though this engagement is changing due to the 'anthropos(c)ene'.

In providing a social constructivist perspective of Anthropocene geoscience, this thesis is standing on the shoulders of scholars who have studied science (and technology) not as a set of testable knowledge claims but as a social phenomenon. This field, called Science and Technology Studies (STS), owes a lot to traditional scholarship in the history, philosophy and sociology of science but has also developed distinctive theories and research practices. Thomas Kuhn (1996) paved the way for STS by opening the content of science for critical inquiry. Previously, scholars in sociology had focused on the social institutions of science (Merton, 1996) and philosophers had outlined a positivist epistemology of science (Popper, 1972) but they had largely ignored that the content of science is contingent on its social context.

In the 1970s, a group of British sociologists advanced a post-Kuhnian research agenda emphasizing that scientific knowledge is inherently social, not merely the result of rational intellectual pursuit (Barnes and Bloor, 1982; MacKenzie, 1981; Shapin, 1975). The seminal work of David Bloor (1991) articulated four main principles of this agenda in what he called the 'strong programme': causality, impartiality, symmetry and reflexivity. The most influential of these principles is 'symmetry', postulating that STS should treat true and false beliefs the same, and should not, as had been the tradition

STS approaches have provided about the dynamics of knowledge production in science and technology development.

in history and philosophy of science, explain the former in reference to nature and the latter in reference to society (Hess, 1997a: 5).

STS has developed significantly since Bloor's first articulation of the symmetry principle, which has been progressively extended to new areas, e.g. in Actor-Network Theory which draws symmetries between human and non-human actors (Latour, 1987). STS is an evolving field that is far from being unified by a single theory or method. Nevertheless, work in STS coheres around and gains distinctiveness by way of the idea that science and technology are socially constructed. As such, STS contrasts with realism that fundamentally claims that 'truths are more dependent upon the natural world than on the people who articulate them' (Sismondo, 2010: 58).

1.3. Contributions of STS to understanding the Anthropocene

In the past three decades, the global environment has been a leading research theme in STS, showing how global nature is represented through social practices of science. The major contribution of STS to environmental debates has been the notion that 'environmental "facts" do not speak for themselves independently from the realm of the social. Environmental facts, rather, speak because we do (although not all with an equal voice)' (Carolan, 2004: 498). Especially global environmental issues, as they are framed as spanning the globe, are separated from people's life-worlds; their complexity and scale is then not directly recognisable. Climate change, for example, is disconnected from 'ordinary human experience at […] four interrelated levels: communal, political, spatial and temporal' (Jasanoff, 2010: 237). As a result, the global environment requires representation, which creates imaginative or practical 'linkages between people, and between people and the world of animate and inanimate phenomena' (Castree, 2013: 139). Historically, science has been dominant in doing such representing (Beck, 2007; Becker and Jahn, 2006) as its specialised methods are seen as particularly suited to transcend local experiences of the environment (Jazeel, 2011). The case of Anthropocene geoscience indicates that this prerogative persists. To further investigate the role of the geosciences in Anthropocene debates, this thesis focuses on the following three dimensions that align with the STS tradition: the effects of geoscientific practices on representations of the Anthropocene; the normative and political consequences of scientific representations of the

Anthropocene; and the effects of wider Anthropocene discourses on geoscientific practices.

1.3.1. Effects of scientific practices on representations of the Anthropocene

STS scholars provide a critical perspective of the representational practices of science, teaching us that the prerogative of science is the result of specific social constellations and active decisions by people. They have demonstrated which social processes have allowed entities like the Pacific Ocean, the equator or the Earth as a whole (Cosgrove, 2008) to be accepted as valid scientific representations of global nature. Similarly, an STS perspective of the Anthropocene will elucidate the geoscientific practices that produce the Anthropocene as a valid object of both academic investigation and broader societal concern. Existing STS analyses of the Anthropocene have already demonstrated that the IGBP has been a major actor in constructing the Earth system as an object of scientific research (Bondre, 2015) and political concern (Uhrqvist and Lövbrand, 2013). It has also been shown that Crutzen's standing as a Nobel laureate transferred quasi-scientific authority to the term before its validity could actually be assessed (Barber, 2018).

1.3.2. Normative and political consequences of scientific representations of the Anthropocene

STS scholars who critically attend to the social production of scientific representations have also shown that the latter engender specific social values and political responses. Although the geosciences normally do not explicate normative agendas, their representations of the Anthropocene are socially and politically powerful because the Anthropocene would not exist in the same way as a recognisable matter of wider concern without the geoscientific discourse (c.f. Urry, 2011). In highlighting this 'Earth system governmentality' (Lövbrand et al., 2009), STS can outline the societal consequences of geoscientific representations.

At the same time, most STS scholars refrain from taking normative stances, neither epistemologically nor morally. Consequently, they have been criticised for 'opening the black box of science and finding it empty' (Winner, 1993: 362). Regarding questions of norms in science, STS thus benefits from a cross-fertilisation with the ethics of science,

which has provided concepts such as ‘moral-epistemic hybrids’ that highlight the connections between norms and facts, ‘mak[ing] them communicable – and open to deliberation’ (Potthast, 2015a: 130).[3] Vice versa, STS can contribute to ethical inquiries. As STS illuminates the social processes of science, it provides the basis for exploring possible interventions and alternative actions (Johnson and Wetmore, 2008). In this way, STS offers an opportunity for Anthropocene geoscientists to respond to demands that they should engage more with societal actors (Barnosky and Hadly, 2014) and goals (Schmidt et al., 2016).

1.3.3. Effects of wider Anthropocene discourses on scientific practices

The narratives of the Anthropocene are increasingly multiple; as are the types of scholarship constructed around them. Many academics have discussed not just how they can produce more knowledge about the Anthropocene’s social and physical realities but also how the proposal of the Anthropocene changes their research. The term has prompted reflections on ways that environmental knowledge is produced in disciplines such as human geography (Castree, 2015; Cook et al., 2015), geomorphology (Brown et al., 2017), history (Levene, 2013), conservation biology (Lorimer, 2015) and also in Earth system science (Ellis and Haff, 2009) and stratigraphy (Gale and Hoare, 2012).

An almost unexplored area of interest to STS are the changes that the Anthropocene as a scientific phenomenon of broad resonance induces in geoscientific scholarship. The Anthropocene has moved from the centre of the geosciences onto the boundaries between several fields of study and societal debates, where it initiates ‘conversations and collaborations across significant forms of epistemic difference’ (Lorimer, 2017). In this vein, knowledge about the Anthropocene that is produced elsewhere may stimulate geoscientists to change their research practices. From a social constructivist perspective, these changes require closer analysis since they reveal the social contingency of scientific practice. Interdisciplinarity is one of the principle changes requiring attention because it is often called for as a paradigm shift necessary to study the Anthropocene (Baskin, 2014; Brondizio et al., 2016; Castree, 2014a).

[3] Simon Meisch suggested in 2014 that the Anthropocene should be conceptualised as a ‘moral-epistemic hybrid‘.

2. Goals

The general aim of this thesis is to provide an STS perspective on Anthropocene geo-geoscience. Such an analysis is indispensable for understanding the Anthropocene because 'the very activity of "knowing nature" shapes the knowledge [and action] that result' (Yearly, 2008: 293). Following the above discussion, the STS investigation of Anthropocene geoscience, and particularly of Anthropocene stratigraphy, provided here will focus on three specific questions that cut across the five publications.

1. Social contingency of Anthropocene geoscience

   How do actions of geoscientists influence knowledge about the Anthropocene as a phenomenon? STS scholars have attended to the social practices that bring about scientific facts. In this vein, it is necessary to investigate scientific controversies about the Anthropocene and the actors and actions involved in settling them.

2. Societal relevance of Anthropocene geoscience

   What are the normative and political implications of geoscientific representations of the Anthropocene? As the geoscientific discourses enable societal actors to 'think' the Anthropocene, it also shapes their responses to the Anthropocene. How geoscientific representations of and societal responses to the Anthropocene are linked, needs to be studied in detail.

3. Changing forms of geoscientific scholarship

   Does the Anthropocene change existing forms of geoscientific scholarship? The novel character and wide popularity of the Anthropocene foster exchanges across different structures and/or forms of knowledge. The effects of interdisciplinary exchanges on the practices of geoscientific research communities thus require as much investigation as the question how geoscientists adapt to deal with this grown societal relevance of their work.

3. Results and Discussion

3.1. Results

This chapter summarises the results of the individual publications that comprise this thesis. The following summaries provide the basis for discussing synergies between those publications in Chapter 3.2. The full papers are to be found as appendices.

3.1.1. Parameters of the Anthropocene

Paper (1) examines the literature on the Anthropocene and demonstrates how authors define the Anthropocene and assess its value. This analysis is limited to literature published until 2015, yet it remains valid because its focus is derived from an examination of the wider literature as well as the etymology of the Anthropocene, which prioritises two aspects of the Anthropocene amidst an ever broadening discourse. First, it highlights the debate about the geological dimension of the Anthropocene (-*cene*), in which the validity of the Anthropocene as an official geological Epoch is examined. Second, it analyses discussions about the human dimension of the Anthropocene (*Anthropo*-), which contain different conceptions of human agency in causing Earth system change.

Regarding the geological dimension, the official criteria used in stratigraphy to assess the validity of geological time units are introduced. Moreover, the paper identifies disagreement in the literature about whether or not the Anthropocene fulfils these criteria and if it should be officially included in the Geological Timescale. The paper then examines the reasons of this disagreement and traces it back to different perspectives of stratigraphic practice rather than different views of Earth system change. Across the geoscientific literature, authors agree that humans have caused pivotal changes of the environment which describe a new period in Earth history. But, as evidence of the Anthropocene's geological dimension is inconclusive, they disagree on whether the Anthropocene is a scientifically viable concept or not. The paper shows that scientific disagreement about the validity of the Anthropocene is caused by the different aims of different scientific inquiries. Whereas some geoscientists reject the Anthropocene as an official geological epoch because they prioritizes consistent

stratigraphic practice, others are more concerned with an adequate representation of Earth system changes and hold that stratigraphy should be practiced flexibly to reflect such changes. The paper suggests that disagreement about the geological dimension of the Anthropocene, in this way, fosters reflection of research practices in stratigraphy.

In addition, the paper shows that the Anthropocene is judged not just by examining the geological dimension of the Anthropocene but also by assessing its human dimension, i.e. the activities of humans that drive the changes of the Anthropocene. It has been argued that dominant scientific representations of the Anthropocene encompass a 'species narrative', which highlights the inherent ability of *Homo sapiens* (rather than a subset of it) to shape planetary processes. The paper reveals the different ways in which authors attend to this narrative. Proponents think that the species narrative enables a long-term and integrated perspective on the history of humans on Earth. Opponents point to the narrative to criticise naïve Malthusian explanations of environmental change and deterministic views of human-nature relationships, which mirror development trajectories of industrialised societies in the Global North. In both cases, the paper argues, the species narrative raises the Anthropocene above ground and shifts the focus from undifferentiated geological impacts towards the interactions of human beings in society. Consequently, the validity of the Anthropocene becomes subject to interlocutors' views on the genesis of human-environment relationships, i.e. what they think the Anthropos should be representative of. Many authors have thus highlighted that specific social relationships have caused the Anthropocene but that they are not representative of socio-ecological systems in the Anthropocene overall.

The analysis presented in this paper shows how the Anthropocene is constituted in different communities, which assess its human and its geological dimension respectively. It also highlights that both communities internally disagree over the proxies (i.e. the specific social relations or stratigraphic markers) that adequately represent Earth system change and that should be used to characterise the Anthropocene. As such, the paper shows that whether or not the Anthropocene is judged to be an appropriate representation of Earth system change, depends on the proxies that investigating academics deem valuable and appropriate.

Overall, this paper introduces the scientific debates on the Anthropocene. It outlines controversies within geoscientific research on the Anthropocene as well as those that the geosciences neglect (i.e. the human dimension of the Anthropocene). In doing so, the paper helps to establish the focus of this thesis on the stratigraphic community, while outlining possible other routes of inquiry.

3.1.2. Disentangling descriptions of & responses to the Anthropocene

STS understands science and society as co-produced; it highlights that scientific debates about the Anthropocene are influenced by their social context and, reciprocally, that they influence social processes, as noted above. Paper (2) answers the question how scientific representations of the Anthropocene induce social and political responses to the Anthropocene. It analyses the normative logics incorporated in different geoscientific representations of the Anthropocene and it demonstrates which responses to global change they can produce. Analysing publications that employ the concept of the Anthropocene to discuss the human impact on the Earth system, the paper provides an answer in three steps: after 1) showing that representations of the Anthropocene from Earth system science differ in their interpretations of contemporary Earth system changes, the paper 2) analyses the specific normative logics that these representations imply and 3) it demonstrates how they are connected to opposing proposals for political and technological responses to Earth system change.

The two opposing representations identified are the Anthropocene as a crisis of sustainability and the Anthropocene as an opportunity for sustainability. 'Anthropocene as crisis' presents the Holocene conditions of the Earth system as parameters of Earth system functioning and of human development. The paper outlines that the increasingly popular concept of Planetary Boundaries plays a crucial role in this as it provides a framework to assess the risks and uncertainties of deviating from Holocene conditions. Planetary Boundaries quantify a 'safe operating space' within which biophysical processes can change before the functioning of the Earth system becomes unstable and unpredictable. However, alternative accounts suggest that humans have always altered ecosystems to support human livelihoods – with *global* environmental consequences. The paper outlines how this alternative view of the history of humans

on Earth ensues a representation of the ‘Anthropocene as opportunity’ for sustainability because it draws parallels to past socio-ecological systems. The Anthropocene, from this perspective, is the most recent advancement of the human ability to overcome natural limits. While unintended, the conditions of Anthropocene Earth system are portrayed as offering an opportunity for development rather than posing risks to the latter. The human ability to manage and adapt to these new environmental conditions, rather than hard Planetary Boundaries, is considered a principle determinant of future socio-ecological systems.

By highlighting the differences between the ‘Anthropocene as crisis’ and the ‘Anthropocene as an opportunity‘, the paper indicates disagreement within the geoscientific community and demonstrates the contradictory narratives that the Anthropocene contains.

In a second step, the paper extends this argument to the contradictory normative logics of geoscientific representations of the Anthropocene by investigating their different attitudes towards nature’s normative function. On the one hand, the ‘Anthropocene as crisis’ implies a ‘naturalist logic’ which takes human flourishing as inherently circumscribed by thresholds of the Holocene Earth system. Holocene conditions are normalised as the state of the Earth system that is optimal for human functioning. In this way, ‘Anthropocene as crisis’ prescribes which environmental conditions humans should value most; it raises nature as a guide for decision-making. On the other hand, the ‘Anthropocene as opportunity’ implies a ‘culturalist logic’ in which human actions can shape natural processes. As a result, this logic rejects an a priori environmental baseline for normative judgements such as the Holocene. Although this logic too includes a normative view of what nature is, it is seen as insufficient for decision-making. The paper further explains what responses to Earth system change could be deduced from these different logics. It shows that the ‘Anthropocene as opportunity’ extends the spatial and temporal scales of acceptable human intervention in the environment and proposes intentional management of change. Conversely, the ‘Anthropocene as crisis’ defines the maximum of acceptable Earth system change and urges that it be limited.

By way of this analysis, the paper opens the normative logics of scientific representations of the Anthropocene for debate and, in a third step, illustrates what political responses they engender. Analysing existing proposals for *Earth system governance* and *geo-engineering*, the paper not only raises awareness about the political entanglements of scientific research on global change but also offers an in-depth examination of the rationales behind these two response options.

Earth system governance (Biermann, 2014) is an approach to international environmental governance developed in the political sciences to foster political mechanisms and institutions that effectively solve the sustainability problems described by science on a global scale. In line with the scientific representation of 'Anthropocene as crisis', Earth system governance has built on Planetary Boundaries and committed to the Holocene as an a priori environmental guideline, while paradoxically arguing that the latter does not suffice as a sole basis for political decisions. The paper investigates this paradoxical relationship and concludes that Earth system governance adopts Planetary Boundaries precisely because they call for political action but remain neutral about concrete measures. The paper argues that this approach legitimises Earth system governance by way of Earth system science and thus effectively de-politicizes environmental politics because it raises environmental over social parameters for decision-making.[4] Defining environmental parameters is inherently normative and therefore potentially political. But to use Planetary Boundaries as a basis for decision-making without acknowledging this normative dimension, deprives the latter of social antagonism and contestation because it denies the heterogeneity of existing socio-ecological systems and their possible trajectories (Swyngedouw, 2011).

Planetary Boundaries, or other concepts of natural limits, do not feature prominently in debates about geo-engineering, which is the second response to the Anthropocene discussed in this paper. Contrary to Earth system governance, geo-engineering follows the scientific representations of 'Anthropocene as opportunity' by advocating the intentional alteration of global environmental processes through technological

[4] Although Kate Raworth (2012) has emphasized that Planetary Boundaries should describe not just a 'safe' but also a 'just space for humanity', this notion had, at the time of analysis, not been incorporated in the idea of Earth system governance.

interventions in solar radiation affecting the Earth and in the Earth's carbon cycle. Moreover, the 'Anthropocene as opportunity' raises the momentum for geo-engineering. The paper shows that the former normalises largescale human interference in the environment by extending the spatial and temporal scale of acceptable human disturbance. Spatially, 'Anthropocene as opportunity' suggests that the difference between ecosystem engineering and geo-engineering is marginal. Temporally, it provides a historical point of reference for contemporary global change.

By conducting these three steps, the paper demonstrates the link between specific representations of the Anthropocene and specific societal responses to Earth system change.

3.1.3. Marking the boundaries of stratigraphy

Paper (3) investigates how the stratigraphic community is involved in the endeavour of defining the Anthropocene. Although a various scientists are working to define the Anthropocene, the paper argues that stratigraphic knowledge plays a special role because it evaluates the geological dimension that is fundamental to the Anthropocene. The paper conceptualises this epistemic authority to define the Anthropocene and examines the stratigraphic literature published between 2011 and 2017 to determine if the stratigraphic community is able and willing to assume this authority. The material was gathered through a Web of Science search and an examination of three journals, identified as providing important forums for discussion. Publications were analysed only if their author(s) could conceivably be regarded as part of the geoscience community, and if they contributed to discussion about the geoscientific formalisation of the Anthropocene.

The analytical approach taken in this paper follows the 'strong programme' in Science and Technology Studies (STS), understanding science as a social activity of communities of practice in specific social contexts (Barnes and Bloor, 1982). In particular, it draws upon the work of Thomas Gieryn who described epistemic authority as the legitimate ability 'to define, describe and explain' a phenomenon (Gieryn, 1999: 1). Gieryn demonstrated that scientists shape the areas over which they hold epistemic authority and are thus involved in 'boundary work'. In this vein, the paper demonstrates

how stratigraphy co-produces the boundaries of its epistemic authority over the Anthropocene. The paper proceeds in three steps to achieve this aim.

In step one, the paper identifies the parameters of stratigraphy's epistemic authority by outlining stratigraphy's contributions to and its function in the Anthropocene discourse. Firstly, stratigraphy contributes to the conceptual distinctiveness and popularity of the Anthropocene by defining its geological dimension, which emphasizes the scale of Earth system change. Secondly, stratigraphy fulfils an important epistemic function in the interchange of knowledge about Earth system change; it produces formalised scientific expertise that supports existing discourses about Earth system change in different academic communities, in the media and amongst decision-makers. By highlighting these two aspects, the paper shows why stratigraphy is seen to legitimately define and explain the Anthropocene.

In step two, the paper identifies two challenges that the Anthropocene poses for stratigraphic analysis, and it examines the arguments employed in the stratigraphic literature that responds to them. On the one hand, the Anthropocene challenges stratigraphy to consider unusually short and recent stages in Earth history. This raises the question if stratigraphy, with its established principles, methods and nomenclature, is able to assess the diachronous and evolving manifestations of anthropogenic Earth system changes in the rock record. The analysis of the stratigraphic literature reveals a lack of consensus over this 'question of ability'. The paper argues that this disagreement is rooted in different approaches to codified stratigraphy, i.e. liberal or conservative ones, and it thus shows that scientific norms of practice are constantly negotiated. On the other hand, the paper demonstrates that stratigraphic markers of the Anthropocene can change understandings of Earth system change and its causes. Consequently, the question arises if Anthropocene stratigraphy is willing to consider and account for the potential philosophical and political implications of its research. The analysis suggests that authors of stratigraphic publications mostly do not address this question. Where they do, they either portray no willingness at all or they acknowledge potential societal implications of stratigraphic research without taking them into account because they fear that science will be politicised, i.e. that science becomes a proxy for political conflict, being expected to add arguments to existing

options for decision-making rather than expanding the range of those options (Pielke, 2004).

In step three, the paper outlines how the different answers given to these two questions draw different boundaries around stratigraphy's epistemic authority over the Anthropocene. Whereas negative answers to the 'question of ability' demarcate a small and homogenous domain of epistemic authority, positive ones allow for an expansion of the latter. As answers to the 'question of willingness' were shown to be more ambiguous, the paper took a closer look at their boundary effects by examining one particular stratigraphic controversy about the Anthropocene. This confirmed that answers to the 'question of willingness' create an impermeable or a semi-permeable boundary between stratigraphic and (non-scientific) societal discourses. Judging the former approach to be untenable, the paper shows how the latter approach affords flexibility to simultaneously expand the epistemic authority and protect the autonomy of stratigraphy. In addition, the paper reveals the crucial role that the 'ideal of value-free science' plays in this 'boundary work' between stratigraphy and society as well as in the distribution of authority within stratigraphy.

By conducting these three steps, the paper not only shows how stratigraphy deals with the proposal for a new geological epoch, which originated outside of stratigraphy, but it also sketches out how this treatment within stratigraphy affects the epistemic authority of stratigraphy over the Anthropocene. Accordingly, the paper explains stratigraphy's epistemic authority over the Anthropocene both with the role that society grants stratigraphy and the role that stratigraphy successfully claims for itself.

Two additional implications are brought to light by the analysis of epistemic authority conducted in this paper. Firstly, the examination of the questions of ability and willingness reveals that the development of stratigraphic facts about the Anthropocene is surrounded by controversies. In line with other STS studies (Klintman, 2002; Whatmore, 2009), the paper provides an insight into the process through which the Anthropocene Epoch gets constructed as a natural fact before it becomes 'black boxed' (Latour, 1987). Secondly, the paper highlights the prominent function of the 'ideal of value-free science' in contexts that otherwise afford an extension of the epistemic authority of science and its societal impact. The paper revealed that the

boundary that stratigraphy creates with society is flexible; stratigraphers move between appealing to and expelling (the concerns of) non-stratigraphers from the territory of stratigraphy's epistemic authority.

3.1.4. The Anthropocene Working Group and its (inter-)disciplinarity

Paper (4) follows the tradition of STS to study institutions that accompany the development of new knowledge about the environment and that help to accredit this knowledge (Jasanoff, 2004). It presents a qualitative study of the Anthropocene Working Group (AWG), an expert commission tasked with evaluating the stratigraphic case of the Anthropocene as an official geological epoch. This analysis is justified because the AWG drives stratigraphic research on the Anthropocene, which has been replicated in many academic and public discourses about the Anthropocene.

The paper is based on a content analysis of seventeen online surveys and eleven semi-structured interviews with AWG members, conducted to understand the internal workings and outside relations of the AWG. Although several themes emerged from this data, the paper focuses on the question how interdisciplinarity and disciplinarity affect the research practices of the AWG.[5] This is a salient question because the AWG simultaneously experiences a pull towards interdisciplinarity amidst widespread advocacy for interdisciplinary research on Earth system change, and a push towards disciplinary rigor by parts of the stratigraphic community criticizing the AWG for side-lining stratigraphic conventions. Given this context, the paper tested the hypotheses that interdisciplinarity characterizes the research practice of the AWG and that its relationship with the stratigraphic community is problematic. The data showed that AWG members reflect on the benefits and limits of interdisciplinarity in the AWG as well as on the relationship between the AWG and the stratigraphic community.

Concerning the benefits of interdisciplinarity, AWG members appreciated it for the interesting and constructive exchanges that it enables and they regard the AWG as exemplary in this sense. But they also differentiate the specific benefits that social scientists and natural scientists who are not stratigraphers bring to the group. Other

[5] Other themes that appeared in the data are the contributions of stratigraphy to the Anthropocene discourse or the way in which AWG members engage the public.

natural scientists are seen to provide insights that complement stratigraphic knowledge, thus increasing confidence in the latter and making it more relevant to non-stratigraphic users of the Geological Timescale. Most important here are the real-time observations of ESS that describe actual contemporary changes in the latter, which have helped to develop a geochronological narrative of the Anthropocene beginning in the mid-20th century. Social scientists are seen to improve the mutual exchange between the AWG and non-academic audiences by translating research results of the AWG and, conversely, raising awareness within the AWG about the wider Anthropocene discourse. At the same time, participants believe that the AWG encounters the limits of interdisciplinarity when working to prepare a formal proposal to the ICS, for which the stratigraphers in the Group need to position the geochronological narrative of the Anthropocene in sedimentary successions.

Regarding the relationship of the AWG with the stratigraphic community, participants emphasize the value of a constructive relationship for studying the rock record of the Anthropocene but they also admit that there has been a lack of communication and a related lack of trust between the AWG and the institutions of stratigraphy, especially with the International Commissions on Stratigraphy (ICS). As a result of this mismatch, the AWG has recently sought to improve the relationship by incorporating feedback from the stratigraphic community and by forging closer collaborations with representatives of the ICS.

On the basis of these findings, the paper characterizes interdisciplinary collaboration in the AWG and it discusses the relationship between the AWG and the stratigraphic community with reference to the dual potential of interdisciplinarity to bring about innovation in or fragmentation of established disciplines.

Firstly, the paper characterizes the exchanges between disciplines in the AWG as ‘narrow’ in scope and ‘multidisciplinary’ in type. This means that other disciplines are represented but they do not infuse the disciplinary research practices of stratigraphers. Social scientists take a largely non-scientific role in the AWG and the involvement of natural scientists in research activities is guided by the objectives of stratigraphy. Although the other disciplines are invited to translate and contextualize the stratigraphic work of the AWG, they are not extensively involved in data collection and

analysis. The paper shows that this partial interdisciplinary engagement aims at widening the accountability of the Group ('logic of accountability'), at responding to the Anthropocene as a new type of geological epoch that poses methodological challenges ('object-orientation'), and at stimulating creative debate between researchers ('practice-orientation') without rejecting the dominance of one discipline.

Secondly, the paper reveals that stratigraphy remains the main point of reference for the AWG despite internal calls to reform stratigraphic practice in light of the Anthropocene, which indicate the epistemological strength of an evolving specialised research community. In this vein, the paper suggests that the AWG's recent incorporation of feedback from the stratigraphic community depicts 'pragmatic working arrangements' that help the AWG to pursue formalisation and the ICS to ensure cohesion in stratigraphic practice. Moreover, the paper indicates endogenous and exogenous factors that prevent the evolution of a specialised research community: while the conservative approach of the stratigraphic community renders innovation within stratigraphy unlikely, the weakly institutionalised funding structure and social networks of the AWG inhibit a fragmentation of Anthropocene stratigraphy into a self-contained inter-discipline.

Altogether, the study presented in this paper supports existing theories arguing that novel research endeavours need to position themselves in the landscape of established disciplines but it also shows that these endeavours can simultaneously solicit interdisciplinary knowledge to contextualise and translate its research. The research practices of the AWG indicate a dynamic engagement between the benefits of crossing disciplinary boundaries and those of orienting academic work towards a specific disciplinary community. As such, the study does not confirm the initial hypotheses deduced from published debates: instead of following a pull of interdisciplinarity, the AWG remains shaped by the established practices of stratigraphy, and, rather than being onerous, the relationship of the AWG with the stratigraphic community is being managed pragmatically to conciliate disciplinary controversy.

3.1.5. Anthropocene: Be wary of social impact

The background of Paper (5) needs some explanation: In December 2016, a comment by Erle Ellis and colleagues questioned the distinction between anthropogenic environmental change before and after the 1950s, which had been proposed by the AWG to mark the beginning of the Anthropocene (Ellis et al., 2016). The authors refer to broader insights from natural and social sciences as well as the humanities to make this argument. Concurrently, they recommend changes in the process of formally defining the Anthropocene as a geological epoch especially regarding its transparency and inclusiveness.

While these authors predominantly discuss the interdisciplinarity of the Anthropocene Working Group (AWG), which is analysed in Paper (4), their comment also questions the processes through which knowledge about the Anthropocene is legitimately produced and gains credibility more generally.

This issue resonated with different researchers, who replied to Ellis et al. in a series of short comments focussing on the role of different actors in the process of defining the Anthropocene stratigraphically. Jan Zalasiewicz and colleagues (2017a) emphasize that the mandate of the ICS and the role of the AWG within this mandate are limited. Although the AWG works with interdisciplinary researchers, it necessarily provides a stratigraphic analysis, which is subject to the scrutiny of the ICS and Subcommission on Quaternary. Noel Castree (2017: 289) argues that the social sciences, rather than contributing to an interdisciplinary, universally agreed upon definition of the Anthropocene, can highlight that scientific representations of the world are inevitably 'varied and contingent'. Lucy Edwards et al. (2017) defend the existing formalisation processes because the precise stratigraphic boundaries that they produce foster communication about Earth system change throughout history.

Paper (5) adds to these comments and argues that official scientific definitions, including a formal stratigraphic definition of the Anthropocene, shape how interactions between humans and their environment are perceived. Social scientists, I argued together with my co-authors George Holmes and Jacob Barber, can analyse the credibility that science holds within society. This is important because the authority of

science to describe contemporary environmental phenomena is often taken for granted. Highlighting the origins of this authority debunks the notion that science speaks truth to power (Hilgartner, 2000) and thus enables innovations in science-policy interactions around global environmental change.

3.2. Discussion

As science and society grapple with the Anthropocene, this thesis demonstrates connections of the two spheres in two ways.

First, it explores the social aspects of Anthropocene research in the geosciences. By investigating the actions of geoscientists and specifically stratigraphers in producing scientific facts about the Anthropocene, the thesis confirms that ambitions of geoscientists to provide a direct route to nature are specious. Geoscientific facts about the Anthropocene are socially contingent representations of natural processes and are not themselves natural. In response to the first research question regarding the social contingency of Anthropocene geoscience, three aspects are revealed.

Second, this thesis evaluates the social and political relevance of geoscientific representations of the Anthropocene. This theme is captured by the second research question, evaluating the links between scientific conceptions and societal responses to the Anthropocene as well as geoscientists' reflections of this societal relevance.

Cutting across these two themes is the third research question, which concerns the changes in geoscience scholarship that are induced by the Anthropocene. The papers of this thesis raise two aspects of this changing scholarship. On the one hand, the analysis shows how the Anthropocene discourse changes the social processes in the geoscience community through which controversies are decided, credibility is achieved and the relevance of research is determined. On the other hand, it is revealed how geoscientists deal with the implications of their research for social and political responses to the Anthropocene and if they adapt their practices accordingly.

In the following, I shall discuss how the different papers help to understand these three aspects. The numbers of the papers are indicated in brackets.

3.2.1. Social contingency of Anthropocene geoscience

The thesis reveals three ways in which actions of the geoscientists affect knowledge about the Anthropocene. It highlights that geoscientific knowledge about the Anthropocene is the result of a) particular settlements of scientific controversies through geoscientists, b) processes through which resulting facts gain credibility within the research community, and c) boundary work that renders geoscientific knowledge relevant to Anthropocene discourses.

First, geoscientific knowledge about the Anthropocene requires stabilisation if it is to pass as facts amidst prevailing controversies about the Anthropocene across disciplines. My analyses of scientific controversies in Anthropocene research have two implications. On the one hand, they show that alternative understandings of the Anthropocene exist simultaneously (1, 2) and that the validity of the Anthropocene is judged in various ways both across and within disciplines. Consequently, and as the possibility for multiple Anthropocenes is highlighted, the idea that nature is an agreeable collective becomes questionable. This 'multinaturalism' (Latour, 2004) is relevant also for the organisation of science itself because it challenges modern science-policy arrangements, 'where scientists speak for Nature; providing facts and politics speaks for society, which must adapt to the facts' (Lorimer, 2012: 597).

On the other hand, the analysis of geoscientific controversies reveals the processes through which the Anthropocene is being stabilised as singular entity and established as a scientific fact (5). The stratigraphic community is involved in formalising the Anthropocene as an official epoch within the Geological Timescale. Because scientific labels matter (5), this thesis attends to their production by analysing the inner workings and outside relations of the stratigraphic community (3). In particular, Paper (4) studies the AWG to elucidate the ontological politics of this stratigraphic formalisation process; it reveals that the AWG (as it converges to formally propose a mid-20th century boundary for the Anthropocene) increasingly excludes alternative proposals for stratigraphic markers as well as interdisciplinary evidence that was essential to create this geochronological narrative in the first place.

Second, knowledge claims about the Anthropocene achieve credibility within the geoscientific community as researchers align them with the guiding principles of that community. By investigating scientific controversies, Papers (1, 3, 4) show how geoscientific knowledge is created, transferred and maintained among geoscientists. The Anthropocene not only causes geoscientists to controversially debate the physical properties of recent rock formations, but it also provides a platform for negotiating stratigraphic principles (1, 3, 4). The case of the AWG suggests that these negotiations succeed when researchers within a scientific community communicate directly and trust each other; they are likely to fail when innovators and conservatives compete relentlessly. As novel research results and existing research practices often stand in an '"essential" tension' to each other (Whitley, 2006: 13), the results of my analysis of the stratigraphic community usefully indicate pathways to align them. Stratigraphers do so by collaborating on concrete research challenges of the Anthropocene's rock record and by forging pragmatic working arrangements within their scientific union, the ICS. These cooperations allow differing approaches to exist simultaneously in the stratigraphic community while enabling stratigraphers to maintain a common epistemic basis. This common epistemic basis is essential for stratigraphic knowledge on the Anthropocene as it founds a community of people who agree on relevant expertise and validate related knowledge (c.f. Evans and Collins, 2008).

Third, geoscientific knowledge claims require active work by geoscientists to gain relevance for understanding the Anthropocene. Scientific 'claims do not just spring from the subject matter into acceptance, via passive scientists, reviewers, and editors. Rather, it takes work for them to become important' (Sismondo, 2010: 61). In this vein, the thesis demonstrates that the geoscientific knowledge becomes relevant to the Anthropocene discourse only as the epistemic authority of the geosciences is thus designated. Paper (3) indicates two ways in which the published discourse amongst stratigraphers draws boundaries around their authority to describe, define and explain the Anthropocene. On the one hand, stratigraphers assess differently their ability to study recent manifestations of anthropogenic Earth system change in the rock record, so that the reach of stratigraphic knowledge is either expanded or restricted. On the other hand, stratigraphers draw a semi-permeable boundary between their scientific work and societal concerns, thus defending their objectivity and autonomy. This kind of boundary work is conducive to geoscientific representations of the Anthropocene

gaining wider relevance in the discourse and impacting society in the ways illustrated in the following section.

3.2.2. Societal relevance of Anthropocene geoscience

In addition to analysing the social aspects of Anthropocene geoscience, this thesis determines how geoscientific knowledge of the Anthropocene affects perceptions of Earth system change as well as related social values and political actions. At the same time, Paper (3) reveals that many geoscientists are reluctant to account for the socio-political implications of their research.

First, geoscientific knowledge of the Anthropocene affects societal discourses of Earth system change on a conceptual level (3, 5). Although phenomena such as climate change or biodiversity loss are widely recognised, the geological dimension of the Anthropocene changes their temporal and spatial scale. Embedding the environmental impacts of human activities in the 'deep time' of the Earth's rock record underlines their historical significance and signifies a permanence that surpasses human history. This functions to corroborate existing discourses. By adding a geological dimension to Earth system change, stratigraphy brings the Anthropocene into existence as a recognizable matter of concern.

Second, specific geoscientific representations of the Anthropocene engender normative logics that have socio-political implications. The heuristic of 'Anthropocene as crisis' and 'Anthropocene as opportunity' used in Paper (2), advances our understanding of the societal responses to Earth system change that scientific representations of the Anthropocene invoke. Similarly, Paper (3) indicates that proposed Anthropocene starting dates set different temporal baselines for the global and permanent effect of anthropogenic environmental change and they thus cohere with different socio-political logics. Unlike classical conceptions of natural sciences' societal effects assume (c.f. Mittelstraß, 1989), geoscientific knowledge does not drive societal change through new technologies; rather it can influence support for environmental consciousness and world views regarding the place of humanity in the Earth system.

These connections between geoscientific knowledge about the Anthropocene and societal debates, however, contrast with geoscientists' reluctance to accept responsibility for the socio-political implications of their research (3). Referring to an ideal of value-free science, AWG members either advocate a total separation between societal and stratigraphic debates or they acknowledge their societal impact but simultaneously reject social values in stratigraphic practice. This pattern is not unusual as the 'division of labour between natural experts and ethical experts is now institutionalized, accepted almost as a matter of course' (Shapin, 2010: 388). Although science, has achieved ever more influence in communal and individual decision-making, many scientists in the 21st century, referring to the Naturalist Fallacy that prescription cannot be derived from a description, caution that they hold no special moral authority and are unable to say what ought to be done.

3.2.3. Changing forms of geoscientific scholarship

From this analysis of the status quo of geoscientific research on the Anthropocene follows the question whether the novel character and wide popularity of the Anthropocene prompts changes in geoscience scholarship. The thesis evaluates two changes in geoscience scholarship.

First, as the Anthropocene designates unusually short and recent stages in the Earth history, stratigraphers disagree on whether their principles, methods and nomenclature are appropriate to study the Anthropocene. Consequently, some liberal geoscientists have advocated a flexible interpretation and changes of established geoscientific practices (1; 3; 4). The changes suggested include e.g. innovations in the dual hierarchy of stratigraphy, an update of classification systems for stratigraphic evidence and even a division of a new branch of stratigraphy. The conservative approach that dominates the stratigraphic community, however, renders such innovation within stratigraphy unlikely. Second, the Anthropocene discourse raises the societal relevance of geoscientific research (2) and thus challenges researchers to find forms of scholarship that responsibly deal with this relevance. Yet Paper (3) shows that even where societal implications are considered, a change in practice is rejected by most geoscientists because they fear that their research will become politicised and thereby lose credibility in the sciences.

Amidst widespread advocacy for interdisciplinary research on Earth system change (5), paper (4) specifically analysed changes in geoscientific scholarship that result from interdisciplinary cooperation around the Anthropocene. The study of the AWG showed that established stratigraphic research practices prevail over potentially innovative approaches that are inspired by interdisciplinary exchanges about novel phenomena and ways to study them. In the work of the AWG, stratigraphy remains the guiding discipline, while other disciplines translate and contextualise stratigraphic research. Regarding the first aspect described above, the interdisciplinarity of the AWG does not herald a change in principles, methods and nomenclature of stratigraphy. What the second aspect is concerned, permitting social scientists to be official members of the AWG is a first step in dealing responsibly with the societal relevance of geoscientific research on the Anthropocene. Although social scientists are not directly involved in the research activities of the AWG, they translate geoscientific insights for other stakeholders and vice versa. This, however, does not amount to a change in the practices of geoscientists towards more reflexivity but rather to an extension of their epistemic authority.

3.2.4. Alternative ways of doing Anthropocene geoscience

In line with other studies in this field, the STS perspective provided here highlights the tension between the 'up-curve of the reach of science in our social and political life [and][…] the down-curve of scientists' acknowledged moral authority' (Shapin, 2010: 388). Even though the insights provided by geoscientists are closely linked to wider conceptions of the Earth system, the actions derived from these conceptions are typically seen as separate from the community of geoscientists. In response to the first research question, this thesis shows which actions of the geoscientific community affect knowledge about the Anthropocene. The thus revealed social aspects of geosciences demonstrate that geoscientists have agency to influence the results of their research. On the basis of such agency, geoscientists are arguably accountable for the social consequences of their knowledge claims (Seel, 1989), which were demonstrated in response to research question two, outlining the connections between, on the one hand, 'Anthropocene as crisis' and Earth system governance,

and, on the other hand, 'Anthropocene as opportunity' and geoengineering.[6] At the same time, we have seen that geoscientists are reluctant to consider the socio-political implications of their research (3); geoscientific scholarship is not changing in response to the Anthropocene.

The above argument provides a rationale for exploring alternative actions by geoscientists that account for the socio-political implications of their research. What remains to be done is to propose what these actions could be. As interest in the validity of scientific knowledge extends to new audiences, STS scholars have often emphasized that the sciences should turn from a paradigm of integrity, which springs from the ideal of value-free science, to a paradigm of accountability (Beck, 2012; Jasanoff, 2010b). However, the lack of concrete propositions is a common shortcoming of such STS analyses (Potthast, 2015a). The final paragraphs of this thesis therefore draw on ethics of the sciences to complement the analysis so far and attempt an outlook of alternative ways of doing geoscience in face of the Anthropocene. I provide an epistemological critique of the ideal of value-free science, which underpins geoscientists' reluctance to account for the socio-political implications of their research. On this basis, I propose that geoscientists should take social values into account.

Geoscientists, who are represented in the publications, interviews and survey analysed in this thesis, largely operate under the ideal of value-free science in order to protect their credibility (3). They regard social values as a threat to scientific integrity, producing '"bad" science, practiced only by the corrupt or inept' (Longino, 1990: 7). The reason for this is that they perceive the relationship between social and epistemic values in zero-sum terms, suggesting that social values diminish the role of epistemic values, which ultimately define what counts as science. In Anthropocene geoscience this perception has led to a fear of politicization. The interlocutors involved in the 'Orbis controversy' (3)[7], for example, accuse each other of political bias when they apply differently the supposedly objective stratigraphic principles that they view as the vanguards of epistemic values and good stratigraphic practice.

[6] A related theme is the responsibility that public discourses attribute to the geosciences for affirming the Anthropocene hypothesis in particular ways. This responsibility and the way in which the geosciences deal with it are worthwhile areas for future investigations in STS and science ethics.

[7] Referring to the controversial discussion amongst geoscientists about the "Orbis hypothesis", which marks the beginning of the Anthropocene around 1610, when Europeans colonised the Americas.

However, the ideal of value-free science faces significant challenges. Particularly, the characterisation of epistemic values as endogenous and social values as exogenous to science is simplistic: the two types of values are not easily distinguishable as social values can play an important role in scientific practice. This is especially the case because social values 'provide reason[s] for adopting certain epistemic values, or more precisely, certain standards for their realization' and they can even contribute to a change in these standards (Doppelt, 2008: 303). This critique of the ideal of value-free science is not an ideological one arguing for social values to replace empirical data to support hypotheses that correspond with political imperatives. It rather is an epistemological one emphasizing the social context, in which scientific hypotheses come to be accepted.

In Anthropocene geoscience, where uncertainty is great, social values need not compete with but can complement geological evidence e.g. by helping to determine the extent and quality of the evidence for a given Anthropocene boundary. Even if new interpretations of geological evidence fail to ensue, a communitywide acknowledgement of the role of social values in geoscientific practice can help to understand scientific controversies surrounding the Anthropocene Epoch and it may contribute to their resolution (e.g. whether to interpret the Stratigraphic Guide liberally or conservatively). Hence, social values should be permitted to play an indirect role in Anthropocene geoscience by 'guid[ing] interpretations and suggest[ing] models within which the data can be ordered and organized' (Longino, 1990: 219).

Opening up to social values as an important (though not determining) factor in Anthropocene geoscience is one way of integrating the established ethos of scientific rationality with an ethos of scientific responsibility. Such integration is particularly necessary as the role of science in society increases (Nida-Rümelin, 2005). Moreover, the approach suggested above follows an approach of ethics in science, 'which addresses the question of responsibility already in the sciences themselves, instead of considering it as a separate field for ethicists only' (Potthast, 2015b: 51). As such, it does not extend general ethics to science but protects the autonomy of science by permitting scientists to determine which values are most important at different stages of their research. Prominent geoscientists have argued as early as 1904 that their

colleagues should be less ‘generous in allowing other people to make their philosophy for them’ (Baker, 2013: v). Science ethics offers a theoretical rational as well as practical means of doing so. First steps into this direction have been taken by interdisciplinary scholars who have started to conceptualise the emerging field of ‘geoethics’ (Potthast, 2015b: 51) and proposed the application of practical approaches such as the Ethical, Legal and Social Aspects (ELSA) or Broader Impact 2.0 techniques in the geosciences (Frodeman et al., 2013)

3.3. Conclusion

This thesis analyses the relationship between the practices of geoscientific communities, the Anthropocene as a recognised phenomenon and societal debates about the latter.

In response to research question one, it reveals how social practices of the geosciences shape knowledge about the Anthropocene. In line with the insight of STS that truths are dependent on the people who articulate them, the papers enhance understandings of social practices through which the Anthropocene is defined, described and explained in science. These geoscientific representations of the Anthropocene depend on particular settlements of scientific controversies; processes through which they gain credibility within a research community; and work that renders them relevant to Anthropocene discourses. Altogether, analysing these practices demonstrates that geoscientific facts about the Anthropocene are social representations of natural processes and not themselves natural.

In response to research question two, the thesis shows how geoscientific knowledge affects conceptions of and societal responses to the Anthropocene. Geoscientific representations of the Anthropocene add a geological dimension to Earth system change and thus bring the Anthropocene into existence as a recognizable matter of concern in Earth history. At the same time, geoscientific representations of the Anthropocene interpret contemporary Earth system changes differently, i.e. either as a crisis of sustainability or as an opportunity for sustainability. Moreover, the normative implications of these representations differ as one accepts the Holocene as an a priori environmental basis for normative judgements and the other views it as insufficient in

this regard. Concerning societal responses to the Anthropocene, one of them suggests intentional management of Earth system change, whereas the other urges that change should be limited.

In response to research question three, the thesis highlights that geoscientific scholarship is persistent; the social practices of the geosciences have generally not changed due to the novel character or wide popularity of the Anthropocene. Established geoscientific research practices prevail over potentially innovative approaches, and geoscientists uphold an ideal of value-free science that externalises societal implications of research because of a fear of politicisation.

This research provides the basis for reflecting possible changes in geoscientific practice so to reconcile the societal reach of geoscientific knowledge with the agency of geoscientists to influence the knowledge that they produce. Specifically, the discussion (Chapter 3.2) proposed that opening up to social values as an important (though not determining) factor in Anthropocene geoscience can be one way of integrating the established ethos of scientific rationality with an ethos of scientific responsibility. The Anthropocene discourse provides an opportunity for the geosciences to extend the relevance of their research. Responsibly embracing this opportunity, may require a change in paradigm from a vision of the geosciences that seeks to protect its integrity by safeguarding a value-free practice and established rules and procedures, to one seeking to advance its accountability by taking account of interdisciplinary knowledge and social values that are relevant in this context. Only geoscientists themselves can decide if such a change would rejuvenate their field of study or leave it unrecognizable.

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Appendices

Appendix 1

Parameters of the Anthropocene

Parameters of the Anthropocene

Johannes Lundershausen

1. Introduction

In 2000, Nobel laureate in Chemistry Paul Crutzen termed the Anthropocene, which purportedly describes a new era in which "humankind has become a global geological force in its own right [that is] largely responsible for moving the earth out of the Holocene" (Steffen et al. 2011a, 843). At the very basis of the Anthropocene is the idea that humans, through their cumulative actions, have the capacity to induce environmental changes that surpass the spatial and temporal scales that were previously considered relevant in this context. Although a variety of such changes can be associated with it,[1] the relative novelty of the Anthropocene derives from its geological claim which enables a long-term perspective onto socio-ecological relationships both into the past and into the future. Since the year 2000, the concept has enjoyed an impressive career as a framework for thinking about anthropogenic environmental change on the global level. Although its content and validity has been discussed particularly within Earth system sciences and geology, increasingly researchers from the social sciences and humanities are becoming involved in the debate. Moreover, journalists, artists, bloggers and curators too have reported on and interpreted the Anthropocene. But while the pertinence of the concept to different epistemic communities is intriguing, it also raises questions about the coherency of its meaning.

The central question of this section thus concerns the parameters by which commentators define the Anthropocene and assess its value. I ad-

1 Climate change 'is only the tip of the iceberg. In addition to the carbon cycle, humans are (i) significantly altering several other biogeochemical, or element cycles, such as nitrogen, phosphorus and sulphur, that are fundamental to life on the Earth; (ii) strongly modifying the terrestrial water cycle by intercepting river flow from uplands to the sea and, through land-cover change, altering the water vapour flow from the land to the atmosphere; and (iii) likely driving the sixth major extinction event in Earth history' (Steffen et al. 2011a, 843).

dress this issue by examining peer-reviewed journal articles that reflect upon the Anthropocene as an idea rather than taking it as a mere background condition. But rather than focussing on the extent to which the idea of the Anthropocene corresponds with reality (i.e. with observed or predicted changes in Earth system processes) or not, I will evaluate the validity of the Anthropocene from a pragmatist point of view. Although I will not delve into the philosophical discussions about the various shades of pragmatism, I take from it the basic insight that definitions of the Anthropocene should be viewed as tools for achieving certain purposes which, however, vary according to the communities in which the concept is discussed (Barnes 2008). Because pragmatism is based on the anti-foundational understanding of truth, there can justifiably be a number of understandings about the content and validity of the Anthropocene.

Since an evaluation of the entire Anthropocene discourse within academia is beyond the scope of this (and arguably any) single paper, I will elucidate this question by outlining the debates about two aspects of the Anthropocene, the focus on which I derive from an examination of the wider literature as well as the etymology of the Anthropocene. On the one hand, Anthropocene's suffix 'cene' embeds the term within the nomenclature of stratigraphy that concerns itself with the study of layers of rock in the Earth's crust including the definition of a geological time scale, in which the Anthropocene denotes the most 'recent' epoch within the Cenozoic (see figure 1). But in order to be officially recognised as such, the Anthropocene must pass the high barriers "to the development, recognition, and amendment of a timescale relevant to Earth's history", which the codified approach of formal stratigraphic practice provides (Autin/ Holbrook 2012, 60). With this purpose in mind, an extensive discussion has evolved about the stratigraphic evidence for the geological impacts that the Anthropocene designates, as well as about the thus deducible starting date of the surface processes that caused those impacts.

On the other hand, the trunk of the Anthropocene denotes that this new geological epoch is that 'of humans', i.e. human dominated. In this context, Palsson et al. (2013) termed the word 'Anthropos' to refer to the central role of humans in the household of life ('oikos') and to raise questions about how human agency, individually and collectively, is perceived under the sign of the Anthropocene.

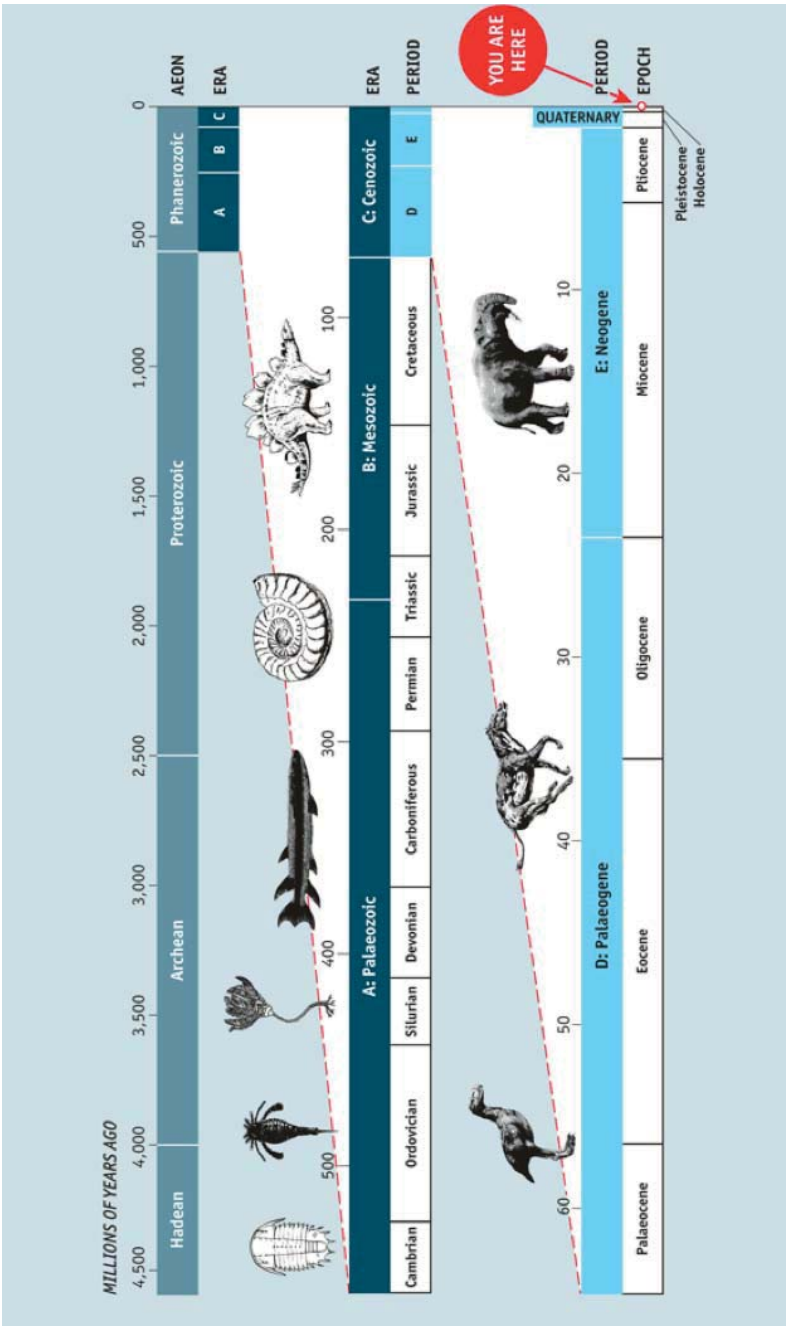

Figure 1: Adapted geological timescale vaguely indicating start of the Anthropocene; source: The Economist (2011)

Essentially, the Anthropocene can be seen to affect human subjectivities by linking individual human identities to a collective form of human conduct and environmental impact. This latter aspect, moreover, is impregnated with ontological issues because it characterises human existence by reference to geological processes. Accordingly, the expedience of the Anthropocene may not lie as much in its validity as a chronostratigraphic unit as in the ability of its underpinning claims to shape human self-perception and conduct.

This paper provides a meta-analysis of the discourses on those two aspects of the Anthropocene. In doing so, I do not intend to pass judgement on the validity of individual arguments proposed but rather to assess how the Anthropocene is constituted within the different communities. Starting with two separate evaluations of the geological and human dimensions, I will conclude by outlining their similarities and differences.

2. The Geological Dimension of the Anthropocene

A focal point in the career of the Anthropocene was the decision by the Union of Geological Sciences in 2008 to mandate its Commission on Stratigraphy (ICS) to seriously consider the feasibility of incorporating the Anthropocene in the official geological timescale. While this decision is pending until 2016, the geological claim of the Anthropocene that human activity is shaping an internally consistent and distinguishable rock layer has caused widespread debate. In the following, I outline the fundamental points of contention relating to this and, as such, focus on the feasibility of the Anthropocene to fulfil the established criteria of chronostratigraphy.[2] Secondly, I examine and contrast alternative approaches that have been proposed to the standard definitional practices of stratigraphy. Moreover, I will argue that these alternatives help to differentiate between the different aims that the interlocutors in this debate seek to achieve in defining (or not) the Anthropocene stratigraphically.

2 Chronostratigraphy is the branch of geology that concerns itself with defining the absolute age of rock strata.

2.1 Defining Geo-Chronological Units

The most important stage in the process of officially adopting a new unit on the geological timescale is the definition of its chronology including its starting point, which is determined through internationally sanctioned benchmark points known as the Global Boundary Stratotype Sections and Points (GSSP) (Gale/Hoare 2012). The GSSP comprise "two marker points ('golden spikes') in two boundary stratotype sections[3][, which] are used to define a span of geologic time" (Walsh et al. 2004, 202). Although a different measurement (the Global Standard Stratigraphic Age) is historically accepted for some geological units, all of the latter apart from the Hadean are now in the process of being defined by GSSPs in order to provide a universal language for geo-history (Cohen et al. 2013). Reflecting the importance of the GSSP in the process of defining geological units, the discussion about the Anthropocene, to a large extent, has been a discussion about the appropriateness of stratigraphic markers. Following this approach, some have rejected the markers initially proposed for the Anthropocene by Crutzen (2002) as insufficient on the grounds that they follow chronometric (GSSA) rather than chronostratigraphic indicators (GSSP) (Rull 2013; Gale/Hoare 2012). While Crutzen's original markers included CO_2 and CH_4 levels in the atmosphere as well as changes in biological composition of lake sediments, a number of alternative ones have since been proposed. But so far none has been universally adopted.

2.2 The Relationship between Stratigraphic Markers and Surface Processes

At the same time, the discussion about the starting date of the Anthropocene is not only about the type of stratigraphic marker but also about their relationship to surface processes. This is best illustrated by the 'early-Anthropocene hypothesis' which builds on the same markers as Crutzen

3 "Since there is no locality at which all the chronostratigraphic units which make up the global scale are exposed, individual boundaries are identified through stratotype sections allocated across the world. In other words, the best exposed example of the boundary between each unit is selected as typical, and designated as a stratotype section, usually through international agreement" (Doyle et al. 2001, 53).

but has prominently challenged his original assertion that the Anthropocene started with the industrial revolution in the latter part of the 18th century. Examining methane levels in ice cores, William Ruddiman and his colleague Jonathan Thomson first contended in 2001 that major anthropogenic changes in the composition of the atmosphere did not start with the Industrial Revolution but rather that they commenced after 5000 years before present. Particularly, they attributed the CH_4 rise in the atmosphere during that time not to natural but to several anthropogenic causes like inefficient rice cultivation. Not surprisingly, the "outrageous hypothesis" (Crowley 2003) of Ruddiman has caused much debate amongst scientists (Ruddiman et al. 2011). But as Ruddiman's hypothesis is more and more presented as a counter-narrative to the 'industrial era' or 'late Anthropocene' view of Crutzen and colleagues, it has prompted the originators of the latter to rethink their initial proposal (Crutzen/Steffen 2003).

2.3 The Anthropocene as a Geo-chronological Unit

As the debate about appropriate stratigraphic markers is ongoing, scientists are increasingly discussing the more fundamental question whether it is possible at all to define the Anthropocene as a chronostratigraphic unit proper. Three main arguments are discernable in this discussion. Firstly, it remains unclear if evidence of a human imprint in the geological record is sufficiently distinctive and permanent to define a new geological epoch (Autin/Holbrook 2012). Secondly, the stratigraphic definition of the temporal boundaries of an Anthropocene epoch may be inhibited by the global diachroneity[4] of human impact on the environment. Accordingly, it is argued that the varied land-use-histories across regions, including for example the development of different agricultural practices, call for more detailed local and regional studies before they can be globally integrated (Ellis et al. 2013; Ruddiman 2013). Finally, the precision of prevailing dating methods may not sufficiently correspond with the high resolution of stratigraphic records available for the Holocene. As Autin and Holbrook note: "stratigraphic boundaries commonly appear as abrupt in the rock record but are often imprecise in time" (2012, 60). While the dating uncertainties

4 Diachroneity refers to "the idea that units of uniform lithology may have formed at different times and in different places" (Doyle et al. 2001, 281).

inherent in current measuring techniques are negligible on the scale of millennia, they become significant when measuring recent boundaries of short timescales like that of the Anthropocene which would require dating precision below a century or even decade (Rull 2013). This issue is also considered substantial for the aforementioned diachroneity, which "is lost in dating uncertainty in distant times [but] may span a sizeable slice of the epoch when it comes to the Holocene" (Gale/Hoare 2012, 1492).

2.4 Alternative Approaches to the Standard Definitional Practices of Stratigraphy

The methodological difficulties outlined above inhibit the definition of a GSSP for the Anthropocene and therefore prevent the recognition of the latter as an official geo-chronological unit. Moreover, they inhibit the temporal definition of surface processes that could be seen as causes of the Anthropocene. As such, the question arises what alternatives exist to define and validate the Anthropocene as a geological epoch. As a response to this question, a variety of scientists have argued that an officially sanctioned GSSP for the Anthropocene may be unnecessary in order to appreciate the value of the Anthropocene. Although this turn away from established stratigraphic practice is evident across the debate, it is, to be sure, not sufficiently homogenous to substantiate the consensus on a starting date of the Anthropocene observed by Smith and Zeder (2013). Rather it highlights the different aims that interlocutors have in mind when assessing the Anthropocene as a geological epoch.

On the one hand, it has been argued that because the codified approach of stratigraphic practice (represented by the GSSP) can momentarily not be approximated, the scientific community should officially, even if maybe preliminarily, adopt a relatively broad, and therefore widely agreeable, geo-chronological boundary for the Anthropocene. It could for example span the last 50-250 years (Smith/Zeder 2013) and be demarcated by way of an, otherwise outdated, GSSA (Zalasiewicz et al. 2011). In this vein, originally antagonistic assessments such as those of an 'early' and a 'late Anthropocene', are increasingly coalescing around the idea that there may be several stages of the Anthropocene (Ruddiman 2013). Indeed, Jan Zalasiewicz, convener of the Anthropocene Working Group at the ICS, which sanctions the adoption of new geo-chronological units, has argued that the stratigraphic difficulties outlined earlier are neither particularly problematic nor unusual. He thus contends that the lack of precise and

synchronous geological evidence is a common characteristic of many chronostratigraphic units (Zalasiewicz et al. 2012), and that anthropogenic geological changes will likely appear "abrupt and globally synchronous" from a future perspective (Zalasiewicz et al. 2010, 6008). The aim of the discussants taking this line of arguments, is thus to settle the question about stratigraphic evidence and move on to other aspects of the Anthropocene.

On the other hand, some commentators call for an *exclusively informal use* of the term Anthropocene *outside of stratigraphic practice*, altogether moving away from official attempts to define and validate the Anthropocene as a geo-chronological epoch (Ruddiman 2013). Accordingly, current efforts to embed the Anthropocene within the official stratigraphic nomenclature are seen as "esoteric" (Autin/Holbrook 2012, 61) or "compulsive' and inconsistent (Rull 2013, 1200). The emphasis in this line of argument lies with the notion that while the Anthropocene may be an accessible interpretation of the human role within Earth system processes, global awareness about environmental change is a fundamentally separate issue from the definition of practical stratigraphic units.

Both of these two positions are responses to the difficulties of defining stratigraphic markers for the Anthropocene and both emphasise the value of the Anthropocene as an explanation of global environmental change. But they differ in their orientation towards stratigraphic formality. Whereas the latter appropriates the established discourse of stratigraphy by positioning the Anthropocene outside of it, the former advocates a flexible interpretation of the processes and rules that have been used to define previous stratigraphic boundaries. While, on the one hand, the Anthropocene is considered to fail the test against chronostratigraphic criteria and to perhaps even menace the reputation of the discipline (Autin/Holbrook 2012, 61), on the other hand, a static application of the unidisciplinary methods of stratigraphy is disregarded as an adequate account of the complex and diverse environmental processes signified by the Anthropocene (Zalasiewicz et al. 2012, 21).

Furthermore, these positions are highlighted by a related debate that is evolving around the wider implications of the Anthropocene's place within the stratigraphic hierarchy – particularly with regards to the consequences for adjacent chronostratigraphic units. In the current stratigraphic nomenclature, the suffix –cene situates the Anthropocene at the level of an epoch, together with such other ones as the Holocene, Pleistocene or Pliocene (see Figure 1). But this particular position is not self-evident and the

Anthropocene could alternatively hold the rank of an age within the Holocene (i.e. anthopocenian) (Autin/Holbrook 2012, 60) or even a period like the Quaternary (i.e. anthropogene) (Gerasimov 1979). Rull (2013, 1200) discusses the effects of adopting the first two of these options for the stratigraphic nomenclature:

> [Whereas] the use of Anthropocene, as an epoch, implies that the Holocene has ended, which is incompatible with the definition of the Holocene as the present interglacial, […] [the use of the Anthropocene] as an age […] implies that the next glaciation will be able to impose its stratigraphic signal over the human one, whatever the reason.

As opposed to most commentators who focus on the onset of the Anthropocene, Rull thus draws attention to the fact that a conclusive characterisation of both the Holocene and the Anthropocene requires dating their end points through the onset of another epoch. In doing so, he highlights that individual chronostratigraphic units are only meaningful in relation to adjacent ones and, he argues, a consistent framework for their definition.

In contrast to Rull, Smith and Zeder propose a "linked nomenclature change" reflecting the idea that "the Anthropocene epoch extends back across the entire Holocene, and that the various boundary points that have been proposed in the past […] are […] recognized as defining successive phases" (2013, 2). Commentators such as Ruddiman (2013) and Ellis et al. (2013) who are concerned with an adequate representation of the complexity of local human history, may arguably agree with these authors' assertion that this approach "broadens the scope of inquiry regarding human modification of the earth's ecosystems" and moves away from an (excessively) detailed analysis of possible stratigraphic markers (Smith/Zeder 2013, 6). Moreover, Smith and Zeder believe that a "Holocene-Anthropocene epoch" could be more easily adopted by the ICS because the need to establish an entirely new epoch would be removed since the Holocene can continue to be used for scientific purposes and the Anthropocene in popular discourse.

2.5 The Purpose of Discussion

From a pragmatist point of view, two issues are especially intriguing in this discussion about if and how to define the Anthropocene as a geological epoch. Firstly, in spite of weak stratigraphic evidence for the geological impact of human activities, the different authors do not question the Anthropocene as an adequate tool to represent anthropogenic environmen-

tal change more generally. In contrast, I would argue that if such evidence is indeed insubstantial, the Anthropocene would cease to be the "geology of mankind" (Crutzen 2002). If, instead, the Anthropocene is then seen to derive its usefulness from evidence of extensive anthropogenic environmental change, it could conceivably be replaced by such a concept as the 'biosphere of mankind' or 'Anthroposhere' (Cornell et al. 2012). The reason for this, I would argue, is that the participants in this discourse do, in effect if not in intention, not set out to evaluate the content of the Anthropocene but rather the purpose of their inquiries is to determine whether the established stratigraphic methods are efficacious tools to validate the Anthropocene. This is more immediately apparent with those who take a flexible approache towards stratigraphic practice but, as has been shown, it is also true for those who are protective of the latter. Accordingly, the positions that I juxtaposed in this section differ not in their opinion on what the Anthropocene means but rather in their stance towards how to render it a scientifically viable concept.

Secondly, at the heart of the discussion outlined above is the social character of knowledge. Accordingly, knowledge is always dependent on a social agreement about what it is to be true (Barnes 2008). Such an agreement within the stratigraphic community is clearly at stake due to the challenges that the Anthropocene poses but, at the same time, it remains an essential aim on either side of the argument for or against a flexible application of stratigraphic rules. In the discussion about the wider implications of the Anthropocene's place within the stratigraphic hierarchy, for example, Rull as well as Smith and Zeder uphold the stratigraphic community as a reference point in the production of environmental knowledge – even if they have different views on what would be damaging to it. While Rull believes that defining the Anthropocene is not worth risking epistemological unity that is crucial for the settlement of other (maybe more strictly disciplinary) issues, Smith and Zeder hold that a recognition within the stratigraphic nomenclature is crucial for pertinence of the Anthropocene and can be easily implemented.

3. The Human Dimension of the Anthropocene

The Anthropocene as a concept investigates the environmental, or more precisely the geological impact of human activities. The discussion about the stratigraphic evidence starts from these impacts and contemplates their possible causes only in a second stage. But the abovementioned difficul-

ties of defining the relationship between stratigraphic changes and surface processes show that such a deduction is a challenging undertaking at best. Possibly as a result of this, the human activities causing the Anthropocene have been discussed somewhat separately from its stratigraphic evidence; and stratigraphers have played a marginal role in those debates. Nevertheless, reconstructions of those causes remain inevitably (i.e. conceptually) linked to geological impacts that the Anthropocene characteristically devises. Accordingly, the Anthropocene depicts a *collective* human entity because the 'geology of mankind' is an *aggregate* effect of numerous interactions of humans with their environment. Chakrabarty (2009, 206-207) illustrates this point when he argues that

> To call human beings geological agents is to scale up our imagination of the human. Humans are biological agents, both collectively and as individuals. They have always been so. […] But we can become geological agents only historically and collectively, that is, when we have reached numbers and invented technologies that are on scale large enough to have an impact on the planet itself.

Outlining, as the Anthropocene does, a unitary geological impact then implies a common form of conduct inherent in human agency.

3.1 Species Narrative

This issue of collective agency has been discussed controversially within the literature and it has often been informed by the biological concept of species. Malm and Hornborg, who are sceptical about such a species narrative, emphasize that it is nevertheless essential for the Anthropocene. The ability to shape the Earth System, they argue, must necessarily be rooted in species-wide characteristics because "anything less would make […] [the Anthropocene] a geology [not of mankind but] of some smaller entity, perhaps some subset of Homo sapiens" (Malm/Hornborg 2014, 63). One prominent interpretation of this species narrative is Nigel Clark's account (2012) in which he draws on the idea, proposed initially by Stephen Pyne (1997), that biological life has evolved together with fire including the geochemical processes that afford the latter. Moreover, he considers fire especially important for the evolution of humans because it makes for their biological niche, thus rendering them a 'fire species'. The most recent advancement of this strategy, so Clark, is the utilisation of fossilised biomass through combustion which has enabled a globalised carbon economy. Although he emphasises elsewhere that this trajectory is only one of "the possible expressions of a geological potentiality" (Clark 2013, 49),

Clark's account of species is enabled by recourse to the common species ability to capitalise on geochemical processes.

At first, this central role of the species narrative in the discussion about the human dimension appears paradoxical because it signifies the application of an established biological concept to interactions that purportedly surpass the realm of biology and encompass geomorphological ontologies. A species, by definition, categorises organisms along relational or internal biological properties such as phylogenetic, morphological, ecological characteristics or reproductive isolation (Sandler 2012). Although biological practice thus applies a plural conception of species, the latter is typically distinct from environmental or geological impact which, however, are characterising the Anthropocene narrative.

Nevertheless, the biological species has been a popular point of reference in the discussion about the human dimension, even if some authors build on such contrasting visions as the Marxist account of 'species being' (Žižek 2011). The reason for this, I would argue, is precisely because (and not in spite of the fact that) an inclusion of species helps to raise the Anthropocene *above ground* in that it shifts the focus away from geological impacts towards the interactions of living beings on planet Earth. Although long-standing discussions among biologists about the correct use of species are relevant here, a strictly biological conception of species insufficiently accounts for the separate, and varying, functions that the species narrative fulfils for different contributors in this discussion. For proponents, the species narrative enables a long-term perspective onto human and planetary history (Chakrabarty 2009) that links planetary conditions to human biological evolution and contemporary environmental subjectivities like individual carbon footprints (Clark 2013). For critics, as we will see, the species narrative and especially the application of 'species realism'[5] to the Anthropos, allows a critique of universalistic and thus deterministic views onto human-nature relationships because it supposedly implies a marginalisation of differences between humans (Malm/Hornborg 2014).

5 Species realism refers to the idea that "species are real categories […] [that are] reflective of the fundamental features of living things" rather than being mere tools to make sense of the world (Sandler 2012, 4).

3.2 Problems with Collective View on Human Agency

The species narrative has thus helped to spark debates about the causal role of humans in the Anthropocene that essentially surpasses controversies about species as a biological category. The central point of contention goes back to a collectivistic understanding of human agency that, critics fear, misrepresents globally diverse human-environment relationships and creates a standard, normalised account of the latter. In response, critics have sought to specify that part of the global population which the Anthropos does signify (i.e. those individuals and groups that *are* collectively shaping Earth system processes) and they have broadly identified the relatively affluent participants in the international fossil economy who follow a Western development trajectory (Crist 2013; Malm/Hornborg 2014; Yusoff 2013). Equally, the social, political and economic transformations that are widely regarded as important causes of the Anthropocene have their roots in the historical developments of industrialisation (Ogden et al. 2013), which remain predominantly characteristic of the Global North. As Luke therefore argues, the Anthropos points towards "the technological, scientific, modern, commercial, and acquisitive agent at work in the projects of Western nation-building, empire-expansion, and capitalist-development" (Luke 2013, 3).

The ability to change the Earth system then lies not with humanity but with distinct groups of people dwelling in very specific economic, cultural and technological systems (Luke 2013; Jaquet 2013, 898). Speaking of humanity when referring to the Anthropos thus means to extrapolate an inherent human property from a relatively small (although growing) percentage of the global population. Advocates of the concept of the Anthropocene, to be sure, have not been altogether ignorant of this contingency and they have acknowledged that "only 25% of the world population" have caused the impacts associated with the Anthropocene (Crutzen 2002, 23) as well as that "global aggregates mask the way in which the distribution of wealth and the impacts of ecosystem services decline are skewed, between nations and within them" (Steffen et al. 2011b, 750).

Basing, as the originators of the Anthropocene have done, accounts of human agency and ensuing behaviour on observations from western, educated, rich, industrialised and democratic societies is indeed common (Henrich et al. 2010). But to assume that those 'standard subjects' are representative of humanity is politically and conceptually problematic. Firstly, it suggests that environmental change is a problem of population

(Yusoff 2013, 782). Although quantitatively speaking the unprecedented rise in global population may be suggestive (Evans/Reid 2014), it is evidently not population growth but growth in levels of consumption that has caused anthropogenic environmental change (Satterthwaite 2009). Secondly, viewing the Anthropos as an undifferentiated biological formation entails a teleological understanding of human history. This, on the one hand, disavows the structural causes of the development trajectory of the Western fossil economy and thus negates the fact that levels of consumption currently exhibited in industrialised countries could not possibly be universalised (Malm/Hornborg 2014, 63-65; Luke 2013, 3). On the other hand, the teleological outlook contradicts the idea that "humans are overwhelming the great forces of nature" (Steffen et al. 2007) and that they are thus able to determine their own fate independent of a greater natural cause (Crist 2013).

3.3 Alternatives to Collective View on Human Agency

As the last paragraphs show, the idea of the Anthropos is, above all, characterised by a tension between particularity and universalism. How to resolve this tension, however, is part of an ongoing discussion between commentators who view the current understanding of the Anthropos as insufficient. It evolves around the question what aspects would need to be included in an alternative conceptualisation of the Anthropos so to better represent the situations in which the majority of the global population finds itself. As a result, a variety of alternative '-cene'-neologisms have evolved including the Mediacene[6], Econocene[7] or Thanatocene[8]. Although these alternative neologism can hardly be seen to represent the seven billion specimen of Homo sapiens that are currently inhabiting the planet, strikingly, they all accentuate specific social relations rather than linking recent geological impacts ('-cene') to a universalised human subject. They thus capture what Malm and Hornborg call the 'sociogenic' (as compared

6 In which Earth systems are visualised and rationalised "under the auspices of digital media's simulative effects" (Gurevitch 2014, 103).

7 Referring to "the 50-fold increase and the globalization of economic activity during the 20th century" (Norgaard 2013, 1).

8 Referring to the role of wars, particularly World War II, in shaping societies for the Anthropocene (Bonneuil/Fressoz 2013).

to the 'anthropogenic') nature of contemporary global environmental change (2014, 5). Their respective emphases, to be sure, vary considerably and, as such, they analytically privilege certain social relationships over others. But in their very specificity, they arguably undermine the determinism that underpins the idea of a universalised Anthropos and instead highlight that 'typical' representations are just that: representations of very distinctive qualities of a very particular type of person or thing.

This is not to say that such 'sociogenic' accounts of the Anthropocene are uncontroversial. Yusoff, for example, has poignantly argued that sociological and cultural analyses of the Anthropocene are incomplete because they only account for fossil fuels once "they become productive in the social worlds" e.g. as commodity, geopolitical power, or political economy (Yusoff 2013, 790). Her point can be illustrated by a discussion about another alternative neologism, the 'Capitalocene'. Whereas its originator Jason Moore (2014b; 2014a) views it as a pertinent reminder that capitalist production is a structural cause of global environmental change; others regard as an important but limited focus (Chakrabarty 2009; Rowan 2014, 10). They believe that it underestimates the extent to which social relations surpass internal human spheres and historically interact with the more-than-human world including other species and planetary conditions, which are independent of relations of production.

Such scholar, who often call the humanities their home, thus add to accounts of social scientists like Malm and Hornborg by contending that not only our social but also our more-than-social and material relationship afford historical specificity in the Anthropocene. Paraphrasing Malm and Hornborg's neologism, scholars such as Clark (2012) and Yusoff (2013) thus highlight that global environmental change as importantly, though not exclusively, 'geogenic', that is, subject to the material conditions of planet Earth. Accordingly, geogenic accounts seek to put the Anthropocene back into the ground. In doing so, however, they do not re-focus, in the vein of stratigraphy, on impacts but they retain attention to the relationships that have caused the Anthropocene. Whereas sociogenic analysis stresses the enduring independence of social relations from environmental conditions, geogenic accounts thus highlight the inherent connection between the animate and the inanimate world.

3.4 Anthropos as a Parameter of the Anthropocene

As has been shown in this section, the value of the Anthropocene is not self-evident even if human impacts on the environment were clearly discernible in the rock record. The reason for this is that the collective form of human agency, which the Anthropocene implies in addition to a geological changes, requires explication. Talking about an Anthropos in relation to the species narrative has arguably enhanced the discussion about the Anthropocene by attracting attention to the relationships that have caused the latter. But concerns have simultaneously been raised about the risks of an undifferentiated understanding of human agency. Particularly, the latter may be problematic because it provides a teleological account of human history that views global environmental change as a problem of population. In order to address this problem, commentators have outlined alternative conceptual visions of the Anthropos that highlight more specific processes as contributing factors to the Anthropocene.

'Of what' the Anthropos should be representative, however, remains debated and replies to this question depend on the interlocutors' views about the ontological genesis of human-environment relationships. An important determinant in an answer to this question are the kind of links that different authors seek to accentuate. Whereas many social scientists stress that social inequality is the very condition of the processes that are now signified by the Anthropocene, humanities scholars add to this account by contending that social processes in the Anthropocene are also materially contingent.

Although a conclusive answer about the validity of the Anthropocene cannot be expected from such a discussion, this section shows that the perceptions of the Anthropos is an important parameter when evaluating the usefulness of the Anthropocene. Depending on their view of the Anthropos, different authors thus diverge in whether they see the Anthropocene as an adequate description of anthropogenic environmental change more generally. The important criticism that has come out of the debates between them, however, is that a universalistic understanding of the Anthropos is inappropriate because it seeks to capture the totality of interdependencies while concealing that different human communities interact with and shape their environments differently. Accordingly, the Anthropocene only enhances an understanding of anthropogenic environmental change if and when it attends to the various separate aspects of human-

nature relationships that have cumulatively led to the impacts signified by the Anthropocene.

4. Conclusion

The analysis above examines the discourses about the geological and the human dimension of the Anthropocene separately. Nevertheless, similarities between the two are evident. Not only are both aspects negotiated by using respective proxies (i.e. species and stratigraphic markers), both also contain discussions about the tension between particularity and universality of those proxies. The issue especially concerns the question how representative these proxies are of the complex interactions between humans and their environments. As such interlocutors on the human dimension ask whether the population of the Global North, as a standard species subject, is characteristic of the socio-ecological relationships that have caused the Anthropocene. But, as outlined above, these authors disagree on how to resolve these issues. Similarly, in the discourse about the geological dimensions of the Anthropocene, the diachroneity of stratigraphic evidence is seen to pose a substantial problem to the geological claim of the Anthropocene. The question, if the specific stratigraphic markers can represent the geological manifestation of the varied environmental histories across regions has divided commentators. As a consequence, interlocutors in both discourses have sought alternatives to those initial categories.

The disagreements between participants in the two discussion about particularity and universality, however, occur at very different levels. While the debate about the geological dimension of the Anthropocene largely revolves around the appropriate application of the methods and nomenclature of stratigraphy to the Anthropocene as well as the challenges that this poses to disciplinary paradigms; the human dimension is examined more directly in relation to the ontological and historical genesis of contemporary global environmental change. Crucially this is not self-evident since one could imagine a discussion about species that emphasises scientific arguments about the biological evolution of Homo sapiens and e.g. its phylogenetic modification in the Anthropocene. Solnick (2012), for example, contemplates the possibility of advanced evolutionary modification as a response to global environmental change. In the same vein, the geological dimension of the Anthropocene is not necessarily limited to stratigraphic markers but could equally include historical processes that have caused a geological imprint. Rull (2013) accordingly

advocates the use of the term ‘industrialisation’ instead of ‘Anthropocene’ in order to better differentiate between the different types of human impact on the stratigraphic record.

Nevertheless, in reality the discourse about the geological dimensions of the Anthropocene predominantly focuses on the scientific practice of measuring geological impacts of human activities, whereas the discussion about the human dimensions of the Anthropocene is concerned mainly with the reconstruction of the causes of anthropogenic environmental change. One reason for this, I would argue, is the explicit inclusion of the Anthropocene in nomenclature of stratigraphy, rather than the binominal nomenclature of zoology. Had Paul Crutzen termed a ‘Homo geologiae’ instead of the Anthropocene, we would possibly witness a more intense discussion between biologists about the methods of defining a new species. Whereas such counterfactual arguments are analytically limited, it is clear that the time, name, rank and stratigraphic markers of new geological time periods need to be approved by the International Commission on Stratigraphy (Ogg 2004), which is not the case for the identification and labelling of new species. Although the International Commission on Zoological Nomenclature provides guidelines and acts as a dispute resolving body, it does not “become involved in taxonomic issues except where they have nomenclatural implications” (ICZN undated). Accordingly, the emphasis of the discourse about the geological dimension of the Anthropocene on questions of stratigraphic methodology and paradigms likely derives, to some extent, from the strong regulative role of the stratigraphic code of practice.

Importantly, this I not to argue that the disciplines of biology is more open towards an analysis of the historical causes of environmental change. Rather, I want to suggest that embedding the Anthropocene in the stratigraphic nomenclature first prompted stratigraphers and scientists from adjacent disciplines to respond to the hypotheses it poses. Being the first to thus occupy this issue area, they shaped the subsequent debate according to the questions crucial to their discipline. Such different aspects of the Anthropocene as that of the Anthropos, on the other hand, remained comparatively open for various other disciplines to make their contribution to the wider discourse of global environmental change. It is suggestive in this regard that interlocutors on the issue of the Anthropos have not necessarily come from the discipline of biology but, predominantly, from the humanities and to some extent the social sciences.

Furthermore, the involvement of these different disciplines is reflected in the different levels of criticism that have been stimulated by the discussion about the representative nature of stratigraphic markers and species, respectively. On the one hand, the discussion about the human dimension has raised questions about environmental justice and historically unequal power relationships that affect social-ecological relationship. On the other hand, the discussion about stratigraphic markers mainly questions if Anthropocene can fulfil established criteria of stratigraphy. Accordingly, the discussion about the Anthropos, more so than the one on the geological dimension, provided a vehicle for reflection on the Anthropocene narrative generally and its contribution to an analysis of global environmental change. Although the extent to which authors are sceptical of the Anthropocene still varies between social scientists like Luke (2013) and humanities scholar such as Latour (2014) who have been more accommodating of the "geologic turn" (Clark 2013, 48), scientists like stratigraphers tend to be more interested in clearly defining the Anthropocene and less accommodating of the ambiguity and performativity of such definitions.

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Appendix 2

(Dis)entangling descriptions of and responses to the Anthropocene: Norms & implications of scientific representations of the Earth system

3 Disentangling descriptions of and responses to the Anthropocene

Norms and implications of scientific representations of the Earth system

Johannes Lundershausen

Introduction

In 2000, Nobel laureate in chemistry Paul Crutzen and biologist Eugene Stoermer termed the 'Anthropocene' – the most recent epoch in Earth history in which the cumulative actions of (some) humans are driving the Earth system out of its Holocene state (Crutzen and Stoermer 2000). In spite of the ongoing debate about the official geological status of the Anthropocene (Zalasiewicz et al. 2017a), it has become a popular term within and outside of academia highlighting the vast extent and novel quality of anthropogenic Earth system change.

On the side of policy, decision makers increasingly refer to the Anthropocene for an explanation of global change and sustainable responses to it (Steiner 2016; Ban 2014; Hendricks 2015). From a political science perspective, researchers connect the empirical insights about the Anthropocene analysis to recommendations of how to act on global changes (Future Earth 2014; Whitmee et al. 2015). As Steffen et al. (2011b, 741) have argued: "One of the key developments in moving from problem definition to solution formulation is the concept of the Anthropocene" (Steffen et al. 2011b, 741). These efforts are idiosyncratic because the original description of the Anthropocene reveals relatively little about the social driving forces and consequences of global change (Bonneuil and Fressoz 2016; Palsson et al. 2013). But the interest in the Anthropocene as a framework for solutions indicates that "the Anthropocene is implicated in the deepening ethical-political entanglements of scientific research" (Clark 2014, 26). Commentators have argued that scientists are responsible to "guid[e] society towards environmentally sustainable management during the era of the Anthropocene" (Crutzen 2002, 23; Barnosky et al. 2014; Brasseur and van der Pluijm, B. 2013), and Anthropocene-specific research agendas have been advanced to achieve this aim (Kotchen and Young 2007; Bai et al. 2015).

In this chapter, I highlight the normative logics incorporated in scientific descriptions of the Anthropocene and demonstrate which ways of acting on the Anthropocene they can produce. In order to do so, I proceed in three steps. Firstly, I identify two relevant scientific representations of the Anthropocene that are based on very different interpretations of past and contemporary Earth system

changes and the concomitant development of human civilisations. Whereas one depicts the Anthropocene as 'a crisis for sustainability', the other regards it 'as an opportunity' to increase human well-being. Secondly, the chapter shows that these scientific interpretations also contain certain normative logics. I refer to the 'end of nature' debate in order to demonstrate that the lack or adherence to an *a priori* environmental baseline defines the different normative outlooks of the two interpretations. Thirdly, I sketch out the connection between these normative logics and existing policy responses to global change. Namely, I explain how the normative logics identified respectively invigorate proposals for Earth System Governance and for geo-engineering. The chapter concludes by providing an outlook of the kind of approaches needed to generate different responses to the Anthropocene.

The co-production of scientific knowledge and social practices

This chapter starts from the socio-political embeddedness of the scientific analyses of the Anthropocene. Scholars in the field of science and technology studies (STS) have highlighted that knowledge about the world (including the Earth) is inseparable from the ways in which we govern our lives. This idea of 'co-production' between social and natural order, prominently advanced by Sheila Jasanoff (2004, 2–3), draws attention to the social performativity and contingency of scientific knowledge: "Scientific knowledge … both embeds and is embedded in social practices, identities, norms, conventions, discourses, instruments and institutions – in short, in all the building blocks of what we term the social".

Incorporating this insight into an understanding of the Anthropocene is consequential. Brian Cook and Angeliki Balayannis (2015, 277) emphasised that recognising "the co-production of knowledge and governance means that proposals such as the Anthropocene … must take into account the normative commitments entailed" in the Earth system sciences in which the term originates. The concept of co-production thus challenges both producers and users of scientific knowledge about the Anthropocene to consider if their normative commitments align with those of the scientific analyses of the Anthropocene. In this vein, Lauren Rickards (2015, 338) highlights that "the Anthropocene is a call (back) to science": we are asked to examine the prescriptive claims underpinning the representations of the Anthropocene require closer examination. This chapter follows this call by highlighting the logics for acting on the Anthropocene that inhere in scientific descriptions of the latter.

Two representations of the Anthropocene Earth system

Before evaluating the 'Anthropocene as crisis' and 'Anthropocene as opportunity', it needs to be emphasised that the two representations comprehensively describe neither the science of the Anthropocene nor its popular discourse (Dalby 2016). The debate about the Anthropocene is constantly evolving and this evolution is

periodically assessed by commentators (Castree 2014). In this chapter, I focus on a limited number of seminal contributions to the debate. I am concerned predominantly with norms and implications of the science of the Anthropocene and thus attend to publications that are most revealing in this regard. I focus on articles that employ the concept of the Anthropocene to discuss the human impact on the Earth system. As a result, I do not review publications that debate the status of the Anthropocene as an official stratigraphic unit.

Given the diversity of the debates, categorising the scientific descriptions of the Anthropocene as two opposed paradigms is inevitably a simplification. But this dichotomy is a defendable heuristic that advances our understanding about the actions that scientific descriptions of the Anthropocene invoke, in spite of our limited knowledge about their actual socio-political consequences. Several academics writing on the Anthropocene justify this approach by cautiously contrasting positions at the ends of a wider spectrum (Cook et al. 2015; Cook and Balayannis 2015; Davison 2015; Karlsson 2015; Steffen et al. 2016). They emphasise the multiple ways in which the grand narrative of the Anthropocene can be interpreted, rather than to suggest that there are only two such interpretations. In this vein, the dichotomy between descriptions of the Anthropocene 'as crisis' and 'as opportunity' highlights the contradictory qualities that the Anthropocene combines.

The Anthropocene as a crisis of sustainability

Many scientists originally working on the Anthropocene define it as an anthropogenic state of the Earth system that is both unprecedented and unsustainable (Crutzen and Steffen 2003). This judgement is made because the Anthropocene would end "the Holocene-like state … of the Earth system [which] is the only one that *we can be sure* provides an accommodating environment for the development of humanity" (Steffen et al. 2011b, 753 – emphasis added). This negative representation of the Anthropocene draws on the observation that humanity required the 'safe operating space' of the Holocene Earth system to develop complex civilisations with historically exceptional levels of human welfare. Although it is possible from this perspective to imagine human development in alternative Earth systems, this is generally disregarded as a counterfactual vision of the past that is not supported by empirical observation. To leave the safe space of the Holocene risks permanently overwhelming current strategies to maintain and increase present levels of human development. the Anthropocene marks a transition towards a new state of the Earth system that is exceedingly more variable and inherently more dynamic than known modes of Earth system functioning (Steffen et al. 2004; Steffen et al. 2016). This is unlike climate change, which may be regarded as a temporary (if long on human timescales) perturbation within regular patterns of Earth system variability between glacial and inter-glacial phases (Steffen et al. 2011b, 755).

The instability of the Anthropocene and the associated notion of unsustainability is further quantified by the concept of Planetary Boundaries, which articulates

the negative representation of the Anthropocene in a more openly normative fashion (Castree 2014, 441). Even though the concept of Planetary Boundaries and that of the Anthropocene have different origins, many prominent scientists regard the former as a normative operationalisation of the latter (Brown 2015).

The concept of Planetary Boundaries starts from the notion that biophysical processes underpin the functioning of the subsystems of the Earth and that an alteration of these processes beyond certain thresholds risks non-linear changes in those subsystems and, for some 'core boundaries', the Earth system itself (Rockström et al. 2009b; Steffen et al. 2015). On the basis of these considerations, Planetary Boundaries define the safe distance from these thresholds. In case of climate change, for example, the control variables of atmospheric CO_2 concentrations and radiative forcing should stay below the limits of 350–450 ppm and +1.0–1.5 W m^{-2} compared to pre-industrial levels, respectively (Steffen et al. 2015).

Regardless of the recognition that the idea of Planetary Boundaries is "surrounded by large uncertainties and knowledge gaps" (Rockström et al. 2009b, 1) concerning both scientific understanding of thresholds (e.g., their globality and interactions) and normative judgements on acceptable environmental change (Steffen et al. 2015), this quantitative operationalisation of the idea of a 'safe operating space' is an explicitly normative one that aims to "meet the challenge of maintaining the Holocene state" of the Earth system (Rockström et al. 2009a, 472). Planetary Boundaries add a sense of urgency to that aim by showing that four of the specified boundaries (climate change, loss in biodiversity, land-system change, altered biogeochemical cycles) have already been crossed (Steffen et al. 2015).

In doing so, the concept of Planetary Boundaries contributes to a vision of the Anthropocene as an 'emerging limit experience' (Alberts 2011, 7). In terms of the current trajectory to confront those limits, Planetary Boundaries indicate a crisis of human development on a finite planet. In any case, the idea of the 'safe operating space' of the Holocene implies that entering the Anthropocene would risk not only the demise of humanity's potential to shape the Earth system but also the end of contemporary societies (Steffen et al. 2015).

While the concept of Planetary Boundaries consequently constitutes a normative framework to weigh the uncertainties and risks associated with leaving the Holocene Earth system, its advocates ground it in Earth system science. Although proponents of the concept acknowledge that what it means 'to be safe' is a normative question and that their answer to it is informed by a risk-averse and conservative approach to human development (Rockström et al. 2009b, 3), they are adamant that planetary thresholds "exist independent of human actions or desires" (Steffen et al. 2011a, 860) and that Planetary Boundaries are a first attempt to define the '*non-negotiable* planetary preconditions' of human development (Rockström et al. 2009b, 2 – emphasis added). To be sure, this approach does not deny that humans are increasingly able to influence Earth system changes intentionally. But this ability is circumscribed by the geophysical thresholds of the Holocene Earth system that cannot be surpassed by human ingenuity.

The Anthropocene as an opportunity for sustainability

The negative description of the Anthropocene can be contrasted with a positive one that emphasises the benefits of the ability of humans to alter their environment and overcome environmental limits. In this positive description of the Anthropocene, contemporary Earth system change does not primarily depict a crisis of human development on a finite planet but evidences the unprecedented capacity of humans to transform their environment on a planetary scale and thus to change the conditions of their very existence. The human activities that have led to extensive global change were not undertaken with the intention of causing the latter. Yet, the human potential to do so has led to the idea that they should embrace Earth system change as a solution to some of the predicaments of contemporary socio-environmental relations, rather than as an invigoration of their problematique. Highlighting the human ability to navigate environmental changes in advantageous ways thus enables a description of the Anthropocene Earth system change as a positive development that affords opportunities to achieve long-term sustainability.

The same rationale appears in the wider debate about 'novel ecosystems', i.e., ecosystems that differ from pristine ones in that they are created by and embedded in human systems (Hobbs et al. 2006). Although many existing novel ecosystems, like brownfields or agricultural land, were not intentionally created as sanctuaries of ecological diversity, the prospects of using these artificial habitats as sites of socio-ecological experiments entice restoration ecologists. These ecosystems are seen to provide new opportunities for focusing on what humans want to create rather than on the risks they seek to reduce (Marris 2009; Lehman and Nelson 2014). The contentious extension of these arguments to the global scale is a central feature of positive descriptions of the Anthropocene.

A prominent positive description has been advanced by Erle Ellis who first described a 'good Anthropocene' in a 2011 publication of the Breakthrough Institute (Ellis 2011a) that has been at the forefront of a 'new environmentalism' movement (for a critique see Szerszynski 2015). Ellis outlined a historical perspective on Earth system change and argued that modern humans have always extensively altered ecological systems across most of the terrestrial biosphere. This argument aligns with the suggested 'early Anthropocene' hypothesis that dates anthropogenic environmental change back to the Neolithic Revolution thousands of years ago (Ruddiman et al. 2011). Stratigraphers officially tasked with defining the inception of the Anthropocene have challenged this hypothesis (Zalasiewicz et al. 2017b) and Ellis (Ellis et al. 2016) has reacted by developing his arguments. As a result of setting an early baseline for extensive anthropogenic impact on the environment, changes to the Earth system in the Anthropocene appear not as fundamentally new but as a recent advancement of the human potential.

This view of historical socio-environmental relations implies a 'logic of human ingenuity': humans have always been able to shape their environment, so it becomes conducive to their development. Following this arguments, 'human system boundaries' (Ellis 2011a, 37–38) will define human activities in the

Anthropocene more than Planetary Boundaries. For, transgressing natural boundaries and adapting to new environmental conditions have been central means of human development

At the same time, the 'logic of human ingenuity' is contingent on the idea that the Earth system is already locked into an Anthropocene future that cannot completely be reversed to a Holocene trajectory even if 'human system boundaries' such as social values, systems of governance and technologies were to change (Ellis 2011b). Since the Earth system cannot be returned to the Holocene, pragmatism ostensibly relegates concerns with environmental limits. From this perspective, focusing on the possibilities provided by novel ecosystems or 'anthropogenic biomes' (Ellis and Ramankutty 2008) allows for adapting to and mending the conditions of an Anthropocene Earth system. Although Ellis does not contend that a human-driven Earth system is 'particularly good' (Ellis 2011a, 42), attending to these 'planetary opportunities' (DeFries et al. 2012) will arguably help to create a beneficial version of the Anthropocene.

Normative logics for Earth system change in the Anthropocene

The discussion above shows that scientific descriptions of the Anthropocene differ regarding their interpretation of past and contemporary Earth system change. From the perspective of philosophy of science, it is not unusual that interpretations are incommensurable with each other, even if they are consistent with the evidence (Evans and Collins 2008). This section takes this argument further by showing that these different scientific interpretations contain certain normative logics. They are 'epistemic-moral hybrids', i.e., scientific analyses of reality that are closely linked to evaluative and normative statements (Potthast 2010).

The competing normative logics that underpin the Anthropocene 'as crisis' and 'as opportunity' are elucidated a wider discussion about whether or not nature has ended. This debate gained prominence particularly after the publication of Bill McKibben's *The End of Nature* in 1989 (2006) in which he maintained that the traditional empirical understanding of nature as apart from humans is no longer viable. The acknowledgement of close interactions between humans and natural systems is central to both descriptions of the Anthropocene 'as crisis' and 'as opportunity'. They differ, however, on whether or not geophysical processes inevitably provide the basis of human conduct. While, in the negative description of the Anthropocene, Earth system processes constrict and enable intentional human action (Clark 2014), they cease to be the residual context of such action in the positive description (Dalby 2014).

In this sense, the description of the 'Anthropocene as opportunity' implies a 'culturalist logic' in which natural processes are determined by human actions. Ellis's comment that 'nature is gone' is suggestive here (Ellis 2009, unpaginated). It is because of this culturalism of some scientific representations that the Anthropocene analysis has been criticised for underestimating the nature-constructedness of humans (Clark 2012) and for unifying nature and culture under the mastery of the latter (Baskin 2014). In contrast, the description of the 'Anthropocene as crisis'

highlights that human flourishing is inherently circumscribed by thresholds of the Earth system. It thus stresses that there is an essential quality to the Earth system that requires protection. As such it carries a 'naturalist logic' which is diametrically opposed to culturalism and seeks to understand social phenomena through natural processes.

This difference is consequential for the normative outlooks that the two perspectives enable. In the 'naturalist logic', contemporary civilisation will – by design or by disaster – have to adhere to the limits of the Earth system. In the 'culturalist logic', environmental conditions can be surpassed in order to advance human development. The former logic insists on the primacy of nature. Consequently, it lends itself to proposals to strictly prevent further change of the Holocene Earth system state which is regarded as the only operational mode of the Earth system. In doing so, the 'naturalist logic' already outlines a specific normative understanding of what humans should value most in nature. Such an understanding is missing in the 'culturalist logic', which rejects the notion of an 'optimal' past state of the Earth system. This logic thus lacks an explicit *a priori* environmental baseline upon which normative judgements and decision-making can be based. This is not to say that the 'culturalist logic' refrains from normalising a certain view of the Earth system. But its normalisation is not based on geophysical parameters of that system.

Conservation biology provides a good reference point when characterising these normative logics because conservation biologists have recently surrendered a strict distinction between fact and value when talking about the normative content of scientific representations. The 'naturalist logic' is in line with concerns to preserve or restore the integrity of natural ecosystems, reflecting in terms of norms the breath of traditional environmental ethics (Elliot 1995). In contrast, the 'culturalist logic' better reflects the recently popular idea of 'intervention biology' (Hobbs et al. 2006) as well as the norms of eco-modernism (Fisher and Freudenburg 2001).

To summarise the above argument, scientific descriptions of the Anthropocene Earth System are not neutral. They embody normative logics about whether humans should advance their influence on the Earth system or give ground to geophysical processes of the latter and respect their limits. At the basis of these statements lie different answers to the question if there is an essence to nature that provides the inevitable background for sustainable development and can thus function as a normative guide.

From representations of the Anthropocene towards responses to it

In this section, I show that the normative logics identified above engender different ways of acting on the Anthropocene. Whereas the focus in the 'naturalist logic' is on limiting the magnitude of global change, managing the direction of that change is of foremost importance in the 'culturalist logic'. I make this case by drawing parallels between the two scientific representations analysed above and proposed responses to the Anthropocene. On the one hand, Earth System Governance,

which promotes political institutions that produce more sustainable socio-environmentalrelations, builds on an understanding of the 'Anthropocene as crisis' and the embodied 'naturalist logic'. On the other hand, the vision of 'Anthropocene as opportunity' and the connected 'culturalist logic' enables geo-engineering, which advocates deliberate large-scale intervention in the Earth system as a sustainable response to global change.

It needs to be emphasised, however, that neither the desirability nor the likelihood of different political measures can be deduced from the scientific representations of the Anthropocene. There is no linear relationship that would lead "politics and ethics [to] simply flow from science" of the Anthropocene (Randalls 2015, 334; Schmidt et al. 2016). Scientific descriptions of global change do not automatically result in corresponding action because the former cannot fully dissolve political disagreement about the latter (Oreskes 2004). Yet, while scientific representations of the Anthropocene cannot tell us what we ought to do, their scientific logics do engender different political logics. The ways in which we know a phenomenon affect the ways in which we act upon that phenomenon (Lövbrand et al. 2009). This is particularly the case for responses to global phenomena of environmental change, which are contingent upon the scientific discourse. These phenomena would not exist as recognisable matters of concern without that discourse (Urry 2011).

Governing the crisis of the Anthropocene

Global environmental governance is a long-standing concern of political science. Recently, it has been aligned more closely with scientific approaches that focus on the Earth as an integrated system. Accordingly, proposals have been developed for Earth system governance (hereafter ESG), which purportedly responds both to scientific insights and the needs of policymakers (Biermann et al. 2010). The integrative approach of ESG promises to go beyond "traditional notions of environmental policy, … [which] do not capture current global developments that transform the bio-geophysical … processes of our planet" (Biermann et al. 2010, 203). This section shows that ESG has lately fulfilled this raison d'être by referring to Planetary Boundaries as a justification for political action as well as its own approach.

From an ESG perspective, the sustainability problems of the Anthropocene largely result from political processes and institutions that inadequately govern the human impact on the environment (Schroeder 2014). ESG does not, as the name might suggest, advocate direct management of the Earth system but it aims to steer the political processes that have adversely changed the latter (Biermann 2014b). ESG seeks to invest in *political ingenuity* to induce social changes that reduce human interference with the Earth system. Accordingly, it differs from the 'Anthropocene as opportunity', which puts hope in the *technological ingenuity* of human systems to advance the means of controlling nature.

Furthermore, the maintenance of the Holocene Earth system is a specific motivation of ESG (Biermann 2014b 59) and functions as an *a priori* environmental

baseline for decision-making. ESG is underpinned by the 'naturalist logic'. This is the more evident because ESG adopts Planetary Boundaries as conceptual framework (Galaz et al. 2011). Frank Biermann, who has notably advanced the idea of ESG, most clearly outlines the relevance of Planetary Boundaries for governance by arguing that the concept "specifies an overall environmental target corridor" (Biermann 2012, 4) and thus helps to concretely define and balance the three pillars of sustainable development.

To be sure, the relationship of ESG to Planetary Boundaries and the primacy of nature argument is ambiguous. Although Biermann values a further quantification of Planetary Boundaries, he also cautions that they cannot generally guide governance because they are in 'principle neutral to human values' and simply highlight widely agreed relationships in the Earth system (Biermann 2012, 5). The normative questions that inhere in a quantitative definition of Planetary Boundaries (such as the assessment of scientific uncertainty, cost-benefit analyses and risk indicators), according to Biermann, acquire relevance only when the concept is 'operationalised' by political actors. But critics have argued that the science behind the Planetary Boundaries concept, rather than being absolute and independent, implies normative judgements regarding e.g., trade-offs between the multiple costs and benefits of environmental change (Nordhaus et al. 2012).

A plausible explanation why ESG nevertheless adopts Planetary Boundaries can be provided by referring to Simon Lewis (Lewis 2012, 417) who argues that Planetary Boundaries are

> Conceptually brilliant and politically seductive: clear, quantitative measurements with no obvious judgements on what is 'right' or 'wrong' to include. It is also liberating. Here is humanity's safe space: within it, do what you want.

In this vein, the primary function of Planetary Boundaries for ESG is to highlight the urgency of political action. The effect of this is twofold. On the one hand, the reference to ostensibly value-neutral and politically uninstructive Planetary Boundaries leaves considerable freedom as to the concrete measures of how to achieve sustainability. The proposed institutional reforms (Biermann 2014a, 2012), for example, are articulated quite independent of the individual Planetary Boundaries and instead encompass issue-specific solutions which largely follow social activities. On the other hand, the Planetary Boundaries concept helps to support the raison d'être of ESG. Whatever political solutions and institutional reforms are suggested by proponents of ESG, they can be legitimised as responses to the urgent "challenge of maintaining the Holocene state" (Rockström et al. 2009a, 472).

However, this double function incorporates a paradox: how can Planetary Boundaries simultaneously be indifferent to political choices and yet function to support concrete policy options? The paradox can be explained by Erik Swyngedouw's concept of 'de-politicisation of the environment' (2011), which demonstrates the normative importance of an *a priori* environmental baseline and of the 'naturalist logic' for ESG. The continuous commitment of the "normative theory of Earth System Governance … [to the] needs and necessities of Earth system

stability" (Biermann 2014a, 27) prescribes what humans should value most in nature. This is the case even where Planetary Boundaries are not explicitly highlighted as the basis for Earth System Governance (Biermann 2014a, 2014b). Consequently, the foremost criteria for evaluating suggested policies becomes whether or not the Earth system stays within the quantitatively defined limits delineated by the Planetary Boundaries concept.

An alternative framing of environmental governance that is more closely aligned with the description of the 'Anthropocene as opportunity' highlights the consequences of employing this normative logic. In contradistinction to the 'naturalist logic', John Dryzek (2014) has argued that global change requires current 'Holocene institutions' to overcome their path dependency on ideas of a stable non-human world including that of static boundaries. This difference to ESG is relevant for the concrete governance responses to global change. Because ESG focuses on governance options within a defined natural operating space with finite boundaries, it is much more concerned with allocation of and access to resources (Schroeder 2014). To the contrary, Dryzek (2014) suggests that adaptive governance (only one amongst five analytical problems of ESG (Biermann 2007)) is paramount because the subsystems of the Earth are not characterised by fixed thresholds but by instability and dynamism.

Geo-engineering as an opportunity of the Anthropocene

Another measures suggested to respond to the Anthropocene is geo-engineering. In spite of their long history (Fleming 2006), proposals for geo-engineering continue to be surrounded by considerable ambiguity relating e.g., to their demarcation from other technologies (Galaz 2012) as well as to their heterogeneous ethical and political implications (Hulme 2012). Notwithstanding this ambiguity, geo-engineering is increasingly seen as requiring strategic consideration (Dibley 2012). That this trend is strengthened by the arrival of the Anthropocene has been described as 'hardly surprising' (Clark 2012, 259) and 'inevitable' (Hamilton 2012, unpaginated). In this vein, geo-engineering has been called the 'poster-child of the Anthropocene' because it depicts the increasing power of humans to influence the environment on a global scale (Scott 2013, 316).

Conceptually, both 'Anthropocene as opportunity' and geo-engineering support the direct management of nature as a solution to Anthropogenic challenges. Particularly, geo-engineering's "'artificing of nature' [by] intentionally tweaking some of the Earth's basic processes" to create sustainable conditions (Preston 2012, 191) is evocative of the 'culturalist logic' of the 'Anthropocene as opportunity'. Proponents of geo-engineering like Schäfer et al. (2014) and Crutzen (2006), who also refer to the Anthropocene, are convinced that the development of geo-engineering technology and its deployment in the natural world can largely be determined by human intentions. This outlook aligns with the 'culturalist logic' that nature, even if it cannot be controlled fully, does not frustrate the realisation of human intentions (Yusoff 2013). In this logic, the historically grown capacity of humans to transform their environment on a large-scale is an opportunity to deal with

current sustainability challenges. Whereas many of the phenomena that characterise the Anthropocene have been side-effects of the pursuit of various managerial and political goals, in conjuncture with the 'culturalist logic', they point towards the feasibility of managing the Earth system intentionally. As such, the 'culturalist logic' enables an endorsement of geo-engineering, which assumes that research and development can amplify the human capacity to direct Earth system processes to chosen ends (Hamilton 2012). The empirical analysis of the 'Anthropocene as opportunity' thus provides a 'geohistoric moment' (Yusoff 2013, 2800) that renders the deployment of geo-engineering imaginable.

Like in the scientific description of the 'Anthropocene as opportunity', natural limits rarely feature in geo-engineering debates. Instead, human system boundaries such as governance and research are emphasised. Where governance is highlighted, it is distinct from Earth System Governance in that it seeks to advance institutional and procedural arrangements in order to enhance the management of nature itself and govern the competing interests involved in this. Conversely, Planetary Boundaries highlight the difficulty of realising intentional management of the Earth system by drawing attention to the possibility that respecting the boundaries of one subsystem of the Earth may lead to the crossing of another (Steffen et al. 2004). Geo-engineering has hence been described as 'antithetical' to the idea of Planetary Boundaries (Steffen et al. 2011a, 860) and is incompatible with the 'naturalist logic'.

It goes to show that some commentators have contributed both to Anthropocene and geo-engineering debates. Although only a few geo-engineering advocates directly refer to the Anthropocene, several Anthropocene scientists propose geo-engineering as a response option (Crutzen 2006; Steffen et al. 2011a, 2011b). They consider geo-engineering as a future possibility and advocate 'low-tech' mitigation measures such as afforestation as proximate solutions. In doing so, they follow the geo-engineering advocacy discourse, which seeks to break the taboo on the scientific exploration of associated technologies while remaining aware of geo-engineering's "dual prospect of large benefits and harms" (Parson and Keith 2013, 1278; Allenby 2007).

Fundamentally, the description of the 'Anthropocene as opportunity' provides a historical reference for large-scale human interference in the environment and thus extends the spatial and temporal scale of acceptable human disturbance**.** Even though authors like Simon Dalby (2016) have highlighted that a belief in technological solutions will not inevitably lead to geo-engineering, the description of the 'Anthropocene as opportunity' means that geo-engineering could be seen as a mere difference in degree rather than in kind to previous forms of environmental management. Spatially, authors like Ellis and Ramankutty (2008) imply that it is a small step from evident 'ecosystem engineering' to Earth system engineering. This thin line between faith in technological and ecological progress is a clear indicator for ecomodernist conception of the Earth (Davison 2015, 4).

Temporally, the description of the 'Anthropocene as opportunity' provides a historical analogy for global change and thus extends the futurism that underpins geo-engineering into the past. This bodes particularly well for a refutation of the

common criticism that the deployment of geo-engineering would require considerable temporal commitment because it does not address the causes of anthropogenic environmental change (like rising carbon dioxide emissions) but merely treats its symptoms (Steffen et al. 2011b). According to critics (Preston 2012), the ensuing permanent and active management of the Earth system would assign humans an unbearable responsibility. But the description of the 'Anthropocene as opportunity', in conjuncture with the 'early Anthropocene hypothesis', legitimises such a commitment by arguing that humans have influenced the Earth system for millennia.

Conclusion

This chapter has dichotomised the scientific descriptions of the Anthropocene 'as crisis' and 'as opportunity' in order to highlight the co-constitution of scientific and normative statements. It has explicated the normative logics about desirable states of the Earth system that these descriptions incorporate, and illustrated their implications for responses to Earth system change.

The analysis of scientific representations of the Anthropocene as 'epistemic-moral hybrids' (Potthast 2010) will trouble scientists who fear that their objectivity is being challenged. But the analysis conducted in this chapter should not be read as a judgement on the validity or the credibility of these representations. The latter are important not because they are right or wrong, objective or subjective, but because they can invoke action (Thrift 2004). This effect exists irrespective of the desirability of these actions. While the moral value of responses to environmental change can be judged by ethical analysis (Jamieson 2008), this has not been the aim of this chapter. Opening up normative logics of scientific representations and their political implications for debate, as done in this chapter, helps scientists and political actors alike to understand the entanglement of scientific research on global change in ethical and political decision-making.

Doubts may arise that the descriptions of the Anthropocene reviewed in this chapter can meaningfully contribute to distinctive responses to global change of unprecedented magnitude. Indeed, critics have questioned that Anthropocene representations can ground anything else than existing approaches to environmental management. They hold that its very analysis perpetuates, in case of the 'Anthropocene as opportunity', an anthropocentric worldview and destruction of nature (Crist 2013; Davison 2015), and, in case of the 'Anthropocene as crisis', "foregrounds a political imaginary of threat", precluding a focus on the particular processes that have led to the environmental crisis in the first place (Evans and Reid 2014, 4; Houston 2013).

We cannot expect different outcomes if we maintain the same normative assumptions. Although empirical descriptions of the Anthropocene advance our understanding of contemporary Earth system change, they need to be based on non-dualistic approaches to the 'end of nature' if they are to foster distinctive responses to the latter. A variety of such non-dualistic approaches have been developed within the social sciences and humanities (Lorimer 2012; Bingham

and Hinchliffe 2008). They highlight that the Earth system is established both by different social ascriptions of objects as distinctive parts of it and by various practices that enact the materiality of these objects. Although the scientific representations of the Anthropocene analysed in this chapter highlight interrelations between the human and material world, future research needs to pay more attention to the actual practices of these processes. In addition, more reflection is required on the changed social, including scientific, ascriptions of objects and processes as constitutive of the Earth system.

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Appendix 3

Marking the boundaries of stratigraphy: Is stratigraphy able and prepared to define, describe and explain the Anthropocene?

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RESEARCH ARTICLE

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Marking the boundaries of stratigraphy: Is stratigraphy able and willing to define, describe and explain the Anthropocene?

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This paper investigates the involvement of the stratigraphic community in the endeavour of defining the Anthropocene. Although much of the debate about the Anthropocene takes place outside of stratigraphy, the concept of the Anthropocene derives its distinctiveness and popularity from its geological dimension. In this context, the epistemic authority of stratigraphy is extended from ratifying geological epochs to verifying the Anthropocene more generally. The paper conceptualises this authority and examines the published stratigraphic literature to determine to what extent the stratigraphic community is able and willing to assume it. In doing so, the paper demonstrates how stratigraphy co-produces its epistemic authority in regards to the Anthropocene.

KEYWORDS
Anthropocene, boundary work, Earth system, epistemic authority, scientific expertise, stratigraphy

1 | INTRODUCTION

This paper investigates the epistemic authority of stratigraphy in Anthropocene discourses. The focus is not on stratigraphy in a strict sense, that is on layers of rock and their relative chronology, but on stratigraphy as a scientific community embedded in wider discourses about Earth system change. Although a variety of scientists are working to define the Anthropocene, I argue that stratigraphy plays a special role because it evaluates the geological dimension fundamental to the official definition and approval of the Anthropocene. How the stratigraphic community positions itself in relation to this task is the focus of this paper. The paper builds on the "strong programme" in Science and Technology Studies (STS) to view science as an inherently social activity comprising communities of practice that are embedded in a social context (Barnes & Bloor, 1982).

This interest in stratigraphy relates to wider concerns with the interactions and shifting boundaries between geoscience and socio-political contests over who knows what, how and with what effect about nature (Castree, 2005; Demeritt, 2001; Forsyth, 2003; Hulme, 2009; Jasanoff & Martello, 2004). Recent debates over Anthropocene science demonstrate how our ability to think about the Anthropocene is shaped by specific scientific practices (Castree, 2014b; Cook et al., 2015; Lövbrand et al., 2009) and the connections between ways of thinking and ways of governing nature and society (Cook et al., 2015; Lövbrand et al., 2015; Wissenburg, 2016). Related studies explore how stratigraphy and the geological designation of the Anthropocene affect environmental thinking and practice (Braje, 2015; Swanson, 2016; Szerszynski, 2012). Human geographers have strongly indicated the political ramifications of studying Anthropocene strata (Clark, 2017; Rickards, 2015b; Yusoff, 2017).

This paper adds to these debates by examining stratigraphy's epistemic authority over the Anthropocene, which is defined as the authority "to define, describe and explain" the Anthropocene (Gieryn, 1999, p. 1). The paper demonstrates

how stratigraphic discourses, by way of representing stratigraphic practice, designate boundaries of this epistemic authority. The remainder of the paper is organised in four parts, which help to achieve this ambition.

Part one (section two) analyses the discourse about the Anthropocene, identifies the basis of stratigraphy's epistemic authority over the Anthropocene. It shows how stratigraphy contributes to the concept of the Anthropocene through its function as a scientific discipline with formalised rules and procedures. Part two (section three) draws on theoretical perspectives from "Science and Technology Studies", using Gieryn's work on epistemic authority as a relational achievement that scientists themselves help to produce, to understand Anthropocene stratigraphy in relation to the wider performance of scientific expertise in society. This theoretical approach justifies the analytical focus on the "boundary work" conducted in stratigraphic discourses developed in part three (section four). This part examines the published stratigraphic literature on the Anthropocene in regards to two analytical questions that arise as stratigraphy examines the proposal that the Anthropocene has started. The "question of ability" asks whether stratigraphy is able to evaluate the manifestations of anthropogenic Earth system changes in the rock record. The "question of willingness" inquires whether stratigraphy is willing to consider and account for the potential philosophical and political implications of its research on the Anthropocene. Part four (section five) examines how stratigraphic publications answer the "question of willingness" and draw boundaries around the epistemic authority of stratigraphy over the Anthropocene. Analysing one particular stratigraphic controversy about the Anthropocene, I argue that these answers afford flexibility to both expand the epistemic authority and protect the autonomy of stratigraphy. The "ideal of value-free science" contributes to this "boundary work" between stratigraphy and society as well as to the distribution of authority within stratigraphy.

The material analysed was gathered through a Web of Science search for publications including in their topic the terms "Anthropocene + stratigraphy" and "Anthropocene + stratigraphic". For the timespan from 2011 to January 2017, this search yielded 75 results, which were further refined to 55 publications by selecting only those in the research area "geology". This search was complemented by an examination of three journals, identified as providing important forums for discussion among stratigraphers about the Anthropocene: *Nature*, *GSA Today* and the *Anthropocene Review*. Using the same search terms and over the same time span, this second review enriched the material analysed by generating 39 additional publications. Publications were analysed only if their author(s) could conceivably be regarded as part of the geoscience community, and if they contributed to discussion about the formalisation of the Anthropocene. The final set of 68 publications were analysed to reveal how stratigraphy deals with the proposal for a new geological epoch of the Anthropocene and, in part four, to show how stratigraphic discourse draws boundaries around its own epistemic authority. Theoretically, this paper presupposes that stratigraphic discourse, which I analyse, adequately represents stratigraphic practice.[1]

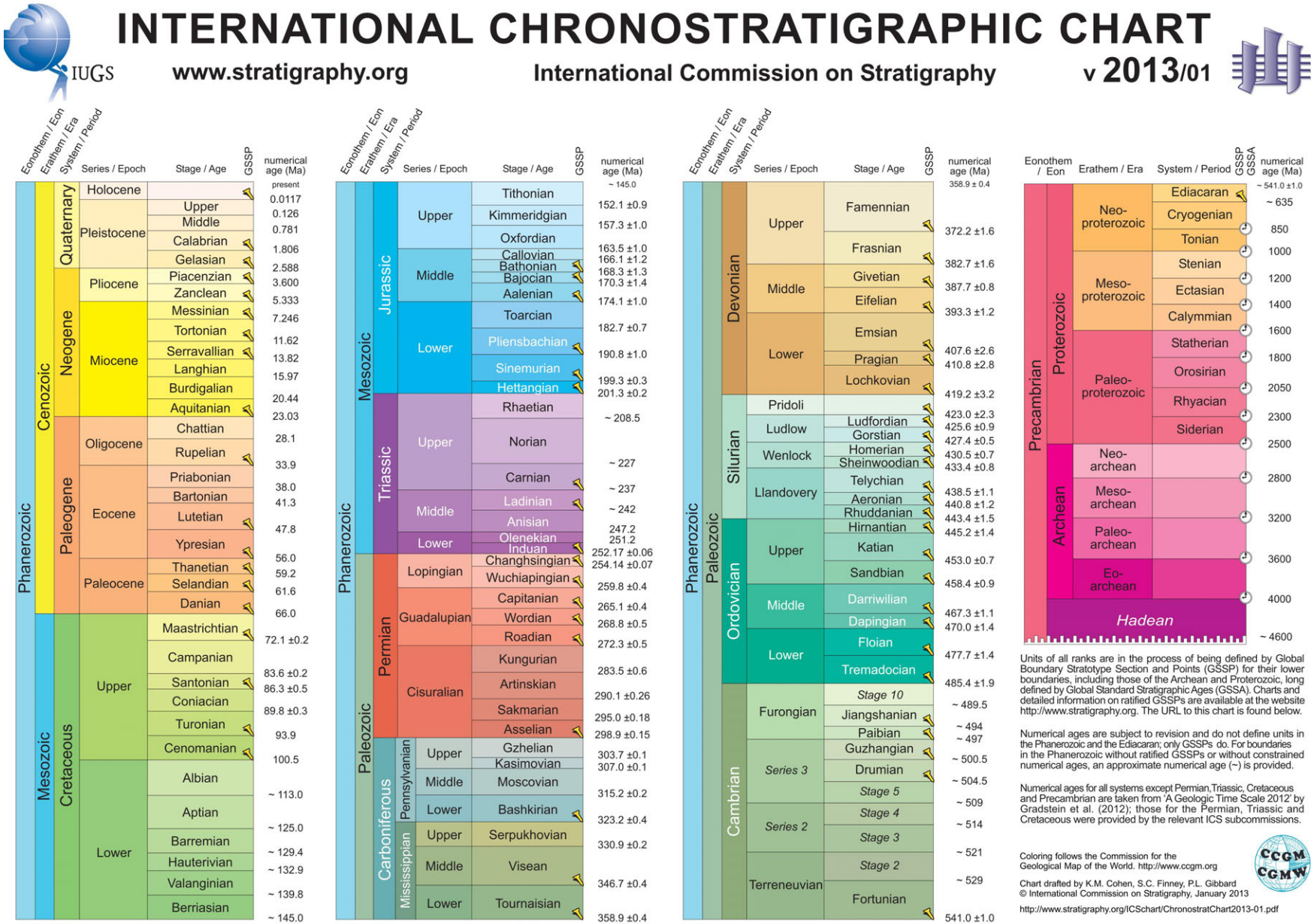
The "question of ability" and the "question of willingness" reveal controversy in the development of stratigraphic facts, following established approaches in STS (Klintman, 2002; Whatmore, 2009) which seek to prevent complex phenomena from being "black boxed" (Latour, 1987). This paper provides timely insights into the process through which the Anthropocene Epoch gets constructed before it "acquires an air of inevitability" (Sismondo, 2010, p. 120) and contributes to geographical efforts that seek to keep debates about the Anthropocene open (e.g., Castree, 2015).

2 | THE EPISTEMIC AUTHORITY OF ANTHROPOCENE STRATIGRAPHY

This part of the paper argues that the epistemic authority of stratigraphy rests on two key factors. First, stratigraphy's study of the Anthropocene's geological dimension contributes to the conceptual distinctiveness of the term. Second, stratigraphy comprises a group of experts that functions to add weight to discourses about Earth system change.

2.1 | The epistemic contribution of stratigraphy to the concept of the Anthropocene

Even though various and disparate interpretations of the "Anthropocene" exist (for reviews, see Lorimer, 2017; Moore, 2015), they commonly refer to the geological dimension which indicates that anthropogenic changes to the physical environment are so vast that they will be permanently inscribed into the rock record and human accounts of Earth history. This common reference derives from the original usage of the Anthropocene as the "geology of mankind" (Crutzen & Stoermer, 2000) and from its stratigraphic etymology, which indicates the start of an official geological epoch driven by human influences on the environment. The geological dimension sets the Anthropocene apart from existing descriptions of contemporary Earth system change. Although phenomena such as climate change or biodiversity loss are widely recognised, the geological dimension changes their temporal and spatial scale. Embedding the environmental impacts of human activities in the astonishingly "deep time" of the Earth's rock record underlines their historical significance and signifies a permanence that surpasses human history.



Cohen, K.M., Finney, S.C., Gibbard, P.L. and Fan, J.-X., 2013, The ICS International Chronostratigraphic Chart, Episodes, v. 36, no. 3, pp. 199-204.

FIGURE 1 The international chronostratigraphic chart (Cohen et al., 2013, pp. 200–201).

Although the geological dimension of the Anthropocene advances conceptualisations of Earth system change, stratigraphic research on the Anthropocene as a geological epoch differs from research on the Anthropocene as an Earth system. Whereas stratigraphy assesses the physical manifestation of human activities in the rock record, Earth system science studies human activities as a constituent part of Earth system functioning. The two endeavours are complementary (Steffen et al., 2016; Zalasiewicz et al., 2012) and both draw on interdisciplinary data but they differ in how they validate research results. The model-based research of the "super-discipline" Earth system science (Clifford & Richards, 2005, p. 379) depends on "the assent from diverse disciplinary and social groups" (Jasanoff, 2012, p. 265) rather than experimental or empirical demonstrations to a closed community of peers. In stratigraphy, forms of validating research results are "disciplinary and disciplin[ed]" (Barry et al., 2008, p. 21) by the subject's codified approach to formalising geological epochs.

Central aspects of stratigraphic practice are shaped by formalised rules and procedures. Particularly, the codified approach of stratigraphy demands that a stratigraphic marker, a single physical manifestation of change in the rock record, represents the distinctive character of every epoch. The International Commission on Stratigraphy (ICS), one of seven scientific commissions of the International Union of Geological Sciences (IUGS), administers the identification of appropriate stratigraphic markers. The ICS ratifies the time, name and rank of new geological periods before they are formally included in the International Chronostratigraphic Chart (Figure 1) (Ogg, 2004).

The geological dimension of the Anthropocene, however, is yet to be formally recognised by the ICS. Although the Anthropocene Working Group, which has been assessing the evidence since 2008, concluded in 2016 that the Anthropocene is stratigraphically real and "map[ped] out a route towards a formal proposal on formalization" (University of Leicester, 8/29/2016, unpaginated), several steps remain before the executive committee of the IUGS will reach a final decision on the Anthropocene Epoch (Finney & Edwards, 2016b).

A positive decision by the ICS would influence the trajectory of debates about the Anthropocene outside of stratigraphy because interpretations of Anthropocene as an Earth system gain distinctiveness by way of the geological dimension of the Anthropocene Epoch. Stratigraphers do not control the term (Autin, 2016) which was originally promoted in the Earth system science community (Crutzen & Stoermer, 2000; Steffen, 2013) and has since permeated into other scientific and social spheres (Autin, 2016; Brondizio et al., 2016). But the notion of the Anthropocene Earth system and stratigraphic insights about the Anthropocene Epoch resonate with each other.

2.2 | The epistemic function of stratigraphy in the Anthropocene discourse

Stratigraphy is important for interdisciplinary and societal discourses because it produces new knowledge about the Anthropocene *and* because it fulfils a unique epistemic function. Anthropocene stratigraphy strengthens existing discourses about Earth system change not just because it has conceptual contributions to make but also because it comprises a new group of experts with definitional practices that are highly institutionalised and provide seemingly "rock-solid" (Whyte, 2017) evidence of anthropogenic Earth system change. Although stratigraphy's contributions are undeniably valuable, stratigraphic knowledge is expendable for acknowledging or understanding Earth system change generally. Stratigraphy's epistemic authority over the Anthropocene fundamentally derives from the epistemic function that it fulfils in the interchange of knowledges about Earth system change.

Stratigraphy's formalistic assessment of the Anthropocene Epoch has informed and legitimised discussions about global change in academia, the media and politics. Most prominently, stratigraphic expertise corroborates the assertion of Earth system scientists that human activities have profoundly affected the functioning of the Earth system. Earth system scientists seeking to condense this message into the single keyword of the Anthropocene have required stratigraphic support because they cannot, despite their prominent positions, adjudicate changes in the International Chronostratigraphic Chart (Monastersky, 2015), which would conclusively inscribe human activities into our account of Earth history. This is why references to the Anthropocene did not spike with the first publication of the term by Crutzen and Stoermer (2000) but after the professional interest of stratigraphers started to grow in 2007. If the ICS confirmed the status of the Anthropocene as an official geological epoch, the popularity of the Anthropocene as a signifier of unprecedented anthropogenic Earth system change would further increase.

Social scientists and humanities scholars have equally embraced the stratigraphic etymology of the Anthropocene despite moving away from stratigraphy's focus on the material manifestations of Earth system change to its differentiated social drivers. They have appropriated stratigraphic discourse by retaining the suffix "-cene" for their own neologisms, which has lent scientific authority to terms such as "Capitalocene" (Moore, 2014), "Mediacene" (Gurevitch, 2014) or the "Plantationocene" (Haraway, 2015, p. 162).

Outside academia, media outlets have looked to the ICS for new evidence of anthropogenic Earth system change. Newspapers, including *The New York Times*, *The Guardian*, *The Independent*, *Die Zeit* and *Süddeutsche Zeitung*, have capitalised on developments within Anthropocene stratigraphy to renew attention to this scientific field. Similarly, in an example of political adoption of the language of Anthropocene, German government ministers have portrayed stratigraphic research on the Anthropocene as confirmation of the political imperative for environmental protection (Hendricks 5/19/2015).

As shown is this section, stratigraphy makes epistemic contributions to the concepts of the Anthropocene and fulfils a unique epistemic function in wider discourses about the Anthropocene. These two factors provide the basis of stratigraphy's epistemic authority over the Anthropocene: stratigraphy is widely acknowledged to hold "legitimate power to define, describe and explain" (Gieryn, 1999, p. 1) what the Anthropocene is.

3 | THE AUTHORITY OF SCIENCE IN MODERN SOCIETIES

The epistemic authority of stratigraphy is inseparable from the constitution of modern societies and the authority that science holds within them. In this vein, it has been contended that:

> The debate surrounding the adoption and dating of the [Anthropocene as an official geological] epoch has little, if anything, to do with stratigraphy [as conventionally perceived]. Indeed the quest for this endorsement is mainly a reflection of our desire for the imprimatur of scientific authority. (Baskin, 2014, p. 5)

STS has provided various case studies to show that science is "constitutive" (Shapin, 2008) and "constitutional" (Jasanoff, 2012) of contemporary societies because the politics and economies of the latter can only be understood by attending to the performance of the former (Hilgartner et al., 2015). Governments in liberal democracies frequently justify their decisions with scientific research (Ezrahi, 1990). Even where decisions are not legitimised by way of science, science and rule are intertwined because the ways in which we know a phenomenon affect the ways in which we act upon it (Lövbrand et al., 2009). The scientific framing of global environmental change is especially consequential. Global phenomena such as climate change, or the Anthropocene, are recognisable in the first place only because scientists have assembled and conceived of "relatively separate scientific processes … as part of a consistent and unified account of past, present and future climates" (Urry, 2011, p. 23). Accordingly, social and political responses to these phenomena are contingent on scientific discourses about them (Rommetveit et al., 2010).

In modern societies, science is the principle bearer of epistemic authority as it "stays metonymically … for legitimate knowledge" (Gieryn, 1999, p. 1). As the previous paragraph indicates, this authority can be analysed by focusing on the constitution of modern societies and the way scientific knowledge shapes political, economic and cultural institutions (Beck, 2007; Ezrahi, 1990; Jasanoff, 2007). A complementary approach in STS attends to the constitution of modern science and how it is shaped by these institutions. This approach shifts the analytical focus from the consumption of scientific knowledge to its production, and from the social performativity of science to its social embeddedness. I adopt this focus to understand how stratigraphic discourse influences the epistemic authority of stratigraphy over the designation of the Anthropocene.

3.1 | Epistemic authority as "boundary work"

Scholars focusing on knowledge production have traditionally sought to explain the epistemic authority of science with universal characteristics that distinguish science from other types of knowledge. They have contended that science is able to represent the world more adequately than other knowledge practices because of its methods, theories or organisation (Kuhn, 1996; Merton, 1973; Popper, 1972). But STS scholars have rejected this essentialist explanation as they question that these criteria are universal enough to fundamentally demarcate science from non-science (Collins & Evans, 2007; Shapin, 2008). They have convincingly proposed that epistemic authority is, instead, a relational achievement; it results from flexible negotiations that attribute or deny different actors the status as experts over a given knowledge domain (Evans & Collins, 2008).

Since the 1970s, STS scholars have attended to the foundation of scientific expertise by studying the relationship between scientific claims and their credibility. David Bloor (1991) first broke with the seventeenth century tradition to conflate the validity and credibility of scientific claims. Many empirical studies followed that show how scientific claims win credibility and major factors in this process have been formulated (Barnes & Edge, 1982). As a result, STS has come to regard credibility as a requirement of scientific knowledge that science achieves outside the "discovery" phase (Grinnell, 2009) when local experience of a phenomenon becomes part of a collectively held system of knowledge. STS initially

attended to the public credibility of scientific claims and later included "the economy of credibility internal to scientific practice" (Shapin, 1995, p. 269). This paper is concerned with the latter aspect of credibility which is aptly operationalised by Thomas Gieryn's idea of "epistemic authority".

Gieryn advanced a constructivist explanations of epistemic authority by highlighting the role of science in "credibility contests" (Gieryn, 1999) which take place across social spheres. Scientists are particularly successful contestants because they have attributed 'selected characteristics to the institution of science (i.e., to its practitioners, methods, stock of knowledge, values and work organisation) for purposes of constructing a social boundary that distinguishes some intellectual activities as "non-science"' (Gieryn, 1983, p. 782). The more a phenomenon cannot be experienced by non-experts, the more scientists control the conditions of their own credibility (Shapin, 1995). The Anthropocene, as an aggregate of aggregates, clearly falls within this category.

Gieryn called this social practice of demarcation "boundary work". It takes place in concrete scientific controversies, when science meets political debates (Jasanoff, 1987) or in such mundane settings as in popular science books (Mellor, 2003). While the "boundary work" of Anthropocene stratigraphy appears in mundane settings too (Kasting, 2012), this paper focuses on scientific controversies in Anthropocene stratigraphy, and on the science-sensitive, socio-political context in which Anthropocene stratigraphy is embedded.

4 | STRATIGRAPHY FACING THE CHALLENGES OF THE ANTHROPOCENE

I proceed in the vein of the second strain of analysis outlined above, analysing the arguments employed in stratigraphic publications to respond to two related challenges posed by the proposal of the Anthropocene. The fifth section will examine the boundaries thus drawn around the epistemic authority of stratigraphy.

4.1 | Anthropocene debates: challenges for stratigraphy

The proposal of the Anthropocene poses two challenges for stratigraphy. First, the proposal is controversial within stratigraphy and has induced reflection on stratigraphic practice. Stratigraphy usually applies its specialised methods and established nomenclature to study the deep past. The proposal for the Anthropocene, however, asks practitioners and professional associations of stratigraphy to consider recent and short stages in Earth history. Rather than studying environmental change retrospectively through the rock record (Braje, 2015; Castree, 2014a; Görg, 2016; Hamilton, 2015), they are now asked to practice a "real-time stratigraphy" (Steffen et al., 2016, pp. 17–18) that accounts for observational and historical evidence to anticipate the geological impact of contemporary environmental change.

Second, stratigraphers are challenged to reflect on the socio-political implications of formalising the Anthropocene Epoch and defining a point of its inception (Cook & Balayannis, 2015; Rickards, 2015a, 2015b) as public attention to the blending of human and geological history grows. Stratigraphic markers can convey political messages despite the fact that stratigraphy is indifferent to societal developments and that geological time units do not always coincide with major events in Earth history. Stratigraphic research can shape environmental awareness and decision-making because it exceeds the examination of rock layers; it establishes a time history of these rocks and interprets "them in terms of the environment in which they were deposited" (Doyle et al., 2001, p. 9). Defining geological subdivisions and linking them to environmental events has advanced understanding of the effects and drivers of past changes in the Earth system. Although studies of contemporary environmental change complement this interpretation of rock records with observations of environmental processes and historical records of social developments, a stratigraphically sanctioned starting date of the Anthropocene may narrow down the wider understanding of anthropogenic Earth system change and its causes.

Even though researchers have commented on the socio-political narratives underpinning Anthropocene science (Bonatti, 2014; Crist, 2013; Jaquet, 2013; Rickards, 2015b; Veland & Lynch, 2016), no systematic evaluation of the socio-political implications of different Anthropocene starting dates currently exists. It is beyond the scope of this paper to fill this gap but indications can be given. The three most prominent options for an inception of the Anthropocene are: an "Early Anthropocene" relating to changes in atmospheric chemistry back to land use changes associated with the beginning of agricultural development around 11,000 years ago (Ruddiman, 2003; Ruddiman et al., 2015); an "Industrial Revolution" option highlighting the growth in global signatures such as a rise in atmospheric "greenhouse gases" in the second part of the eighteenth century (Crutzen, 2002); the "Great Acceleration" focusing on a mid-twentieth century spike in radioactive isotopes caused by above-ground nuclear weapons tests and the rapid global dissemination of anthropogenic materials (Waters et al., 2016).[2]

As these proposals set different temporal baselines for the global and permanent effect of anthropogenic environmental change, they also cohere with different socio-political logics. The "early Anthropocene" corresponds with eco-modernist evaluations "that there has been no recent qualitative change [in human influence on the environment] and thus there is no need for a radical response" (Angus, 2015, unpaginated); the "industrial revolution" option draws attention to the evolution of a fossil-fuelled global capitalist system built on historically uneven distribution of resources (Malm & Hornborg, 2014);[3] and the "Great Acceleration" highlights the increase in population and consumption levels after World War II (Steffen et al., 2011).

The two challenges draw attention to the *ability* and *willingness* of stratigraphy to act as an arbiter of the Anthropocene. They indicate that the extent to which stratigraphy is methodologically *able* to act as an authoritative voice on the Anthropocene requires as much reflection as the extent to which it is *willing* to fulfil the societal function that this entails. In what follows, I examine the stratigraphic literature on the Anthropocene for answers to two analytical questions mirroring these challenges. First, the "question of ability" asks whether stratigraphy, with its established principles, methods and nomenclature, is able to evaluate the potential and actual manifestations of anthropogenic Earth system changes in the rock record. Second, the "question of willingness" asks if stratigraphers are willing to consider the potential philosophical and political implications of their work and account for them when designating the Anthropocene Epoch.

4.2 | The "question of ability"

As stratigraphy studies the layers and relative chronology of rocks, the question posed by the Anthropocene is if an internally consistent rock section caused by humans can be distinguished from other sections in the rock record. Normally, stratigraphy answers this question by characterising the content of that rock section and by defining its boundary to adjacent geological units. These two tasks are complementary but it is the choice of a stratigraphic boundary which provides the breakpoint for formalisation of geological time units and for stratigraphic controversy around the Anthropocene.

Since no single rock section exists where all the geological units are evident, "the best exposed example of the boundary between each unit", the so-called "Global Stratotype Section and Point" or GSSP, is conventionally selected as reference point by international agreement (Doyle et al., 2001, p. 53). Stratigraphers employ a variety of methods to detect potential stratigraphic markers and ultimately select one GSSP according to standardised criteria (Murphy & Salvador, 1999). This selection process has become central to stratigraphic practice because GSSPs ensure that practitioners defining geo-history speak a universal language (Cohen et al., 2013).[4] The criteria applied carry "heavy historical baggage" (Aubry et al., 2000, p. 208) and, as we will see, can be interpreted flexibly. But they persist as *standards* for determining the value of designated geological units.

The Anthropocene Epoch poses technical difficulties for stratigraphers seeking to conform with these standards because anthropogenic Earth system change is a comparatively recent phenomenon. As such, it delineates a very short period in Earth history characterised by a deposition of anthropogenic sediments and a subsequent formation of rocks that does not match those of other geological units (Finney & Edwards, 2016b; Gale & Hoare, 2012; Rull, 2016a; Walker et al., 2015; Zalasiewicz et al., 2014a; Zalasiewicz et al., 2014b). Consequently, the human imprint in the rock record so far has limited distinctiveness and permanence, which poses the following methodological difficulties for stratigraphers.

First, various development trajectories of human societies across the globe mean that the anthropogenic rock record is characterised by apparently similar material that, however, varies in age from place to place (Brown, 2014; Brown et al., 2013; Edgeworth, 2014; Edgeworth et al., 2015; Gale & Hoare, 2012; Oldfield et al., 2015; Streeter et al., 2015; Waters et al., 2014a; Wolfe et al., 2013; Zalasiewicz et al., 2014a; Zalasiewicz et al., 2012; Zalasiewicz et al., 2014c; Zalasiewicz et al., 2016a). Even though this "diachroneity" is a feature of much of the Earth's rock record (Doyle et al., 2001, p. 31), it cannot easily be resolved in the thin record of the Anthropocene (Autin & Holbrook, 2012a). Here imprecision has a greater effect than in epochs such as the Pleistocene whose rock record has accumulated over 2.5 million years.

Second, the stratigraphic events of the Anthropocene are still unfolding and its rock record remains incomplete (Edgeworth, 2014; Edgeworth et al., 2015; Gibbard & Lewin, 2016; Walker et al., 2015; Zalasiewicz et al., 2014c). Consequently, defining an upper stratigraphic boundary, conventionally called for to reliably characterise the full stratigraphic content of geological units, is not yet possible for the Anthropocene (Autin & Holbrook, 2012a; Barnosky, 2014; Rull, 2016a; Wolfe et al., 2013). Third, and closely related to the last point, the continuing human "bioturbation", or reworking of the developing rock record, means that stratigraphers assessing this record in the future may reach different conclusions about its content and boundaries than those working today (Coughlan et al., 2015; Zalasiewicz et al., 2016a). This raised

the concern that today's stratigraphic evidence may not be obtainable in the distant future; such concerns are aggravated by the often limited preservability of anthropogenic deposits used to characterise Anthropocene sediments (Ferreira et al., 2016; Gale & Hoare, 2012; Oldfield et al., 2015; Waters et al., 2014a; Wolfe et al., 2013; Zalasiewicz et al., 2014a).

These difficulties evoke a gap between established stratigraphic practices and the multidisciplinary evidence for the anthropogenic Earth system changes, which will potentially manifest in the rock record. Amid growing evidence that the Anthropocene is stratigraphically real (University of Leicester, 8/29/2016; Waters et al., 2016), stratigraphers debate if the recognition of the Anthropocene is within the scope of their discipline or not. At the base of this controversy lie different opinions on how conservatively and liberally established principles and procedures of stratigraphy, many of which are plainly set out in the International Stratigraphic Guide (Murphy & Salvador, 1999), should be applied in practice, for example, when evidence for phenomena of such a novel type as the Anthropocene amounts. The case of the Anthropocene thus demonstrates that the codified approach of stratigraphy represents "normative decisions of one generation of geologists" that are re-negotiated by each successive generation (Walsh et al., 2004, p. 214). Although this discussion includes many voices, two approaches at the ends of a broad scale illustrate the debate.

A liberal approach views the Stratigraphic Guide as a flexible framework for the recognition of novel phenomena with stratigraphic relevance even if they originate outside the discipline and pose challenges for the established practice (Gibbard & Lewin, 2016; Waters et al., 2016). From this perspective, methodological difficulties that the Anthropocene poses should not inhibit its stratigraphic recognition within existing frameworks. On the one hand, some of the aforementioned difficulties are common to many investigations of several stratigraphic boundaries (Brown et al., 2013; Gibbard & Lewin, 2016; Gibbard & Walker, 2014; Williams et al., 2014; Zalasiewicz et al., 2012; Zalasiewicz et al., 2014b; Zalasiewicz et al., 2015b; Zalasiewicz et al., 2016b). As ambiguity prevails even with established boundaries, the GSSP for the Cambrian is currently being challenged and the beginning of the Quaternary Period was recently redefined (Zalasiewicz et al., 2015b).

On the other hand, even if no GSSP can be found, a liberal approach includes the possibility to use a numerical date in the form of an otherwise non-operational Global Standard Stratigraphic Age (GSSA), to give consistent meaning to the Anthropocene (Certini & Scalenghe, 2011; Wolfe et al., 2013; Zalasiewicz & Williams, 2014; Zalasiewicz et al., 2011a; Zalasiewicz et al., 2014a; Zalasiewicz et al., 2015b). Even more enterprising positions propose that the abovementioned methodological difficulties highlight shortcomings in and warrant adaptation of established stratigraphic practice.

The wide-ranging adaptations suggested in the literature include an update of classifications for stratigraphic evidence so that technological artefacts and anthropogenic minerals would be recognised (Edgeworth, 2014; Edgeworth et al., 2015; Howard 2014; Ford et al., 2014; Waters et al., 2014b; Zalasiewicz et al., 2016a). Some authors suggest the division of a new branch of stratigraphy that better reflects recent stratigraphic changes caused by humans (Richter, et al., 2015; Zalasiewicz et al., 2014d; Zalasiewicz et al., 2016b; Ford et al., 2014). Others problematise the rationale behind stratigraphic boundary choice by proposing to change the formal requirements for precise and globally synchronous boundaries as they differ from a significant proportion of archaeological and geological evidence of diachronous sedimentary processes (Edgeworth et al., 2015, p. 19; Poirier et al., 2011; Rickards et al., 2015a, 2015b).

As a swift implementation of these proposals is unrealistic, a liberal approach often resorts to advocating an informal use of the Anthropocene. Zalasiewicz et al. (2011b) argue that as long as frameworks of analysing past and present Earth system change diverge, formalisation of the Anthropocene is unlikely and an informal definition will best serve the working sciences. At the same time, mounting geological evidence for the Anthropocene Epoch has given hope to liberal authors that formalisation of the Anthropocene is achievable *within* the established rules and procedures of stratigraphy (Waters et al., 2016). Unaffected by this, authors taking a conservative approach are convinced that this evidence departs from official requirements. Formalisation, they suggest, should at best be postponed into the distant future (Finney & Edwards, 2016b; Walker et al., 2015).

In addition to discounting evidence for the Anthropocene Epoch in this way, the conservative approach upholds the established stratigraphic standards because individual geological time units are only meaningful in relation to a coherent framework for their definition. As such, units adjacent to a proposed Anthropocene Epoch, such as the Holocene that precedes it, should not be terminated lightly. The criteria for GSSPs should be consistently applied in order to provide a universal language for stratigraphy (Finney & Edwards, 2016a, 2016b; Walker et al., 2015).

From a conservative perspective, the Anthropocene Epoch puts the stratigraphic nomenclature and the discipline as a whole at risk (Autin & Holbrook, 2012a) because it incites a wilful alteration of the Geological Time Scale (GTS), "'one of the greatest achievements of humanity"' (Monastersky, 2015, p. 145; Rull, 2016b). Formalisation of the Anthropocene Epoch would impede the principle function of the GTS: aiding interpretation of Earth history (Walker et al., 2015). In fact, the Anthropocene Epoch would conclude the GTS as it would end only if humans ceased to influence the Earth system; this would require "a dramatic demographic reduction and a deep cultural disruption, after which the continuity of the

current GTS may not be guaranteed" (Rull, 2016b, p. 3). As a consequence of these repercussions, a conservative approach to stratigraphic practice advocates either an exclusively informal use of the term Anthropocene as a historical term (Gibbard & Walker, 2014; Walker et al., 2015), or rejects even this informal use because it misleadingly implies an official recognition by the ICS (Rull, 2016a).

Although some publications favour a conservative and others a liberal approach, the distinction between these two approaches is blurred when looking to individual authors. Gibbard and Lewin (2016), for example, equally emphasise the historical flexibility of stratigraphic analyses and the importance of a consistent formalisation practice regarding the use of GSSA and GSSP. Even if they cannot be attributed to individual authors, the liberal and conservative arguments stated in the literature show that the "question of ability" is relatively well reflected by contributing authors. The stratigraphic debate about the Anthropocene Epoch seems to be as much an evaluation of anthropogenic sediments as of the ability of stratigraphy to incorporate this evidence into its existing conceptual framework. The abovementioned arguments exceed a selection of the most appropriate methods for recognising the Anthropocene Epoch to deal with the challenges posed by associated sediments; they indicate how stratigraphy ought to be practiced. Accordingly, whether the "question of ability" is answered affirmatively or negatively depends on what is considered "good" stratigraphic practice.

4.3 | The "question of willingness"

Compared with the methods of studying the relationship between rock layers, the philosophical and political implications of this study are neglected in the stratigraphic discourse about the Anthropocene. Only 15 of the publications reviewed suggest answers to the "question of willingness"; that is, if stratigraphy should account for the societal implications that a choice of the stratigraphic boundary and formalisation of the Anthropocene Epoch may have.

This limited reflection is unsurprising given that political and philosophical considerations are generally unfamiliar to geology, the umbrella discipline in which stratigraphy is one field of investigation. Indisputably, geology has reflected on its relationship to society by considering its contribution to sustainable economic growth, including the environmental impacts of its research practices and of industries using the results of stratigraphic research (The Geological Society of London, 2014). But stratigraphic research on the Anthropocene is unlikely to have a direct environmental effects, change industrial practices and contribute to economic growth because it is concerned with the adaptation of the Chronostratigraphic Chart (Figure 1), a more conceptual issue.

The finding that political and philosophical implications have been overlooked in stratigraphic research on the Anthropocene is confirmed by the limited number of research articles ($n = 4$) with relevance to the "question of willingness" (Autin & Holbrook, 2012a; Finney & Edwards, 2016b; Gibbard & Lewin, 2016; Rull, 2013). All other publications are contributions to commentary sections without rigorous peer review of journal editors. Notwithstanding this exclusion of the political and philosophical implications from the formal publication spaces of stratigraphic research, the following analysis of stratigraphic publications shows that some stratigraphers reflect on the implications of their research. While they do so in heterogeneous ways, two opposing answers to the "question of willingness" appear in the stratigraphic literature, of which the second combines ostensibly inconsistent positions.

First, some authors have opposed any involvement of stratigraphy in societal debates about the Anthropocene. Autin and Holbrook (2012a), for example, argue that the stratigraphic community should not judge the benefits and costs of Earth system change and, instead, be wary of examining the stratigraphic case of the Anthropocene, particularly because of the term's popular appeal. The rationale behind their argument is that "awareness about environmental change is a separate issue from the definition of practical stratigraphic units" and to mix the two would threaten the reputation of stratigraphy as a credible discipline (Autin & Holbrook, 2012a, p. 61). Similarly, Valenti Rull (2013) has protested that suffixes with accepted meaning in stratigraphy such as "-cene" should be removed from popular debates about Earth system change. This forthright rejection of willingness is arguably an attempt to prevent doubts being cast over the value neutrality of stratigraphy. The former Chair of the ICS, Stan Finney, fears that political matters will trump stratigraphic ones when the Anthropocene is being considered for adoption within the GTS, leading to a focus on calendar dates rather than stratigraphic content (Finney & Edwards, 2016b).

Second, a number of authors acknowledge that defining the inception of the Anthropocene Epoch can affect conceptualisations of humanity's place in Earth history, and change international law (Zalasiewicz, 2013), societal concerns with environmental protection and social justice (Zalasiewicz et al., 2010, p. 2231) as well as research agendas into these issues (Lewin & Macklin, 2014). Moreover, some stratigraphers embraced the public interest in Anthropocene stratigraphy and stratigraphy's ensuing influence in societal discourses (Gibbard & Lewin, 2016; Stewart, 2016; Zalasiewicz et al., 2012). Jan Zalasiewicz (2013, p. 9), for example, argued that a decision on formalising the

Anthropocene should perhaps "not only depend on scientific justification (as that is a given), but also on its use to the world beyond geology". In portraying such willingness, these authors risk what Autin and Holbrook (2012b) dread; an association with geoscientists suspected of having deliberately moved into the realm of politics while using science to disguise their true motivation to combat the environmental crisis (Luke, 2013; Baskin, 2014; Castree, 2014a, pp. 247–248; Davison, 2015).

To pre-empt such association both by colleagues and commentators, "willing" stratigraphers increasingly combine an acknowledgment of the societal implications of their research with a denouncement of social values of environmental protection in stratigraphic practice (Zalasiewicz et al., 2016b). This combination is best illustrated by a controversial debate about a paper by Lewis and Maslin (2015b) that rejects existing proposals for a starting date of the Anthropocene as these lack a synchronous stratigraphic marker. Their preferred "Orbis hypothesis" marks the beginning of the Anthropocene in 1610, when Europeans colonised the Americas which they regard as advantageous because it combines geological and historical significance (Lewis & Maslin, 2015b).[5] Historically, the arrival of Europeans in the Americas initiated the first global trade network and sparked war, famine and diseases that led to the largest decline of regional population in the past 13,000 years. Geologically, international trade resulted in an unprecedented global exchange of plant species, whose pollen are preserved in marine and lake sediments. More importantly, the decline in regional population caused a near cessation of farming and the subsequent regeneration of forests led to a dip in atmospheric CO_2 of 7–10 ppm ("Orbis dip"), which serves as an adequate GSSP, so the authors.

Lewis and Maslin have debated their proposal with other stratigraphers, who criticise, for example, that the "Orbis dip" is within the range of natural variability and not necessarily of anthropogenic origins (Zalasiewicz et al., 2015a).[6] The interlocutors in this debate (hereafter the "Orbis controversy") speak to the "question of willingness" in the variable way alluded to above.

On the one hand, the authors accept that stratigraphic research can influence societal discourses. In their original paper, Lewis and Maslin (2015b) highlight that the Anthropocene may change perceptions of Earth system change in the same way that scientific discoveries have changed worldviews in the past. Particularly, choosing a starting date for the Anthropocene points to different causes of the Anthropocene. The "Orbis hypothesis", they contend, highlights unequal power relationships, globalised trade and fossil fuels as causes of the Anthropocene. Even if the specific stratigraphically defined start for the Anthropocene should prove philosophically insignificant, they add in their reply to Clive Hamilton (Maslin & Lewis, 2015), the formal adoption of the Anthropocene confirms a scientific and philosophical paradigm change that puts humans back into the centre of planetary processes. This contention is re-emphasised by Lewis and Maslin (2015a) and also accepted by Zalasiewicz et al. (2015a).

On the other hand, the interlocutors in this debate exclude societal concerns related to stratigraphic knowledge from stratigraphic practice. Lewis and Maslin (2015b) caution against religious beliefs or political ideologies that have inappropriately influenced geological study in the past. To avoid such biases, the assessment of stratigraphic evidence for the Anthropocene should be guided by formal stratigraphic procedures and kept separate from more general agreements with the scientific notion of anthropogenic Earth system change (Maslin & Lewis, 2015). Zalasiewicz et al. (2015a) equally argue that the Anthropocene's stratigraphic boundary should be "pragmatically and dispassionately chosen". But they employ this argument to allege that Lewis and Maslin (2015b) fail to do so and use social narratives as a key criterion in selecting a stratigraphic boundary instead. Lewis and Maslin reciprocate this criticism by contending that the exceptionalism that many stratigraphers (e.g., Zalasiewicz et al., 2015b) are claiming for the Anthropocene is "biased and ideologically driven" (Lewis & Maslin, 2015a, p. 130).

As this debate demonstrates, some stratigraphic publications acknowledge that stratigraphic research can influence societal discourses by inadvertently drawing attention to different historical periods as starting points of anthropogenic Earth system change. Simultaneously, these publications reject the influence of social values on scientific research despite its societal relevance. "Willing" accounts acknowledge potential philosophical and political implications of stratigraphic research but they reject any implications for researching the stratigraphy of the Anthropocene. The implications of this approach will be demonstrated in the next section.

5 | DRAWING THE BOUNDARIES OF VALUE-FREE ANTHROPOCENE STRATIGRAPHY

The different answers given to the "question of ability" and the "question of willingness" draw different boundaries around stratigraphy's epistemic authority over the Anthropocene. Even though no consensus exists in the stratigraphic community

on the "question of ability", it is well covered in the literature and its implication for "boundary work" can be easily deduced. A conservative approach favours a negative answer and demarcates a small and homogenous domain of epistemic authority. A positive answer, which is more likely under a liberal approach, allows for an expansion of stratigraphy's epistemic authority to domains previously occupied by other experts in global change science. The "question of willingness" is more indirectly addressed in the stratigraphic literature and a distinction between two distinct approaches is more difficult than for the "question of ability". In what follows, I further analyse the "Orbis controversy" to demonstrate how stratigraphic publications create a semi-permeable boundary between stratigraphic and societal discourses about the Anthropocene, which rests on a "value-free ideal of science".

5.1 | The semi-permeable boundary between Anthropocene stratigraphy and society

The analysed publications suggest that the stratigraphic community either separates itself from societal discourses as much as possible or endorses a unidirectional interaction with society; the boundary constructed between stratigraphic research and societal discourses is either impermeable or semi-permeable. The notion of impermeability is untenable due to the social character of scientific knowledge (Longino, 1990). The construction of a semi-permeable boundary demonstrates the flexibility of "boundary work" to move between the "purification" and "impurification", which Gieryn (1999) describes as central means to protect both the autonomy and the authority of science. Adopting this flexible approach, some stratigraphic publications simultaneously legitimise the ability of stratigraphic insights to migrate into societal discourses and the inability of societal discourses to influence stratigraphic research. The "Orbis controversy" illustrates this flexibility of "boundary work" in Anthropocene stratigraphy.

On the one hand, interlocutors in the "Orbis controversy" open the boundary between production and consumption of stratigraphic knowledge by contemplating the political and philosophical consequences of choosing a stratigraphic boundary for and officially formalising the Anthropocene. This "impurification" works to demonstrate that stratigraphic research is relevant to a wider audience and thus expands the epistemic authority of stratigraphy into new domains.

On the other hand, the authors in this controversy reinforce the boundary between production and consumption of knowledge by advocating the exclusive use of stratigraphic criteria in research on the Anthropocene Epoch and rejecting any influence of political or philosophical considerations on their work. This "purification" monopolises the criteria used in stratigraphic practice and detaches stratigraphy from downstream consequences when others use stratigraphic knowledge. Purification thereby helps to protect the autonomy of stratigraphy from "intrusive demands for accountability" (Gieryn, 1999, p. 17) to non-stratigraphers as well as from non-stratigraphers seeking to exploit the epistemic authority of stratigraphy to their own ends.

The above analysis elucidates that stratigraphic publications on the "Orbis hypothesis" move between appealing to and expelling (the concerns of) non-stratigraphers from the territory of stratigraphy's epistemic authority. Hence, I would question Heather Swanson's statement that "the Anthropocene concept is proving politicising, not depoliticising [for stratigraphers] – providing ways for them to bring power, colonial histories, and human inequalities" into their analysis (Swanson, 2016, p. 161). The authors of the analysed publications advocate an in-depth study of the Anthropocene not just to attract public interest and influence political processes. Politicisation and de-politicisation occur simultaneously as Anthropocene stratigraphy acknowledges the relevance of stratigraphic research to worldviews but ultimately emphasises scientific objectivity to maintain its autonomy. Rather than comprising an attempt by scientists to politicise science, as described by Roger Pielke (2004), the semi-permeable boundary constructed in the "Orbis controversy" is a means to negotiate the epistemic authority of stratigraphy regarding the Anthropocene.

5.2 | The "ideal of value-free science" in Anthropocene stratigraphy

The "boundary work" outlined above is based on an ideal of science as free of social values, that is, free of the aims and moral principles of a particular society. The "ideal of value-free science" accepts only epistemic values as legitimate causes of scientific controversies and changing scientific standards (Douglas, 2009). As such, it attributes selected characteristics to the institutions of science and thus wrongly legitimises the epistemic authority of science. The following discussion is concerned with the effects of this ideal on epistemic authority rather than with the relationship between the freedom and social responsibility of science, a longstanding issue in science ethics (Nelkin, 1977; Reydon, 2013).

Two related premises justify the "ideal of value-free science". First, value freedom defines what counts as science and what does not. From this perspective, scientific knowledge production depends on changing evidence and the methods with which a scientist perceives this evidence (Doppelt, 2008). This relationship between a scientist and the available evidence

should be guided by epistemic values such as empirical adequacy, scope or simplicity. If social values such as environmental justice became a factor in determining the relevance and value of available evidence, knowledge production would cease to be scientific. In this framing, epistemic values are "constitutive" of science whereas social values are by definition located outside of its boundaries (Longino, 1990). The consequence of this conception of science is that social values become relevant only in the *external use* of scientific knowledge when research results are interpreted by societal actors for application (Kincaid et al., 2007).

The second premise is that the "ideal of value-free science" protects science from relativism. It is rooted in the idea that social values "lack truth value" (Lacey, 1999, p. 7) because they are subjective expressions of personal preferences and immune to rational argument (Potthast, 2015). According to this meta-ethical defence of the "ideal of value-free science", accepting social values into science would lead to arbitrary judgements of the relationship between evidence and hypotheses. From this perspective, a unified treatment of phenomena and an objective scientific inquiry require a focus on hypothesis testing (i.e., the relation between method, data and theory) that excludes "subjective" background conditions (Longino, 1990).

These two premises are evident in the stratigraphic publications analysed, regardless of whether they construct an impermeable or semi-permeable boundary around stratigraphy. In the following, however, I focus again on the "Orbis controversy" and outline how the semi-permeable boundary constructed by the authors involved is based on the "ideal of value-free science".

Reflecting the first premise, the authors conceptualise their influence on societal discourses as processes of knowledge application that take place outside of science, separate from stratigraphic practices and the epistemic values that guide them. Lewis and Maslin (2015a), for example, argue that consideration of the societal implications of stratigraphic research is important but should only be done *after* the scientific work of choosing a stratigraphic boundary for the Anthropocene is concluded. From this perspective, social values are coincidentally implied in stratigraphic insights and only become relevant once that knowledge is used outside of stratigraphy.

In the vein of the second premise, the authors uphold the established rules and procedures of stratigraphy as vanguards against the presumed relativism of social values. In particular, the use of a GSSP is portrayed as a signifier of epistemic values, which ensures that the selection of a stratigraphic boundary for the Anthropocene is not "arbitrary" (Lewis & Maslin, 2015a, p. 131). This is why Lewis and Maslin argue that the Anthropocene should not be exempt from an established definitional process (Maslin & Lewis, 2015, p. 116) and why Zalasiewicz et al. (2015, p. 123) contend that the established criteria for selecting stratigraphic boundaries should be employed and kept separate from social narratives.

5.3 | Value freedom as "boundary work"

Although scientists use the "ideal of value-free science" to justify, often successfully, their epistemic authority (Beck & Mahony, forthcoming), philosophers of science reveal that this justification is a selective representation rather than a universally valid account of scientific practices. They have criticised the premises behind this ideal as simplistically dichotomising social and epistemic values (Doppelt, 2008), and they have proposed alternatives that allow social values to influence research results indirectly by "guid[ing scientific] interpretations and suggest[ing] models within which the data can be ordered and organized" (Douglas, 2009; Longino, 1990, p. 219). In this vein, Gieryn (1995, p. 406) contends that "'essential features" of science are provisional and contextual results of successful boundary-work, not determinants of who wins' credibility contests.

The employment of the "ideal of value-free science" in the stratigraphic controversies about the Anthropocene is not just a means to "purify" the boundary between stratigraphy and society as described above. In addition, the "ideal of value-free science" is used for "expulsion", another function of "boundary work" highlighted by Gieryn (1999). In this "boundary work", scientists contest among themselves for epistemic authority to clarify whose claims qualify as science and whose are denied this privileged status. Terms like "science" and "scientific", as much as "stratigraphy" and "stratigraphic", are membership categories that are socially attributed or denied (Lynch, 2004). The interlocutors involved in the controversy surrounding the "Orbis hypothesis" conduct this "boundary work" by accusing each other of political bias when they apply differently the ostensibly objective stratigraphic principles to the stratigraphic evidence for the Anthropocene. The "ideal of value-free science" affects where the boundary of epistemic authority is drawn both *around* and *within* stratigraphy.

6 | CONCLUSION

This paper explains the legitimate power of stratigraphy to define, describe and explain the Anthropocene with the role that society grants stratigraphy and the role that stratigraphy successfully claims for itself. Even though stratigraphy's

epistemic authority over the Anthropocene is conditional upon a wider societal "desire for the imprimatur of scientific authority", if and how it materialises depends on the "boundary work" of stratigraphy, that is, how stratigraphic practice is represented in stratigraphic discourse. This paper shows how stratigraphy responds to the two challenges of considering its ability to study the Anthropocene (the "question of ability"), and defining ways of operating in the face of the philosophical and political implications of its work (the "question of willingness"). The stratigraphic literature reveals a lack of consensus over the ability of stratigraphers to study the Anthropocene using their discipline's established principles, methods and nomenclature. Whether stratigraphy should continue to occupy a small but consistent territory of authority or if it should expand this territory remains subject to debate. Regarding the "question of willingness", stratigraphic discourse either portrays no willingness or it constructs a semi-permeable boundary to society, in which potential societal implications of stratigraphic research are acknowledged but not taken into account because of a fear that stratigraphic practice might become politicised. In taking this approach, the stratigraphic Anthropocene discourse flexibly moves between the "purification" and "impurification" of the boundary between stratigraphy and society. This can be seen as an attempt to expand the authority of stratigraphy and simultaneously protect its autonomy. A closer analysis of the arguments behind this approach showed that it is motivated by the "ideal of value-free science" which works further to protect the autonomy of stratigraphy from external demands and to draw the boundaries of epistemic authority within stratigraphy itself. It is in these ways that the stratigraphic discourse produces the epistemic authority of stratigraphy in regards to the Anthropocene.

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NOTES

[1] I accept communication as a central characteristic of disciplinary practice (Weingart, Carrier, & Krohn, 2015) and analytically regard geoscientists who contribute to the stratigraphic discourse about the Anthropocene as part of the stratigraphic community. Even if their membership is limited to exchanges about the Anthropocene, the geoscientists cited in this paper share a language and points of reference (e.g., the International Stratigraphic Guide) with researchers who actually practice stratigraphic research.

[2] However, the distinction between chronostratigraphy and geochronology has been a point of contention in stratigraphic discussions about the Anthropocene (Finney & Edwards, 2016b).

[3] Malm and Hornborg criticise that the mainstream scientific interpretation of the Anthropocene conceals, rather than reveals, this connection.

[4] The geological units within the Hadean, which is the Eon beginning with the formation of the Earth 4.6 billion years ago and ending 4 billion years ago, are exempt from this because they lack sufficient resolution in the rock record.

[5] Lewis and Maslin also consider a second alternative marking the beginning of the Anthropocene around 1964 when the radionuclide fallout of atomic bomb tests spiked, but they have come to prefer the Orbis hypothesis.

[6] This exchange began in the correspondence sections of *Nature* (Zalasiewicz, 2015) and *Science* (Lewis & Maslin, 2015c), and was extended in a series of paper-length comments (Hamilton, 2015; Zalasiewicz et al., 2015a) and respective responses (Lewis & Maslin, 2015a; Maslin & Lewis, 2015) in the *Anthropocene Review*.

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Appendix 4

The Anthropocene Working Group and its (inter-)disciplinarity

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The Anthropocene Working Group and its (inter-)disciplinarity

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ABSTRACT

This article investigates the internal dynamics of the Anthropocene Working Group (AWG), an expert body tasked with evaluating the stratigraphic case of the Anthropocene. The investigation focuses on the role of interdisciplinarity and disciplinarity in the AWG. The article draws on surveys and interviews with AWG members to characterize interdisciplinary collaboration in the AWG and discusses the relationship of the AWG to the stratigraphic community. The results reveal that the exchanges between disciplines in the AWG are 'multidisciplinary' and of limited scope. While social scientists in the group take a non-scientific role, the involvement of natural scientists in research activities is guided by the objectives of stratigraphy. Moreover, a lack of communication and trust had shaped the relationship between the AWG and the stratigraphic community until they devised pragmatic working arrangements that led the AWG to adapt its research practice and rationale. Despite calls to reform stratigraphic practice, the disciplinarity of the AWG prevails over innovative research practices inspired by interdisciplinary exchanges. In terms of theory, the study confirms that disciplines continue to provide the context in which interdisciplinary endeavors need to position themselves. Notwithstanding the pull of interdisciplinarity, the AWG's main point of reference remains the stratigraphic community.

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Introduction

As applications of the term multiply, the Anthropocene is becoming a keyword in debates about contemporary environmental change. Ever since the idea was raised in the Earth system sciences to describe the extension of resource exploitation by humans (Crutzen and Stoermer 2000), many other fields of studying socio-ecological systems have embraced the term. They include biology (Kidwell 2015), anthropology (Gibson and Venkateswar 2015), literary studies (Clark 2015), and social theory (Delanty and Mota 2017). While Earth system and other natural scientists have studied the effects of human activities on the Earth system as a whole (e.g. Steffen et al. 2015), social scientists have accentuated the interactions between specific social relations and their environments (e.g. Malm and Hornborg 2014), and humanities scholars have highlighted the inherent connections between the animate and the inanimate world (e.g. Yusoff 2013). The discussions in different communities have diversified the meaning of the Anthropocene, creating a heterogeneous discursive space.

The prevalence of the Anthropocene has been reviewed critically (Lorimer 2017; Swanson, Bubandt, and Tsing 2015). This engagement has included research practices that render the Anthropocene a knowable phenomenon and thus enable wide debates about it (Lövbrand, Stripple, and Wiman 2009; Cook and Balayannis 2015; Wissenburg 2016). Stratigraphy is particularly important in this regard because its research on the Anthropocene is replicated in many academic and public discourses. Accordingly, observers of the Anthropocene discourse have reflected on stratigraphic research related to the Anthropocene (Szerszynski 2012; Braje 2015; Monastersky 2015; Rickards 2015; Swanson 2016; Clark 2017; Warde, Robin, and Sörlin 2017). But the group that drives Anthropocene research in stratigraphy, the so-called Anthropocene Working Group (AWG), has not yet been studied in depth. This article fills this gap by analyzing the research practice of the AWG.

The AWG was established in 2009 as a working group within the International Commission on Stratigraphy (ICS), which regulates the way in which the time, name, rank, and stratigraphic markers of new geological periods are approved (Ogg 2004). Many such working groups exist, tasked with selecting and defining the boundaries between geological units (International Geological Union 2002), but they have no final decision-making power. They are

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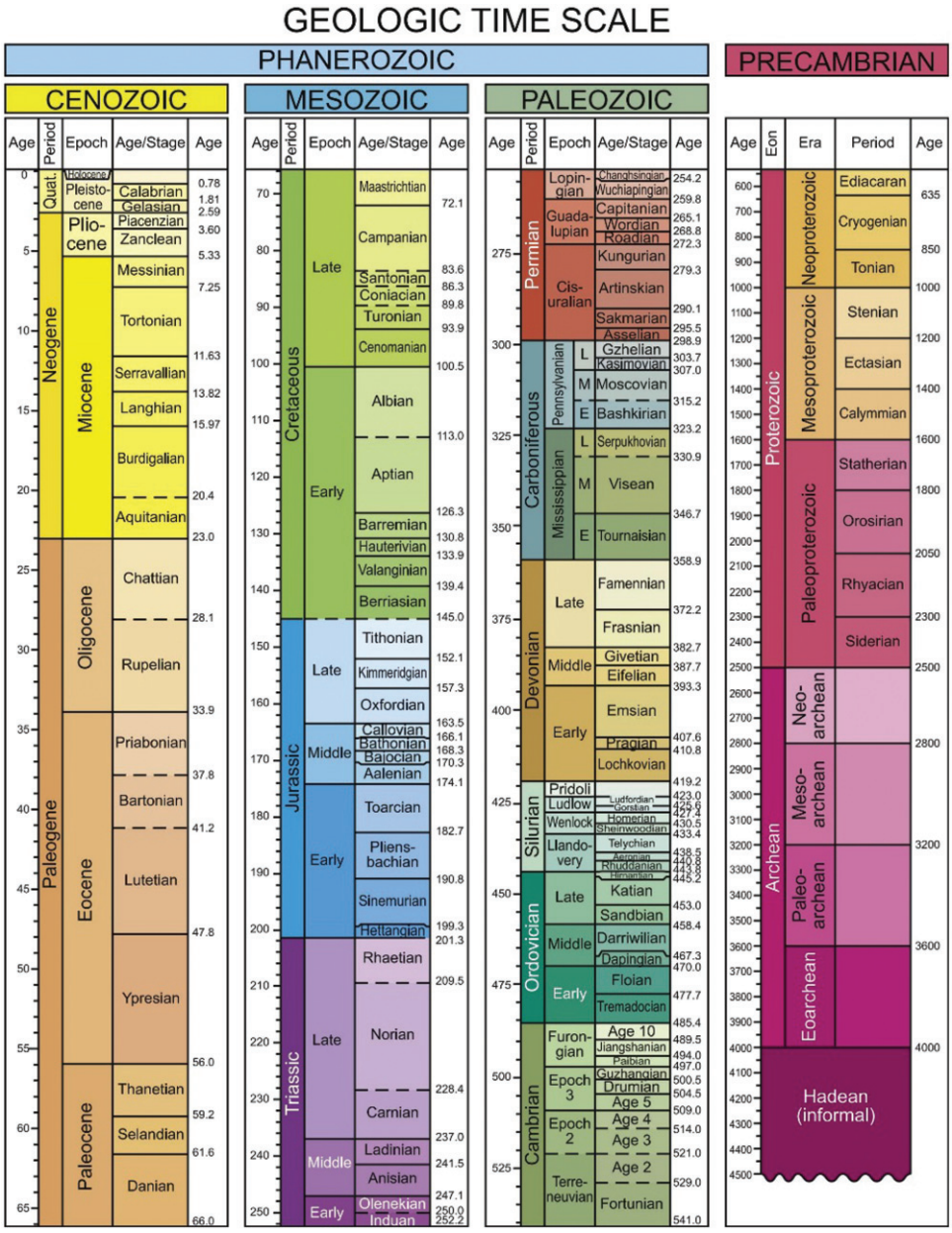

Figure 1. The Geological Time Scale (Gradstein et al. 2012).

temporary bodies (normally eight years) whose members report their work to the subcommissions under which they reside. Which boundaries are officially adopted for the Geological Timescale (see Figure 1) is eventually decided by the executive committee of the International Union of Geological Sciences (Finney and Edwards 2016b). Accordingly, the AWG is the first among several expert bodies that will examine and debate the geological case of the Anthropocene. The AWG has been preparing a formal proposal to its parenting Subcommission on Quaternary Stratigraphy (SQS) and the stratigraphic community at large. Although a preliminary recommendation was widely noticed when presented in 2016 at the International Geological Congress (Zalasiewicz and Waters 2016), the process of formalization is ongoing (Zalasiewicz et al. 2017).

Institutions such as the AWG serve to accredit emerging bodies of knowledge and they are thus important research areas of science and technology studies (STS). In the words of Sheila Jasanoff (Jasanoff 2014, p. 40): '[w]hen environmental knowledge changes, … new institutions emerge to provide the web of social and normative understandings within which new characterizations of nature … can be recognized and given political effect'. The research of the AWG affects how people conceive the Anthropocene discourse because it is currently the only body that officially examines whether or not the Anthropocene Epoch exists. Although it is a temporary body and has limited decision-making power even in the field of stratigraphy, the AWG makes for the most visible representative of stratigraphic expertise, which 'is widely acknowledged to hold "legitimate power to define, describe and

explain" (Gieryn 1999, p. 1) what the Anthropocene is' (Lundershausen 2018, p. 9). In this vein, the AWG is an important vehicle for developing knowledge (and action) regarding the Anthropocene.

Research question

While the AWG can be examined from several angles, this article focuses on the disciplinarity and interdisciplinarity of the AWG. It asks to what extent the AWG is interdisciplinary and what its relationship with its parent discipline stratigraphy is. Published debates about the Anthropocene and global change research suggest that interdisciplinarity characterizes the research practice of the AWG and that its relationship with the stratigraphic community is difficult.

It stands to reason that the AWG experiences a pull toward interdisciplinarity amid a wide discourse advocating interdisciplinary research (Nida-Rümelin 2005; Krohn 2012; Costanza 2013) particularly in studies of the Earth system (Cornell et al. 2012; Brasseur and van der Pluijm 2013; Pahl-Wostl et al. 2013). In the vein of this discourse, commentators often view the Anthropocene as a 'bridge' between disciplines (*Nature* 2011; Jahn, Hummel, and Schramm 2015; Brondizio et al. 2016, p. 318). For many, the term promises deeper (Berkhout 2014; Johnson et al. 2014; Castree 2017) and wider collaborations between different disciplines (Kotchen and Young 2007; Palsson et al. 2013; Johnson et al. 2014). Mirroring this hope, all three journals holding Anthropocene in their titles advocate and claim an interdisciplinary approach.[1]

The membership of the AWG suggests that this pull has affected the AWG. It unconventionally comprises a large group of 35 members with a great variety of disciplinary backgrounds (Zalasiewicz, Waters, and Head 2017). Although the members of other ICS working groups are diverse to the extent that they represent the methodological diversity in stratigraphy, the AWG is different in that only half of its members have official training in geology (*Nature* 2015). Some of them are trained in the social sciences such as law or communication studies. This diversity could be justified with the unusual character of the Anthropocene, the stratigraphic study of which ostensibly benefits from insights of other disciplines about environmental change on the Earth surface (Zalasiewicz et al. 2010; Steffen et al. 2016).

But while some geoscientists deem it necessary to include social scientists and humanities scholars in the stratigraphic ratification process of the Anthropocene (Ellis et al. 2016), others have defended the separation between a stratigraphic definition of the Anthropocene as a geological epoch and definitions of the Anthropocene advanced by other disciplines (Maslin and Lewis 2015; Finney and Edwards 2016a). Within the stratigraphic community, the value of stratigraphic research on the Anthropocene, generally, and the way it has been conducted by the AWG, specifically, is controversial due to concerns that it does not follow established stratigraphic practice (Autin and Holbrook 2012; Finney and Edwards 2016b). These published debates suggest that the standing of the AWG in the stratigraphic community is imperfect.

The co-constitution of disciplines and interdisciplinarity

The abovementioned debates in Anthropocene geoscience reflect concerns in the theoretical literature about the apparent tension between interdisciplinary research and disciplines. This tension is illustrated by the common usage of the abstract noun for 'interdisciplinarity' and the concrete noun for 'discipline', which indicates that interdisciplinary research is often seen as theoretically and methodologically open, whereas disciplinary research is regularly portrayed as stable and homogenous in these regards. This epistemic dichotomy has allowed advocates of disciplinary research and its interdisciplinary critics to argue, respectively, that disciplines enable or restrict the production of scientific knowledge (Schaffner 2014). Characterizing the disciplinarity and interdisciplinarity of the AWG can contribute to two central concerns of this literature.

First, studying the AWG reveals if the epistemic dichotomy is justified or if disciplinarity and interdisciplinarity are actually co-constituted as increasingly popular terms like 'inter-discipline' and 'disciplinarity' suggest. These terms are the result of work which demonstrates that disciplines are often internally divided (Potthast 2010) and that their external boundaries are porous (Osborn 2014). Julie Thompson Klein (1996) has prominently argued that the crossing of disciplinary boundaries is an intrinsic part of the formation of disciplines and epistemic innovation within them. Klein contends that the very criteria used to demarcate boundaries between disciplines (such as material fields and problems, analytical tools and methods, or theories, laws, and concepts) also connect different disciplinary practices. Consequently, disciplines and interdisciplinarity are increasingly recognized as co-constituted. Huutoniemi et al. (2010, p. 80) argue that the 'fundamental challenge of creating a valid measure of interdisciplinarity originates from the complexity of identifying a discipline in a conceptually and empirically acceptable way'.

Second, the study of the AWG can contribute to understanding the degree of social and organizational competition between established disciplines and emerging fields of interdisciplinary research. The STS literature, even when it has questioned the epistemic dichotomy, has highlighted this competition by examining both the established influence of disciplines in the social order of knowledge production and the challenges that interdisciplinary research poses to it. Barry, Born, and Weszkalnys (2008, p. 20–21) comprehensibly describe the ensuing tension in the following way:

> Disciplines discipline disciples. [They] ensur[e] that certain disciplinary methods and concepts are used rigorously and that undisciplined and undisciplinary objects, methods and concepts are ruled out. By contrast, ideas of interdisciplinarity … imply … that the disciplinary and disciplining rules, trainings and subjectivities given by existing knowledge corpuses are put aside or superseded.

Disciplines, though diverse in size and structure, are institutions with a historically developed, officially recognized and institutionalized capacity to influence scientific knowledge production (Stehr and Weingart 2000). Disciplines are powerful particularly because they are able to police and effectively stabilize scientific communication, for example, through disciplinary journals for peer review and scientific associations that control the nomenclature of and accreditation to a field of study (Weingart, Carrier, and Krohn 2015). As a result, the main point of reference and accountability for scientists is often their disciplinary community.

Gibbons et al. (1994) have prominently argued that interdisciplinary research challenges this social order established by disciplines. They state that the pluralization of scientific knowledge production has weakened the monopoly of disciplines. Recent commentators add that science, especially climate science (Beck 2012), is increasingly expected to be accountable not just to the disciplinary communities but also to public and political communities that hold stakes in the validity of scientific claims (Jasanoff 2012). This 'logic of accountability' is such a prominent rationale for interdisciplinary practice that it has found its way into a seminal typology of the latter (Barry, Born, and Weszkalnys 2008).

In reality, the crossing of disciplinary boundaries is as much epistemically potent as it is socially challenging for disciplines. Particularly the literature on the specialization of disciplines shows that boundary-crossings hold a dual potential for strengthening existing disciplinary communities through internal innovation and for fragmenting them through the formation of new disciplines. Firstly, a discipline can evolve internally by developing a specialized research community that communicates in reference to its members as well as to the disciplinary community at large (Weingart, Carrier, and Krohn 2015). This internal specialization does not diminish the integrity of the discipline and can even support it by allowing for innovation in knowledge production, which creates a wider knowledge base on which the discipline rests (Klein 1996). A second form of discipline specialization occurs when groups of researchers start to disassociate themselves from their original disciplinary community. Specialized communities of researchers then build internal communicative connections that subvert those with the parent discipline or existing disciplines generally (Weingart, Carrier, and Krohn 2015, p. 44). As a result, a hybrid discipline (Klein 1996, p. 44) or inter-discipline can emerge that seeks to formally establish itself.

Methods: case study of the AWG

The investigation presented in this article builds on a qualitative case study of the AWG that set out to better understand stratigraphic practices in face of a wider Anthropocene discourse. The internal workings of the AWG, as well as their relation to outside communities and discourses, were major interests in the online survey and semi-structured interviews conducted with AWG members for this study. The resulting analysis is a qualitative case study of the Anthropocene Working Group. The insights provided are valuable not by way of being generalizable across research on the Anthropocene, stratigraphic or otherwise, but by being specific to a particular way of researching the Anthropocene (Clifford, French, and Valentine 2010). Although these insights are based on a small sample, their contextual nature can usefully complement theoretical accounts of interdisciplinary and disciplinarity. This study was initially prepared together with Jacob Barber (University of Edinburgh) and George Holmes (University of Leeds) to maximize access to AWG members and to increase the variety and quality of questions posed to them. The result of this collaboration was a pool of data that was subsequently used for separate research projects of the different researchers.[2]

The pool of data was generated in the following way. The secretary of the AWG, Colin Waters, kindly assisted in sampling participants by sharing the invitation to complete the survey with all AWG members. Although not all AWG members participated in this study (see Table 1), the survey provided an overview of the diverse opinions within the group. To accommodate for the various areas of expertise in the group, the survey comprised 21 open-ended question, which inquired into the

Table 1. Number of participants.

	Survey	Interview	Total
Participants	17	11	18
Stratigraphers	11	8	12
Natural scientists	3	2	3
Social scientists	3	1	3

internal dynamics of the AWG, its influence on society, and the stratigraphy of the Anthropocene including its formalization as an official geological epoch. The semi-structured interviews complemented the rigid structure of the surveys that produce reliable results but raise questions about validity (Conrad and Schober 2010, p. 173). They add adequacy by providing a possibility for clarification both on behalf of the researcher and the respondents. The interview questions follow up on answers given in the survey. While these questions were prepared collaboratively, the interviews, which lasted between 38 and 126 minutes, were conducted individually by different researchers of the team.

The open-ended interviews enabled participants to provide their personal accounts of the AWG's work. This approach is problematic to the extent that AWG members are part of a scientific elite capable of providing 'the public relations side of events rather than their own opinion' (Mikecz 2012, p. 484). However, the agency of participants in 'actively construct[ing] the information provided in the interview' is not exclusive to elite interviews and needs to be addressed generally (Faircloth 2012, p. 270). Applying critical judgment while taking participants' accounts seriously is the right approach to this issue. This study reconstructed the statements of participants in comparison to each other and within the context of the Anthropocene debate. Contradictory statements could thus be revealed and greater meaning attributed to the individual perspectives of participants.

Qualitative content analysis (Schreier 2012) was chosen as an appropriate method to evaluate the pool of data. It systematically explores the content of a text by detecting themes in the material and specifying what is said about these themes by creating subcategories. I initially followed themes from a previous review of the published stratigraphic literature (Lundershausen 2018). In addition, I used an inductive approach to coding, following the concepts that emerged rather than applying pre-existing theoretical concepts to the material. As a result, new themes become apparent, including 'the constitution of disciplinary communities', 'the meaning of interdisciplinary exchanges' as well as 'the engagement of science with the public and the media'. I ultimately focused on these themes, and reorganized the material that they comprised into two issues, i.e. 'interdisciplinarity and disciplinarity' and 'the role of stratigraphy in Anthropocene discourse'. The choice to attend to interdisciplinary and disciplinarity in this article is informed by the abovementioned prevalence of proposals for interdisciplinary research as well as the controversy surrounding such proposals in the stratigraphic literature on the Anthropocene.

In the following section, I describe the accounts given by participants in this study. They reflect both on the benefits and limits of including researchers from disciplines other than stratigraphy in the AWG, and on the relationship between the AWG and the wider stratigraphic community. To be sure, the opinions of all participating AWG members have been carefully analyzed without seeking to 'discover' an unmediated group experience (Silverman 2011). The accounts of participants presented in the following, therefore, highlight possible ways in which the research practice of the AWG is understood by some of its members without claiming that these instances are necessarily commensurable. AWG researchers conduct most of their research outside of the AWG; their positions are therefore shaped as much by the context of their individual scientific work as by their common experience as members of the AWG. In this vein, I follow a phenomenographical approach (Larsson and Holmström 2007) that studies variations in peoples conceptions of AWG's internal dynamics, especially its interdisciplinary and disciplinarity; this study, therefore, does not aim to discover the essence of this phenomenon.

Results

The benefits and limits of interdisciplinarity in the AWG

Participants gave various reasons why the involvement of non-stratigraphers in the AWG is beneficial but they were also concerned that this involvement may distract from stratigraphic matters. Notably, the stated reasons differ for the involvement of natural scientists and social scientists.

On the one hand, participants stated that natural scientists from disciplines other than stratigraphy were invited to join the AWG to provide additional information that could alleviate a possible bias of geology and gain greater confidence in stratigraphic knowledge. The most significant partner discipline in this regard is seen to be Earth system science, whose real-time observations of the Earth can scrutinize stratigraphers' interpretations of the rock record (and vice versa). Data from Earth system science, so the participants, have been necessary particularly to develop a geochronological narrative of the Anthropocene. As such, the data have supported the AWG's decision to move toward a mid-20th-

century boundary of the Anthropocene. As stated, an advantage of including other natural scientists more broadly is that they can raise awareness within the AWG about the needs of researchers who ultimately use the Geological Time Scale. Accordingly, participants also consider other disciplines on whose 'toes we are treading'.

On the other hand, participants regarded the inclusion of social scientists as advantageous because the latter has improved the exchange between the AWG and non-academic audiences. Firstly, social scientists have apparently helped to 'translate' AWG results for the public and disseminate information 'to the wider world'. Particularly the journalist Andrew Revkin is used as an example because he has drafted AWG press releases in a strategic way so that information is communicated efficaciously. Secondly, social scientists have helped to raise awareness in the group about the wider Anthropocene discourse and about the social implications of their stratigraphic work. Here, the legal scholar Davor Vidas is explicitly mentioned because he has explained the legal implications of ratifying the Anthropocene.

Notwithstanding these beneficial contributions of other disciplines to discussions within the AWG, participants were concerned that the presence of non-stratigraphers (both natural and social scientists) distracts from stratigraphic matters. Interdisciplinarity may particularly impede the preparation of a formal proposal to the ICS, which is restricted to stratigraphic insights and requires the identification of concrete Global Stratotype Section and Points (GSSPs). One participant stated clearly that 'the contribution of the non-geoscientists has resulted in distractions from the goal of the working group since they have not understood the factors that are required by the International Stratigraphic Code'. Accordingly, participants highlighted the limits of interdisciplinarity especially as the AWG moves toward submitting a formal proposal. The forthcoming attempt to position a geochronological narrative of the Anthropocene in sedimentary successions will require a greater focus on the stratigraphic expertise in the group. Consequently, participants contemplate whether the membership status of non-stratigraphers needs to be changed and their voting rights limited.

Notably, these concerns of participants exist parallel to abstract favorable statements that interdisciplinarity makes the AWG 'a wonderful place to fly and debate new ideas'. For some participants, the AWG even exemplifies and provides a legacy for a constructive interdisciplinary exchange, in which researchers learn from each other's different perspectives on the same phenomena. Regardless of the prospects of including non-stratigraphic insights into a formal proposal to the ICS, for these participants, the AWG offers 'a safe space for people to amicably discuss, even very strong differences of opinion, and also not to be afraid to say that they do not know or do not understand something'.

The relationship of the AWG to the stratigraphic community

Regarding the relationship of the AWG with the wider stratigraphic community, participants argue that it has, until recently, been difficult. Simultaneously, they emphasize the value of a constructive relationship with other stratigraphers.

Participants point to difficulties in the relationship by reflecting on the criticism that the AWG has received for not adhering to established procedures in the stratigraphic community. Firstly, the AWG has been criticized by other geologists for not following the conventional dual hierarchy of stratigraphy. Although the latter requires geological units to be defined both in geochronological (GSSA) and chronostratigraphic (GSSP) terms, the AWG 'tentatively' suggested in 2015 to only use a GSSA for the Anthropocene. Secondly, some parts of the stratigraphic community think that the AWG should work 'in a more closed environment' and only report its final results. They are critical of the public approach that the AWG has taken by engaging the media and feeding preliminary results back into the scientific community.

The origins of this criticism are seen to lie in a lack of communication and a related lack of trust. Participants highlighted that the AWG and the geological community have often not engaged with each other directly. The work of the AWG has been conducted 'almost independently' even of its parent institutions, the ICS and SQS, with which it has communicated merely through short annual reports and the media. Consequently, the AWG has been unable both to engage some of its strongest critics, many of which have held prominent positions within these institutions and to learn about the formal requirements of the ICS and the SQS. By making this point, participants highlighted the lack of communication as a root cause of the abovementioned criticism. The lack of communication has also contributed to a lack of trust that manifests not directly in the abovementioned criticisms but in the associated allegation that the AWG is aiming to push for formalization by circumnavigating official procedures. Within the AWG, in turn, this allegation has strengthened the sentiment that it 'can never win' because its work is deliberately misinterpreted and unfairly criticized.

At the same time, participants emphasize that a constructive relationship with the stratigraphic community is crucial. Firstly, a constructive relationship with the wider community of stratigraphers would enable the AWG to collaborate with researchers who can provide needed stratigraphic analysis of sediment samples. Secondly, a better relationship with the ICS institutions would increase the likelihood of formalization. The ICS is also important for the AWG because the two are institutionally linked. As members of an ICS Working Group, participants accept that their primary task is to make a proposal for formal recognition of the Anthropocene to the ICS. Generally, participants recognize the ICS as the 'police' of stratigraphy, which ensures that stratigraphic terms are clearly defined and appropriately used. As a result of this regulative role, ignoring ICS positions would destine the Anthropocene to end up like 'many examples in the past in stratigraphy where opposing camps get set up and iron gets into the soul, people set up the machine guns in the trenches and that's it'.

In order to avoid this destiny and enable a constructive relationship, participants emphasize, the AWG has started to incorporate feedback from the stratigraphic community. For example, the preference voiced by the stratigraphic community for a GSSP has led the AWG to move away from a GSSA. Similarly, the AWG has committed to a hierarchical level of the Anthropocene that complies with the preferences of other ICS Working Groups. Specifically, they have confined the Anthropocene to the Epoch level, which allows the Holocene Working Group to continue working relatively independently of any conclusions reached within the AWG. Furthermore, the AWG has sought closer collaboration with the ICS. In particular, the recent AWG membership of Martin Head, the Chair of the SQS, has facilitated direct communication to the extent that a joint meeting is planned, in which the AWG will have the opportunity to present its proposal informally and demonstrate that its approach is in line with established stratigraphic practice.

In the following, I discuss these accounts given by participants with reference to the question what role do interdisciplinarity and disciplinarity play in the AWG? To this end, I will first characterize the interdisciplinary collaboration taking place in the AWG by drawing upon the language provided by different typologies of interdisciplinarity. Secondly, I will discuss the reflections that participants provided on the relationship of the AWG to the stratigraphic community. I will do so by assessing the dual potential of boundary-crossings in the AWG to bring about innovation or fragmentation in stratigraphy.

Discussion

The scope, type, and goals of interdisciplinarity in the AWG

Based on participants' accounts, interdisciplinarity in the AWG can be characterized by following Huutoniemi et al. (2010) who distinguish between scope, type, and goals as important characteristics of interdisciplinarity. Firstly, it is narrow in scope because mainly natural science knowledge is integrated into the research of the AWG, despite also having social science members in the commission. Secondly, it is multidisciplinary in type since even the integration of natural scientists comprises a bridge building between disciplines rather than a unification of existing bodies of knowledge and a change of disciplinary practices. Finally, the goals that the AWG pursues through this partial interdisciplinary engagement are, on the one hand, to widen accountability of the Group and, on the other hand, to respond to the Anthropocene as a new object that stratigraphy cannot deal with in isolation from other disciplines. In addition, interdisciplinarity is valued as an end in itself.

Regarding the scope, the research of the AWG builds on natural science knowledge while inviting social scientists to provide post-research services such as knowledge dissemination and awareness raising. The interdisciplinary research within the AWG remains 'narrow' (Newell 1998) in terms of the concepts, methods, paradigms, and epistemologies incorporated in it. Participants in this study and recent publications by members of the AWG (Steffen et al. 2016) emphasize that the Earth system sciences are the focus of interdisciplinary collaboration because they complement the scientific approach of stratigraphy. The AWG is not unusual in this respect. Making environmental knowledge from the social and the natural sciences compatible is more demanding than doing so between disciplines that hold similar epistemological and ontological assumptions (Donaldson, Ward, and Bradley 2010). In interdisciplinary research projects on Earth system change, social scientists often receive 'an auxiliary, advisory and essentially non-scientific' role (Holm et al. 2013, p. 1). Although insights of social scientists are central to understanding Earth system change (e.g., Pahl-Wostl et al. 2013), the AWG confirms the tendency to involve social scientists as contributors not to the scientific analysis but to the policy dimensions of research projects. Social scientists in the AWG first and foremost assume the task of translating insights of the Group for other, especially public communities and vice versa. They provide a service of translation to the dominant natural science disciplines and, as such, operate in a

'subordination-service mode' (Barry, Born, and Weszkalnys 2008).

The engagement with other natural sciences diverges from this mode but it remains 'multidisciplinary' in type (Potthast 2010). An actual transfer between hitherto different practices, theories, and methods, which for example stratigraphy and Earth system science bring to the analysis of the Anthropocene, does not take place. Instead, different types of knowledge are coordinated so they add to one another. Far from operating in an 'integration-synthesis mode' (Barry, Born, and Weszkalnys 2008, p. 28), in which different forms of natural science knowledge are integrated in a relatively symmetrical fashion and thereby surpass previous ways of thinking, the research practices of stratigraphy and those of other natural sciences in the AWG run parallel to each other. Given the disciplinary setting of the AWG as a working group within the ICS, it is not surprising that the rules and needs of stratigraphy, rather than shared standards of different natural sciences, determine 'how integration is done'. Research activities of the AWG either are carried out in the disciplinary fashion of stratigraphy from the start, or they are coordinated so that non-stratigraphic research becomes relevant to the main field of stratigraphy. Accordingly, the contribution of other natural science disciplines is to contextualize stratigraphic research, for example, by helping to define an integrated narrative of the Anthropocene upon which chronostratigraphic analysis can be based. This 'contextualizing interdisciplinarity' (Boden 1999) means that knowledge from other natural science disciplines is applied to provide integrated background information for a stratigraphic research project that remains largely unchanged in theory and methodology.

Correspondingly, the goals that the AWG pursues with this narrow multidisciplinarity can be differentiated according to 'who is involved'. On the one hand, the foremost benefit that participants ascribe to an AWG membership of different natural science disciplines is a broader understanding of the Anthropocene as a phenomenon. This widening of the stratigraphic perspective is caused by the challenges that the Anthropocene poses for stratigraphic analysis. Participants outline, for example, that the novelty and diachroneity of Anthropocene deposits, as well as the much higher time resolution and continuing development of the Anthropocene strata, diminish the functionality of established stratigraphic methods in this case. Accordingly, the inclusion of natural scientists in the AWG is 'object-oriented', seeking to solve methodological problems in response to a new object that cannot be tackled by the existing discipline of stratigraphy alone (Barry, Born, and Weszkalnys 2008, p. 29–30). On the other hand, participants argue that the AWG can benefit from a membership that includes social scientists who translate research insights for other stakeholders. Here, the AWG follows the aforementioned 'logic of accountability'. The rationale is that involving social scientists will enhance the communication of scientific insights and thus increase the accountability of stratigraphy to society.

Beyond these differences in how and why social and other natural scientists are involved in the AWG, interdisciplinarity itself emerges as a goal of the group. Rather than assessing the benefits of boundary-crossings exclusively in terms of its contributions to a formal proposal to the ICS, participants also value them because they stimulate creative debate about the Anthropocene. Participants' approach to interdisciplinarity can then also be described as 'practice-oriented' because they appreciate the social collaboration between experts of diverse domains as an end in itself (Barry, Born, and Weszkalnys 2008, p. 30). To be sure, this does not entail a widening of the scope and type of interdisciplinarity, which requires not just appreciation of and trust in the co-workers trained in other disciplines, but also an equality of the different scientific perspectives, methodologies, and practices. This equality is generally rare because it means to reject the idea of a dominant discipline ('Leitwissenschaft') that determines methods, aims, and theories (Potthast 2010, p. 182). In cases like the AWG 'where a disciplinary division of labor persists, cross-disciplinary collaboration is [instead,] idealized as a value in itself, and one that outweighs any particular project' (Barry, Born, and Weszkalnys 2008, p. 30).

Disciplinarity of the AWG

Amid this multidisciplinarity of limited scope, the disciplinarity of the AWG is well established. The AWG has conducted itself in relation to the rules and procedures of stratigraphy particularly as it has sought to improve its difficult relationship with the stratigraphic community. The accounts of participants showed that the AWG has done so especially by changing its research practice in accordance with ICS feedback about how to apply the dual hierarchy, about the appropriate hierarchical level for the Anthropocene, and by collaborating more closely. In addition to these details of disciplinarity highlighted by participants, it can be shown that the AWG has adapted the rationale of its work according to ICS recommendations. Not only has the preparation of a formal proposal become more important to its activities but the AWG has also developed a new way of rationalizing its past work that has not directly

contributed to such a proposal.[3] Participants outline that the nature of the Anthropocene required the creation of a geochronological narrative before the search for an appropriate GSSP and the preparation of a formal proposal could be pursued. The fact that this research rationale was originally proposed by Martin Head, the Chair of the ICS Sub-commission on Quaternary Stratigraphy, demonstrates the influence of the ICS on the AWG.

Paradoxically, participants recognize the regulative role of the ICS on stratigraphic research practice and simultaneously proclaim the need to reform stratigraphic practice. One participant contends that 'the unique aspects of anthropocene strata are already challenging geologists to modify their assumptions, frameworks and stratigraphic codes'. Participants argue that methodological and theoretical innovations in stratigraphy are necessary because the discipline was originally established to study evidence from the deep past that represents broad changes in strata. The Anthropocene unusually depicts evidence of recent events that have left detailed but minuscule traces in the rock record. In addition, publications authored by AWG members have already suggested concrete innovations in stratigraphic practice. They include interdisciplinary classification schemes for the study of anthropogenic deposits and human artifacts (Ford et al. 2014; Zalasiewicz, Kryza, and Williams 2014) or a biostratigraphic practice that includes 'technofossils' as a distinct type of anthropogenic trace fossil (Waters et al. 2014). These suggestions could form the epistemic basis of an internal specialization or even of an evolving inter-discipline of 'technostratigraphy' (Zalasiewicz et al. 2014). They indicate 'epistemological strength' which is one factor in the evolution of a specialized research community (Klein 2012, p. 22).

These requests for reform shed a different light on the disciplinarity of the AWG. They suggest that the abovementioned ways in which the AWG has been adapting to disciplinary rules and procedures of stratigraphy are not ideal exchanges between colleagues but 'pragmatic working arrangements' (Barry, Born, and Weszkalnys 2008, p. 27). For the AWG, these arrangements prevent the stratigraphic community from discarding the Anthropocene as a candidate for official recognition within the geological timescale. They also provide opportunities for the AWG to convince adversaries in the stratigraphic community of the need to integrate different approaches that exist within the discipline. For the ICS, these arrangements serve to ensure cohesion in stratigraphic practice and compliance to the codified rules of stratigraphy. As such, they help to 'discipline disciples' (Barry, Born, and Weszkalnys 2008, p. 20) and defend the definitional power that characterizes scientific unions like the ICS (Weingart, Carrier, and Krohn 2015).[4] Juxtaposing these different ambitions of the ICS and the AWG suggests that pragmatic working arrangements within disciplines can translate across internal boundaries as well as work to deny and prolong internal divisions (Barry, Born, and Weszkalnys 2008). In both cases, they indicate (temporary) appeasement in a disciplinary controversy. Similarly, the pragmatic working arrangements between ICS and AWG prevent calls for innovation in stratigraphic practice from challenging the disciplinarity of the AWG.

Despite indications of epistemological strength, however, structural reasons obstruct the evolution of the AWG into a self-contained specialized research community. One of the reasons endogenous to the stratigraphic community is that the latter takes a conservative approach and is unlikely to accept innovative methods and theories developed in the AWG. While such resistance from the core of the disciplinary community often results in a disassociation of the pioneers from the parent discipline (Weingart, Carrier, and Krohn 2015), additional, exogenous factors obstruct the formation of Anthropocene stratigraphy as a specialization. Both the conservative approach of the stratigraphic community and three exogenous factors are discussed in detail below.

Firstly, specialization depends not just on the epistemological strength of the interdisciplinary practice but also on the ability of a parent discipline to integrate innovative methods and theories (Weingart, Carrier, and Krohn 2015). Although participants agree that the stratigraphic community is generally conservative, changes in stratigraphic practice are more acceptable to some of them than to others. Some participants stress that stratigraphy is a flexible discipline that has historically evolved to solve practical problems and accommodate for novel phenomena. They argue the changes necessary to study the Anthropocene are not 'revolutionary' compared to changes of the past that are widely accepted today, including the use of fossils for stratigraphic analysis, precise GSSPs for formalization, or indeed the acceptance of the Holocene. But other participants fear that unnecessary changes of the stratigraphic nomenclature and guiding concepts would complicate communication within the discipline and risk politicization of research.

Whether or not participants agree with this conservative perspective, they all believe that it dominates the stratigraphic community. 'The tribe of stratigraphers … [is generally] cautious, conservative, trying to downplay stuff' and resistant to changing

the GTS. Many stratigraphers tend to embrace established concepts and interpret innovations as attempts 'to rock the boat'. In regard to the Anthropocene, many stratigraphers find it difficult to accept the idea that geological processes dwarf human influence on the environment, that an epoch should have started within their own lifetime or that anthropogenic deposits should be used as stratigraphic evidence. Participants outline, moreover, that many stratigraphers are particularly concerned with the status of the Holocene, which 'clues people' together and may be altered by the Anthropocene. The Anthropocene is 'very disconcerting and different from what … [many stratigraphers] normally do'. It could be seen as 'the antithesis of useful with the [geological] community because it's disrupting the literature, disrupting everything'. This limited ability to redefine 'what is considered intrinsic and extrinsic to a discipline' (Klein 1996, p. 38) suggests that considerable innovation in stratigraphic practice is unlikely.

Secondly, exogenous factors play a role in the specialization of disciplines (Klein 1996, p. 36). In combination with the publicly available information on the AWG, participants' accounts indicate that social, cultural, and economic capital of the AWG are differently developed. The following shows that although the AWG holds considerable cultural capital, its funding and its social networks continue to lack institutionalization.

Social capital relates to networks of an evolving specialized community and the ways in which it is institutionalized through positions. Although the social capital of the AWG has recently improved, it generally remains weakly developed. One reason for the weak social capital is that the recruitment process of the group, which participants describe as informal and improvised, means that the AWG relies on personal networks for enlisting expertise. Another reason is that these networks are weakly institutionalized. This manifests in the global distribution of AWG members, which has limited communication among the members to an exchange of emails (*Nature* 2015) and joint publications to smaller groups of members that converge around different aspects of the Anthropocene. Having said this, the University of Leicester has recently increased its institutional support of the AWG. Apart from issuing press releases of the AWG (Zalasiewicz and Waters 2016), the secretary of the AWG has been appointed honorary chair at the University, which has provided an 'opportunity to develop a more formal relationship' between some AWG members. One participant anticipates that this institutionalization of social capital may provide a chance for an increase in economic capital, too.

Economic capital relates to the resources that are available to an evolving specialized community to conduct research or organize exchange among its followers. Like other working groups, the AWG lacks economic capital since it receives no independent funding from the ICS. One effect of this is that the meetings of the AWG have to be co-sponsored and remain rare. During its nine-year tenure, the AWG has only met four times: in October 2014 in Berlin, in November 2015 in Cambridge, in April 2016 in Oslo, and in September 2018 in Mainz. Moreover, participants suggest, greater economic capital would enable a more professional recruitment of a greater diversity of researchers, thus improving social capital. In this sense, the lack of economic capital also affects the research of the AWG. One participant highlights that especially the analysis of sediment cores would require the involvement of more researchers.

Cultural capital encompasses the embeddedness of a research community in popular culture such as in books and the arts but also in the educational system. That the cultural capital of the AWG is relatively well developed is indicated by the fact that almost all participants report to have given public talks, collaborated with artists, or contributed to online fora and media reports. Furthermore, popular science books authored by AWG members (Zalasiewicz and Williams 2013), public meetings of AWG members[5], and their participation in school events[6] suggest a relatively strong embeddedness in popular culture. The AWG assumes public prominence compared to other research groups in the geosciences but its public visibility, overall, remains limited given the transdisciplinary appeal of the Anthropocene.

Conclusion

Amidst a diversifying discourse on the Anthropocene, this article starts from the assumption that research finds wider conceptions of the Anthropocene. This justifies an in-depth investigation of stratigraphic research on the Anthropocene and of the AWG, which drives this work. The analysis presented in this article has focused specifically on the question how interdisciplinarity and disciplinarity affect the AWG. This question is salient because the stratigraphic community, during a period of widespread advocacy for more interdisciplinary research on the Anthropocene, has disagreed about the value of stratigraphic research on the Anthropocene generally and specifically the research conducted by the interdisciplinary group of researchers that comprises the AWG.

To be sure, (inter-)disciplinarity is one of many aspects under which the AWG could be

investigated. Other themes that appeared in the data are the contributions of stratigraphy to the Anthropocene discourse and the way in which AWG members engage the public. Moreover, alternative methods of studying the AWG exist such as an ethnographic approach or a different sample of AWG members that involves more social scientists. These alternative methods are likely to generate additional insights but attempts to pursue them were deferred due to considerations about the workload acceptable to AWG members. Generally, this study attends to the internal dynamics of the AWG in conjunction with those of stratigraphy. This focus is strengthened by the method employed, which largely relies on accounts given by a limited sample of AWG members. Internal dynamics are important aspects in the constitution of (inter-)disciplines (Abbott 2007) but they are not autonomous from the economic and political context of academia (Shapin 1992). A deeper investigation of the exogenous dynamics that influence stratigraphic research on the Anthropocene could therefore usefully complement the study presented in this article. Methodologically, accounts by more AWG members, by representatives of other ICS bodies, by the Earth system science community, or by organizations that have given institutional and economic support to the AWG would be valuable.

The study presented in this article yields two insights about the internal dynamics of the AWG. They are interesting because they diverge from the hypotheses about interdisciplinarity and disciplinarity of the AWG that could be deduced from the published debates. Instead of following a pull of interdisciplinarity, the AWG remains shaped by the established practices of stratigraphy. Moreover, rather than being onerous, the relationship of the AWG with the stratigraphic community has recently been managed pragmatically.

Firstly, the exchange in the AWG between stratigraphy and other disciplines is multidisciplinary and of limited scope. This means that other disciplines represented in the AWG do not infuse the disciplinary research practices of stratigraphers in the AWG. While AWG members associate multiple goals with interdisciplinary boundary-crossings, these goals are advocated separately from a change in stratigraphic research practice. The goals of solving methodological problems ('object-orientation'), of increasing accountability to society ('logic of accountability'), and of stimulating creative debate between researchers ('practice-orientation') are not reflected in the actual participation of other disciplines in research activities. Although other disciplines are invited to translate and contextualize the work of the AWG, they are not granted an extended involvement in data collection and analysis.

Secondly, although the AWG occasionally crosses the boundaries to other disciplines, its main point of reference remains the stratigraphic community. Accordingly, the disciplinarity of the AWG prevails over potentially innovative research practices that are inspired by interdisciplinary exchanges about novel phenomena and ways to study them. This does not mean that the AWG has wholly renounced suggestions to reform stratigraphic practice in light of the Anthropocene to the disciplinary rules and procedures of stratigraphy. Rather, it has entered into pragmatic working arrangements with the institutionalized quarters of the stratigraphic community, namely the ICS. While this has come at the expense of igniting innovation of stratigraphic practice, it shows that the disciplinarity of the AWG is conditional on social spaces in which it can be negotiated with other members of the stratigraphic community.

The insights provided on the internal functioning of the AWG can be used to complement existing understandings of interdisciplinarity and disciplinarity. Although the AWG is only one example of Anthropocene research, its internal dynamics suggest that disciplines will continue to provide the context for interdisciplinary research (Weszkalnys and Barry 2014; Jasanoff 2014). The case of the AWG particularly highlights the institutional context (here provided by ICS) of interdisciplinary endeavors (Strathern and Rockhill 2014). Even though interdisciplinarity is regarded as beneficial in the AWG, participants accept that any associated innovation in research practices must observe existing disciplinary rules. To be sure, this insight is not generalizable across interdisciplinary fields of study; cybernetics, for example, has managed to avoid most constraints of disciplinary policing (Pickering 2014). At the same time, the case of the AWG suggests that even 'research … which cannot escape the shadow of disciplines, … can move towards ways of working in which the disciplines are not the most important things' at all stages (Donaldson, Ward, and Bradley 2010, p. 1534). Parallel to forms of disciplinary peer review, ideas prominent in interdisciplinary practice like the 'logic of accountability' or 'practice-orientation' are also evident in the AWG.

Overall, this study shows that both disciplinarity and interdisciplinarity affect the way in which the AWG conducts its research – albeit with different outcomes. The activities of the AWG indicate dynamic engagement between the benefits of crossing disciplinary boundaries and those of orienting academic work toward a specific disciplinary community. This dynamic is not reflected in

standard accounts of interdisciplinarity and disciplinarity, which assume that research is either confined to disciplinary quality criteria or open to interdisciplinary insights. The case of the AWG raises questions about this epistemic dichotomy, which future research could answer by providing and comparing more case studies of this type. At the same time, future research could further explore how epistemic openness can be positioned within an existing landscape of disciplines that wish to secure the boundaries of their territories. The AWG makes for an interesting example of opening up to interdisciplinary insights while maintaining legitimacy within a disciplinary research community. More so than other research groups in stratigraphy, the AWG performs on multiple 'stages' (Hilgartner 2000) some of which lie outside the disciplinary theatre of stratigraphy. As it manages these stages simultaneously, disciplinary and interdisciplinary activities converge into a research practice of narrow multidisciplinarity.

Notes

1. These journals are the *Anthropocene Review, Anthropocene, and Elementa – Science of the Anthropocene*.
2. In addition, this collaboration resulted in a comment about the role of social scientists in defining a start of the Anthropocene. See Holmes, Barber, and Lundershausen (2017).
3. While early publications of AWG members considered the definition of the Anthropocene linked but not identical to formalization by way of a GSSP (Zalasiewicz et al. (2015); Zalasiewicz et al. (2016), participants in this study regard a formal proposal as their primary task. They thereby follow criticism from the ICS that any geological definition needs to follow the formal procedures set out by the ICS (Finney and Edwards 2016b).
4. Although the ICS itself is, to be precise, not a scientific union, it forms one of seven scientific commissions in the International Union of Geological Sciences and thus is integral to the latter.
5. https://www.hkw.de/en/programm/projekte/2014/anthropozaenprojekt_ein_bericht/anthropocene_working_group_1/anthropocene_working_group_forum.php
6. https://www.geolsoc.org.uk/expired/ESW-Schools-Event

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Appendix 5

Anthropocene: Be wary of social impact

Correspondence

Crop-health survey aims to fill data gaps

The frequency and extent of crop losses caused by plant diseases and pests is another gap in our knowledge and understanding of agrifood systems (see P. Sukhdev *et al. Nature* **540,** 33–34; 2016). This information is crucial for developing sustainable strategies to manage crop health.

Such losses can never be eliminated completely, and occur in many ecosystems. Declining crop health affects farmers, consumers and societies through higher input costs, lower outputs and damage to environmental and human health through the abuse and misuse of pesticides.

To try to quantify the problem, the International Society for Plant Pathology's online global survey of experts in crop health (https://globalcrophealth.org) is determining the importance of crop pests and diseases in five staple crops: wheat, rice, maize (corn), soya bean and potato. So far, around 75% of responses report losses every season, with one-third experiencing yield reductions of 5–60% each year.

The survey, which ends on 31 January, has revealed large geographical gaps in the available expert knowledge on crop losses. Such gaps must be addressed to improve access to crop-health information and to increase understanding of today's needs and priorities for future sustainable food systems.

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**On behalf of 7 correspondents (see go.nature.com/2jtajyz for full list).*

Anthropocene: be wary of social impact

As social scientists studying the work of the Anthropocene Working Group of the International Commission on Stratigraphy, we believe that the expertise of social scientists goes beyond developing a 'better' stratigraphic definition of the Anthropocene (E. Ellis *et al. Nature* **540,** 192–193; 2016). Such knowledge should also be used to understand the likely consequences of any definition, particularly those given the weight of scientific credibility.

However it is defined, the Anthropocene could alter people's concepts of how humans interact with the natural world (see also N. Castree *Nature* **541,** 289; 2017). Labels matter — a formal stratigraphic description might normalize human impacts on the planet and undermine efforts to minimize them, or lead people to ignore responsibilities for creating and managing the Anthropocene, which are unevenly spread around the world. Alternatively, it could inspire positive change and have a bigger impact on society than on stratigraphy. Social science can be used to develop concepts and a language for explaining the Anthropocene in both stratigraphic and political terms.

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Anthropocene: keep communication clear

Regarding definitions of an Anthropocene epoch, we disagree with Erle Ellis and colleagues' contention that "Earth sciences long ago moved away from defining precise stratigraphic boundaries to developing records of continuous change"(*Nature* **540,** 192–193; 2016).

Precise boundaries are the basis for defining geological time, a prerequisite for the correlation of abiotic and biotic events and the understanding of the rates and timing of biological and geological processes on our planet. Earth sciences, through the International Commission on Stratigraphy of the International Union of Geological Sciences, continue to this day to define precise global boundaries, which in turn allows scientists to communicate with each other and with the public alike.

Developing records of change (continuous, discontinuous or one-time-only) in the study of Earth's history neither competes with nor detracts from scientists' key contribution in providing tools for unambiguous communication.

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Detecting particles of dark matter

Your article on the Axion Dark Matter eXperiment (ADMX) suggests that the lattice quantum chromodynamics (QCD) calculation by S. Borsanyi *et al.* (*Nature* **539,** 69–71; 2016) might be bad news for the ADMX because it could place the axion mass beyond the detector's reach (see *Nature* http://doi.org/bxf8; 2016). We find this inference misleading.

The axion is a very well-motivated hypothetical particle because it solves a puzzle in the standard model of elementary particles (the 'strong CP problem'; see J. E. Kim and G. Carosi *Rev. Mod. Phys.* **82,** 557; 2010) and because a cold population of axions is naturally produced in the early Universe that may constitute dark matter today.

The properties of the axion depend for the most part on a single parameter that may be taken as the axion mass. Unfortunately, the mass is poorly constrained and might plausibly range from 10^{-6} to 10^{3} microelectronvolts. Inconclusive theoretical arguments have been put forth in support of each part of that range.

The only way to find out the axion mass is through experimental observation. Axion dark-matter detection methods are emerging that, in principle, cover the whole mass range. Experiments that use the resonant cavity technique, such as ADMX, are capable of discovering axions today. They should be vigorously pursued. The aforementioned lattice QCD calculation does not change this fundamental picture.

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Progressive taxes for sustainability

One way to achieve a more sustainable society would be to impose progressive taxes on goods that are particularly detrimental to the environment when consumed. Marginal tax rates would increase with an individual's consumption of those goods — for example, a person's annual flight history could be used to compute the fee for his or her next ticket.

Fixed-rate consumption taxes present equity issues, which hinder their applicability and effectiveness by placing much of the burden on those with low incomes (see, for example, C. A. Grainger and C. D. Kolstad *Environ. Resour. Econ.* **46,** 359–376; 2010). Implementing progressive consumption taxes on specific goods is now possible because of the widespread use of smartphones, credit cards and the Internet, which mean that we can keep track of individual consumption patterns.

Although such taxes may be perceived as a limitation on our freedom, in my view they would be a credible implementation of the 'polluter pays' principle.

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