abundance and diversity and utilization in diverse environmental and social contexts (Matthews *et al*. 1997a). Field and micromorphological archives and samples, moreover, provide enduring records that can be reflexively re-examined as research questions and analytical techniques develop and change, and the examples here were reviewed to provide new insight into the sustainability of ecological and social practices and strategies. The field and micromorphological sections from the NERC project spanned 7000–1800 BC and geobotanical zones in Turkey, Syria, Iraq and Bahrain. In particular, these case-studies re-examined the extent and importance of wetlands to early agricultural settlement at Çatalhöyük, the use of clay resources in the site environs, and the networks of communication, building material sources, and mudbrick pits and water management at Tell Brak. At Çatalhöyük we established the prevalence within buildings that were previously interpreted as shrines of both everyday and ritual practices. We also identified the diverse renewable energy sources used across the Middle East to sustain occupation at individual settlements over millennia. In relation to these examples, the global challenges today that require urgent action include: the implementation of strategies to reverse potentially catastrophic biodiversity loss by increasing and safeguarding wetlands as – although they only 'cover around 6 per cent of the Earth's land surface, 40 per cent of all animal and plant species live or breed in wetlands…[and] they are disappearing three times faster than forests' (UNEP 2021); the creation of sustainable networks, transport and built environments; and the development of renewable energy supplies and carbon capture to reduce global warming and pollution (UN 2020).

By continuing to re-examine field and micromorphological records and archival samples we can investigate both new questions and old chestnuts. Charly's legacy is certainly of a magnificent branching canopy.

An archaeology of the Anthropocene: uncovering lost landscapes with Charly French

Nicole Boivin

Sometime relatively early during my Cambridge years, I found myself driving through the countryside with Charly French. I can't quite remember how I ended up there, or what exactly we were doing. I recall that Charly had to go to some archaeological digs that were underway, and I had volunteered to go with him. I have vague memories of rain and friendly British excavators – perhaps in spite of the latter, the former was part of what led me not to do my archaeological research in the British countryside. The details have all slipped away, but what has stayed with me always is the way that Charly utterly transformed my understanding of the world around me that day.

I was at that time a student, I'm pretty sure it was my MPhil year from 1995 to 1996. I had joined Cambridge's archaeology course from the natural sciences, where I had studied things like cell biology, gene transcription and basic chemistry, and spent a lot of time in a white lab-coat. The world of archaeology was entirely new. So was the British landscape, as I had moved to Cambridge from Canada via Japan. The British countryside was lovely and quaint and full of gently sloping hills. It was nice to get out of the city, and to be out in nature, especially after three years of living in the fairly dense urban conglomeration that is greater Osaka.

But as we drove through the countryside, Charly started to point things out that were invisible to me. They lay below the surface, but somehow he could see them. Iron Age hillforts, prehistoric ditches, medieval pits. Hills that were not hills but rather ancient sites. Natural undulations that were not natural but the result of human activities thousands of years ago. Processes of erosion that were already ancient by the time something vaguely resembling English began to be spoken in Cambridge or anywhere else in England. When I started the journey, I saw a natural landscape on top of which humans were living; by the time I had finished, I saw the vague outlines of an extraordinary palimpsest that was neither nature nor culture but some indistinguishable melding of the two.

Many years have passed since then, and my memory has greatly blurred the details of that day. But I have recounted the story many times of how Charly fundamentally changed my perception of the world I lived in. The details have gone, but the fascination has not, and indeed the flame he lit that day has gradually grown brighter. I now have run my own archaeology department, and one of our core interests has been in exploring how humans have transformed the natural world. We draw on a broad range of methods – including geoarchaeology, the field that Charly introduced me to – in order to examine the diverse ways in which humans have reshaped the earth over many millennia.

While some of the ways we package things are a little different, the research we are doing is essentially a continuation of the ideas that Charly spent a research career developing. When we as archaeologists talk about the Anthropocene (Braje 2015; Kidder & Zhuang 2015; Ellis *et al*. 2016; Fitzpatrick & Erlandson 2018; P. Roberts *et al*. 2018; Boivin & Crowther 2021) or cultural niche construction (Boivin 2008; Clement

& Cassino 2014; Kluiving 2015; Boivin *et al*. 2016; Arroyo-Kalin 2018) we are talking about the processes Charly studied across so many decades – processes of landscape change caused by deforestation, erosion, desertification and other processes, many of them human-linked. He has unravelled these processes in many different regions of the world (e.g. French & Whitelaw 1999; French 2003; French *et al*. 2009; 2018; Zhuang *et al*. 2013; 2014; Friesem *et al*. 2016; Neogi *et al*. 2020), but nowhere more thoroughly than in the country that has become his adopted home, where he developed an intimate knowledge of English landscape evolution through time (e.g. French 2003; 2017; French *et al*. 2003; 2007; 2012).

We can draw on some of these long-standing research trajectories, together with new ideas and terms, to outline a set of key Anthropocene-related themes in archaeology, many of which Charly and his numerous students have been instrumental in developing. In a brief essay like this, I have space to only briefly summarize some major research trajectories and reference a few case studies. The archaeological research I touch on summarizes thousands of studies and many volumes and monographs – some key ones counting amongst Charly's prolific output. In the sections that follow, I outline a number of key ways that humans have altered global environments over the long term, shaping the world we live in today in fundamental and enduring ways.

Linking agricultural expansion and deforestation

As I write this in the midst of a global pandemic, it is hard not to be viscerally aware of the impact of modern-day deforestation. Covid-19, like other coronaviruses of recent times, almost certainly made the jump to humans as a direct result of tropical deforestation bringing humans and deeply stressed wildlife into closer and more regular contact (Afelt *et al*. 2018; Brancalion *et al*. 2020). Today, as many Western nations reverse century-long trends to increase forest cover, tropical forests globally are under more pressure than ever (Roberts *et al*. 2017; Roberts 2019) – indeed many countries that have undergone a forest transition (shifting away from deforestation) have simply displaced land use beyond their own borders (Pendrill *et al*. 2019).

As Charly's work first showed me several decades ago, deforestation is not, of course, new. In the British Isles the introduction of agriculture from the continent initiated a process of long-term deforestation (e.g. French 1990; 2003; French *et al*. 2012; Scarre & French 2013; Woodbridge *et al*. 2014), as did the expansion of farming across Europe more broadly (e.g. French 2003; Fyfe *et al*. 2015; N. Roberts *et al*. 2018). This trend accelerated in the Bronze Age in Europe, with the emergence of more intensive agricultural economies linked to increasing populations, trade and production (Kaplan *et al*. 2009; French *et al*. 2010; N. Roberts *et al*. 2018). Similar patterns are observed elsewhere. In Mesoamerica, pioneer agriculture was associated with pervasive forest clearance (Beach *et al*. 2006; McNeil *et al*. 2010). Agricultural expansion and population increase in China similarly led to a gradually increasing human footprint, with progressive deforestation a key component in the mid- to late Holocene (Shen *et al*. 2006; Ren 2007; Cao *et al*. 2010; Zhuang & Kidder 2014). The arrival of Iron Age communities into the Central African rainforest has also been linked to dramatic forest opening from human clearance (Garcin *et al*. 2018; Malhi 2018; Bayon *et al*. 2019).

Deforestation also followed human colonization of many islands globally during the Holocene (Argiriadis *et al*. 2018). Polynesian expansion across the Pacific appears to have been linked to extensive land clearance, though patterns and rates of deforestation likely varied substantially between islands. In New Zealand, high-resolution palaeoecological data reveals that extensive burning and forest clearance occurred within the initial decades after Polynesian arrival (McWethy *et al*. 2010; 2014). Revised chronologies suggest the same pattern of rapid, decadal-scale deforestation may also be true for Hawaii (Rieth *et al*. 2011). In Rapa Nui (Easter Island), however, deforestation appears to have been more gradual, and to have resulted from combined human and climatic shifts (Rull *et al*. 2015; Rull 2020). In the Mediterranean, the pattern is also variable between islands, with more rapid impacts suggested for Malta (Carroll *et al*. 2012) and more gradual changes on Corsica (Poher *et al*. 2017), for example.

Like today, ancient deforestation was linked to habitat fragmentation, erosion, and possibly climate change. Several researchers have suggested pre-industrial forest clearance and agricultural expansion were on a scale sufficient to generate climatically significant levels of carbon dioxide (Fuller *et al*. 2011; Ellis *et al*. 2013; Ruddiman *et al*. 2016). This 'early anthropogenic hypothesis' (Ruddiman 2007) is intriguing but requires more systematic testing. Nonetheless, Lewis and Maslin (2015) argue that large-scale population collapse in the Americas after AD 1492 led to sudden reversal of long-term deforestation trends and an associated dip in atmospheric carbon dioxide between 1570 and 1620 that is documented in high-resolution Antarctic ice core records.

Land use and soil erosion in prehistory

Charly's work, of course, has centred on soils. Lying at the base of all human subsistence systems, soils are central to human societies around the world (McNeill

& Winiwarter 2004; Boivin & Crowther 2021). The global expansion of agriculture had broad-scale implications for soil, promoting soil erosion in a diverse array of times and places (van Andel *et al*. 1990; Bell & Boardman 1992; Bintliff 2002; McNeill & Winiwarter 2004; French 2010a; French *et al*. 2010). The research of Charly and his students has contributed deeply to our understanding of these ancient processes, and to establishing significant soil mobilization as one of the primary outcomes of the transition to farming.

Erosion was exacerbated by intensification of crop cultivation as well as pasturing of animals. In the Aguas Valley of southeastern Spain, for example, intensive wheat cultivation in the third millennium BC precipitated widespread soil erosion, filling the wide alluvial floodplain with eroded soil to a depth of several metres (French 2010a). Intensifying arable use of the River Avon valley of southern England in the first millennium BC exacerbated soil erosion, transforming regional downland and floodplain landscapes (French *et al*. 2012). Land clearance combined with intensive grazing facilitated extensive Roman-era erosion in north central Sicily (Ayala & French 2005). Maya deforestation is thought to have precipitated widespread and substantial erosion in Mesoamerica (Anselmetti *et al*. 2007).

While soil erosion can be traced back in numerous regions to the earliest phases of agriculture, geoarchaeological research also demonstrates how many societies responded to such trends by instituting land management strategies that enabled soil conservation and curtailed erosion (French 2010a). Charly's research shows that the adoption of such practices often enabled relatively sustainable farming practices until recent times. In Ethiopia, for example, geoarchaeological research suggests that the Aksumite Period (*c*. 400 BC to AD 900) witnessed considerable landscape stability and resilience, whereas the pace of alluvial aggradation has increased markedly in the last few centuries, reflecting a growing population and arable intensification (French *et al*. 2009; French 2010a). Similarly, despite soil erosion and desertification, agriculturally based societies persisted in the Aguas Valley (see above) through careful land management, only giving way with the introduction of monoculture farming, field amalgamation and water abstraction in the last few decades (French 2010a).

Ancient soil degradation and soil enrichment

Soils are not only displaced, they are also transformed. Today, some of the most challenging ecological and food security issues we face relate to soil degradation and attempts to address nutrient stripping by the addition of synthetic fertilizers. Soil quality suffers not only from erosion, but also salination, acidification, nutrient depletion, leaching, declines in organic matter and loss of soil biodiversity, amongst other factors (Jones *et al*. 2013; Lal 2015). Today these processes are especially severe in the tropics and sub-tropics, where they have been documented to reduce soil ecosystem services by as much as sixty per cent (Lal 2015). The synthetic fertilizers intended to address many of these problems create their own knock-on problems, impacting water quality and coastal and freshwater ecosystems (Foley *et al*. 2005).

Charly and his students closely examined human-wrought changes to soil quality in the past, feeding important studies into a growing network of research findings and discoveries. One key method they employed was soil micromorphology. This method was used to show rapid soil degradation and calcification in Neolithic Malta (French *et al*. 2018), and depletion of former woodland soil and incursion of windblown sand in the Neolithic Channel Islands (Scarre & French 2013), for example. To counteract these soil depletion processes, research shows that humans increasingly found it necessary to input nutrients and organic material through fertilization. Manuring has been documented as early as the sixth millennium BC in central Europe (Bogaard 2004). Charly and colleagues drew on soil micromorphology to demonstrate that manuring was practiced by Late Neolithic rice farmers in the Lower Yangtze River, in China (Zhuang *et al*. 2014). Charly's work also showed that manuring with midden-derived material continued on the island of Hern in the Channel Islands from the fourth to the late second millennium BC, but was ultimately insufficient to enable sustained cultivation of the island's agriculturally marginal land (Scarre & French 2013).

But geoarchaeological research has also revealed diverse ways in which past societies sustainably managed and even enriched soils. Research by Charly and colleagues in south-central highland Peru demonstrates that local agriculturalists initially depleted soils, but over the last 900 years were able to farm the landscape more sustainably through the construction of irrigated terraces and the use of crop cycles dependent on long fallowing (Nanavati *et al*. 2016). Severe erosion as a result of forest clearance in Mesoamerica was offset by indigenous soil conservation that evolved into successful land management (Beach *et al*. 2006).

Perhaps the most fascinating work in this regard, however, has emerged from the Amazon, where archaeological research demonstrates that pre-Columbian societies profoundly enriched the highly weathered, low fertility soils that dominate the region through the long-term addition of charcoal and other organic waste (Lehmann *et al*. 2003; Glaser & Birk 2012). The resulting human-modified terra preta soils are characterized by high organic matter and nutrient contents that support agricultural fertility, enabling settled agriculture in the Amazon (Glaser *et al*. 2001; Glaser 2007; Arroyo-Kalin 2010). Other ancient societies similarly enriched soils, the Maya for example adding algae to their gardens (Fedick & Morrison 2004; Sedov *et al*. 2007), while farmers in early societies added seaweed to topsoils around the Baltic Sea (Acksel *et al*. 2017). Archaeological Dark Earths are found also in the Andes, Africa, New Zealand and Australia (McFadgen 1980; Sandor & Eash 1995; Fairhead & Leach 2009; Downie *et al*. 2011). Modern science has taken interest not only in their agricultural utility but also their carbon sequestration properties (Woolf *et al*. 2010; Downie *et al*. 2011).

Long-term anthropogenic alterations to biodiversity

Linked to patterns of deforestation, habitat destruction, erosion and climate change today is a major biodiversity crisis. As we witness the anthropogenic extirpation and extinction of countless species, some before they can even be described by researchers, some scientists have suggested that we are in the midst of the planet's sixth mass extinction event (Wake & Vredenburg 2008; Ceballos *et al*. 2015; 2017). But while rates of extinction today are unprecedented in human history, it is clear that the current crisis is the culmination of long-term patterns similarly linked to anthropogenic changes to ecosystems (Grayson 2001; Dupouey *et al*. 2002; Boivin *et al*. 2016; Ellis *et al*. 2016; Braje *et al*. 2017). As agriculture spread, opening up and reworking landscapes on a vast scale (Stephens *et al*. 2019), biodiversity was similarly reshaped. Today this has culminated in a world in which wild terrestrial mammalian biomass is vanishingly small in comparison to the biomass of humans and our suite of domesticated animals (Smil 2011).

While humans likely had a role to play in the Late Quaternary extinction of megafauna (Koch & Barnosky 2006; Braje & Erlandson 2013; Sandom *et al*. 2014; Bartlett *et al*. 2015; Boivin *et al*. 2016), the clearest evidence for anthropogenic impacts to biodiversity comes from the Holocene. And in the Holocene, some of the best evidence comes from islands. Following human arrival, many islands saw significant reductions in terrestrial and avian fauna (Fitzpatrick & Keegan 2007; Rick *et al*. 2013; Boivin *et al*. 2016; Ellis *et al*. 2016; Braje *et al*. 2017). In the Pacific, for example, thousands of species of passerine birds went extinct following Polynesian colonization (Duncan *et al*. 2013). Endemic reptiles, rodents and many other types of birds also disappeared (Steadman 1989; 1995; Holdaway & Jacomb 2000; Athens *et al*. 2002; Steadman *et al*. 2002). So too did numerous plant species (Prebble & Dowe 2008). While altered predation, fire regimes and deforestation certainly had a role to play, the commensal species transported both deliberately and inadvertently to islands were also key (Wilmshurst *et al*. 2008; Boivin *et al*. 2016; Braje *et al*. 2017; Swift *et al*. 2018). Polynesians carried with them 'transported landscapes' of cultivatable plants, domestic animals, weeds, and commensal species like rats that preyed on the eggs and seeds of endemic island species (Anderson 1952; Kirch 1982; Grayson 2001). The same types of patterns played out in many other regions of the world, including the Mediterranean, Caribbean, and Channel Islands (Fitzpatrick & Keegan 2007; Rick *et al*. 2012; Braje *et al*. 2017).

But biodiversity was also remade on continents. Vast numbers of species were moved around in continental-scale biological exchanges that long preceded the better-known Columbian exchange (Boivin *et al*. 2012; 2016; 2017; Prendergast *et al*. 2017; Hofman & Rick 2018). Long-distance mobility, travel and trade accelerated this trend, gradually driving numerous rodent and other commensal species to near global distributions well before the age of European colonialism. These translocations enriched diets, improved human health and led to a vast new array of useful products, but also homogenized ecosystems. Pressure on wild species squeezed into ever-contracting natural habitats, leading to extirpations and extinctions. Agricultural expansion and population growth in ancient Egypt, for example, contributed, together with climatic change, to the collapse of food webs and faunal communities, leading to the extinction of more than three quarters of large-bodied mammalian species still present at the start of the Holocene (Yeakel *et al*. 2014). The Roman appetite for wild fauna to stock sacred groves and hunting enclosures, to support religious ceremonies, and for entertainment and slaughter was similarly on a scale sufficient to reduce biodiversity in source areas (Hughes 2003; Morley 2007; Boivin 2017). Human activities globally reshaped biodiversity in fundamental ways over thousands of years, on a scale that is only gradually being recognized (Heckenberger *et al*. 2007; Boivin *et al*. 2016; Boivin 2017).

The implications of the past today

Charly's work has been part of a vast phase of data production in archaeology in relation to human impacts on the earth that was underway by the 1970s, but took off in particular in the 1990s. This work clearly demonstrated that the surface of the Earth we live on today is a palimpsest of human activities over thousands of years. Even seemingly pristine environments like the Amazon are now recognized to have been altered by millennia of human occupation and activity

(Heckenberger *et al*. 2007; 2008; Clement *et al*. 2015). In unearthing buried soils and lost landscapes, Charly and his many students have played an important role in cataloguing the extraordinary scale of anthropogenic environmental change by past societies.

This work, while far from complete, has begun to reshape the very discipline that engendered it. As datasets have accumulated, archaeologists have begun to ask – what does it all mean? Where do we go from here? How do we make our work meaningful on a planet that now faces levels of human impact unprecedented in the archaeological record – levels of impact large enough to suggest that we have entered a new geological era, the Anthropocene, in which humans themselves are now the dominant force shaping Earth systems (Crutzen 2002; Steffen *et al*. 2018)? And while the answers remain far from clear, one thing is certain – our findings demand that our discipline becomes one in which advocacy, policy shaping, and public engagement are key (Riede *et al*. 2016; Rick & Sandweiss 2020; Rockman & Hritz 2020; Boivin & Crowther 2021). As a stand-alone discipline, we learn about the past, but as a discipline that engages with other disciplines and beyond academia, we also contribute to shaping the future.

These next steps are being taken by researchers all around the world. Archaeological findings are increasingly playing a role in conservation projects, helping establish baselines and critical data needed to restore ecosystems (Wolverton & Lyman 2012; Braje & Rick 2013; Rick & Lockwood 2013; Amano *et al*. 2021; Boivin & Crowther 2021). Archaeological data and indigenous traditions are being drawn upon to shape fire management policies, for example in Australia (Yibarbuk *et al*. 2001; Whitehead *et al*. 2003; Russell-Smith *et al*. 2013) and North America (Black *et al*. 2006). Other archaeologists are trying to understand how ancient cities, including numerous global examples of low density, urban agriculture, can contribute to creating more resilient and sustainable cities in the future (Heckenberger *et al*. 2008; Isendahl & Smith 2013; Barthel *et al*. 2019), and how archaeology can play a role in increasing food security and agricultural sustainability (Guttmann-Bond 2010; Fisher 2019; Reed & Ryan 2019). Climate change scenarios increasingly invite policy-oriented application of archaeological data (Rick & Sandweiss 2020). The work of Charly and his former students is contributing to this emerging agenda, exploring how past can be linked with future (e.g. French 2010a; Sulas & Pikirayi 2018; Boivin & Crowther 2021), and how archaeological data can play a role in shaping policy (e.g. French 2004; French 2009; French *et al*. 2017; Boivin & Crowther 2021). There is much work still to do, but as we push our discipline in new directions in future, we will build on the foundations established by pioneers like Charly and the fascination they have instilled in us to foster a new archaeology for the Anthropocene.

Firmly on the ground: science and a three-dimensional past

Martin Jones

In January of 1989, *New Scientist* published an article on the newly expanding field of archaeological science, mentioning nine UK institutions leading the way. Cambridge was not among their number (Pollard 1989). Two and a half years later, Winifred McDonald was laying the foundation stone of the outcome of her late husband's endowment, the McDonald Institute for Archaeological Research at Cambridge, containing laboratories conducting leading research in zooarchaeology, archaeobotany, archaeogenetics and geoarchaeology. Just two months into his post, a person central to the instigation, maintenance and expansion of that endeavour had taken up the newly created position of lecturer in archaeological science. That person was my longstanding colleague, Charly French.

Just to backtrack a bit, a turning point for UK archaeological science had been a report prepared in 1985 by the renowned physicist Michael Hart for the Science and Engineering Research Council, challenging the UK community to get its act together in a field that clearly had great potential (Hart 1985). At Cambridge, the two subsequent developments of relevance to addressing Hart's challenge were a pair of very generous endowments that arrived as a consequence of the energetic endeavours of Colin Renfrew, one that established the George Pitt-Rivers Professorship, to which I had the good fortune to be elected, the other establishing the above-mentioned McDonald Institute of Archaeological Research. A third, very significant contribution came in a somewhat convoluted and less conspicuous manner, from the public purse.

By the early 1990s explicit algorithmic models had come into favour for determining public funding in the UK, often relying on some fairly straightforward metrics. One such algorithm brought together 'unit costs' devised by the University Funding Council with a revised subject classification formulated by the University Central Council on Admissions (Johnes *et al.* 1993). The resultant funding model enabled a small group of universities active in archaeological science, thankfully now with Cambridge on board, to lay claim to a recurrent and not insignificant additional resource. That enabled both an expansion of our technical and support staff (the department previously had just one