Chapter 2
Geocultural Setting

Since ancient times, major impacts of human culture on the landscape have been generally associated with the growth of agriculture and cities. Hence, the nature and global extent of anthropogenic soils is linked to the sociological and geographical aspects of civilization (geocultural setting). The history of anthrosoils can be traced back to the early days of agriculture in the "fertile crescent," and the first city-based civilization in ancient Mesopotamia about 5000 years ago. Here some of the first anthrosoils were formed as a consequence of long-term horticultural activities and salinization resulting from irrigation. Anthropogenic soils were widely produced as a result of agriculture-induced soil degradation, and partly contributed to the demise of ancient civilizations. The rate of anthrosoil formation began to increase rapidly on a global scale during the 18th century when the Industrial Revolution initiated an ongoing period of exponential population growth and urban expansion. The rates have increased even faster since the end of WWII as a consequence of globalized economies, and the explosive growth in population, industrialization and urbanization. The rate of urban soil formation is increasing as a result of the shifting of populations from rural to urban areas. The current human-impacted chapter of Earth history has come to be known as the Anthropocene Epoch. The appearance of anthropogenic soils in the stratigraphic record has been proposed as a possible "golden spike" for defining the onset of the Anthropocene.

2.1 Introduction

The nature and extent of anthropogenic soils depends to a large extent on geocultural setting, i.e. the geographical and sociological aspects of a form or stage of civilization. Since ancient times, major impacts of human culture on the landscape have been generally associated with agriculture and cities. Hence, the creation of significant areas of anthrosoils and anthrosediments can be traced back to the rise of civilization in Mesopotamia about 5000 years ago. The impacts of urbanization on

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soils remained relatively localized and limited until the 18th century when the Industrial Revolution initiated an ongoing period of exponential global population growth and urban expansion. The rates of population growth, industrialization and urbanization have increased even faster since the end of WWII, along with a growing trend of shifting population from rural to urban areas. The global impact of industrialization and urbanization has become so profound that there is now a proposal being debated that the geologic time scale be amended to include an "Anthropocene Epoch," corresponding to the current human-impacted chapter of Earth history.

2.2 Ancient Civilizations

Agriculture originated during the early Holocene about 9000 B.C., and there is evidence for early irrigation by ~7500 B.C. (Brevik and Hartemink 2010). The first urbanized, state-level societies based on cities were present in Mesopotamia and Egypt by about 3200 B.C. (Fagan 2011). A city is a central, relatively densely populated settlement, which provides services for surrounding agricultural villages in a given region. The city is dependent on these villages, and typically serves as a marketplace and trading center for food and other goods. A city has a population of at least several thousand, and more complex social and economic organization than that of small farming communities. The earliest cities were small (<1000 ha in size), often surrounded by a protective wall (Childe 1950), and had no more than 5000–15,000 inhabitants. Their size was limited by agricultural production because 50–90 farmers were probably required to support one city-dweller (Davis 1955).

Although the reasons for the development of city-based civilizations are still being debated, it seems clear that ancient cities usually grew from small settlements founded in specific locations as a result of local geological conditions. Key geological features included soil fertility, surface water navigation, such as river crossings and ocean ports located along coasts or at the mouth of rivers, drinking water supply, natural military defense, supply of suitable building materials, and mineral deposits (Legget 1973). Whether or not it was the principle factor, soil fertility obviously played a major role in the origin and growth of cities. Early settlements were often sited on alluvial floodplains because of soil fertility. Indeed, the "cradle of civilization" is also known as the "fertile crescent," a region extending along the valleys of the Tigris-Euphrates and Nile Rivers. Irrigation agriculture, large food surpluses, and a diversified farming economy, were also probably important factors contributing to the origin of civilization (Fagan 2011). Thus, the impacts of ancient human culture on the landscape were determined partly by the original locations chosen for the founding of cities.

It is well known that many civilizations have risen and fallen over the past 5000 years. Although each civilization has a unique story, with multiple factors influencing its demise, soil degradation and other detrimental human-impacts on the landscape definitely help explain why early civilizations collapsed. Ancient peoples abused their soils and environment, and their civilizations declined as a result of adverse ecological consequences. The fact that ancient populations were often greater than those of modern times shows that some civilizations never recovered. Mayan soils still have not recovered, even after more than 1000 years of abandonment to the rainforest (Olson 1981).

Early cities were able to grow because of the domestication of cattle and other livestock, and the contemporaneous development of irrigation and the plow about 5500 B.C. This greatly increased agricultural productivity and reduced the number of farmers needed to support each city resident (Montgomery 2012). The Sumerian city of Uruk is thought to have had a population of about 50,000 by 3000 B.C., and at its peak about 1800 B.C., the Mesopotamia Empire may have had a population of 15–20 million. Similarly, the population of the Mayan civilization grew from 200,000 in 600 B.C., to perhaps 6 million in A.D. 800 (Lowdermilk 1953). Unfortunately, agriculture in fertile valley bottoms allowed populations to grow excessively. Once all of the available space for farming on bottomlands was used up, it became necessary to plant crops and carry out animal husbandry on sloping land. Overgrazing by sheep and goats reduced or eliminated vegetal cover, trampling of soil by livestock reduced infiltration, deforestation, and plowing across the contour all promoted gullying. Continuous exposure of bare soil to rainfall and surface runoff caused geologically rapid erosion of hillslope soils. The ancient histories of the Middle East and China are replete with cases where soils were eroded to bedrock, and buildings downstream were partially buried by the resulting anthropogenic sediment (Lowdermilk 1953). The collapse of the Mesopotamian civilization is thought to have occurred largely because eroded soil produced silt that plugged-up irrigation systems. Soil erosion can be dramatically rapid, or so slow that farmers do not perceive that it is happening. In ancient times, crop failures also resulted from salinization caused by irrigation of salty dry climate soils, and by depletion of nutrients and organic matter (Artzy et al. 1988; Montgomery 2007, 2012).

Early civilizations typically had cities with populations numbering in the tens of thousands, but cities with populations >100,000 began to appear during the Iron Age after about 1300 B.C. This population growth is attributable partly to the development of iron plows, which further increased agricultural productivity. Alexandria, Egypt probably had a population in excess of 600,000 by 200 B.C., and Rome, Italy had 1,000,000 inhabitants by about A.D. 1. Although many early civilizations recognized differences in soils and adjusted their cropping patterns based on differences in soil fertility, the ancient Greek, Roman, Chinese, and Mayan civilizations had developed relatively advanced agricultural methods by about 500 B.C., and this development continued into the Middle Ages (Brevik and Hartmink 2010). Thus, major human impacts on deforestation and soil erosion were widespread by 1000 B.C., particularly in China, and accelerated after A.D. 1000. By the sixteenth century, soil degradation was out of control throughout the civilized world as more advanced societies began engineering their environments.

2.3 Industrialization and Urbanization

In modern times, anthrosoils are not only primarily a consequence of agriculture but also urbanization, which is the process by which towns and cities are established, and become larger through construction of buildings, streets, railroads, and other artificial infrastructure. Urbanization has been increasing exponentially as a result of the global population explosion. This is being fueled by industrialization, a process that transforms an agrarian society into one with an economy based on manufacturing. The Industrial Revolution began in Britain about A.D. 1750, and had spread throughout Europe and the United States by 1900. It was based initially on the use of fossil fuels and the invention of steam-powered machinery. The rates of population growth, industrialization and urbanization increased sharply after WWII in what has been called “the Great Acceleration” (Steffen et al. 2011). This phenomenon has been further stimulated by globalization, i.e. the global exchange of cultures, products and services, and the development of an international network of economic systems. The global integration of economic and cultural activities can be traced back to the 19th century, or earlier, as a result of technological advances in various forms of transportation. However, the global development of interdependent economic systems was greatly enhanced by the reduction of international trade barriers, and the advent of electronic communication, particularly mobile phones and the Internet, which connected billions of people in new ways, beginning around 2000.

At the start of the Christian Era ~ A.D. 1, the total population of the world was about 250 million. Global population increased three-fold in seven centuries reaching 700 million by 1750. As a result of the Industrial Revolution global population increased from 1 billion in 1800, to 3 billion in 1950. During the Great Acceleration, world population doubled in just 50 years reaching 6 billion by 2000. Global population reached 7.6 billion in 2016, and is projected to reach 9.6 billion by 2050. The magnitude of this growth rate can be appreciated by considering the fact that in A.D. 1800 no more than 50 cities worldwide had a population >100,000. Today, there are thousands of cities with a population >100,000, and hundreds with populations >1,000,000. Modern cities often consist of a vast metropolitan area, i.e. a central city together with its suburbs. There are also many regions comprised of a number of cities, large towns, and other urban areas that have merged to form one continuous urban and industrially developed area known as a conurbation or urban agglomeration. The conurbations of Osaka, Karachi, Jakarta, Mumbai, Shanghai, Manila, Seoul, and Beijing in Asia each have populations over 20 million people, whereas Delhi and Tokyo are each projected to approach or exceed 40 million people within the coming decade. Elsewhere, Mexico City, São Paulo, New York, Lagos, Los Angeles, and Cairo will each soon have a population of more than 20 million people.

Another factor that has influenced the origin and extent of anthrosoils is the move of populations from rural to urban areas. In A.D. 1950, only 20% of the world population lived in cities. By 2008, half the global population lived in urban areas,

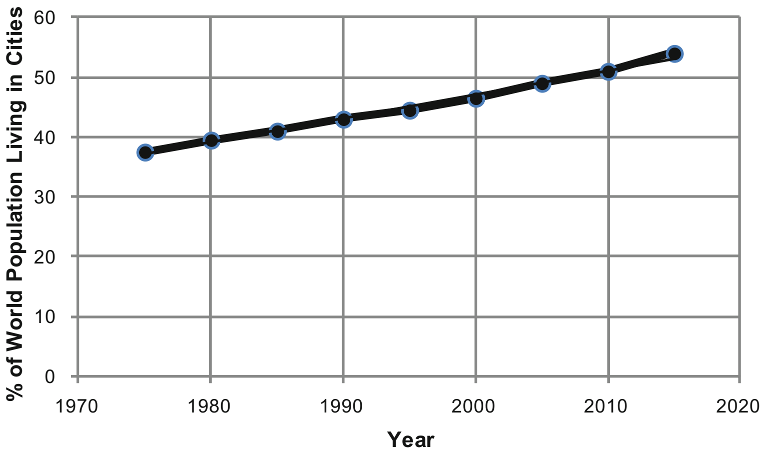

Fig. 2.1 Proportion of the world population living in urban areas. After United Nations (2014)

and the United Nations projects that by 2050, 86% of the developed world's population will be urbanized (Fig. 2.1). Although city size is not necessarily directly related to population size, because of variations in population density, the amount of urban land worldwide has increased dramatically with global urban population growth. The amount of urban land in the U.S. quadrupled between 1945 and 2002 (Lubowski et al. 2006), and urban land is expected to triple in size worldwide between 2000 and 2030 (Seto et al. 2012).

The 20th century saw the invention of gasoline- and diesel-powered engines, and the explosive growth of the automobile industry beginning in the 1920s. These inventions also led to the development and proliferation of mechanized earth-moving and farm equipment, especially during the Great Acceleration following WWII. Mechanized farm equipment, organochlorine pesticides, crop genetics and other agricultural developments increased crop production to the point that even a relatively small number of farmers could support vast numbers of urban residents. Mechanized equipment used for earth moving, mining, terracing, and logging led to global signals in increased sediment discharge in most large rivers. However, by the 1950s, sediment discharge had decreased for most major rivers as a result of dam building. These collective impacts caused major changes in terrestrial sediment transport, and in sediment volumes discharged into the oceans (Syvitski et al. 2011). By the 1990s, it was recognized that the amount of soil and rock moved by humans was equal to, or greater than, that of natural processes (Hooke 1994). The rate at which humans are moving earth is increasing exponentially in response to global population growth (Hooke 2000; Wilkinson and McElroy 2007). It is now estimated that 50% or more of the Earth's surface has been modified by human activities such as agriculture, mining and urbanization (Hooke et al. 2012). Urban renewal has further increased the formation of urban anthrosoils especially through building demolition. As major cities age, there is a need for rebuilding infrastructure

Fig. 2.2 Aging infrastructure is common in major urban areas worldwide: **a** building demolition during urban renewal; **b** demolition debris typical of that found in modern urban soils (wood, brick, mortar, concrete, cinder block, etc.). Photos by J. Howard

and repurposing vacant urban land created by building demolition (Fig. 2.2). Large tracts of vacant urban land are now found in major cities worldwide.

2.4 Stratigraphy and Archaeology

Stratigraphy is the scientific study of strata (layers of rock and sediment) for the purpose of formally naming and classifying them in terms of the geologic time scale, i.e. the global system of organizing strata according to intervals of geologic time. Traditionally, the youngest interval of geologic time was the Holocene Epoch, which began 10,000 ^{14}C years before present (A.D. 1950), or 11,477 ± 85 calendar years ago (Orndorff 2007). However, the term “Anthropocene” was introduced recently to describe the current human-impacted epoch of Earth history (Crutzer and Stoermer 2000; Crutzen 2002). Subsequently, there has been a growing discussion by geologists about whether the stratigraphic code should be amended to include the Anthropocene as a formal Epoch of the Quaternary Period and, if so, how it should be defined (e.g., Zalasiewicz et al. 2010, 2011; Gale and Hoare 2012). Many different indicators have been cited as possibly marking the onset of the Anthropocene Epoch including the extinction of Pleistocene megafauna, the advent of agriculture, the domestication of plants and animals, shell middens, changes in the gas composition of Earth’s atmosphere, airborne deposition of coal combustion products, radioactive fallout from nuclear explosions, changes in sediment production, artificial ground, and so forth (e.g., Crutzen and Stoermer 2000; Ruddiman 2007; Syvitski et al. 2011; Price et al. 2011; Erlandson 2013; Smith and Zeder 2013; Oldfield 2015; Waters et al. 2016). It has also been suggested that the first appearance of anthropogenic soils in the geologic record be used as a “golden spike” for defining the base of the Anthropocene (Certini and Scalenghe 2011).

Two basic opposing views have emerged, which can be referred to as the late versus early Anthropocene boundary hypotheses. When the term Anthropocene was originally proposed, a “late” start date was suggested which coincided with the onset of the Industrial Revolution in Great Britain about A.D. 1800 (Crutzen and Stoermer 2000). This start date seemed to be embraced by the geological community at first (e.g., Zalasiewicz et al. 2010, 2011; Steffen et al. 2011; Price et al. 2011). However, a Holocene-Anthropocene boundary corresponding to the beginning of the “Great Acceleration” at A.D. 1945 was subsequently proposed (Ford et al. 2014; Waters et al. 2016). This boundary seemed to gain favor because it was thought to be recognizable worldwide based on the unique presence of radioactive fallout in the geologic record marking the end of WWII. At the other end of the spectrum, Ruddiman (2007, 2013) proposed an “early” Anthropocene start date of 8000–5000 yr B.P. defined by increased atmospheric methane attributed to the advent of agriculture. Some archaeologists have proposed an even earlier start date, suggesting that the Holocene be replaced by, or merged with, the Anthropocene (e.g., Smith and Zeder 2013; Erlandson 2013; Erlandson and Braje 2013). The Anthropocene Working Group of the International Stratigraphic Commission recently voted in favor of the WWII start date (Voosen 2016), but the debate appears to be far from over.

Archaeology is the scientific study of the origin, development, and varieties of human beings and their societies based on material remains (e.g., fossil relics, artifacts, and monuments) found in the geologic record. Archaeology (anthropology) and stratigraphy are inextricably linked (Fig. 2.3), hence it is understandable that archaeologists are arguing for a definition of the Anthropocene Epoch consistent with archaeological stratigraphy. The erosional unconformity separating the undisturbed natural part of the geologic record, from the anthropogenic deposits

Fig. 2.3 Complex stratigraphy at a historical (19th century) archaeological site. Layer of natural soil (*I*) is overlain by anthropogenic sediments (layers *II–IV*). Photo by Don Adzigian

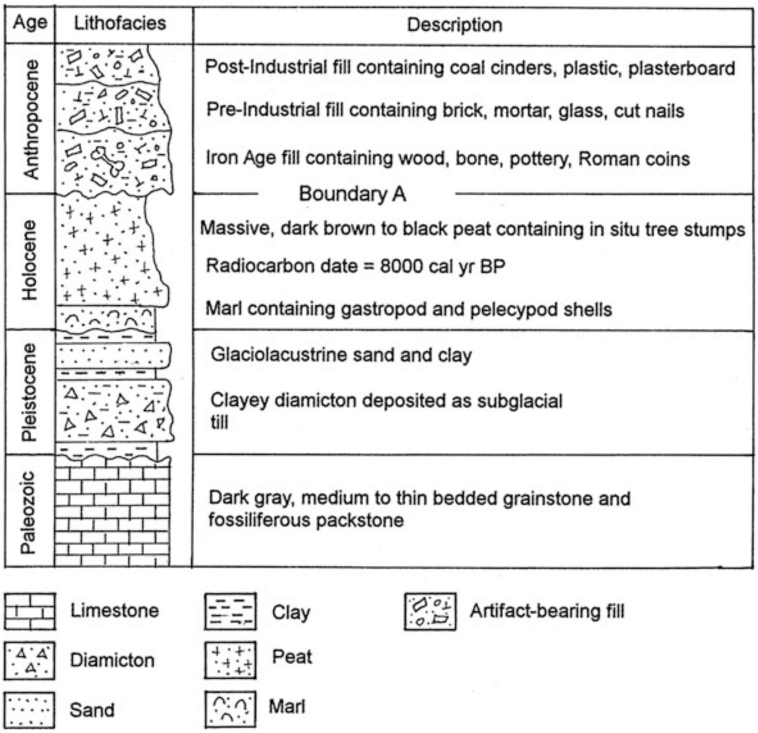

Fig. 2.4 Hypothetical stratigraphic column showing the physical basis for recognizing the Anthropocene Epoch as coincident with the historic archaeosphere. Anthropogenic strata lie above a visible unconformity (Boundary A) marking the top of undisturbed natural Holocene sediments

locally comprising the uppermost part of the geologic column, has been referred to by archaeologists as Boundary A (Fig. 2.4). The collective global package of archaeological strata lying above Boundary A comprises the archaeosphere (Edgeworth 2014; Edgeworth et al. 2015). Thus, from an archaeological point of view the archaeosphere is physically equivalent to the Anthropocene Series as a chronostratigraphic unit. Geologically, this is a problem because Boundary A is time-transgressive, and thus fails to meet the requirement for a stratigraphic "golden spike" (Edgeworth et al. 2015).

Regardless of how the Anthropocene is eventually defined, Fig. 2.5 shows that there are multiple archaeological events that coincide with the rise of civilization in Mesopotamia about 3300 B.C., including the development of the first known city-based states and the world's oldest known written historic record (Anthony 2010; Fagan 2011). These events represent multiple, diagnostic archaeological indicators whose stratigraphic ranges converge to define a "time line" at ~6000–5000 cal yr ago in a manner analogous to an assemblage biozone. This "time line" corresponds to the first appearance in the geologic record locally of cities, state formation, social hierarchies, writing, and metallurgy (copper smelting).

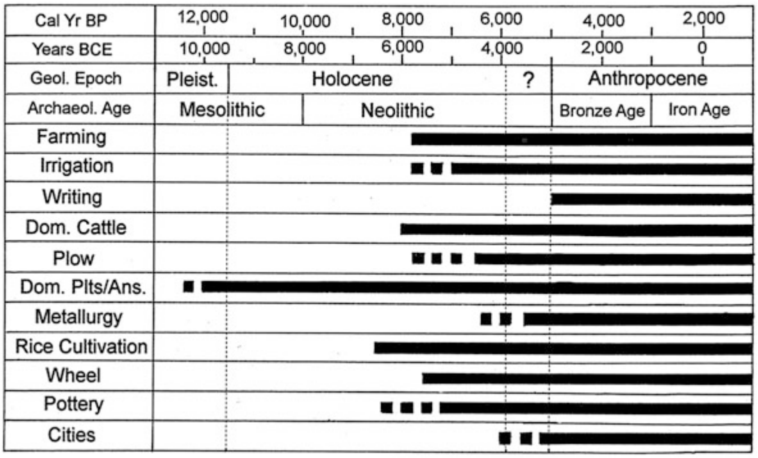

Fig. 2.5 Timeline of archaeological events useful for defining a Holocene-Anthropocene boundary at 6000–5000 cal yr BP coincident with the beginning of civilization in Mesopotamia

Anthropogenic soil erosion and river sedimentation were also occurring in Sumeria by this time (Lowdermilk 1953; Montgomery 2012). As noted above, early cities were able to grow because of the domestication of cattle, and the contemporaneous development of irrigation and the plow about 5500 B.C. The Sumerian city of Uruk is thought to have had a population of about 50,000 by 3000 B.C., and at its peak about 1800 B.C., the Mesopotamian region may have had 15–20 million inhabitants (Lowdermilk 1953). Hence, the “time line” at ~5000 yr BP corresponds to the beginning of the first urban population explosion on Earth. It also marks the beginning of increases in atmospheric CO_2 and CH_4 attributable to human activity (Ruddiman and Thomson 2001). Although Gail and Hoare (2012) argued against the use of anthropogenic soils as a golden spike for the Anthropocene, it seems clear that any artifact-bearing anthropogenic soils and sediments preserved in the geological record eventually will be the best visible physical evidence of the Anthropocene Series.

In addition to proposals to establish an Anthropocene Epoch, it has also been proposed (Howard 2014) that the stratigraphic code be amended to include Anthrostratigraphic units (ASUs) and Technostratigraphic units (TSUs). An ASU is defined as a stratiform or irregularly shaped body of anthropogenic origin in the sedimentary record distinguished and delineated on the basis of lithologic characteristics and/or bounding disconformities. An anthropogenic origin is indicated if the deposit: (1) Lies beneath an anthropogenic landform, (2) Contains artifacts, (3) Shows evidence of artificial mixing or other human disturbance, and/or (4) Was imported from offsite and is allochthonous. The basic unit of anthrostratigraphy is the *anthrostratum*, defined as a mostly stratiform body of artificially mixed earth (rock, sediment, soil, etc.) and artifactual (brick, concrete, etc.) materials. An anthrostratum need only be mappable at a local scale, but anthrostrata of different origins or type may be grouped together as an *anthroformation* if regionally mappable. This terminology is consistent with, and perhaps improves upon, the archaeological “layer” (Gasche and Tunca 1983; Stein 1990), the British Geological Survey’s definition of artificial ground (Rosenbaum et al. 2003; Price et al. 2011; Ford et al. 2014), the U.S. National Resource Conservation Service’s definition of human-transported material (Soil Survey Staff 2014), and what is generally referred to as archaeological stratigraphy (Harris 1989, 2014)

A TSU was defined as a mostly stratiform body of anthropogenic origin in the sedimentary record identified or characterized on the basis of artifact content (Howard 2014). An artifact was defined as any object of anthropogenic origin including: (1) Demolition wastes (brick, mortar, concrete, wood, glass, etc.), (2) Coal-related wastes (coal, coke, carbonaceous shale, cinders, etc.), (3) Petroleum-related wastes (asphalt, “PetCoke,” etc.), (4) Industrial or commercial manufacturing wastes (coal-tar, steel-making slag, etc.), (5) Archaeological objects (stone tools, pottery, coins, etc.), and (6) Miscellaneous rubbish (plastic, cardboard, etc.). The definition included microartifacts, and certain rock materials that can be considered to be artifacts simply because their presence in a site-specific context is due to human activity (Dunnel and Stein 1989). For example, fragments of coal (and associated carbonaceous shale) imported for domestic coal-burning can be considered to be artifacts, whereas detrital limestone and dolostone clasts derived from underlying bedrock are not artifacts.

Zalasiewicz et al. (2014) proposed the term “technostratigraphy” for the use of artifacts (termed technofossils) to date and correlate anthropogenic deposits. In concept, artifacts in TSUs can be used, in a manner analogous to the use of fossils in biostratigraphy, for dating and correlating anthropogenic deposits. TSUs are based on the evolution over time of technology involved in the creation of artificially altered or manufactured objects. That is, anthrostrata in the Quaternary sedimentary record show an overall upsection technological evolution in the artifact assemblages contained in them. For example, “low-tech” objects, pre-dating the Industrial Revolution (Paleolithic stone tools, Neolithic copper, hand-forged wrought-iron nails, etc.), contrast with “high-tech” artifacts of more modern vintage (drywall, galvanized nails, Portland cement, PVC piping, etc.). The date of invention of modern artifacts is known from historic records, thus providing a highly precise dating tool for the anthrostratum. The TSU is useful for chronological analysis of sites too young to be dated by the radiocarbon method. The *technozone* was proposed as the fundamental unit of technostratigraphy, defined on the basis of artifactual (Commercial) ranges (Howard 2014). By analogy with biostratigraphy, an “index artifact” can be used to name a technozone. The TSU supplants the Ethnostratigraphic Unit of previous archaeological classifications (Gasche and Tunca 1983; Stein 1990) which relied on a cultural interpretation of materials making up the unit.

Howard (2014) showed how the Commercial Range (CR) of an artifact could be used as a chronostratigraphic tool, where CR is defined as the time span of availability to society from the beginning to the end of its commercial production (Fig. 2.6). Using the biostratigraphic range of a fossil species as an analogy,

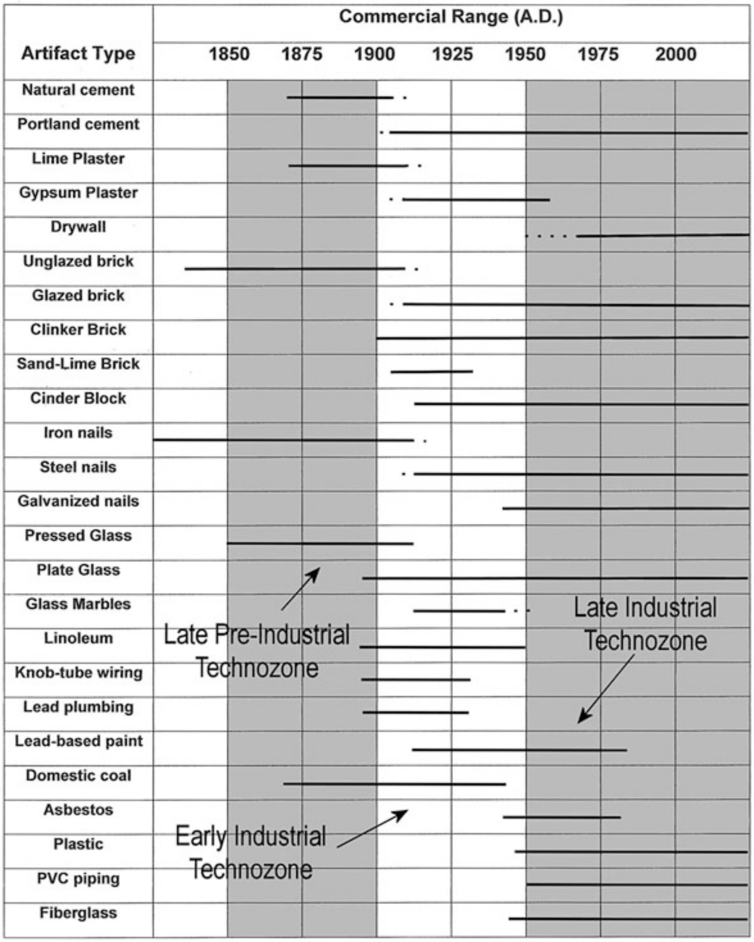

Fig. 2.6 Method for using commercial ranges of artifacts in anthropogenic surficial deposits to define technozones (Howard 2014)

technozones for Detroit, Michigan were defined by first appearances and the overlapping CRs of artifacts in an assemblage. For example, a 19th century anthropogenic deposit from the late pre-Industrial Revolution technozone was identified by an artifactual association of natural hydraulic cement (mortar), unglazed brick, lime-based wall plaster, wrought-iron (square) nails, pressed glass and coal-related wastes. A 20th century early Industrial Revolution technozone was defined by the first appearance of Portland cement (mortar and concrete), gypsum-based wall plaster, glazed brick, steel (round) nails, and glass marbles. An association between linoleum, ceramic tubes (knob-and-tube wiring) and lead plumbing was also diagnostic. The late Industrial technozone was defined by the first appearance of drywall, plastic, PVC piping, fiberglass, etc. Thus, there was a well defined stratigraphic transition from "low-tech" to "high-tech" artifact assemblages in the geologic column of Detroit at ~A. D. 1900.

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