PART TWO

Histories

Everything has a history, and so it is with the concept of the Anthropocene. Good history sharpens our view of the past, connects past to present, and provides guidance as we look ahead. History is also constructed in the present; it is as much a product of the time in which it is written as the period it seeks to analyze and explain. Each of the chapters in this part (and all of those in the book) emerged directly out of the present-day knowledge and perspective of scientists and other professionals who examined past human engagement with earth systems, crafted an explanation that is compelling in the present, and presented a framework for understanding and informing the relationship between people and their environment as we advance into the future. History here takes on additional complexity, ranging from "deep" Holocene-era anthropogenic change to more recent scholarly investigation of human-environment interaction.

It has been over seventeen years since Paul Crutzen declared in 2000 that the earth had entered a new geological epoch in which human action had become the driving force in shaping global environmental change—human action so profound that it left a sedimentary and eventually a stratigraphic record. In chapter 6, Zalasiewicz, Williams, and Smith describe the Anthropocene process as recording "a significant geomorphic signature," which "will continue to evolve and leave a distinctive stratigraphic signature as the cumulative effects of anthropogenic changes work through the earth system." The Anthropocene removes what has become an increasingly artificial divide between human and natural history. As Scarpino notes in chapter 8, "Through the lens of the Anthropocene, the boundaries between natural and human history blur; understanding the present-day environment requires paying as much attention to human agency over time as it does to the evolutionary trajectory of natural processes."

The authors in part 2 consider the Anthropocene through multiple historical lenses—from the geological history of the English Fenland to the industrial history of the Seine to the history of environmentalism. Zalasiewicz, Williams, and Smith offer a case study (with much wider application) of the creation of an Anthropocene landscape in the Fenland, located on the east-central coast of England. They consider a deep history of Holocene deposition extending back to 7,690 B.P. Setting it in the analytic context of profound anthropogenic change, they link contemporary narratives about the past to the geological revolution of the nineteenth century—in their example, linking their research on the Fenland to Sydney Skertchley's geological memoir published in 1877. This geological history points to the new futures for the Fenlands as a result of climate change. Meybeck and Lestel focus in chapter 7 on the River Seine, 1870–2010, from its headwaters to its estuary, noting that "river basins can be used to validate the Anthropocene concept: they are a key component of earth system analysis." They employ archival sources, archaeological investigation, and sedimentary analysis to develop a profile that encompasses reversible and irreversible changes of a much-altered river, facts that must be taken into account when developing management strategies for the Seine basin. Scarpino provides a historical context for the trajectory of scientific investigation and global environmental change that helps to explain the genesis of the Anthropocene and the speed with which the idea caught on once proclaimed by Crutzen. Drawing together the important continuum of past, present, and future, he notes that gaining useful insight "into what people did in the past, how they act in the present, and what they are likely to do in the future" requires paying careful attention "to the complex and subtle tapestry of culture over time."

6

An Anthropocene Landscape

Drainage Transformed in the English Fenland

Jan A. Zalasiewicz, Mark Williams, and Dinah M. Smith

Alterations to the global fluvial system associated with the onset of the Anthropocene have been profound (Syvitski et al. 2005; Syvitski and Kettner 2011; Merritts et al. 2011; Williams et al. 2014). They have involved both direct reengineering of river systems to, for instance, "stabilize" channels, prevent active meandering, and impound water in dams; and indirect changes resulting from land use change, commonly involving such phenomena as increased sediment supply from deforestation and urbanization. However, the spectrum of changes goes beyond such well-documented effects to produce some novel and geologically counterintuitive phenomena that have already produced a significant geomorphic signature. These phenomena will continue to evolve and leave a distinctive stratigraphic signature as the cumulative effects of anthropogenic changes work through the Earth System. Here we describe one such example, from the Holocene deposits of the English Fenland, in which an extensive buried channel system is spectacularly exhumed and then topographically inverted by regional anthropogenic modification. This geologically novel transformation will be a strong influence on the course of future change in the region as global climate warms.

GEOLOGICAL FRAMEWORK

The English Fenland covers areas of Lincolnshire, Cambridgeshire, northern Norfolk, and parts of Suffolk and is the largest area of Holocene deposits (some 4,000 km^2) in Britain. Fenland sedimentary deposits are up to 30 m (more typically up to 20 m) thick, and they show evidence of a complex paleoenvironmental history.

They exist atop a pre-Holocene surface mostly composed of Jurassic clays (French 2003) overlain by Pleistocene tills, sands, and gravels (Wyatt 1984). More resistant Chalk underlies the eastern and southeastern part of the Fenland Basin, and limestone occurs to the north and west. The paleosurface, on which the Holocene deposits rest, is uneven, and areas of higher altitude formed "islands" such as Ely, March, and Thorney. These "islands" are in effect inliers of older strata surrounded by Holocene deposits and are overlain by Pleistocene gravels and till (Hall 1996).

The Holocene of the Fenland has a long history of study (e.g., Skertchly 1877; Godwin 1978; Horton 1989; Waller 1994; Smith et al. 2012), made all the more remarkable because the geology—via rapid wastage of the peat and exposure of the underlying geology—was changing rapidly. So, as these successive studies took place, each generation of researchers was analyzing what was essentially a different landscape. The geological memoir of Sydney Skertchley of 1877 is a largely forgotten classic (Skertchley is now better remembered in Australia, where he later emigrated, than in England), in which close observation of the Holocene deposits is allied with sophisticated study of the tidal dynamics of the Fenland rivers, in a process-based approach that only became commonplace in sedimentary geology a century or so later.

The Fenland succession essentially comprises a tripartite succession of Basal (formerly Lower) Peat overlain by a thick clay-dominated unit (now termed the Barroway Drove Beds), in turn overlain by an Upper Peat (Nordelph Peat); a subsequent, fourth, stratigraphic unit, the silty Terrington Beds, has a more limited distribution to the north and east (fig. 6.1). The succession spans much of the Holocene, commencing an estimated ~7690 B.P. ranging to ~2250 B.P. for the bulk of the succession (Smith et al. 2010 and references therein), though sedimentation continued locally into Roman times and later, while accumulation of peat continued as peat bogs, locally raised, until this was halted, and then reversed by wastage, as large-scale drainage schemes came into operation in the seventeenth century (see below). Sedimentary accumulation today mostly takes place seaward of the seawall, in a relatively narrow prism of intertidal deposits.

ANTHROPOGENIC CHANGE AND REVEALED GEOLOGY

There has since been major change to this succession. The Fenlands were locally drained during Roman and medieval times, but thorough transformation began after the phase of seventeenth-century drainage associated with the Dutch engineer Cornelius Vermuyden (1595–1677), which has continued to the present day. The Upper Peat has almost completely disappeared through drainage and subsequent ablation ("Fen blows") and oxidation, together with some peat cutting for fuel. This was a unit that originally exceeded 4 m in places as seen from evidence such as Holme Post (fig. 6.2)—an iron post hammered into the ground with its

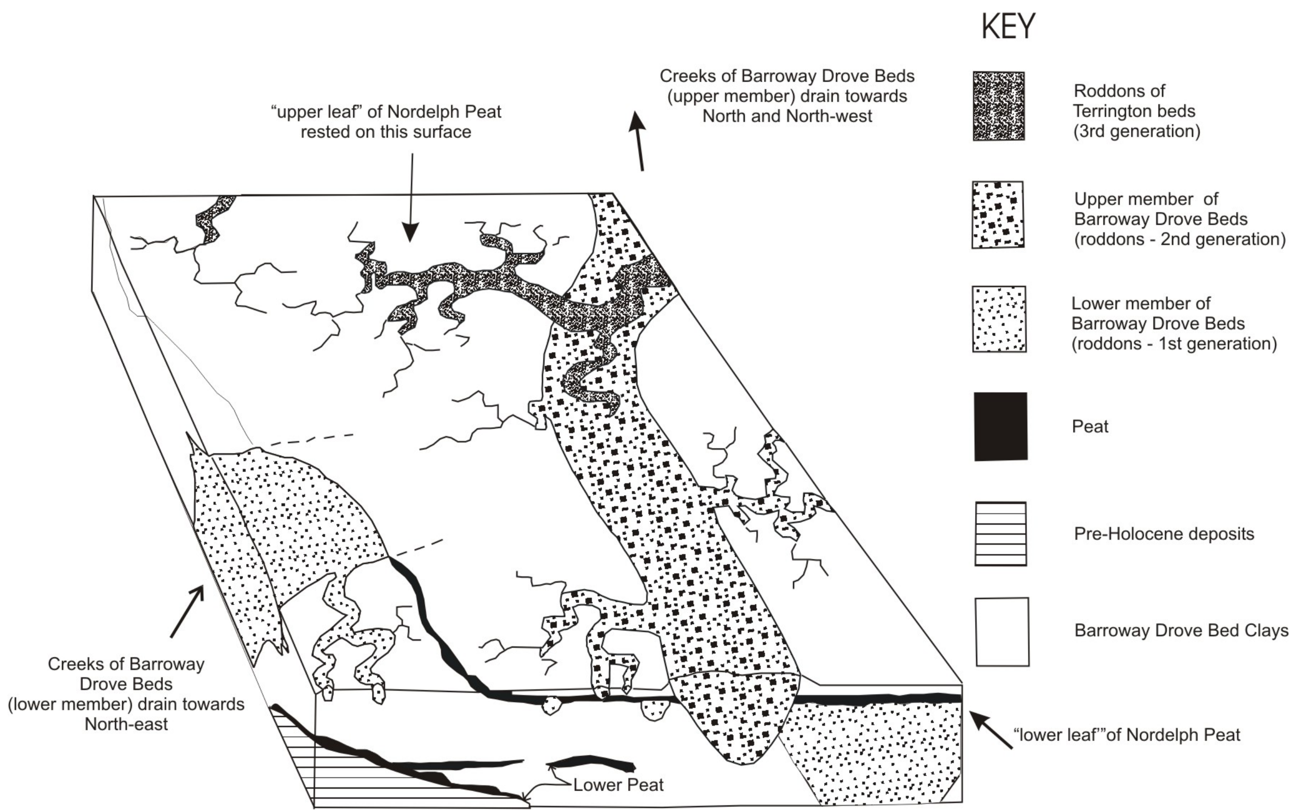

FIGURE 6.1. Diagram illustrating the relationship between the main elements of the Fenland Holocene succession (after Zalasiewicz, in Horton 1989).

FIGURE 6.2. Left: Holme Post, Cambridgeshire (U.K. National Grid Reference [NGR]: TL 205895), showing previous ground levels (image courtesy of Hilary Welch, Conservation Projects for the Fens Tourism Group). Right: J. A. Zalasiewicz standing beside Holme Post in 2008, at about 2 m below sea level.

top at the peat surface in 1848 (i.e., well after drainage of the fens had begun), and the peat likely contained (at least) several hundred million tons of carbon, now released to the atmosphere (R. Eihenbaums, unpublished).

The underlying Barroway Drove Beds clay has been strongly compacted in its uppermost ~2 m, as it is dissected by a closely spaced, regular network of drains and dykes. From these, the water is continually pumped into the Fenland rivers, which are raised by a few meters above the surrounding landscape (which commonly is >2 m below sea level, with the sea being held back by an earth wall), through which it then flows out to the sea.

The landscape has thus been transformed in a manner without precedent in geological history. However, there are some near-parallels in peatlands around the world today. See, for example, the website of the International Peat Society (http://www.peatsociety.org/peatlands-and-peat/global-peat-resources-country) and estimates of peat loss in coastal settings such as the Netherlands (Erkens et al. 2016) and the Florida Everglades (Hohner and Dreschel 2015), many of which, in one way or another, have been profoundly affected by anthropogenic change. For the contemporary Fenland to fulfill its modern use (it is one of the most productive agricultural areas in Britain) it needs continual maintenance and pumping, akin to a patient on a life-support machine. How long that machine may continue to function with global warming is questionable (see below). Nevertheless, one of the results of Fenland transformation has been the exhumation of many major archaeological structures, formerly buried in the peat (e.g., Malim 2005; Pryor 2005), and of a remarkable suite of finely preserved channel structures.

THE FENLAND RODDONS

Incised in the top surface of the drained, compacted Barroway Drove Beds Clay (generally interpreted as former salt marsh clays) there are clearly distinct silt-filled drainage systems—dominantly tidal creeks that include a component of paleorivers—the remarkable, preserved remains of which are locally known as roddons (fig. 6.3). They have been recognized since the peat cover of the fens began to waste away (Skertchly 1877; Darby 1983; Hall 1987). In all, three generations (separate networks) of roddons have been identified (Horton 1989). Two extend across the Fenland, with markedly different channel patterns and orientations (Horton, 1989); a third generation is present mainly to seaward around the Wash (figs. 6.1, 6.4).

Each generation of roddons forms a hierarchical network, the main "trunk" roddons ranging from a few hundred meters to a kilometer across and traversing the entire Fenland area. These major Fenland roddons likely had substantial freshwater input, and a few have been identified as former courses of some of the extant rivers of the Fenland, such as the Ouse and the Little Ouse (Astbury 1958) and the Nene (Smith et al. 2012) Rivers of Cambridgeshire. Tributary roddons of at least

FIGURE 6.3. Roddons visible in fields as slight undulations at Plash Drove, near Guyhirn, Cambridgeshire (NGR TF385063). Optimum times for viewing roddons are during intervals when fields are crop-free (view looking north).

two more generations branch off from the trunk roddons, most of these smaller structures having blind ends inland and previously evidently were salt marsh creeks, with both water and their infilling sediment sourced directly from the sea. The smallest of these tributary structures are as narrow as ~2 meters across. The preserved depth (i.e., thickness of sediment infill) ranges from ~1 m in the smallest channels to in excess of 10 m in the trunk roddons.

The form, structure, and genesis of the Fenland roddons has been most recently examined by Smith et al. (2010, 2012). These structures contrast strongly with most tidal creek/meandering channel deposits in the geological record in that their form reflects preservation of a single channel thread rather than the sheet of laterally stacked point bars, reflecting successive phases in active meandering, which is the more typical record of long-lived meandering rivers or tidal creeks. This pattern strongly suggests that the roddons underwent a short-lived history of incision and then geologically instantaneous infill with silt and fine sand, an inference supported by detailed sedimentary analysis of spring-neap tidal cycles preserved within the infill (Smith et al. 2012), which suggest that the roddons may have converted from active channels to being more or less completely sediment-choked in

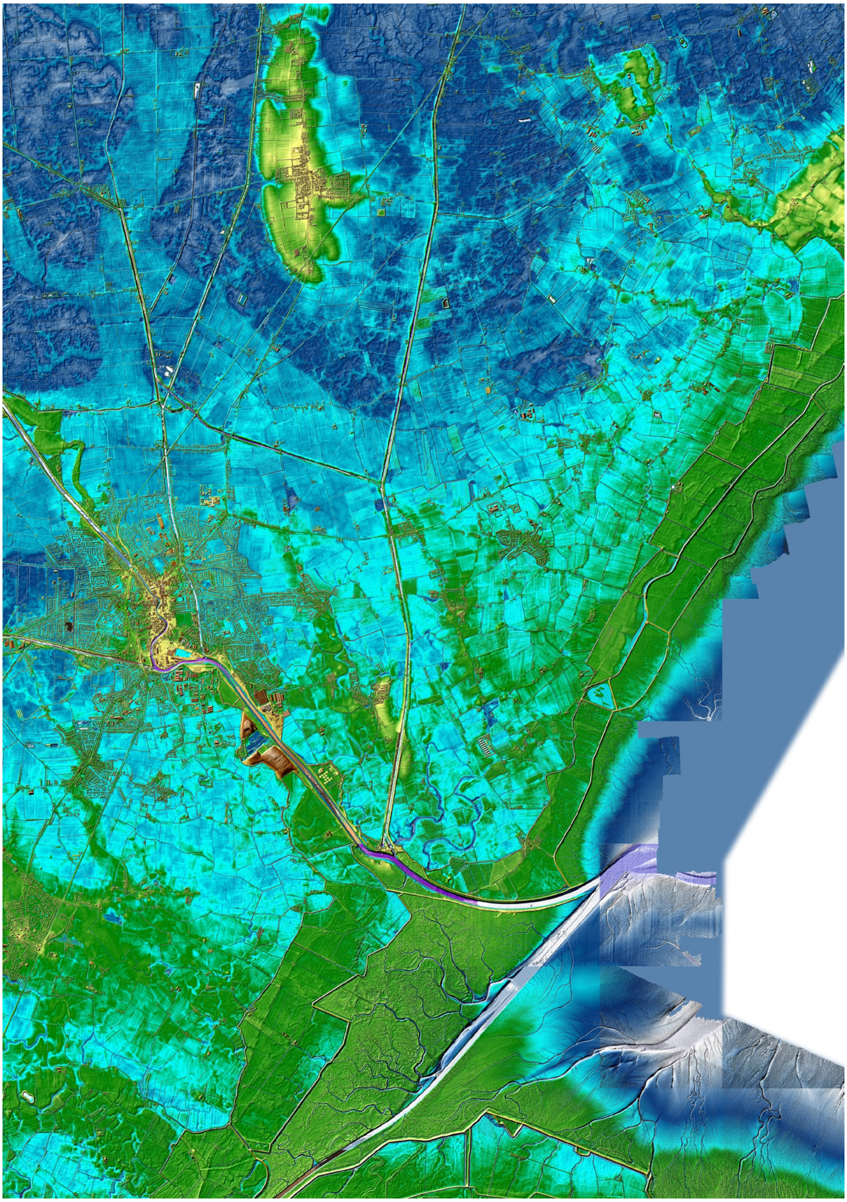

FIGURE 6.4. LiDAR image of the roddons in the Boston-Fishtoft and coastal area in Lincolnshire (at NGR TF329437). These roddons show up as dendritic patterns traversing the countryside from the coast. Roddon systems of the second and third generations (the latter is the youngest) are visible. These tidal channels, which ultimately silted up, are now visible on the LiDAR as roddons. Image courtesy of UK Environment Agency.

only a few years. Locally, a longer-lived depression filled with still or slow-moving water was left, which acted as a site for subsequent human habitation, leaving a rich archeological record in the more slowly accumulated final infill (Smith et al. 2012 and references therein).

We know of no exact counterparts of the Fenland roddon systems elsewhere in the world. Their characteristic morphology clearly reflects the particular context of the extensive nature of the premodified Fenland wetland landscape that was adjacent to a highly active tidal coastline. We have inferred that this coastal zone was subject to abrupt geomorphic change (e.g., through major storms) with consequent effects on the hydraulic geometry of tidal transport paths (Smith et al. 2010). Such changes to the coastal zone could plausibly have led to a change from the system being ebb-dominant (tending to keep the channel system scoured clean of sediment) to flood-dominant (tending to rapidly fill the channel system with sea-derived sediment)—hence rapidly producing the characteristic silty/sandy channel fills that are preserved as the roddons today.

Further, given that both of the main roddon systems occur at the boundary between the salt marsh clay deposits of the Barroway Drove Beds and the overlying peat, it may reasonably be speculated (Smith et al. 2010) that it was the choking of the tidal creek system over a wide area that restricted the access of tidal waters to broad areas of the Fenland, and hence led to the change from clay to freshwater peat deposition. This runs counter to interpretations from Skertchley (1877) on (e.g., Shennan and Horton 2002) that the clay-peat transitions represent sea level changes but is consistent with a recent global analysis (Lambeck et al. 2014) that sea level has been effectively consistent over the past six millennia, prior to its warming-related rise over the past century.

In the context of the present study, though, the significance of the roddons, which were formed as sediment bodies in the conditions of the Holocene, lies in their current morphology, revealed through differential compaction following draining, in what is now an Anthropocene landscape. Rather than being exhumed channel forms, they show strongly inverted topography, as sinuous ridges and (for the wider trunk segments) plateaus that stand up to 2 m higher than the surrounding clay-underlain surface. On the flat landscape of the Fenland, they constitute (other than the raised rivers and some "islands"—inliers of older geology) the only higher ground, such that the local farmhouses and other larger constructions are almost invariably built on them.

FUTURE EVOLUTION

The 5th Intergovernmental Panel on Climate Change report (IPCC 2013) predicts that sea level rise will be 52 to 98 cm by 2100 (and 26 to 55 cm even with aggressive CO_2 emissions reductions). These are conservative estimates, and may need revisiting following recent reassessment of twentieth-century sea level rise that indicates a more rapid increase over the past two decades (now at ~3 mm/year) than had previously been estimated (Hay et al. 2015). Regardless of the precise current trajectory of sea level rise, the formerly peat-covered Fenland area is now about 2 m below sea level (Ordnance Datum [OD]), with the silt-dominated areas lying at or just above 0.3 m OD (Waller 1994).

Over the coming decades and centuries, therefore, the Fenland is likely to be subjected to marine transgressions beyond the norm for the Holocene, and these will take place over an extensive area that has already been anthropogenically modified. The subsidence caused by the drainage (compaction) and peat wastage (removal of surface sediment) is effectively irreversible. It is clear that roddons cannot be reused as channels in future transgression events but will (together with the modern raised river structures) concentrate water flow between them. For a brief interval, before they too are submerged, they may provide a walkway system across the flooded landscape. The future geological record of the Fenland will thus include a striking Anthropocene signature, the result of human-driven modification of some remarkable channelized systems that had their genesis in a vanished sedimentary environment of the Holocene world.

ACKNOWLEDGMENTS

We thank Jason M. Kelly for the invitation to the Rivers of the Anthropocene Conference at Indianapolis in 2014 that stimulated this study and James Syvitski for constructive comments on the manuscript.