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Science studies in physical geography: An idea whose time has come?

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Abstract
Science studies perspectives are largely absent in research on the making of physical geography. In this paper I outline literature from the history and sociology of science that may prove useful both in filling this gap, and in 'bridging the divide' between human and physical geography. I begin with an overview of work that argues for science studies in human geography, physical geography and the history of geology. I then discuss a series of science studies approaches that address questions such as the following. How are the social worlds of science constituted? How do new scientific disciplines emerge and change? How do different groups in a discipline view/contest research? How are scientific identities and careers formed? How does laboratory culture shape the practice of science? How is science distinguished from non-science? How do scientific biographies reflect and change the 'spirit of the age'? Drawing on a biographical science studies approach, I examine key aspects of the life and work of the eminent river scientist Luna Leopold (1915–2006). This then leads to a discussion of the geographical imagination, and particularly how this is grounded in the sociological imagination – where history and biography are entwined. I argue that Leopold's life and writings provide valuable insights into developing 'the geographical imagination'. In conclusion, my aim is to encourage students and researchers in the three fields of human geography, physical geography and science studies to use the 'view from the river' of science studies in research on the making and shaping of physical geography.

Keywords
fluvial geomorphology, geographical imagination, Luna Leopold, physical geography, science studies

I Introduction

The history and philosophy of human geography is a ubiquitous component of Anglo-American geography degrees with a well-established set of key texts (e.g. Gregory et al., 2009; Johnston and Sidaway, 2004; Livingstone, 1992; Peet, 1998). In contrast, courses and books on the history and philosophy of physical geography and geology are notably absent from undergraduate and postgraduate education in geography and the Earth sciences more broadly. Similarly, while the insights from the interdisciplinary field of Science and Technology Studies (STS) have been applied to areas like physics, the life sciences and the history of human geography, there has been little use of STS ideas to explore the science of physical geography. In what follows I outline some literature that may encourage geographers and others to research this area.

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Studies of particular ‘scientific worlds’ are extremely valuable, given that one of the features that scientists, philosophers, historians and social scientists agree about is that science is not monolithic. For instance, it has been shown how scientists in the social worlds of high-energy physics and molecular biology inhabit different *Epistemic Cultures* (Knorr Cetina, 2001). In other words, case studies of different sciences matter as they demonstrate that science, inevitably, is *as* and *in* culture. My aim, therefore, is to encourage students and researchers in physical geography, and those working in human geography and STS, to develop an interest in the history, philosophy and sociology of fields like geomorphology. To put it more pithily, ‘a text without a context is merely a pretext’ (Livingstone, 1987: 3) – which is a convenient pretext for some biographical context.

Once upon a time I was a geography undergraduate at the University of Hull. My first physical geography courses included courses on the *Principles of Hydrology* taught by Roy Ward (Ward, 1975) and on *Drainage Basins* taught by Keith Richards (which became part of his book on *Rivers* – Richards, 1982). However, I was also interested in the history of art, particularly landscape painting, so I also read two books by Kenneth Clark on *The Romantic Rebellion* (1973) and *Landscape into Art* (1976), as I thought geographers should know something about painting and representations of landscapes (Cosgrove and Daniels, 1988). In the winter of 1977 I therefore embodied the tensions between ‘the two cultures’ of the arts and sciences (Snow, 1959), and which is still a feature of much Anglophone geography. One aim of this paper is to argue that a third culture, social science, is a fruitful way to write about both the arts and the sciences, and my reading from my first term at University is reflected in my subsequent sociological research on the British landscape painter J.M.W. Turner (Wainwright and Williams, 2005), and on the American hydrologist and geomorphologist Luna B. Leopold (Wainwright, 2011).

Looking back at my copy of Ward’s (1975) hydrology text, two passages that I marked 34 years ago stand out: the tension between ‘engineering versus geographical hydrology, and the absence of a historical dimension to science. As he puts it:

> The geographer is primarily interested in how the landscape works and in man’s interactions with it ... [The engineer] should be able, through simplification, to generate approximate numbers ... [in contrast] the geographer should have a detailed understanding of hydrological processes. (Ward, 1975: 347)
>
> Few hydrologists have a good knowledge of their heritage or even a broad understanding of how the science has developed to its present imperfect state. (Ward, 1975: 3)

If we conjoin these views we can read this as an argument for understanding the making of physical geography as a set of (contested) scientific practices. This is important, as the leading fluvial geomorphologist Stanley Schumm argues: ‘unfortunately, the scientific literature gives a very misleading perspective of science’ (Schumm, 1991: 25). I take this as an appeal for scientists themselves to take the social practice of science seriously, and, as we shall see later, practising scientists have much to gain here by engaging with the ‘practice turn’ in the history and sociology of science. Such a view also chimes with recent calls by several eminent human geographers for social studies of (physical) geography. For example:

> We desperately need studies of what physical and human geographers *do* – in the field, the archive, the laboratory. (Gregory, 1995: 175, my italics)
>
> The *art* of doing geography, has always also been ... the *act* of doing geography ... There is much to know yet of geography’s intellectual history by listening and talking with those who also wrote, read and mapped ‘the field’. (Withers, 2011: 40 and 47, original italics)

In other words, if we are to understand what scientists do, and why they 'choose' some avenues of investigation rather than others, then we need *social histories* of science, as Livingstone notes:

> A social history of physical geography is a real desideratum ... Cultural geographers find themselves in the same department with physical geographers ... And a golden opportunity is thus provided for what could be called the cultural geographies of the bench scientists and the field worker ... Connecting historical work on the production and circulation of geographical knowledge with ethnographic investigations of the cultures of contemporary geographical practices seems to me a very fertile and exciting line of research. (Livingstone, 2002: 79 and 85)

This paper is a response to these pleas. My interest is in exploring ways of examining the social shaping, social implications and particularly the *social practices* of physical geography and to do this I will cover a wide range of literature. My aim, as a historically minded sociologist, is not to adjudicate on what sort of science, say, geomorphologists should practise (inductive/deductive, empirical/theoretical, quantitative/qualitative, process/form, historical/modelling, etc.), but rather to encourage geomorphologists themselves, together with human geographers and historians and sociologists of science, to examine how these tensions (if they are tensions) have played out as the science of geomorphology has been transformed over (say) the last 50 years or so.

I recognize, of course, that there are many approaches and topics that potentially link human and physical geography, but I have no room to discuss these here. Readers who are interested in topics such as nature and society, risk, science policy, the public understanding of science, and integrating human and physical geography will find a burgeoning literature on all these areas (and Agnew and Livingstone, 2011, Gregory and Goudie, 2011, and Gregory et al., 2009, suggest some ways into these fields; while Harrison et al., 2008, offer 'conversations across the divide' of physical and human geography).

I do, however, have some interest in three topics. The first is STS and the history of human geography. Perhaps the person who has done most to promote this perspective is Trevor Barnes in a series of influential papers on the quantitative revolution, and the changing nature of economic geography (e.g. Barnes, 1998, 2001; for readers looking for a stimulating account of the varied ways in which science studies examines 'social knowledge in the making' I recommend Camic et al., 2011). Second, there is also a growing literature on geographies of field science, and here Richard Powell has written a series of key papers (e.g. Powell, 2007a, 2007b, 2008). Third, the last decade or so has seen a major development in the new field of geographies of science, perceptively delineated in Naylor (2005), and stimulated in large part by the seminal publications of David Livingstone (e.g. Livingstone, 2002, 2003).

So what is the rest of this paper about? I begin with a review of some writings on the history of geology. I then turn to books on the history and philosophy of geomorphology. Next I discuss a roster of STS texts and concepts that, I suggest, could be productively employed in a new programme of research exploring the recent history and sociology of physical geography, and especially geomorphology. This leads to a discussion of the life and work of the fluvial geomorphologist Luna Leopold. In the final part of the paper I round off with a few reflections on the nature of the geographical imagination. I will begin with an outline of work largely written by historians of science on the history of geology.

II Histories of geology and geomorphology

1 History of geology

General books on the history of geology invariably include chapters that discuss 19th-century views on landforms and 'the ice age' and so should have some appeal to physical geographers. The standard introductory text is Gohau (2006), but Oldroyd (1996) offers a more wide-ranging and engaging review of the history of geology, while Good (1998) provides a comprehensive encyclopaedic history of the Earth sciences. Fascinating reviews of the 'popularization' of geology in the 19th century are given by Knell (2000) – on geology, collecting and museums – who employs the perspectives of museum studies in a vivid evocation of the culture of geology; and by O'Connor (2008) – who offers a splendidly illustrated discussion of the emergence of geology, beasts and dinosaurs as public spectacles, in a book informed by the rhetorical perspectives of English Literature.

Charles Lyell's *Principles of Geology* (1997 [1830–1833]), which was aimed at both public and professional readers, became an international bestseller and helped establish key notions such as the principle of uniformitarianism, which later came to be known by the aphorism 'the present is the key to the past'. Major works on Lyell include a biography (Wilson, 1972) and an excellent collection of essays on the influence of Lyell on his geological contemporaries and on contemporary geology (Blundell and Scott, 1998). A brilliantly written book, which reads 'history against the grain', explores the making of geology in 18th-century England, thereby downplaying the idea of 'Lyell and the golden age of nineteenth-century geology' (Porter, 1977).

The definitive history of early 19th-century 'professional geology' in Europe and the rise of historical approaches to the study of the Earth has recently been published by the doyen of historians of geology, Martin Rudwick, in a magisterial diptych of books: *Bursting the Limits of Time* – or *BLT* (2005) and *Worlds Before Adam* – or *WBA* (2008). *BLT* (to use Rudwick's acronym) traces the development of a historicized way of studying the Earth which Rudwick argues matches the Copernican and Darwinian scientific revolutions in scale and importance. From this new viewpoint of geohistory describing the structure and chronology of the Earth is a precursor to the main task of geology, which becomes reconstructing what we now call palaeoenvironments. The second volume, *WBA*, examines how this 'new way of seeing' enabled geologists to construct persuasive representations of former environments. In brief, new ways of thinking (*BLT*) became new ways of doing (*WBA*). These books include much rich material on debates on the formation of landforms and on the development of the revolutionary idea that the world was once gripped by an Ice Age.

The idea that science is subject to revolutions in thought and practice has been central to a whole stream of books on the history of geology; for example, Hallam (1989) offers an excellent review of a series of *Great Geological Controversies*. However, 'the plate tectonics' revolution of the 1960s has produced a raft of books aimed at the public, geologists, historians, and philosophers and sociologists of science. Many of these books also explore the older idea of continental drift (see Hallam, 1973). Oreskes (1999) provides a fascinating historical account of the problems the theory of continental drift faced in the hostile cultural context of 20th-century US geology. In a slightly later work Oreskes (2001) has also produced a valuable edited volume on the history of plate tectonics where many of the original protagonists and antagonists give revealing accounts of their roles in the evolution of a revolution.

In a similar vein both Glen (1982), drawing on interviews with leading geophysicists, and Menard (1986), who offers his personal reflections, provide further rich 'biographical histories' of the development of plate tectonics. All of these books on the history of plate tectonics (except Hallam, 1973, which employs Kuhn's concepts of paradigm shifts in scientific revolutions) are standard narrative accounts that do not attempt to offer alternative philosophical or sociological claims about what these episodes may tell us about the nature of science. In contrast, Le Grand (1988) views the exemplars of continental drift and plate tectonics through a set of philosophical and sociological lenses of theory change in science (chiefly those of the philosopher Larry Laudan, and of sociologists who adopt a social interests approach). The geopolitical and social shaping of science in the history of differing schools of thought on 'drift and tectonics' is explored in Wood (1985).

The contested nature of science as an exemplar of the role of social factors in the shaping of geology is a theme that unites three seminal studies on the standardization of stratigraphy in 19th-century Britain: Secord (1986) explores *The Cambrian–Silurian Dispute*, Rudwick (1985) analyses *The Great Devonian Dispute*, and Oldroyd (1990) examines *The Highlands Controversy*. These three books all set new standards for empirical scholarship and demonstrated how what may seem like arcane knowledge of episodes in the history of geology can also provide telling insights into the (contested) nature of contemporary science. The Geological Society of London played an important role in airing and settling the geological disputes highlighted in these three studies and two recent books offer social histories of this institution's part in the making of geology over the last 200 years (Herries Davis, 2007; Lewis and Knell, 2009).

Other recent books that emphasize developments in 20th-century geology include a valuable edited collection (Oldroyd, 2002), a useful history of sedimentary rocks (Okada, 2005) and Young's (2003) outstanding account of the history of igneous petrology which examines the tensions between 'the lab and the field' in great detail (which remains a central tension in physical geography; Agnew and Livingstone, 2011). All of these books concentrate on battles between leading (heroic) figures in the history of geology. In contrast, a recent book on the 200-year history of the geology of the English Lake District explores the everyday work of the Geological Survey and of academic geologists in constructing the interactions between *Earth, Water, Ice and Fire* – both in making this Lakeland landscape, and in the creation of our current geological knowledge of this region (Oldroyd, 2003). This tension between the 'heroic' and the 'mundane' also lies at the heart of the recent debate over how geographers should write their history (see Driver and Baigent, 2007; Johnston, 2005, 2007). It is striking how the history of geomorphology is usually written in a heroic key – perhaps because so much of this history is written by geomorphologists themselves – as we will see in the next section.

2 History and philosophy of geomorphology

Textbooks typically begin with a brief history of the field – for example, in geomorphology see Chorley et al. (1984). Similarly, books on 'the state-of-the-science', such as *Geomorphology: Present Problems and Future Prospects* (Embleton et al., 1978), also offer interesting historical overviews. Finally, some undergraduate texts also say something on the philosophy of science and how this influences different schools of research in, say, geomorphology (Hugget, 2007). However, over the last 50 years or so a cluster of more specialist texts on the history and philosophy of physical geography, and especially geomorphology, has appeared. That said, as I pointed out in my introduction, in - contrast to human geography there is little evidence that this material is a central part of the Anglophone university geography curriculum.

The history of geomorphology is a field that is well served by introductory and advanced texts – almost all, however, are written by professional geomorphologists. Kennedy (2006) offers a readable short account of the history of landforms. However, a more scholarly and stimulating introduction is provided by Keith Tinkler (1985), who has also edited a valuable collection which covers the *History of Geomorphology* over the last 200 years or so (Tinkler, 1989). A marvellously readable and thought-provoking account of the development of geomorphology in Britain in the 300 years to 1878 is given by Herries Davies (1969). The American historian Stephen Pyne (2007) has written the standard biography of Grove Karl Gilbert – *A Great Engine of Research* – and his role in key developments in US geology in the late 19th century.

A recent useful collection on the interlinking history of the history of geomorphology and Quaternary geology, which is particularly useful for its emphasis on the making of these fields in non-English-speaking countries, is Grapes et al. (2008). In passing, it should be no surprise that most of the books mentioned in the present review are histories with a pronounced Anglocentric bias. Finally, Gregory (2000) provides a valuable overview of the development of Anglo-American physical geography since 1945, focusing on the dominant areas in this area: Quaternary science, and geomorphology (although climatology, hydrology and soils are well covered too).

The definitive history of geomorphology, however, is the collection of 'Chorley and Beckinsale'. Volume 1 explores *The History of the Study of Landforms* before William Morris Davis (Chorley et al., 1964). Volume 2 examines the life and work of William Morris Davis, and the dominance of 'the Master' of the field of geomorphology in the late 19th to mid-20th centuries (Chorley et al., 1973). Volume 3 considers historical and regional geomorphology (largely conducted outside Anglo-America) in the first half of the 20th century (Beckinsale and Chorley, 1991).

After a gap of 17 years, Volume 4 has recently been published (Burt et al., 2008). This grand final tome (a 1,000-page edited collection) examines developments in geomorphology, particularly the shift from 'form to process' studies that occurred in the 20th century (although in reality their history ends in the mid-1960s – so there is ample room for research on developments over the last 50 years or so). Chorley's role in shaping studies of *Process and Form in Geomorphology* are admirably captured in an outstanding volume celebrating his achievements – written by many who worked with and were inspired by him (Stoddart, 1996). The seminal and enduring intellectual value of the first three volumes of *The History of the Study of Landforms* has recently been endorsed through their re-issue in the prestigious 'Routledge Revivals' series in hardback and paperback (Chorley et al., 2009/2010), which clearly shows that the history of geomorphology matters.

The following list outlines some of the topics that could form the beginnings of a more sociologically aware history of geomorphology:

- Process revolution
- Dating revolution
- The role of new technologies in geomorphology
- Rise of tectonic geomorphology
- Growth of planetary geomorphology
- Laboratory/modelling versus fieldwork
- Development of the philosophy of geomorphology
- Making of Earth Systems Science
- Development of Geomorphology as a discipline and profession

Moving on to literature on the philosophy of science, it is striking that standard introductory books on the topic say nothing about the geosciences (e.g. Chalmers, 1999; Rosenberg, 2005). However there is a small cluster of texts, particularly on geomorphology, that examine what sort of science geologists and physical geographers *should do* and *should practise* (and, of course, the growth of various groups who promote particular positions is itself something that is open to historical and sociological scrutiny). The best introductory book to the key philosophical issues is Inkpen (2004) which, although nominally covering the whole of physical geography, is essentially a book on philosophy of science applied to geomorphology. The classic text that promotes critical rationalism (basically, a Popperian falsification of hypotheses approach) as the way to practise 'scientific physical geography' is Haines-Young and Petch (1986). For an advanced discussion of the relations between the geosciences and philosophy of science one may turn to Engelhardt and Zimmerman (1988). For those looking for a more continental philosophical approach to geology then Frodeman (2003) is worthwhile.

All of these books are part of a tradition of geologists reflecting on the philosophical and theoretical assumptions that are typically embedded in their scientific practices. In a similar vein, a series of books by leading geomorphologists endeavours to make explicit a series of implicit philosophical issues – for example, on the nature of geomorphology (Pitty, 1982), on key ways to be wrong as a geomorphologist (Schumm, 1991), and on the nature of theoretical geomorphology (Thorn, 1988). For a valuable volume of essays on contemporary debates and reflections on what it means to be a physical geographer, see Trudgill and Roy (2003). The definitive account on philosophy of science and geomorphology, however, remains the collection brought together in Rhodes and Thorn (1996a). Parts of this book border on the sociological, notably the chapters by Rhodes and Thorn (1996b) who touch on feminist approaches, and particularly Sherman's (1996) provocative review of academic fashions in geomorphology where he concludes:

> There is a struggle going on for the leadership of geomorphology. The struggle is about power, prestige and control ... There has been, and continues to be, pressure to conform to an orthodoxy. Or to change it. (Sherman, 1996: 109 and 106)

This can be read as a call for a 'critical theory' where understanding the history of such orthodoxies enables academics to have more of a chance of changing the world. Such a project – of understanding 'science in action' – lies at the heart of the interdisciplinary field of science studies, and it is on this I focus next.

III Science (and technology) studies

Few STS scholars have written about the *sociology* of the Earth sciences beyond studies of the atmospheric sciences (and especially climate change). The only two books that I am aware of by professional *sociologists* on the geosciences are on the socio-history of industrial geophysics in Canada between the first and second world wars (Bowker, 1994), and a recent excellent ethnography of US meteorologists in the Chicago area and their role in the science of forecasting storms (Fine, 2007).

Although, in principle, STS examines the nature of science through the three perspectives of philosophy, history and sociology, in practice STS is dominated by a combination of sociological and historical approaches (see Hackett et al., 2007). Pickering (1992) remains a seminal STS text, while Biagioli (1999) is still the outstanding collection of 'classic papers' in science studies. Useful introductory STS books include: Erickson (2005, good on the differing approaches of philosophy, history and sociology); David (2005, who takes a 'paradigms' approach, i.e. feminist approaches, etc.); Yearley (2005, who examines how key schools of STS are 'put to work'); and Hess (1997, an excellent introduction to the main intellectual traditions in STS, e.g. social worlds, actor-network theory and so on). The finest introduction, however, is the short book on science studies by Sismondo (2010). By far the most comprehensive book on STS is the *New Handbook of Science and Technology* (Hackett et al., 2007). The earlier edition of this book is also still worth reading (Jasanoff et al., 1995). Other landmark introductions from formative figures include a lively preamble on scientific expertise and the contested nature of science by Collins and Pinch (1998), and advice on how to study *Science in Action* by following scientists as they go about their work (Latour, 1987). Indeed, one of the main achievements of STS is the focus on practice – what scientists do – so that science studies is invariably concerned with the social shaping, social practices and social implications of the co-production of science *and* society (Jasanoff, 2004, 2005).

It is important to stress that many of the best sociology of science books are also histories of science, and that many seminal histories of science are also deeply sociological. This reflects Bourdieu's argument that history and sociology should be flip sides of the same coin, so history should be a historical sociology of the past, while sociology, at its best, is a social history of the present (Bourdieu and Wacquant, 1992). The two standard modern introductions to the history of science, which include some material on the geosciences, are Pickstone (2000) and Bowler and Moros (2005). The shift to a historical sociological emphasis on the social practice and social shaping of science is usually taken to have its *locus classicus* in *Leviathan and the Air Pump: Hobbes, Boyle and the Experimental Life* (Shapin and Schaffer, 1985). The historiography of the intertwining of 'history and sociology of science' is presented in a paper by Secord (2004), and in a book on *Constructivism and the History of Science* (Golinski, 2005). These authors discuss questions of historiography and readers interested in recent debates will find readable and balanced accounts on the practice of history in Jordanova (2006), and in a critique of 'radical postmodern' versions of history in Evans (2001).

The present is an apt time to argue for STS perspectives on physical geography as two recent books on the histories of Quaternary science and geomorphology have both made direct appeals for science studies scholars to research their fields:

> These pages [on the history of Quaternary geology] might, perhaps, offer case study material for the theories of philosophers or sociologists of science. (O'Connor, 2007: 357)

> Almost all history of geomorphology has been written by geomorphologists for geomorphologists ... This volume does not and cannot offer a survey that matches recent preoccupations in other disciplines, science studies in particular ... The field might become attractive to historians [and sociologists] of science ... [in] projects other than ours. (Cox, 2008: 6, 9, 7 and 9)

Such requests chime with my revised version of Chorley's oft-quoted aphorism on the nature of theory in geomorphology: 'The only true prisoners of history [theory] are those that are unaware of it' (Chorley, 1978: 10). Alas, for many scientists the social practice of science is something discussed in the pub rather than in print. The trouble, however, with the published version of science is that it often gives the impression of 'ready-made science' rather than of 'science in the making' (to borrow a phrase from Latour, 1987). Furthermore, practitioner accounts of the history of science face the problems of being *presentist Whig histories of accomplishments*. In other words, the past is seen through the spectacles of the present, the present is seen as 'the best of all possible worlds', and the contested shaping of scientific practice 'in action' is erased. Of course, these three problems are not inevitable, but one potential advantage of outsider histories over insider histories is the lack of a vested interest in promoting a particular version of the past to serve the present, for example, of the exaggerated disparity between the stage versus process views of geomorphology that are supposedly embodied in the work of W.M. Davies and G.K. Gilbert (see Sack, 1992, 2002). In contrast, non-practitioner (outsider) accounts potentially offer new sources, new evidence, new arguments and new concepts in new *social and material histories of practices.*

Such an approach is exemplified in a series of recent books on the environmental sciences by historians and 'sociologists of science' which takes a more cultural and social turn than, say, the standard histories of geomorphology listed above. This outsider perspective emphasizes the cultural shaping of science and the social and material histories of scientific practices. Such intellectual history is a feature of recent books on the field sciences (e.g. on the lab-field interface, Kohler, 2002; and on naturalists as scientists, Kohler, 2006); the earth sciences (Bowler and Pickstone, 2009); the environmental sciences (e.g. on climate modelling, Edwards, 2010, and on a range of environmental sciences, Vetter, 2010); and of the field of human and physical geography too (Agnew and Livingstone, 2011). Recent work in this vein has also employed ethnographic approaches (e.g. on weather forecasting, Fine, 2007; and on biological oceanography, Helmreich, 2008). In addition, a cluster of research texts adopts a biographical approach (e.g. on plate tectonics, Oreskes, 2001; on meteorology and climatology, Gladfelter, 2002; and on careers in the field sciences, Cox, 2002). Taken together, these texts offer a stimulating set of recent intellectual histories on the environmental sciences. In the next section I provide the beginnings of an answer to the pleas of Cox (2008) and O'Connor (2007) that I cited above in a discussion of a science studies research agenda on the making of the science of physical geography.

IV Science studies: a preliminary research agenda

How might STS prove productive in exploring the historical sociology of the Earth sciences? In particular, which key perspectives and concepts from science studies can provide the beginning of a research agenda on a topic like 'the historical sociology of geomorphology'? In what follows I suggest some broad answers to these broad questions by promoting 10 (interrelated) perspectives from science studies. I take it as read, of course, that excellent research will tackle and integrate many of these themes. I also leave it to the reader to make connections between the books on 'history and philosophy of the geosciences' that I discussed above, and the 'sociology of science' texts and case studies that I discuss below. My claim is that these two separate literatures can be profitably combined in new research on the 'sociology of physical geography', for example, by investigating the following issues:

(1) How are the social worlds of science constituted?
(2) How do new scientific disciplines emerge and change?
(3) How do different groups in a discipline view/contest each other's research?
(4) How is science distinguished from non-science?
(5) How do models make and shape science?
(6) How does geography shape science?
(7) How are scientific identities and careers formed?
(8) How does laboratory culture shape the practice of science?
(9) How is the field of science structured?
(10) How do biographies reflect and change the spirit of the age?

The choice of approaches in the above list inevitably reflects my own interests. I have explicitly used the notions of core set (Michael et al., 2007), geographies of science (Wainwright and Williams, 2008), boundary-work (Wainwright et al., 2007a), laboratory culture (Wainwright et al., 2006c), scientific models (Wainwright et al., 2008), and aspects of the conceptual framework of Bourdieu (Wainwright et al., 2009) in a cluster of papers on the sociology of stem cell science and of translational research (the shift from lab to clinic). In addition, social worlds (Williams et al., 2008), the histories of disciplines (Wainwright et al., 2006a) and careers (Wainwright et al., 2006b) are all implicit in these papers. My research before my work on stem cell science was an ethnography of dancers at the Royal Ballet – and social worlds, identities, careers, history and Bourdieu were all central to a cluster of my publications on this different – but in many ways surprisingly similar! – world (see Wainwright and Turner, 2004, 2006; Wainwright et al., 2007b). I hope this shift of focus, from the social worlds of classical ballet to stem cell science to Luna Leopold and physical geography (Wainwright, 2011) shows the value of a geographical education in shaping a geographical imagination. However, before I discuss Leopold and the geographical imagination, let me add a paragraph or two on each of the 10 science studies perspectives that I have listed.

On a personal note, the book that George De Boer encouraged his first-year Geography undergraduate tutor group to read was *The Structure of Scientific Revolutions* (Kuhn, 1970 [1962]). He was committed to a 'historical denudation chronology' approach to geomorphology (De Boer, 1974) and so perhaps he felt that calls for a 'process based geomorphology' as a the paradigm for a new science of landscape were a plea that should make us nascent geographers think about big questions such as 'what is science?' and 'how do we account for scientific change?'. The book left its mark – two of my papers have 'paradigm' in the title (Wainwright, 1997; Wainwright et al., 2008)! *Structure* is usually seen as a foundational text in STS as 'by highlighting the role of tacit knowledge in scientific practice, Kuhn opened the door to empirical studies of scientific procedure' (Livingstone, 2009: 667), and it is to 10 such science studies research perspectives that I now turn.

(1) *How are the social worlds of science constituted? What are the dominant 'ecologies of knowledge' in these scientific worlds?* This *Social Worlds* approach (an application of the seminal Grounded Theory style of inductive qualitative research developed by Glaser and Strauss, 1967) has been employed in some classic historical and ethnographic science studies monographs, for instance, on the genetics of cancer (Fujimura, 1997), on the history of reproductive biology and medicine (Clarke, 1998) and on the development of foetal screening and surgery (Casper, 1998). This approach also spawned a seminal text, *The Right Tools for the Job* (Clarke and Fujimura, 1992), on the cultural practice of science.

Social world's researchers tend to draw on and develop a roster of concepts, such as *the right tool for the job* (e.g. on the development of the Pap smear for cervical cancer – Casper and Clarke, 1998), *boundary objects* that link different domains (e.g. in a case study of trappers, museum curators and the public that enabled the building of Berkeley's Museum of Vertebrate Zoology – Star and Griesemer, 1989), and on researching *do-able* problem, through *articulating alignment* (e.g. between the lab and clinic that enabled the discovery of oncogenes – see Fujimura, 1987). Geographers are likely to be more familiar with the *Actor Network Theory* of Latour (1987) and others and its *concepts of centres of calculation* and *obligatory passage points* (see Barnes, 1998; Powell, 2007a) and partly for this reason I will not discuss this further here. In addition, for many a major advantage of a social worlds approach over the 'flat ontology' of ANT is its commitment to 'a [feminist] political and theoretical perspective that prefers to look over some shoulders more than others' (Casper and Clarke, 1998: 257).

(2) *How do new scientific disciplines emerge and change?* The work of the historian and sociologist Robert Kohler examines this question in three memorable monographs that chart the social and material practices that underpin the making of scientific knowledge. In his first

book Kohler drew on his initial training as a chemist to examine the emergence of biochemistry from medical chemistry (Kohler, 1982). This was followed by books on the development of the laboratory specialism of ‘fruit fly genetics’ (Kohler, 1994), and on the interface between the lab and the field in the materialization of modern ecology and evolutionary biology (Kohler, 2002 – a text widely cited by geographers with an interest in fieldwork). All three books ground what are now seen as major scientific accomplishments in an interrelated set of social and material practices. For instance, Kohler (1994) shows how ‘fruit fly genetics’ came to be a dominant approach to genetic science for a set of social reasons – for example, the flies were easy to keep and breed and their ‘life cycle’ enabled students on short-term research projects to potentially make major scientific breakthroughs which meant that the lab could produce more papers and attract more research grants in a virtuous cycle that enabled the lab to dominate the field (to ride the wave they had created).

Other history of science books that provide exemplars of how the histories of disciplines can be written include Kevles (1995), on the history of the growth of the physics community in 20th-century America, and a text that explores the cultural production of scientific disciplines, particularly the development of aspects of biology, chemistry and physics in 19th-century Germany (Lenoir, 1997). In similar vein, Randall Collins (1998) develops a global theory of intellectual change in his magnum opus on *The Sociology of Philosophies.* Such changes inevitably also reflect the contested nature of academic life, a theme that is addressed in the next question.

(3) *How do different groups within a discipline view/contest each other’s research?* Harry Collins’ work on the ‘core set’ (the conceptual space inhabited by the principal respected experts engaged in research on a particular area) examines the tensions between theoretical and experimental physicists in their search for gravity waves – see his epic ethnography (Collins, 2004) on the tensions between and within the physics communities in Italy, Japan, Australia and particularly the USA. This core set approach is also central to a recent study of personalized medicine, where Hedgecoe (2004) analyses the move from the lab to the clinic in two contrasting case studies: of breast cancer where an alignment of clinicians, scientists and policy-makers enabled translational research; and of Alzheimer’s disease, where the clinicians were not persuaded by the scientists’ claims, and so this ‘breakthrough science’ stayed in the lab. The concept of the core set is also used to frame the concluding discussion in the seminal history of geology text that I mentioned earlier, the *Great Devonian Controversy* (Rudwick, 1985). This was, literally, boundary-making in action and it is to boundary-work that I move next.

(4) *How is science distinguished from non-science? How is ‘more productive science differentiated from ‘less productive science’?* Tom Gieryn’s (1999) seminal study of boundary-work, that is the social and historical construction of the cultural boundaries of science, has produced an efflorescence of interesting case studies on ‘making (and unmaking) science’. In an earlier paper Gieryn (1983) coined the term boundary-work in his analytical account of the demarcation of the strains and interests of different groups as they fought to distinguish science from non-science in areas such as phrenology in 19th-century Edinburgh. The idea has also spawned work on contested boundaries in policy-relevant science (Jasanoff, 1987). A geographical example of the use of the boundary-work concept examines tensions between green activists and the ‘grey science’ of environmental knowledge (Eden et al., 2006). A recent paper that maps biomedical and clinician scientists’ perceptions of social science research shows how the two cultures of scientists and social scientists typically hold very different

models of what counts as good research (Albert et al., 2009) – in similar ways to the tensions between what physical and human geographers would see as what counts as ‘science’ or even ‘research’. Turning to models of a different sort, we can ask the next question.

(5) *How do models make and shape science?* Models were famously seen as an approach with the potential to unite human and physical geography (Chorley and Haggett, 1967). The role of physical 3-D models in scientific disciplines as varied as biology, chemistry, economics, engineering and mathematics is evocatively discussed in a book edited by de Chadaravian and Hopwood (2004). Models matter as they allow scientists to think and do things differently – they can transform practices. Such a transformation has recently been analysed in a major book: *A Vast Machine: Computer Models, Climate Data and the Politics of Global Warming* by the STS scholar Paul Edwards (2010). The central message of this book on the making of climate knowledge is that data and models are deeply co-constituted, so that ‘neither pure data nor pure models exist’ (Edwards, 2010: 282). In this case, and beyond, scientific practice is driven by entwined developments in imaging technologies, computer power, and the social and political organization of science. This ‘practice turn’ – which lies at the heart of science studies – is also highlighted by Stuart Lane in his reflections on his work as a ‘mathematical fluvial geomorphologist’ when he writes: ‘modelling is about practice ... The way I come to trust my own models is a process rather than an end point’ (Lane, 2011: 232 and 234). Given the centrality of models in geography it is appropriate that my next theme summarizes some important writings on geographies of science.

(6) *How does geography shape science?* The production, circulation and consumption of science is examined by David Livingstone (2003) in a real gem of a book. Three recent books on historical geographies of science examine the spatial shaping of science, and all take *where* as seriously as *who* and *when*, by focusing on the Age of the Enlightenment (Withers, 2007), the Victorian period (Finnegan, 2009) and geographies of 19th-century science (Livingstone and Withers, 2011). Given that most geographers will be more familiar with this style of research than with many of my other science studies themes, I will quickly move on to consider something less familiar – historical and sociological research on scientific careers.

(7) *How are scientific identities and careers formed?* The notion of science as a moral vocation has recently been consummately addressed by Steven Shapin (2009) in his ‘20th-century history’ of US science (the focus is on the natural sciences, the life sciences and engineering – alas there is no mention of the Earth sciences!). The passions for the profession of science, and the ways in which institutions (especially universities) shape academic careers are explored in two sociological studies of US physicists by Joseph Hermanowicz (1998, 2009), who writes in a Mertonian fashion that foregrounds the role of scientific institutions and of differing types of American Universities (Ivy League, State Research Universities, and Community Colleges) in shaping the careers of physicists in academia. Such a macro/structural approach to sociology of science is seen by many, however, as rather old hat, and much (perhaps too much) recent work in STS has therefore explored the micro practices of the making of scientific knowledge, and it is to this that I now turn.

(8) *How does laboratory culture shape the practice of science?* The seminal study of *Laboratory Life* by Latour and Woolgar (1986 [1979]) is invariably taken as a key stage in the development of STS (Hess, 1997). However, several other studies based on various styles of ‘ethnographies of science in action’ were part of a dramatic shift from a sociology that focused on the institutional shaping of science (Merton, 1973), to a sociology that concentrated on the laboratory practices entailed in making science.

Key ethnographies of laboratory life include: a (radical) social constructionist take, largely based on the science of plant physiology (Knorr-Cetina, 1981); a historical sociology of particle physics (Pickering, 1984); an ethnomethodological perspective on the neuroscience lab (Lynch, 1997); and a pair of anthropological studies, on high energy physics labs in Japan and the USA (Treweek, 1992), and a Nobel Prize-winning technology that revolutionized the biosciences – *Making PCR* (Rabinow, 1996).

The great strength of the ethnographic approach is its ability to evoke what it is like to be a scientist doing science. That said, a common criticism of this work is that by focusing on the pixels it loses sight of the picture. This is not inevitable, however, and the structural factors that shape scientific practices can be included in ethnographic studies, for example, in a study of how commercial imperatives imbue the everyday decisions of plant scientists working at a large university based lab in the Mid-West of the USA (Kleinman, 2003). This interpenetration of agency and structure, of micro and macro, lies at the heart of the sociology of Pierre Bourdieu, and so I now move on to a brief discussion of habitus, field and the production of distinction.

(9) *How is the field of science structured? What counts, and why, in the field of science?* These questions were posed in Pierre Bourdieu's provocative short book on the *Science of Science* (Bourdieu, 2004). In brief, fields are hierarchies of power within social worlds that produce a set of dispositions (a *habitus*) where agents typically reflect the structures (field) they are embedded in, and where individuals and institutions strive to accumulate 'capital' to maintain (and enhance) their position within a field (by gaining distinction). Capital takes various interrelated forms – economic (money), social (networks), cultural (education), symbolic (status) – and so Bourdieu's schema is useful in understanding the complex (and sometimes hidden) production and reproduction of (unequal) social worlds.

Several writers that we have already met partially draw on Bourdieu in their research on scientific fields (e.g. Kleinman, 2003; Lenoir, 1997), while Burri (2008) productively combines Gieryn's (1999) notion of boundary-work with Bourdieu's concept of distinction in a paper on the rise of new forms of imaging, such as MRI scanning, that are central to the recent rise of the discipline and profession of radiology in the field of medicine. One idea of Bourdieu's that has, so far, been little used in STS is the concept of *illusio* – a person's inclination, ability and investment in a field, or, in Bourdieu's phrase, 'is the game worth the candle?' Hence *illusio* is vital in shaping both individual and institutional (scientific) identities. Of course, the central aim of this paper is to persuade researchers that the 'social study of physical geography' is an academic pursuit that is worth pursuing. This talk of making individual identities neatly brings me to the final STS topic, scientific biography.

(10) *How do biographies reflect and change the spirit of the age?* Our biographies, and the biographies of others, are extremely productive ways through which to make sense of familiar and unfamiliar social worlds. In Hermione Lee's telling prose:

> Biography ... has a duty to the stream as well as the fish ... The subject of a biography ... should seem to be alive, breathing, present in all the totality, there-ness and authenticity of their being. (Lee, 2009: 13, 14 and 3)

Given that science is a difficult vocation it is unsurprising that historians of science such as Shortland and Yeo (1996) have emphasized the importance of personal identities and life histories in the cultural history of science. To expand, four key uses of scientific biography have been identified: as a method for writing contextual history of science; as a means for understanding science-in-the-making; as a mode of public commemoration; and as a labour of love (Soderqvist, 2006: 105). The emphasis on texts in contexts makes such a version of intellectual history a sociological one, as Thorpe makes clear in his book on the rise and fall of the physicist Robert Oppenheim and his role pre-, post- and during the Manhattan Project to develop the atomic bomb:

> To write the biography of Oppenheim is therefore to write simultaneously both the account of an individual life and the history of the making of social, institutional, and cultural forms; it is in that sense *sociological* biography. (Thorpe, 2006: 18, original italics)

'Lifepaths and biography' have also, of course, come to lie at the heart of work on the history of geography (see Daniels and Nash, 2004), and two classic collections of biographical writings by human geographers that physical geographers (and those in science studies too) should find worthwhile are *The Practice of Geography* (Buttimer, 1983) and *Recollections of a Revolution: Geography as Spatial Science* (Billinge et al., 1984). This focus on biography brings me to a review of some vital aspects of the life and work of the geologist Luna Leopold.

V Luna B. Leopold

Luna Bergere Leopold is one of the most highly decorated geoscientists of the 20th century. Leopold published over 150 scientific papers on a broad range of topics, notably geomorphology, hydrology, fluvial processes, weather, climate, soils, landscape aesthetics, environmental policy, and the role of the scientist. Most of all 'he loved geology because of the picnics' (Vita-Finzi, 2008: 250). In other words, Leopold had a deep love of landscapes and a scientific commitment to understanding and protecting them (for a more extensive discussion of his life and work, see Wainwright, 2011, and *The Virtual Luna Leopold Project* at the University of California, Berkeley). In what follows here I discuss his two most famous works of fluvial geomorphology – his paper on *hydraulic geometry* (Leopold and Maddock, 1953), and his book on *Fluvial Processes in Geomorphology* (Leopold et al., 1964). My main aim, however, is to draw on his biographical writings, particularly his oral history (Leopold, 1993 [2010]), to uncover the 'behind the scenes' working of a 'geomorphological imagination in action'. I hope this paper begins to cast light on how 'Luna Berger Leopold's life was one that burst the banks of discrete fields to flood and enrich a broad variety of disciplinary, professional and public plains' (Wainwright, 2011: 97).

Luna B. Leopold was widely considered one of the world's leading authorities on rivers and on the landscapes they create. Leopold was an outdoorsman for all his long life, who revolutionized the study of geomorphology by introducing quantitative methods into a field that had been largely historical and descriptive until the early 1950s (Church, 2010). Leopold was also a very versatile scientist, who trained as an engineer, meteorologist and geologist, and who combined these fields to embark on, and enduringly embellish, interdisciplinary research on rivers and landscapes. Leopold graduated with a Bachelor of Science degree in Civil Engineering from the University of Wisconsin in 1936, and he then joined the US Soil Conservation Service to work in the emerging field of hydrology. During the Second World War, he served in the Army Corps of Engineers Weather Service, and was awarded a Master of Science in Physics and Meteorology from UCLA in 1944. After the war, he became Chief Meteorologist at the Pineapple Research Institute of Hawaii.

Luna Leopold edited his father Aldo's seminal ecological work *A Sand County Almanac* (Leopold, 1949). He received a PhD in geology from Harvard University in 1950, and then combined his interests in hydrology, geology and engineering – and conducted his most important work – during his two decades with the US Geological Survey (USGS). From 1956 to 1966, he was the chief hydrologist for the USGS, and he is credited with transforming its Water Resources Division into one of the world's leading centres of research on hydrology and geomorphology. After retiring from the USGS in 1972, he was appointed as Professor at the University of California, Berkeley (UCB), and he became an Emeritus Professor of UCB in 1987. 'Few have written papers spanning 68 years, and fewer still have had such a great influence on a scientific field or on society' (Gregory, 2010: 120). So far, I have merely listed some of his accomplishments, but what factors influenced Leopold's academic development?

Luna Leopold was part of a family of naturalists. One major influence on his career was his family background, particularly his father and siblings. Luna was the son of Aldo Leopold, who was Professor of Forestry at the University of Wisconsin and one of the leading figures in American conservation. 'I had an advantage, perhaps even a great one: a family of distinction and of enormous help in their constant attention to intellectual and handicraft pursuits' (Leopold, 2004: 1).

His elder brother, Starker (1913–1983), was Professor of Zoology at University of California, Berkeley; his sister Nina Leopold (1917–) became a prominent naturalist and *Director of the Aldo Leopold Foundation*; his brother Carl Leopold (1919–2009) was Professor of Plant Science at Cornell University; and his youngest sister Estella Leopold (1927–) was Professor of Geology at the University of Washington. Remarkably, three of the five Leopold children went on to become members of the *National Academy of Sciences* (Starker, Luna and Estella).

Inspired by his upbringing, Luna included a lot of geology and botany courses in his degree in engineering as he believed that to practise conservation scientifically you needed to work with engineers and 'in order to talk to engineers I have to be an engineer' (Leopold, 1993 [2010]: 27). He combined his innate interest in conservation with his engineering training in his first job as a civil engineer with the US Soil Conservation Service. He resigned after three years as he 'wanted to get work that was more concerned with the war effort' (Leopold, 1993 [2010]: 40). However, he was a great networker and he kept in touch with important figures in both the US Soil Conservation Service and the related US Geological Service (USGS), and these contacts enabled him to take a post with the USGS in 1950. Prior to this Leopold worked as a meteorologist (1940–1950), and Leopold reflects on this decade as a 'weather man' in the following two short quotes:

> Meteorology was very important to me because it made me think of things in a different way to the way other people thought of them. (Leopold, 1993 [2010]: 46)

> My weakness in mathematics meant that I could never achieve real stature in meteorology. This recognition of weakness is an essential aspect of career development. (Leopold, 2004: 5)

In 1950 Luna Leopold switched fields from meteorology to become a hydraulic engineer at USGS, embarking on the research that would establish him 'as an icon in his field' (*Los Angeles Times*, 2006). His PhD thesis (1950), on 'The erosion problem of the Southwest', relates meteorology and climatology to landscape change and was supervised by the leading Harvard geologist Kirk Bryan:

> Kirk Bryan was always talking about . . . the intellectual growth in scientific thought . . . To provide new information to other people by learning new things. That's what science is all about . . . We read all kinds of essays written by the great men. But each time he was saying, 'We must do it a little differently; we must proceed beyond this'. (Leopold, 1993 [2010]: 32)

Doing things a little differently for Leopold meant drawing on his knowledge of his scientific experiences of meteorology and engineering. The period from 1950–1972, when Leopold was a key figure at the USGS Water Resources Division, is seen by many as a golden age for both Leopold and this group. Leopold transformed the USGS Water Resources Division into the premier international agency for water research (Vita-Finzi, 2006), 'the world's leading hydrologic institution; a truly major accomplishment' (Bull, 1995: 51). This is a remarkable feat as when he arrived 'there wasn't a research man in the whole organization of several thousand people' (Leopold, 1993 [2010]: 68). In addition, Leopold produced a seminal series of papers that made major academic and popular contributions to the hydrology and geomorphology of rivers, particularly in establishing key relationships – for example, his work on hydraulic geometry; in pioneering new measurements, for instance, of bedload; in developing new areas of theory, for example, on entropy and indeterminacy; and particularly in examining landscape change, such as the effects of urbanization on fluvial systems (see Wainwright, 2011).

In 1953 Leopold and Maddock published 'The hydraulic geometry of stream channels and some physiographic implications', and (in retrospect) this was the paper that 'established the methodology of the new fluvial geomorphology' (Tinkler, 1985: 187) and which 'defined a new, functionalist, fluvial geomorphological paradigm' (Clifford, 2008: 268). The paper became the second most cited paper in *Geomorphology* (with 503 citations: Doyle and Julian, 2005). With this paper, Leopold helped initiate a new era in the empirical study of rivers, one that involved quantitative approaches that spread to the broader field of geomorphology, and which provided a basis for observing rivers throughout the world in a new and productive way (Clifford, 1996).

Leopold and Maddock (1953) demonstrated how the shape of a river channel and the flow of water through it can be understood through a set of simple mathematical power functions. At any given point along the course of a river, the width and the depth of the channel and the velocity of the water are each proportional to some power of the total quantity of water passing that point per unit of time. Width, depth and speed all increase steadily in the downstream direction. Thus 'hydraulic geometry' relates river channel forms with river channel processes (broadly discharge of water and sediment). On a more personal biographical note, my undergraduate dissertation explored the effect of a reservoir on downstream hydraulic geometry (Wainwright, 1980, supervised by Keith Richards). Leopold and Maddock argue:

> The channel characteristics of natural rivers are seen to constitute, then, an interdependent system which can be described by a series of graphs having simple geometric form [straight lines]. The geometric form of the graphs describing these interactions suggests the term 'hydraulic geometry'. Channel characteristics of a particular river system can be described in terms of the slopes and intercepts of the lines. (Leopold and Maddock, 1953: 18)

This landmark paper was an attempt to address the problems of water resources in the American South West and so reflects a social concern borne out of Leopold's 'dustbowl youth' and background in a 'family of naturalists'. In his summary of the impact of this 'Classics in physical geography revisited' paper, Clifford contends:

> The authors were free to explore concepts and engage in speculation, to an extent that would not be permissible now. Partly as result, the report was as much a strategic document aimed at changing the philosophy of an academic discipline as it was a technical contribution to the literature on water resources ... It is difficult to overestimate the influence of this classic work ... Contemporary fluvial geomorphology owes this paper and its authors a great debt, and this debt will continue for a very long time to come. (Clifford, 1996: 87)

It is remarkable that the 2009 Kirk Bryan Award was given for a paper that identified a critical threshold (of the ratio of stream power to sediment size) that enables researchers to identify in which drainage basins hydraulic geometry is useful, and those basins where it is not helpful, which has important implications for simulations of landscape change and channel engineering (Wohl, 2004). Such 'pure research with practical implications' was a hallmark of Leopold's style of science.

The publication of *Fluvial Processes in Geomorphology* (Leopold et al., 1964) was another major turning point in the history of geomorphology. The book is the most-cited book in *Geomorphology* (Doyle and Julian, 2005). *Fluvial Processes* begins with something of an apology:

> We are aware that the feelings of professional geomorphologists about numbers, graphs, and formulas range from acceptance and enthusiasm to bewilderment and forthright hostility. We have not gone out of our way to be mathematical, but whenever we felt that mathematics contributed either clarity or brevity to the discussion, it has been used. (Leopold et al., 1964: 8)

Clearly, Leopold's background in civil engineering and meteorology was a significant influence on this shift away from what was pejoratively labelled as the 'arm waving' of W.M. Davies and his disciples (Sherman, 1996). Leopold et al. (1964) 'ushered in a new era of process investigation' (Gregory, 2000: 120), and it became 'the "bible" of the new orthodoxy' (Tinkler, 1985: 203), 'a stimulating survey of some of the core concepts of fluvial geomorphology' (Summerfield, 1991: 231) and a 'path-breaking ... classic' (Orme, 2002: 336 and 330); indeed, the book remains 'the "Bible" of fluvial geomorphology' (Charlton, 2008: 9). Barbara Kennedy (2006: 111) puts it perfectly – the book is 'Leopold's most lasting legacy ... This work has enormous verve and appears to reduce the chaos of fluvial landscapes to clear physical principles'.

Alas, there is no room here to say more about Leopold's pioneering research, but to give some measure of the man I will conclude this section with three short quotes from his fellow geomorphologists. Leopold's achievements have been lauded by those that knew him well; for example, in the introduction to Luna's several hundred pages of oral history his collaborator Tom Dunne reflects:

> Leopold's most lasting accomplishment will probably be the huge number of people ... whom he has motivated to develop and promote environmental science and to absorb it into the 'natural way of doing things' so that it is enduring and committed to human welfare. (Dunne, 1993 [2010]: 5)

In similar fashion, part of the citation for Leopold's award of the Penrose Medal of the Geological Society of America in 1985 reads:

> Luna has the courage to accept the risk of failure. The result is a bold, exceptionally innovative career that has created a continuing aura of excitement for a new fluvial geomorphology with a landscape ecology flavor. (Bull, 1995: 51)

While writing on the award of the 2006 Benjamin Franklin Medal in Earth and Environmental Science to (Luna) Leopold and (Reds) Wolman, Scatena and Varrin eulogize:

> The whole field of fluvial geomorphology they helped define arose out of their curiosity and love of rivers and their surrounding landscapes ... They transformed the landscape we lived in and made it a better place to live. (Scatena and Varrin, 2010: 693)

Such transformations are, I suggest, the product of a particularly powerful 'geographical imagination' and so in the next section I explore the nature of the geographical imagination and some of Leopold's insights into the practice of science.

VI From the sociological to the geographical imagination

The main purpose of any academic discipline is to instil in its students, teachers and researchers a particular imagination, a 'way of thinking

Table 1. Luna Leopold and the geographical imagination

Topic	Leopold's thoughts
(1) Inherent and not instrumental values	There are an awful lot of ... professional people, who are willing to sell their souls for money ... the importance of the non-monetary aspect of wilderness ... that's been a very important part of what I've accomplished. (Leopold, 1993 [2010]: 145)
(2) Basic research is a foundation for applied research	You can't solve environmental problems without knowing something about basic processes. (Leopold, 1993 [2010]: 130)
(3) Variety through becoming a generalist specialist	Always have more than one string to your bow. Don't work on just one thing. You ought to be doing three or four things simultaneously. (Leopold, 1993 [2010]: 38)
(4) Study big questions	Any aspects of science may founder temporarily on shoals of small questions of details, as well as the dead-end shallows of description ... The big question is one the answer to which might open up new areas. (Leopold and Langbein, 1963: 192)
(5) Read and practise widely, and take time to think	What I wish to stress here is the relatively long gestation period that is often required for the emergence of a distinctly new idea. Its emergence is often the result of two factors, 1) continual thinking across disciplinary lines, and the application of concepts from one field to a distinctly different one, and 2) the continual admixture of practical work with theoretical and purely intellectual concerns. Well might the modern research man ponder this history. (Leopold, 1974: 425)

about the world' that becomes second nature. The three core concepts of space, place and environment are widely seen as central to the geographical imagination (Matthews and Herbert, 2008: 14), while the notion of 'landscape detectives' lies at the heart of the geomorphological imagination (Goudie and Viles, 2011: 15). Rather than rehearse the various varieties of the geographical imagination here (see Daniels, 2011; Gregory, 2009), I want to focus on Harvey's (2005) reflections on the geographical imagination as rooted in C.W. Mills' (1959) celebrated account of the sociological imagination. Mills' iconoclastic style and aggressive approach to the leading sociologists of the day (whom he famously dismissed as 'grand theorists' and 'abstract empiricists') led to a series of savage reviews on the inadequacies of his book which are wonderfully recounted in an intellectual history of Mills' seminal text, and where Brewer (2004: 319–320) argues: 'Mills famously made sociology the study of the public issues that derive from the private troubles of people ... Sociology thus addresses simultaneously the link between biography and society'.

This focus on the mutual shaping of biography and history is also reflected in Daniels' (2011) recent plea for the pivotal place of the geographical imagination:

> In keeping with the exploratory tradition of geography, it is worth affirming the importance of the geographical imagination, as a matter of *both practical wisdom and scholarly reflection, and not least for its pleasure and enchantment, for people's love of learning about the world and their place in it*. (Daniels, 2011: 186, my italics)

In the next part of the paper I draw on Luna Leopold's 'scholarly reflections, practical wisdom and love of learning' to outline a geographical imagination with a geomorphological flavour (see Table 1). In summary, I suggest we can read Leopold's musings on scientific practice as five facets of 'the geographical imagination'.

First, an emphasis on inherent rather than on instrumental values – which chimes with the 'pleasure and enchantment' in the quote from Daniels (2011) above. Second, and related to this first point, the idea that basic research is a foundation for applied research. Third, the importance of variety, and the need to avoid becoming too much of a specialist – as what is needed is for researchers who are 'generalist specialists'. Fourth, it is important not to be swamped in the marshes of minutiae, and, instead, to research 'big questions'. Fifth, and this develops the need for variety and a focus on grand questions that we have met already, it is vital to read widely. In other words, research needs to have breadth as well as depth and so taking time to think about the connections between seemingly unconnected domains is vital. All of this, I contend, is grist to the science studies mill and so reading and researching the social history of science is also a fruitful way to inspire the development of a geographical imagination.

One of the aims of this paper is to begin to illustrate how biographical methods enable you to think about *your* life, and those of people you know or have an interest in, as a key part of the process of developing your 'sociological imagination' (Mills, 1959) where the links between biography and history (the individual and the world) are central. What lessons, if any, can we draw from all this?

VII Conclusion

On the level of everyday interactions with colleagues, we all have an interest in the interplay between the 'public and private' researcher. Why do academics pursue some research topics and not others? To what extent do they aim to challenge prevailing orthodoxies? How new really are their claims to be producing 'ground-breaking research', or is it no more than 'new wine in old bottles'? This array of topics is part of the fabric that makes meetings and conferences so enjoyable – but such issues should not simply be the topic of what seems like idle chit-chat in the bar. These issues – of what constitutes scientific practice, and the related topic of how science is shaped – form the core of a wide-ranging research agenda of science studies, one set of approaches to which I outlined earlier.

In this paper I have sketched out some literature and themes as a starter for those unfamiliar with recent work on the history and sociology of science. My hope is that this material opens up a myriad of research questions that are important and worthy of study. Much can be done, and so a loose coalition of human and physical geographers, together with historians and sociologists of science, is needed if significant progress is to be made on 'histories of contemporary geoscience practice'. This paper is also a call for researchers in all disciplines to resist 'The curse of overspecialization: [Where] historians [and geographers] dig ever deeper, narrower furrows in ever more desiccated soil until the furrows collapse and they are buried under their own aridity' (Fernández-Armasto, 2002: 149).

Reading the literature on the history and sociology of science broadens the mind and should encourage scientists (and I include social scientists here) to critically reflect on their research careers. My focus on Luna Leopold is underpinned by some implicit 'big questions', such as: how useful are life history case studies for understanding the practices of field science, the shaping of research fields, the making of disciplines, and in making some sense of our own academic lives? To put it more boldly, should we pin a new motto on our study walls: 'By our biographies shall you know us!' (with apologies to Harvey, 1969: 458)? In similar vein, Barnes (2001) also adapts the famous closing sentence of *Explanation in Geography* (Harvey, 1969) in his summary of the shift in outlook that some pioneering positivist human geographers are now exhibiting: 'Ironically, after 30 or 40 years, first-wave theorists are now practising

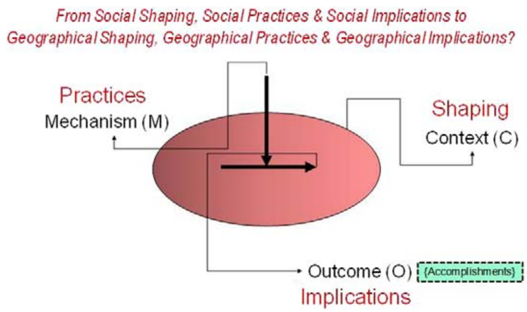

Figure 1. Real sociological and geographical imaginations through research on 'landscapes and lifescapes'
Source: Adapted from Pawson and Tilley (1997)

hermeneutics, relating their work to their lives and times. By our memories, and not by our models, shall you know us' (Barnes, 2001: 562).

In Figure 1, I schematically present a realist re-imagining of the argument of this paper. Rather than simply recounting the *outcomes* of science we need to also examine the *mechanisms* and *structures* that enable (and prevent) the accomplishments of science (to adopt the CMO argot of Pawson and Tilley, 1997). We can, I suggest, translate these CMOs into the implications, and particularly the shaping and practices that have been at the core of this paper, and whose elucidations lie at the heart of contemporary intellectual history. This matters as it is 'in trying to unravel the worlds of the past, we give ourselves the opportunity to re-weave our own' (Brett, 2002: 126).

I began with some personal reflections on C.P. Snow's (1959) two cultures, and I argued that this tension is still being played out between the human and physical wings of geography. One of the things, I propose, that can 'bridge the geographers' divide' is a love of landscape. The entwining of 'art and science' is embodied in the emotional force that landscapes held for Richard Chorley – the pioneering scientific quantitative process system modelling geomorphologist – and is beautifully captured in a quote from Peter Haggett and David Stoddart's luminous account of Dick Chorley's life:

> One limpidly-clear day in autumn 1962 ... in California ... the view suddenly opened up. For mile after mile the eastern, faulted-face of the Sierra Nevada rolled away in its majesty, 9000 feet above the valley floor. We ... left Dick alone, moved to the edge of tears. (Haggett and Stoddart, 2009: 73)

In conclusion, the aim of this paper is to inform, enlighten, stimulate and provoke research on the 'landscapes and lifescapes' of physical geography, by providing a discussion of some key literature on the history of human geography, geosciences, physical geography and science studies. My aim is to encourage academics from these largely separate social worlds to engage with this literature and with each other so as to research and write intellectual histories of the contemporary (environmental) sciences such as physical geography. To rephrase the famous opening sentence of a book on the history of *The Scientific Revolution* (Shapin, 1996: 1), 'There is no such thing as the sociology of physical geography and this is a paper about it'. My hope is that this 'absence' will persuade researchers from various disciplines to take up the challenge of developing an exciting and potentially fruitful new field – histories of the social practices of physical geography.

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