Chapter 8
Multi-millennial Record of Erosion and Fires in the Southern Blue Ridge Mountains, USA

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Abstract Bottomland sediments from the southern Blue Ridge Mountains provide a coarse-resolution, multi-millennial stratigraphic record of past regional forest disturbance (soil erosion). This record is represented by 12 separate vertical accretion stratigraphic profiles that have been dated by radiocarbon, luminescence, cesium-137, and correlation methods continuously spanning the past 3,000 years of pre-settlement (pre-dating widespread European American settlement) and post-settlement strata. Post-settlement vertical accretion began in the late 1800s, appears to be about an order of magnitude faster than pre-settlement rates, and is attributable to widespread deforestation for timber harvest, farming, housing development, and other erosive activities of people. Natural, climate-driven, or non-anthropic forest disturbance is subtle and difficult to recognize in pre-settlement deposits. There is no indication that pre-settlement Mississippian and Cherokee agricultural activities accelerated erosion and sedimentation in the region. A continuous 11,244 years before present (BP) vertical accretion record from a meander scar in the Upper Little Tennessee River valley indicates abundant charcoal (prevalent fires) at the very beginning of the Holocene (11,244–10,900 years BP). In contrast, moderate to very low levels of charcoal are apparent over the remaining Holocene until about 2,400 years BP when charcoal influx registers a pronounced increase. These data are consistent with the idea that Native Americans used fire extensively to manage forests and to expanded agricultural activities during Woodland and later cultural periods over the past 3000 years. However, there is no indication that prehistoric intentional use of fire and agriculture caused accelerated erosion and sedimentation.

Keywords Alluvium • Chronostratigraphy • Holocene • Overbank • Charcoal

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8.1 Introduction

Forests shelter soils on hillslopes from intense rainfall, runoff, and erosion in the southern Blue Ridge Mountains (SBRM). Without forests these mountains would be badlands, because of the highly erodible surface mantle of saprolite (weathered bedrock). Hydrologists posit that under pristine forest conditions surface erosion is minimal because there is complete infiltration of precipitation and virtually no Hortonian overland flow (i.e., rainfall intensity exceeds soil infiltration capacity); and instead, precipitation is delivered to streams via subsurface pathways and as saturation overland flow (Hewlett et al. 1977; Swift et al. 1988; Committee on Hydrologic Impacts of Forest Management 2008). However, disturbance of forest cover has occurred on a variety of spatial and temporal scales exposing bare soil, reducing infiltration capacities, and resulting in erosion and deposition of sediment on nearby bottomlands. Natural pathways and patterns of erosional disturbance typically are driven by destructive tornado swaths and windblown tree-throws (Peterson et al. Chap. 5), landslides (Wooten et al. Chap. 9), ice storms (Lafon Chap. 7), and fires ignited by lightning (Grissino-Mayer Chap. 6; Greenberg et al. Chap. 1, Table 1.6; Greenberg et al. Chap. 12); and the magnitude and frequency of such events is mediated by variations in climate. In contrast, human-induced disturbance primarily includes timber harvest, land clearing for agriculture and settlement, and fires ignited by humans. Floodplain deposits record both natural and human-induced modes of past forest disturbance via changes in sedimentology, which result from changes in the sediment transport and rainfall-runoff regimes, and which, in turn are mediated by changes in climate and vegetation cover. For example, timber harvest and forest clearance for croplands drastically increase sediment concentrations in streamflow, and floodplain sedimentation rates (Happ 1945; Trimble 1974; Walling 1987; Meade et al. 1990; Saxton and Shiau 1990; Knighton 1998; Walling 1999; Knox 2006) because complete removal of the protective vegetation facilitates dislodgment of soil from raindrop impact, sheetflow, and rilling mechanisms of soil erosion. The SBRM are no exception to this rule, because historical human impacts (largely by timber harvest, small farms, and home development) since the late 1800s following widespread European American settlement (post-settlement time) have created land surfaces conducive to higher sediment yields than the pre-settlement landscapes occupied by indigenous people of the Cherokee, Mississippian, and earlier cultures.

The main purpose of this chapter is to describe and explain how bottomland alluvial sediments record past fluctuations in erosional forest disturbance of the SBRM. Paleobotanical records from wetland peat deposits are very important sedimentary sources of information about past forest composition and disturbance (Delcourt and Delcourt 2004), but they have been scarcely studied in this region and are beyond the scope of this chapter. Instead, emphasis here is on past soil erosion and its ultimate deposition on bottomlands and floodplains, and what sorts of information can be gleaned from these widespread stratified deposits. Numerous examples and analyses are drawn from stratigraphic data originally collected by the author and his former students.

The SBRM physiographic province (see Fig. 1.1) is the late Precambrian and early Paleozoic crystalline terrain of high relief mountains in the Blue Ridge province south of the Roanoke River in Virginia, and includes western North Carolina, eastern Tennessee, and northeastern Georgia (Fenneman 1938; Thornbury 1965). This province is broadly representative of forests in the Central Hardwood Region. Bedrock consists largely of metasedimentary rocks (micaceous gneisses and schists) with some outcrops of basement granites and granitic gneisses (Robinson 1992; Thigpen and Hatcher 2009). This highly dissected mountain range has summits up to around 2000 m above sea level and main valley bottoms at around 600 m above sea level. Hillslopes and summits commonly are mantled by 0–10 m of sandy to clayey micaceous saprolite, whereas colluvium and alluvium cover the footslopes and bottomlands (Hatcher 1988; Southworth et al. 2003). Stream and river channels typically exhibit meandering pool and riffle morphology with bed sediment composed of fine to very coarse gravel. Floodplains and recent terraces commonly have a thick vertical accretion mantle (0.5–2.0 m) overlying much thinner lateral accretion and channel lag bedload materials. Much of the data presented in this paper were drawn from the Upper Little Tennessee River valley between Franklin, North Carolina and Mountain City, Georgia (Fig. 8.1), which is centrally located in the SBRM.

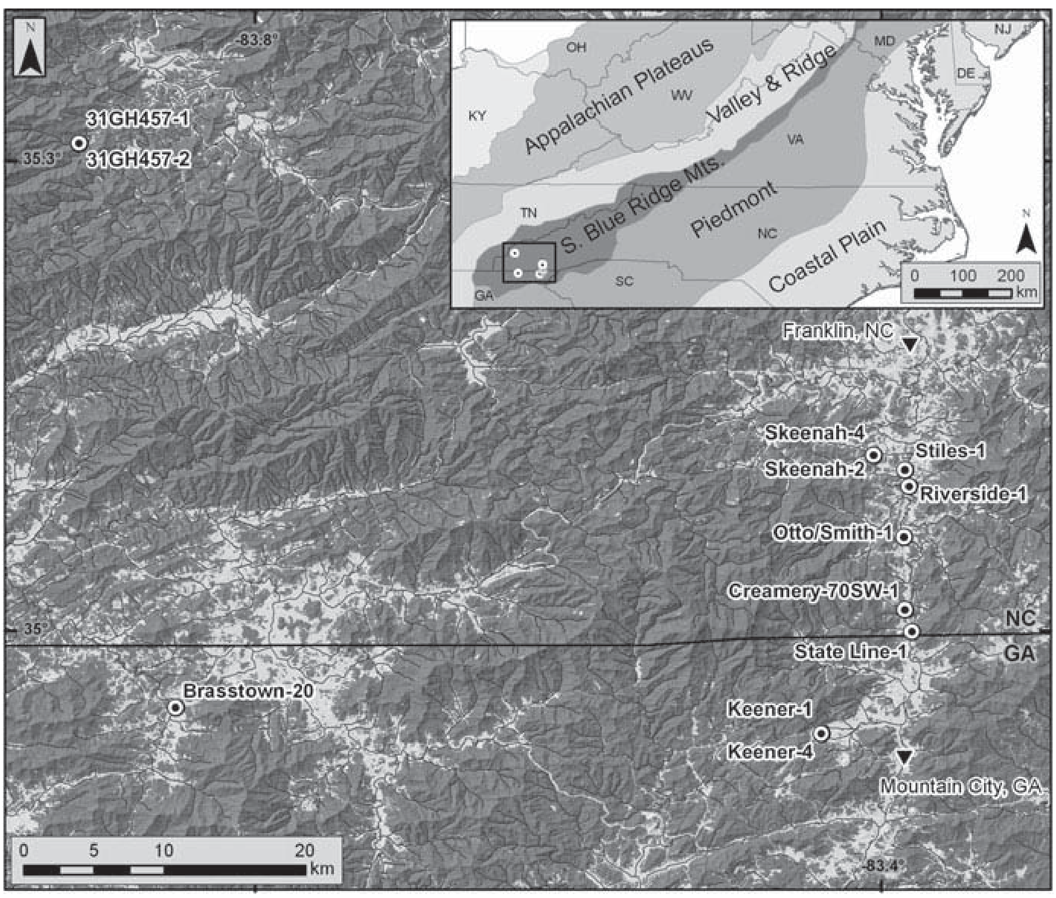

Fig. 8.1 Map showing the southern Blue Ridge Mountains, the Upper Little Tennessee River valley, and other sample locations mentioned in the text

Fig. 8.2 Photographic plate XVB from Glenn (1911), entitled "A well-dissected part of the Asheville Plateau" illustrating the deforested and cultivated appearance of hillslopes in the southern Blue Ridge Mountains in the early 1900s

Ayers and Ashe (1905) and Glenn (1911) were perhaps the first to extensively document human-induced erosive damages to forests and related floodplain deposition in the southern Appalachians. Ayers and Ashe (1905) note that "The three agencies that have wrought changes in the forests of the Southern Appalachians are fires, lumbering, and clearing of lands for farming… During heavy rains the earth of freshly burned or freshly plowed land is rapidly washed away. The streams from such lands are often more than half earth, and the amount of soil thus eroded every year is enormous." Glenn (1911) provides excellent examples, including photographs of eroded land, flooding, and sedimentation (Figs. 8.2 and 8.3) within specific watersheds that had experienced deforestation. For example, he states "Floods on the Tuckasegee are said by old residents, some of whom have known the river for 60 years, to be generally higher, to come more suddenly, to disappear quicker, and to be much more destructive than 50 years ago. Both the river and its tributaries are said to be much muddier during floods and for a considerable time afterwards than they formerly were…" and "…the stream may be overloaded with waste and forced to drop a part of it until it fills its channel. It then flows here and there in irregular shifting meanders across its flood plain, depositing great quantities of waste and building up or aggrading the flood plain. Such flood plains rapidly become useless for agriculture." (Glenn 1911).

The early 1900s were arguably the most erosive decades in history, but it is important to realize that even during the heyday of timber harvest during 1900–1910

Fig. 8.3 A USDA photo from 1901 AD of "A seven acre field on Scott's Creek, which was very badly washed by the freshet of 1901." Scott's Creek flows through Sylva, North Carolina. The photo was taken by E. Block and reproduced by David Leigh (April 2010) from US Archives photo l34Er18, caption label "25316 Inf – Influences, Floods, Effects, Land Damage, North Carolina" (with handwritten number 25540). Notice the thick deposits of fresh sandy alluvium along the fence line to the left and a thin drape of fine sediment along with flood gravels across much of the floodplain. Also, notice the steep deforested hillslopes in the background

the landscape of the SBRM region still retained about 70 % forest cover at any given point in time as clear cut areas were quick to sprout saplings and begin successional reforestation (Ayers and Ashe 1905; Holmes 1911). Thus, only fractional deforestation is necessary to produce very noticeable changes in the geomorphic system, a point which was recently affirmed by Price and Leigh (2006a, b).

Considerable attention has been placed on post-settlement alluvium in the Piedmont province of the southern Appalachian region (see Greenberg et al. Chap. 1, Fig. 1.1) where row-crop agriculture has been more extensive than in the mountains (Fuller 1934; Happ 1945; Trimble 1974; Costa 1975; Jacobson and Coleman 1986; Meade et al. 1990; Ruhlman and Nutter 1999; Lichtenstein 2003; Jackson et al. 2005; Ambers et al. 2006; Hupp et al. 2013; Lecce and Pavlowsky 2014), and these studies generally indicate that about 1–2 m of post-settlement alluvium was delivered to river bottomlands over the span of a couple of centuries. However, very little follow-up to Glenn's (1911) study has been done in the much less agricultural and more forested SBRM. Price and Leigh (2006a, b) provided examples of how

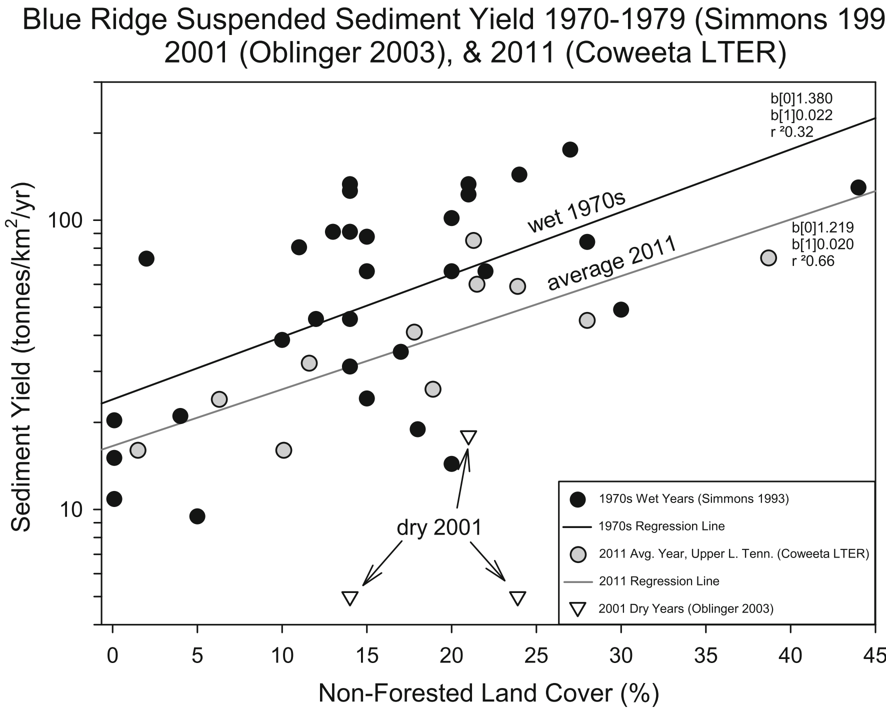

Fig. 8.4 Sediment yield data of Simmons (1993) for samples collected in the southern Blue Ridge Mountains of western North Carolina in 1970–1979, with additional points from the Upper Little Tennessee River valley collected in 2001 (Oblinger 2003) and 2011 (Coweeta LTER unpubl). Separate linear regression lines are for the 1970s (*black*) and water year 2011 (*grey*) with respective parameters and R^2 values stated to the right

relatively modest levels of deforestation relate to significant changes in stream channel morphology and increased levels of turbidity and suspended sediment concentrations in tributaries to the Upper Little Tennessee River. They include radiocarbon-dated stratigraphic sections showing 40–50 cm of post-settlement alluvium. Miller et al. (2005) examined 111 years of reservoir sediment in the SBRM of western North Carolina and found that sedimentation rates progressively increased with fastest rates in the 1990s and 2000s, presumably in association with the widespread development of new house sites.

Simmons (1993) collected hundreds of suspended sediment observations from the SBRM from 1970 to 1979 as part of a statewide study entitled, "*Sediment Characteristics of North Carolina Streams, 1970–1979*." He stratified land use characteristics of Blue Ridge watersheds into four categories, including fully forested (F), mostly forested with minor development (D), non-agricultural rural (N), and agricultural rural (R) types. His results (Fig. 8.4; Table 8.1) clearly illustrate how the *less*-forested watersheds generate considerably more sediment than fully forested ('pristine') watersheds. It is significant to note that Simmons' three 'pristine' watersheds generated an average of 15 tonnes per km^2 per year of suspended sediment (individual observations of 9.5, 15.1, 20.3 tonnes per km^2 per year), and this illustrates the significance of sediment yield from *natural* disturbances in the fully

Table 8.1 Mean and standard deviation values of specific sediment yield of Blue Ridge Mountain streams in North Carolina, 1970–1979 (From Simmons 1993)

Land use class	Sediment yield (tonnes/km^2/year)	n =	±1 SD (tonnes)
F – Entirely forested ('pristine')	15	3	5
D – Mostly forested with minor development	45	4	22
N – Rural with non-agricultural development	79	12	54
R – Rural with agricultural development	82	12	39

forested watersheds (primarily from landslides, tree-throws, and stream bank erosion sources of sediment).

Meteorological events mediated by climate are the main drivers of variations in natural erosive disturbances of forests, but recent attention has been cast on Native Americans as agents of prehistoric erosion and sedimentation. Stinchcomb et al. (2011) argued that indigenous people of the Mississippian culture (ca. 1,000–460 years BP) were responsible for a 50 % reduction in forest cover in tributaries to the Delaware River in eastern Pennsylvania and western New York (largely for maize (*Zea mays*) cultivation), and they claim to recognize the first floodplain sediment attributed to erosive human impact on the landscape (sensu stricto 'legacy sediment' of James 2013) at circa 1100–1600 AD. They referred to it stratigraphically as 'pre-Colonial sediment' which is distinguished by faster sedimentation rates than previous deposits, and they indicated that it may be recognizable throughout eastern North America. Delcourt and Delcourt (2004) argue that Native Americans had been managing forests for thousands of years in the southern Appalachians by use of fire to clear understories for nut harvest and game management, and to clear plots for agriculture (also see Grissino-Mayer Chap. 6; Greenberg et al. Chap. 12). Thus, indigenous people could have caused significant enough erosive impact on the land to be expressed in the pre-settlement stratigraphic record.

Although the focus of this book is on 'natural' disturbances, which would primarily relate to erosion and sedimentation prior to widespread European American settlement (pre-settlement time) (but see Greenberg et al. Chap. 1), this chapter emphasizes sedimentation both before and after settlement, because the later represents the end-member of maximum forest disturbance. In fact, the expression of forest disturbance usually is very subtle in the pre-settlement stratigraphic record, compared to the post-settlement record. If the ultimate objective is to manage forests within the realm of natural disturbance, then it is still useful to understand a frame of reference that includes the pronounced effects of human-induced disturbance that are clearly outside of the natural range of variation. Furthermore, since it has been argued that indigenous people caused significant disturbance to forests via intentional burning and cultivation for agriculture (see Greenberg et al. Chap. 12), understanding sedimentary products of post-settlement forest disturbance is critical for framing the possible impact that indigenous people had on the sedimentary record. Finally, from an academic perspective, "…understanding the timescales and pathways for response and recovery of rivers and floodplains to episodic changes in erosion and sedimentation has been a long standing issue in fluvial geomorphology" (Knox 2006).

8.2 Distinction Between Pre-settlement Versus Post-settlement Strata

Significant human impact on the fluvial system in North America did not begin until after immigration and settlement of large numbers of non-indigenous people, and the time-stratigraphic designations before and after such settlement have been referred to as pre-settlement and post-settlement units (Trimble 1974; Jacobson and Coleman 1986; Knox 1972, 1977, 1987; Wilkinson and McElroy 2007), though *prehistoric* and *historic* time-stratigraphic designations also are commonly used. In many localities the stratigraphic boundary between pre- and post-settlement alluvium is demarcated by a buried paleosol where the upper surface of the buried A horizon represents the soil surface that existed and was buried by the first post-settlement alluvium (Fig. 8.5). Leigh (2010) established a date of 1870 AD (±10 years) for this stratigraphic boundary in the Upper Little Tennessee valley, primarily based on correlation with historical records and census data (Leigh 2010) indicating that population, improved land in farms, and value of products in manufacturing in the region did not begin to expand until about 1870 AD (Fig. 8.6). Also, intensive

Fig. 8.5 Photograph of the river cutbank stratigraphic section at the Riverside-1 site along the Little Tennessee River showing the stratigraphic boundary of pre- and post-settlement alluvium atop a prominent buried A horizon, which dates to circa AD 1870

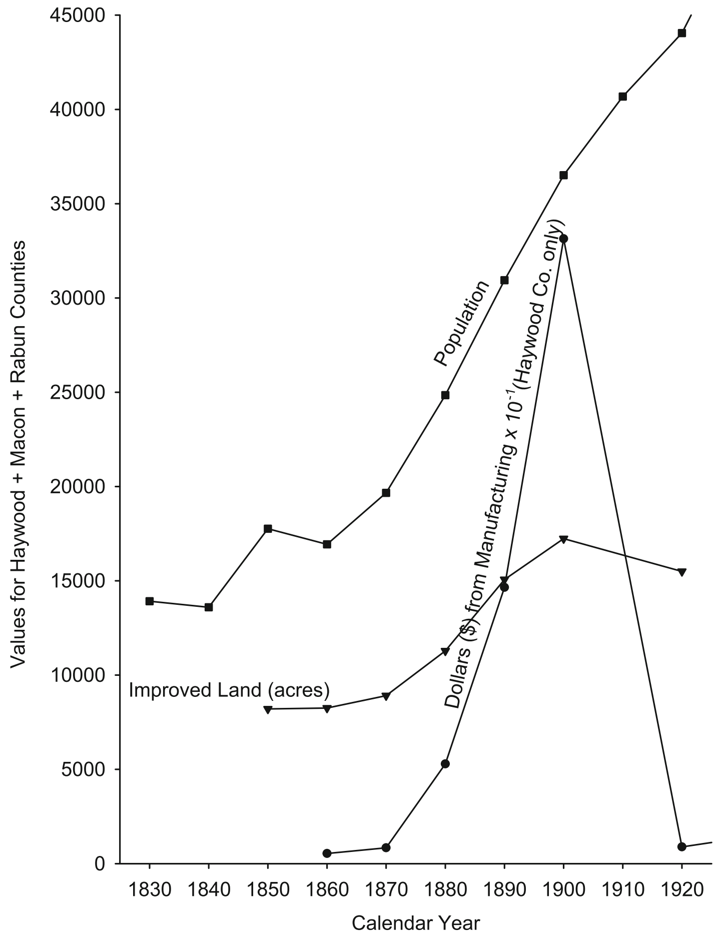

Fig. 8.6 United States Census data for Haywood and Macon Counties, North Carolina and Rabun County, Georgia showing pronounced expansion of human presence after 1870 AD. These counties are the only ones proximal to the Upper Little Tennessee River valley that have complete census records extending back to at least 1860 AD. Dollars from manufacturing line for Haywood County mostly represents timber products

and widespread timber harvest did not begin until after the railroads entered the mountains west of Asheville in the 1880s, which greatly opened accessibility to this rugged terrain. Except for the use of mechanized cultivation equipment and domesticated livestock, sparse European-American settlers prior to 1870 probably used the land in a subsistence fashion similar to their indigenous predecessors. Considering the enormous indigenous population decline due to disease after European contact circa 1540 (Hudson 2002) and the federally mandated removal of Cherokee people in 1835, it is quite possible that the population densities (including both indigenous and non-indigenous people) immediately prior to 1870 were comparable to the pre-1540 indigenous population densities. Indeed, the 1860 USA Census tallied 6004 people in Macon County (1344 km^2) or 4.5 people per km^2, which is much less than estimates of Mississippian indigenous population densities of 16–17 people per km^2 reported by Delcourt and Delcourt (2004) for the lower Little Tennessee River valley in Tennessee.

Many studies have found significant differences in the character of overbank alluvium of post-settlement versus pre-settlement periods, such as in sediment textures (particle size), sedimentology (bedding structures), and sedimentation rates (Lecce 1997; Knox 1977, 1987, 2001, 2006; Benedetti 2003; Leigh 2010). That is, post-settlement overbank alluvium generally is coarser, redder in color (more oxidized), and has sedimentation rates that greatly exceed those of pre-settlement time (Orbock et al. 1993; Knox 2001, 2006; Benedetti 2003).

In addition to the physical characteristics, chemical and paleobotanical characteristics can distinguish post-settlement from pre-settlement alluvium. For example, the lead and zinc content in overbank sediments increased greatly in the upper Mississippi River valley during the 1800s due to mining activities (Knox 1987, 2006). Mercury and gold concentrations are distinctively higher in post-settlement alluvium of the gold belt spanning from northern Georgia through western North Carolina, because gold mining that began in the 1830s involved mercury amalgamation to recover gold from sediment sluices (Leigh 1994, 1997; Lecce et al. 2008). However, such chemical indicators of human agency commonly do not enter into the stratigraphic record until several decades subsequent to the stratigraphic boundary between pre-settlement and post-settlement alluvium, and therefore are not very useful for discriminating the initial onset (or lower boundary) of the post-settlement stratigraphic unit. Pollen preserved within the sediment can help to distinguish the boundary by recognition of the influx of non-native species and weeds indicative of land clearance (Delcourt and Delcourt 2004), but pollen preservation can be poor within the oxidized fluvial sediments due to decay of the organic matter.

Usage of the terminology ‘legacy sediment’ has become very popular within the last decade, and usually it is intended to denote sediment resulting from distinct human-induced erosion of the landscape. Thus, it can be synonymous with the chronostratigraphic terminology of post-settlement alluvium. However, James (2013) recently clarified the definition of ‘legacy sediment’ to relate to any recognizable human impact. Indeed, one of the important questions posed in this chapter is whether or not prehistoric Native Americans engaged in sufficient human impact on the landscape to register a sedimentary signature of ‘legacy sediment.’ Thus, pre- and post-settlement are used throughout this chapter, because they are chronostratigraphic terms that have more precise meaning and distinguish a time of significant population growth of non-indigenous settlers to the region whose land use practices were very erosive.

8.3 Methods

Research presented here relies on 12 stratigraphic sections where both the pre-settlement and post-settlement units occur in the exact same stratigraphic section, and where both units have been well dated by a combination of radiocarbon, luminescence, ^{137}Cs, or correlation dating techniques. The majority of these dated stratigraphic sections are from the Upper Little Tennessee River catchment in northeast Georgia and western North Carolina between Franklin, North Carolina and Mountain City, Georgia (Fig. 8.1, Table 8.2) where they were collected in association with the Coweeta Long-Term Ecological Research (Coweeta LTER) program (http://coweeta.uga.edu/). Exceptions include the Brasstown stratigraphic section (Leigh 1996), which came from the valley of Brasstown Creek in the upper Hiawassee drainage of northern Georgia, and another two sections (at archaeological site 31GH457) that came from the valley of West Buffalo Creek, a tributary to Lake Santeetlah near Robbinsville, North Carolina (Leigh 2011). Ten of these 12 stratigraphic sections are composed entirely of late Holocene alluvium younger than 3,500 years BP, which is most appropriate for comparison of the recent post-settlement alluvium to its immediate predecessor of pre-settlement alluvium. Other stratigraphic sections have been collected in the region (Leigh and Webb 2006; Leigh and Rogers 2007), but do not contain the both the pre-settlement and post-settlement strata in the same section.

Table 8.2 Location and attributes of study sites

Site name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (km^2)	Profile type	Reference
Keener-1	34.933053°	−83.437982°	7	7.6 cm giddings core	Price and Leigh (2006a), Wang and Leigh (2012)
Keener-4	34.932923°	−83.438349°	7	7.6 cm giddings core	Price and Leigh (2006a)
Skeenah-2	35.110998°	−83.404813°	15	7.6 cm giddings core	Price and Leigh (2006a)
Skeenah-4	35.110858°	−83.404828°	15	7.6 cm giddings core	Price and Leigh (2006a)
31GH457-1	35.310047°	−83.912289°	28	7.6 cm hand auger	Leigh (2011)
31GH457-2	35.310247°	−83.912211°	28	7.6 cm hand auger	Leigh (2011)
Brasstown-20	34.949807°	−83.850598°	65	Backhoe pit #20	Leigh (1996)
State Line-1	34.998003°	−83.380416°	146	Right stream cutbank	Leigh (2007), Wang and Leigh (2012)
Creamery-70SW-1	35.012233°	−83.384814°	171	7.6 cm giddings core	Leigh (2007)
Otto/Smith-1	35.058677°	−83.385510°	213	Left stream cutbank	Leigh (2007)
Riverside-1	35.091003°	−83.382106°	313	Right stream cutbank	Leigh (2007), Wang and Leigh (2012)
Stiles-1	35.101464°	−83.384691°	319	7.6 cm giddings core	Leigh this paper

Radiocarbon dating methods mainly involved samples of small angular charcoal or bulk sediment (micro-charcoal fractions and humus) using the accelerator mass spectrometry (AMS) method at the University of Georgia's Center for applied isotope studies. In a few instances large pieces of uncarbonized wood were dated by the conventional scintillation counting method, and the Beta Analytic, Inc. lab was used for the two samples at the Brasstown-20 site (Table 8.3). Charcoal fragments were cleaned and leached of possible carbonates with an acid-alkali-acid pretreatment (1 N HCl-1 N NaOH-1 N HCl) prior to ^{14}C dating. Bulk sediment material was dated following ultrasonic dispersion and sieving through a 125 μm mesh and cleaning with 1 N HCl to remove possible carbonates. Calendar year calibrations were calculated using the program CLAM (Blaauw 2010) based on the IntCal-13 calibration curve (Reimer et al. 2013) and the delta ^{13}C corrected ^{14}C ages. The calendar years before present (years BP) reference 1950 AD as 'present.' Sedimentation rates were calculated by linear interpolation with the program CLAM ('classical' age modeling of Blaauw 2010), which considers the probability distributions of the separate calibrated ages to produce the most probable match for linear interpolation between the two samples. Thus, CLAM produces long-term-average sedimentation rates. Only vertical-accretion facies were used for estimates of sedimentation rates. In cases where lateral accretion facies were dated beneath the vertical accretion, that date was assigned as the basal boundary of the vertical accretion unit, because lateral accretion deposition occurs very rapidly and immediately prior to being overlain by vertical accretion deposits (Bridge 2003).

Although it is possible that charcoal may be detritus and can thereby produce erroneous ages for the actual time of sedimentation, care was taken to selectively date the largest angular fragments of charcoal that exhibit minimal traits of abrasion and rounding. One paired set of radiocarbon samples from the Riverside site (both from 142 to 144.5 cm depth) included dating results from the <125 μm bulk sediment versus charcoal isolated from the <125 μm fraction by flotation separation in sodium polytungstate at 1.7 g per cm^3. Both samples produced almost exactly the same age, $1{,}650 \pm 25$ versus $1{,}710 \pm 25$ ^{14}C years BP, respectively (Table 8.3), and they exhibit overlap at 1,555–1,615 years BP upon calendar year calibrations with two standard deviations. Although, comprehensive conclusions cannot be drawn from only one sample, this single example demonstrates that charcoal is not necessarily much older than associated humus in overbank sediments. It is sensible that charcoal is slightly older than humus, because it has great potential for inheriting ages older than the actual time of sedimentation (i.e., charcoal may have been from tree rings that were hundreds of years older than tree death, transit time of charcoal from the fire site to the deposition site may have taken hundreds of years). Therefore, the bulk sediment date was preferentially used for age-depth modeling in this case and it yielded a best estimate of 1,552 years BP (Table 8.3).

Luminescence dating was applied in a few instances when radiocarbon dating was not feasible, based on the samples of Wang and Leigh (2012). Samples were collected by pounding light-tight PVC tubes (about 15 cm long by 4 cm diameter) into the outcrop and sealing the ends with duct tape upon removal. Ages were measured from sediment extracted from the center of the tubes at the University of Georgia Luminescence Dating Laboratory using the single-aliquot regenerative-dose proto-

Table 8.3 Raw data for samples used for age determinations in each individual stratigraphic section or site

Site	Lab #	Sample depth (cm)	Plot point depth (cm)	Unit & facies	Fraction of VA unit thickness (0 = bottom, 1 = top)	Dating method	Material dated	Material isotopic del ^{13}C	^{14}C years BP	Non-14C age estimate cal. year BP	±1 SD	Best age Est. (cal. years BP)	Inter-sample rate (mm/year)
Keener-1	n.a.	0	0.0	2VA	1.00	GS	Surface 2005	n.a.	n.a.	–55	1	–56	n.a.
Keener-1	n.a.	12–14	13.0	2VA	0.70	Cs137	Flood sediment	n.a.	n.a.	–13	10	–13	3.02
Keener-1	n.a.	43	43.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	79	3.26
Keener-1	UGA-09OSL-672	105–109	107.0	1VA	0.36	OSL	Sandy loam	n.a.	n.a.	1300	50	1,297	0.53
Keener-1	UGA-14484	125	125.0	1VA	0.18	C14	Charcoal	–26.25	1,620	n.a.	40	1,474	1.02
Keener-1	UGA-14485	167	143.0	1LA	0.00	C14	Acorn (uncarb.)	–25.79	1,630	n.a.	40	1,546	2.53
Keener-4	n.a.	0	0.0	2VA	1.00	GS	Surface 2005	n.a.	n.a.	–55	1	–55	n.a.
Keener-4	n.a.	44	44.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	3.24
Keener-4	UGA-14482	133	106.0	1VA	0.00	C14	Charcoal	–26.44	600	n.a.	40	599	1.19
Skeenah-2	n.a.	0	0.0	2VA	1.00	GS	Surface 2003	n.a.	n.a.	–53	1	–53	n.a.
Skeenah-2	n.a.	10–15	13.0	2VA	0.52	Cs137	Flood sediment	n.a.	n.a.	–13	10	–13	3.23
Skeenah-2	n.a.	27	27.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	1.51
Skeenah-2	UGA-13068	113	81.0	1LA	0.00	C14	Wood	–25.31	1,580	n.a.	40	1,469	0.39
Skeenah-4	n.a.	0	0.0	2VA	1.00	GS	Surface 2003	n.a.	n.a.	–53	1	–53	n.a.
Skeenah-4	n.a.	40	40.0	1,2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	3.00
Skeenah-4	UGA-13067	125	112.0	1LA	0.00	C14	Wood	–24.9	2440	n.a.	280	2,494	0.30
31GH457-1	n.a.	0	0.0	2VA	1.00	GS	Surface 2009	n.a.	n.a.	–59	1	–59	n.a.
31GH457-1	n.a.	56	56.0	1/2VA	0.00	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	4.02

(continued)

Table 8.3 (continued)

Site	Lab #	Sample depth (cm)	Plot point depth (cm)	Unit & facies	Fraction of VA unit thickness (0 = bottom, 1 = top)	Dating method	Material dated	Material isotopic del ^{13}C	^{14}C years BP	Non-14C age estimate cal. year BP	±1 SD	Best age Est. (cal. years BP)	Inter-sample rate (mm/year)
31GH457-1	UGAMS-8461	158	158.0	1VA	0.14	C14	Charcoal	−26.7	5,270	n.a.	30	6,057	0.17
31GH457-2	n.a.	0	0.0	2VA	1.00	GS	Surface 2009	n.a.	n.a.	−59	1	−59	n.a.
31GH457-2	n.a.	37	37.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	2.67
31GH457-2	UGAMS-8462	77	77.0	1VA	0.73	C14	Charcoal	−27.1	3,170	n.a.	25	3,401	0.12
Brasstown-20	n.a.	0	0.0	2VA	1.00	GS	Surface 1993	n.a.	n.a.	−43	1	−43	n.a.
Brasstown-20	n.a.	40	40.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	3.26
Brasstown-20	BETA-65972	49–51	50.0	1VA	0.78	C14	Charcoal	n.a.	640	n.a.	60	609	0.19
Brasstown-20	BETA-65973	172–175	96.0	1VA	0.00	C14	Wood/limb (uncarb.)	n.a.	1,880	n.a.	70	1,811	0.38
State Line-1	n.a.	0	0.0	2VA	1.00	CORR	Surface 2005	n.a.	n.a.	−55	1	−55	n.a.
State Line-1	n.a.	73	73.0	2VA	0.54	Cs137	Flood sediment	n.a.	n.a.	−13	10	−13	17.24
State Line-1	n.a.	144	144.0	2VA	0.09	CORR	Flood sediment	n.a.	n.a.	48	10	48	11.77
State Line-1	n.a.	159	159.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	4.65
State Line-1	UGA-09OSL-670	225	225.0	1VA	0.50	OSL	Sandy loam sediment	n.a.	n.a.	1100	50	1,100	0.65
State Line-1	UGA-14480	312	290.0	1LA	0.00	C14	Leaf stem	−26.18	1,380	n.a.	40	1,301	3.24
Creamery-70SW-1	n.a.	0	0.0	2VA	1.00	GS	Surface 2006	n.a.	n.a.	−56	1	−56	n.a.
Creamery-70SW-1	n.a.	37.5–42.5	40.0	2VA	0.69	Cs137	Flood sediment	n.a.	n.a.	−13	10	−13	9.26

Creamery-70SW-1	n.a.	129	129.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	9.62
Creamery-70SW-1	UGAMS-03501	134	134.0	1VA	0.88	C14	Charcoal	−26.7	895	n.a.	25	829	0.07
Creamery-70SW-1	UGAMS-17623	145–147	146.0	1VA	0.60	C14	<125 um sediment	−26.3	1,300	n.a.	20	1,238	0.29
Creamery-70SW-1	UGAMS-17624	204–211	172.0	1LA	0.00	C14	Charcoal	−26.1	1,400	n.a.	20	1,309	3.64
Otto/Smith-1	n.a.	0	0.0	2VA	1.00	GS	Surface 2006	n.a.	n.a.	−56	1	−56	n.a.
Otto/Smith-1	n.a.	62.5–67.5	65.0	2VA	0.68	Cs137	Flood sediment	n.a.	n.a.	−13	10	−13	15.15
Otto/Smith-1	n.a.	204	204.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	14.93
Otto/Smith-1	UGAMS-01602	308	308.0	1VA	0.10	C14	Charcoal	−26.24	3,110	n.a.	60	3,309	0.32
Riverside-1	n.a.	0	0.0	2VA	1.00	GS	Surface 2005	n.a.	n.a.	−55	1	−55	n.a.
Riverside-1	n.a.	40–45	42.5	2VA	0.65	Cs137	Flood sediment	n.a.	n.a.	−13	10	−12	9.90
Riverside-1	n.a.	122	122.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	8.70
Riverside-1	UGAMS-10393	142–144.5	143.3	1VA	0.82	C14	<125 um sediment	−24.9	1,650	n.a.	25	1,552	0.14
Riverside-1	UGAMS-9709	142–144.5	143.3	1VA	0.82	C14	Charcoal in silt fraction	−26.3	1,710	n.a.	25	n.a.	n.a.
Riverside-1	UGA-09OSL-669	198–202	200.0	1VA	0.34	OSL	Sandy loam sediment	n.a.	n.a.	2400	150	2,371	0.70
Riverside-1	UGA-9054	303–305	240.0	1LA	0.00	C14	Leaf	−26.43	2,530	n.a.	23	2,634	1.52
Stiles-1	n.a.	0	0.0	2VA	1.00	CORR	Soil surface in 2009	n.a.	n.a.	−59	1	−59	n.a.
Stiles-1	n.a.	15	15.0	2VA	0.73	Cs137	Flood sediment	n.a.	n.a.	−13	10	−13	3.26

(continued)

Table 8.3 (continued)

Site	Lab #	Sample depth (cm)	Plot point depth (cm)	Unit & facies	Fraction of VA unit thickness (0 = bottom, 1 = top)	Dating method	Material dated	Material isotopic del ^{13}C	^{14}C years BP	Non-14C age estimate cal. year BP	±1 SD	Best age Est. (cal. years BP)	Inter-sample rate (mm/year)
Stiles-1	n.a.	55	55.0	1/2VA	0 or 1	CORR	Top of Ab horizon	n.a.	n.a.	80	10	80	4.27
Stiles-1	UGAMS-9644	67–68	67.5	1VA	0.74	C14	<125 um sediment	−26.1	1270	n.a.	20	1,179	0.11
Stiles-1	UGAMS-9635	99–101	100.0	1VA	0.08	C14	Charcoal	−26.1	2,230	n.a.	25	2,230	0.32
Stiles-1	UGAMS-17408	103–105	104.0	1VA	0.00	C14	<125 um sediment	−26.9	2,870	n.a.	25	2,991	0.05
Stiles-1	UGAMS-12165	111–114	113.0	1VA	0.73	C14	<125 um sediment	−26.69	4,420	n.a.	25	5,011	0.05
Stiles-1	UGAMS-17625	129–132	131.0	1VA	0.64	C14	<125 um sediment	−28.3	5,960	n.a.	25	6,791	0.10
Stiles-1	UGAMS-12164	219–220	219.5	1VA	0.23	C14	Wood	−29.14	9,510	n.a.	30	10,842	0.22
Stiles-1	UGAMS-3978	294	267.5	1LA	0.00	C14	Nut hull (uncarb.)	−27.4	9,850	n.a.	30	11,244	1.20

Abbreviations: *1LA* pre-settlement lateral accretion, *1VA* pre-settlement vertical accretion, *1LA* post-settlement lateral accretion, *2VA* post-settlement vertical accretion, *C14* radiocarbon, *Cs137* cesium-137, *CORR* correlation, *GS* ground surface, *OSL* optically stimulated luminescence, *n.a.* not applicable, *uncarb.* uncarbonized col (Murray and Wintle 2000). The 125–250 μm quartz grains were dated following isolation by flotation in sodium polytungstate and etching in hydrofluoric acid. Light stimulation and emission readings were made with a RISØ® system according to the protocol specified in Wang (2010).

The radioactive ^{137}Cs content of sediments was measured by gamma spectrometry with an Ortec® digital spectrometer in the University of Georgia Geomorphology Laboratory, which is coupled to a 5 cm diameter high purity germanium crystal. Count times of 5,000–10,000 s were used to achieve analytical errors <10 %. The maximum content of ^{137}Cs in the sediment column was assumed to represent the year 1963 AD (Walling and He 1997). In several cases, the 1963 timeline was corroborated by the obvious presence of immediately overlying sandy flood deposits of the 1964 flood, which is the largest flood on record at the USGS gauge (#03500000) on the Upper Little Tennessee River near Prentiss, Tennessee, with records extending from 1945 to present.

Additional correlation dating (age established for a particular feature or stratum in one place is equated to a similar feature or stratum in another place) was used at the State Line site to establish the age of the 1902 flood deposit based on knowledge from old newspaper accounts that the Tallulah Falls Railroad grade crossed the river from Georgia into North Carolina in 1906 AD. That is, the original railroad grade stands only 30–40 m from the radiocarbon dated stratigraphic section, and upon drilling through the artificial fill of the railroad grade there was only approximately 20 cm of post-settlement alluvium that was noted beneath the artificial fill dirt and atop the undisturbed buried A horizon of circa 1870 AD. In addition, a very sandy flood layer occurred at about 5 cm below the artificial fill, which therefore probably corresponds to the 1902 flood, which is the largest flood on record at another USGS gauge (#03507000) on the Upper Little Tennessee River at Judson that collected records from 1897 to 1944.

Charcoal was separated from the >125 μm fraction from all close-interval samples at the Stiles-1 site to produce a time-series of charcoal accumulation rates (pieces per cm^2 per year) or CHAR (Higuera et al. 2009), incorporating the counts, bulk density, and sedimentation rates in a manner similar to that specified by Higuera et al. (2009). Once the >125 μm fraction was sieved and dried, the charcoal particles were counted under a binocular microscope at 40× magnification. Bulk density was measured by weighing selected oven-dried clods, sealing them with plastic spray paint, and immersing the samples in a graduated cylinder of water to determine the volume. Sedimentation rates were calculated by CLAM as described above and then incorporated into the calculation of CHAR.

8.4 Comparison of Pre- and Post-settlement Rates of Sedimentation

Results of age versus depth modeling and calculations of weighted mean values of long-term-average sedimentation rates from the 12 stratigraphic sections show that the post-settlement sedimentation rates were about an order of magnitude faster than latest Holocene pre-settlement rates (Tables 8.3 and 8.4; Fig. 8.7). Pre-settlement rates generally are in the range from 0.1 to 1.0 mm per year, whereas post-settlement rates are in the range from 1 to 10 mm per year, and the median values of the weighted averages of each unit are 0.4 and 3.6 mm per year, respectively. A paired *t*-test indicates that the sedimentation rates at these 12 sites are significantly different (t-statistic of 4.29 and a one-tailed significance level of 0.0006). The ratio of post-settlement to pre-settlement rates derived from individual sites ranged from 2.7 to 46.9 with a median value of 7.8 and a mean value of 12.9 (Table 8.4). Such disparity of pre- versus post-settlement rates is on par with areas of intensive past agriculture, such as the Upper Mississippi River valley region (Knox 2006) and the southern Piedmont (Happ 1945; Trimble 1974, 1975), which is somewhat surprising given the mostly forested condition of the SBRM. However, the Blue Ridge topography is considerably more sloping than those regions, which probably facilitates comparable amounts of erosion and sedimentation.

There is a pronounced difference in both the sedimentation rates and thicknesses of post-settlement alluvium from tributary watersheds draining less than 65 km^2 versus those along the main channel of the Upper Little Tennessee River draining 146–319 km^2. The mean of the long-term-average sedimentation rates of the seven smaller tributaries is 2.9 mm per year versus 9.4 mm per year from five sites along the main channel; and the average post-settlement stratigraphic unit thickness of the tributaries is 41 cm versus 134 cm along the main channel. This disparity may be attributed to the fact that the tributaries have been exhibiting high rates of lateral migration and stream bank erosion since the early 1900s, whereas lateral migration of the main channel has been minimal (Leigh 2010). Such migration enhances sediment concentrations downstream along the main channel because erosion of tributary stream bank sediment is added to the hillslope-derived load. Also, the higher gradient of the tributary streams is more effective in transferring the sediment across the floodplain and further downstream than the lower-gradient main channel. Furthermore, the laterally migrating tributaries have established a new floodplain that inherently reduces vertical accretion rates on the historical terrace that contains much of the post-settlement alluvium. This uneven pattern of sediment erosion, transfer, and deposition adheres to the pattern that Knox (1987, 2006) recognized in tributaries to the upper Mississippi River in southwestern Wisconsin and to Trimble's (1993) 'distributed sediment budget.' Recent real-time observations of sediment concentrations in Upper Little Tennessee tributaries versus the main channel show the same sort of disparity (Rhett Jackson, pers. comm.). Although there are small, but similar, differences in tributary versus main channel sedimentation rates and thicknesses for the pre-settlement alluvium, they are nowhere near the same magnitude of those observed in the post-settlement alluvium (Table 8.4).

Another important difference in pre-settlement versus post-settlement sedimentation rates (in cases where there are three or more age control points within each stratigraphic unit) is that the pre-settlement unit exhibits an exponential decline in sedimentation rates with time, which is the norm for most vertical accretion floodplain sediments (Bridge 2003), whereas the post-settlement unit exhibits a constant linear rate or even an exponential increase with time (Fig. 8.8). This is well

Table 8.4 Basal ages, stratigraphic unit thickness, weighted average sedimentation rates for the entire unit, and ratios of post-settlement/pre-settlement and post-1963/1870-1963 sedimentation rates

Site name	Basal age of pre-settlement VA (cal years BP)[a, b, c]	Post-settlement thickness (cm)	Pre-settlement thickness (cm)	Post-settlement weighted average (mm/year)	Pre-settlement weighted avg. (mm/year)	Post-/pre- ratio of sed. rates	Post-1963/1870-1963 ratio of sed. rates
Keener-1	1,546	43	100	3.2	0.9	3.5	0.9
Keener-4	599	44	62	3.2	1.2	2.7	n.a.
Skeenah-2	1,469	27	54	2.3	0.4	6.0	2.1
Skeenah-4	2,494	40	72	1.6	0.4	4.0	n.a.
31GH457-1	>6,057 (at 14 %)	56	119	4.0	0.2	23.6	n.a.
31GH457-2	>>3,401 (at 73 %)	37	148	2.7	0.1	22.3	n.a.
Brasstown-20	1,811	40	59	3.3	0.3	9.5	n.a.
State Line-1	1,301	159	131	9.5	1.9	4.9	1.5
Creamery-70SW-1	1,309	129	43	9.5	2.3	4.2	1.0
Otto/Smith-1	>3,309 (at 10 %)	204	116	15.0	0.3	46.9	1.0
Riverside-1	2,634	122	118	9.1	0.9	10.4	1.1
Stiles-1	11,244	55	213	4.0	0.2	16.3	0.8
	Median. =	50	108	3.6	0.4	7.8	1.0
	Average.=	80	103	5.6	0.8	12.9	1.2
	±1 St. Dev. =	58	49	4.1	0.7	13.0	0.5
	Tributary avg. =	41	88	2.9	0.5	10.2	1.5
	Main channel avg. =	134	124	9.4	1.1	16.5	1.1

[a]% refers to the percentage of stratigraphic thickness measured upward from the base of unit
[b]VA is the abbreviation for vertical accretion facies
[c]>indicates that a basal age was not determined

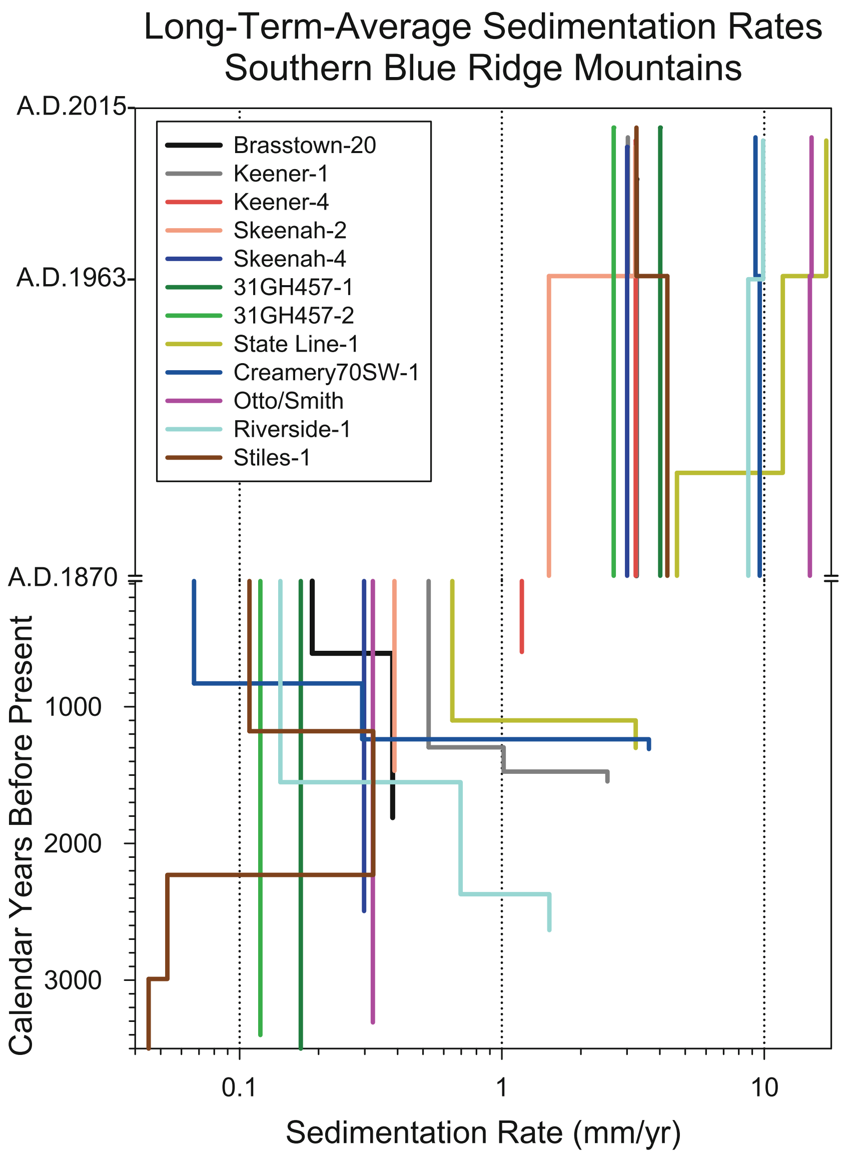

Fig. 8.7 Sedimentation rate plots for the 12 sites. Each site represents a profile of vertical accretion floodplain sediments from stream valleys in the southern Blue Ridge Mountains (see Fig. 8.1) that accumulated over the past 3,500 years. Line ends and right-angle changes in line segments represent age control points

illustrated by the ratio of post-1963 to pre-1963 post-settlement sedimentation rates given that the median ratio is 1.0 and the average ratio is 1.2 (Table 8.4). This indicates that erosive processes of the deforested landscape have remained vigorous since the 1960s, even though much of the deforested land is covered in grasses and shrubs; this is consistent with the findings of Miller et al. (2005) and suggestive that second home development and road/driveway construction is generating considerable sediment. Lateral erosion of the tributaries also contributes to sustained sediment supply to the main stem of the river. Alternatively, the sustained high rates of sedimentation post-1963 may indicate intrinsic mechanisms of the fluvial system,

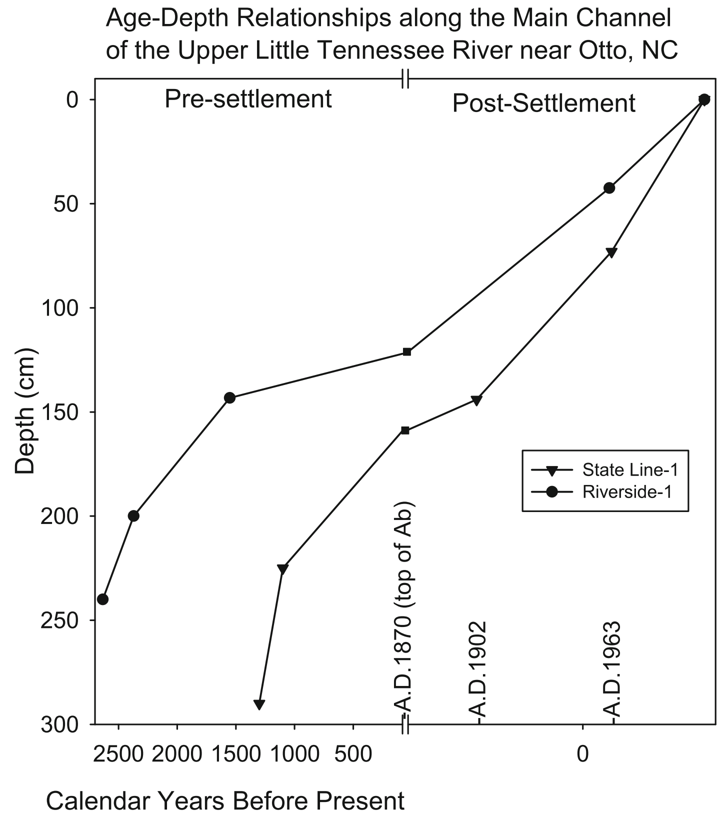

Fig. 8.8 Age-depth plots of the pre-settlement versus post-settlement units at the Riverside-1 and State Line-1 sites illustrating the progressively slower sedimentation rates (decreasing slopes of lines) with more recent age for the pre-settlement unit versus faster sedimentation with time (increasing slopes of lines) for the post-settlement unit. The square point on each plot represents the 1870 AD top of the buried A horizon

namely stream bank erosion and natural levee progradation, so that when sample sites progressively become nearer to the channel due to lateral erosion, this closer proximity to the channel inherently favors faster sedimentation rates (Bridge 2003). However, the Keener-1, Skeenah-2, and Creamery-70mSW-1 sites are not situated on prograding levees, but they still exhibit post-1963 to pre-1963 ratios of about 0.9–2.1 (Table 8.4).

8.5 Natural Disturbance Expressed by Fluvial and Colluvial Sediment

Natural disturbances in the forested mountains typically are not obvious in terms of macro-stratigraphy and long-term-average sedimentation rates, unless a distinctive landslide or debris flow event is preserved in the stratigraphic record. Natural disturbances in the Blue Ridge Mountains that produce recognizable sedimentary records primarily are driven by climatic variations that modulate mass wasting; that is,

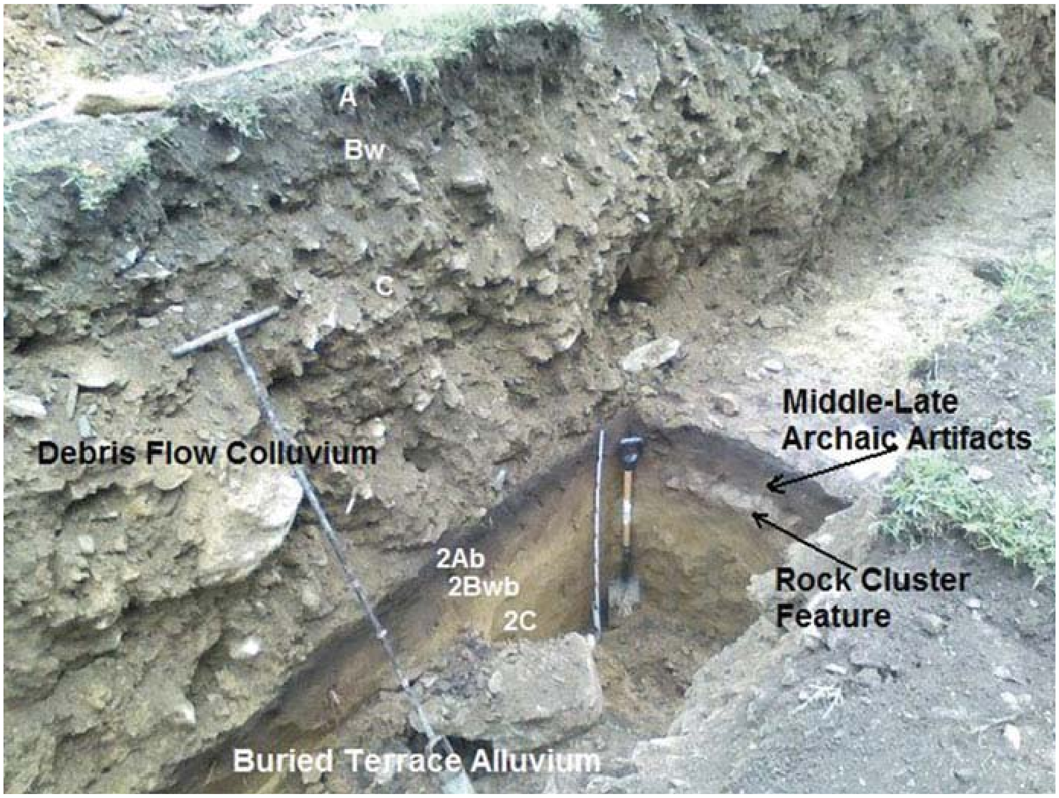

Fig. 8.9 Debris flow deposits (coarse upper stratum) overlying river alluvium at the Ferebee picnic area along the Nantahala River (From Leigh 2011)

wet periods generate more mass wasting events (landslides and debris flows) than dry periods (see Wooten et al. Chap. 9) and mass wasting releases huge volumes of sediment to the fluvial system. In addition, wet periods may stimulate more lateral bank erosion (causing riparian forest disturbance) and thus increase sediment yield from erosion of terraced stream banks (Rogers and Leigh 2013).

An example illustrating that mass wasting events do indeed become deposited within floodplains was documented by Leigh (2009) at the Ferebee picnic area along the Nantahala River in western Carolina (Fig. 8.9). While this sort of evidence clearly indicates that mass wasting definitely has occurred on nearby hillslopes, it is not sufficient to construct any sort of time series for the entire watershed in order to understand variation in the magnitude and frequency of mass wasting events through time. Wooten et al. (Chap. 9) indicate that regional debris flow events in the Blue Ridge province have an historic recurrence frequency of approximately 25–29 years, driven by the passage of tropical storms and their heavy rains. Also, Eaton (2003a, b) was able to construct a millennial-scale time series of mass wasting for the Rapidan River basin in Virginia. He argued that debris flows and landslides are the dominant modes of Holocene sediment production in forests of the SBRM, whereas overland flow and surface erosion are relatively insignificant under native forest cover. Eaton indicated at least a 2500 year recurrence frequency for debris flow activity within any individual tributary of the upper Rapidan catchment, although he was unable to relate debris flow frequency to Holocene paleoclimate drivers of variation in magnitude and frequency through time.

Broad inferences about mass wasting frequency in relation to late Pleistocene and Holocene fluctuations in paleoclimate have been made in a few cases. Delcourt and Delcourt (2004) indicate that a marked reduction in fluvial sediment supply to the lower Little Tennessee River valley occurred at some time between 7,800 and 4,000 years BP in response to a change in sediment flux from forested watersheds, largely related to mass wasting events. In support of their idea Leigh and Webb (2006) suggested that relatively fast footslope sedimentation rates during the early Holocene versus late Holocene possibly were driven by wetter paleoclimate conditions in the early Holocene. Such inferences are broad and somewhat speculative, but they have firm grounding in theory. That is, wetter climatic periods, especially those related to prolonged heavy rains associated with tropical storm events tend to trigger a higher frequency of landslides and debris flows (Wooten et al. Chap. 9) that should be recognizable in the stratigraphic record. However, the temporal resolution needed to derive significant variations in sedimentation rates through the Holocene is difficult and expensive to obtain because of the numerous samples required.

A modern example of sediment yield from forested watersheds in relation to climatic fluctuations is provided by Simmons' data set collected during the relatively wet 1970s (Simmons 1993) when compared to data collected from the same region (Fig. 8.4) during average or drier climatic periods (Coweeta LTER unpubl; Oblinger 2003). Oblinger (2003) observed that annual sediment concentrations and yields were an order of magnitude less during their relatively dry study period in 2001 compared to Simmons' estimates from the relatively wet 1970s. In contrast, Simmons' 1970s sediment yields are only slightly higher than those observed in water-year 2011 by researchers of the Coweeta LTER (Fig. 8.4), which was a slightly above average year in terms of wetness. Also, the sediment yields for the least disturbed watersheds ('pristine' forested watersheds of Simmons 1993) are very comparable to those fully forested sites observed in water year 2011 by the Coweeta LTER researchers.

A forward stepwise linear regression was applied to evaluate the combined sediment yields of the three time periods mentioned above by using three independent variables or predictors: (1) percent nonforest cover values published in Simmons' (1993) for the 1970s and tallies from the National Land Cover dataset for the 2001 and 2011 datasets for the Oblinger and Coweeta LTER data, respectively; (2) catchment drainage area; and (3) measured annual-mean runoff at the USGS Prentiss gauge (USGS #03500000) as an indicator of wetness. The wetness variable of annual-mean runoff essentially is a 'dummy variable' (values of 12.7 m^3 per second for the 1970s; 5.44 m^3 per second for 2001; and 8.97 m^3 per second for water year 2011). The results found all three independent variables to be highly significant at probability levels less than 0.01 and the three-variable model explains 52.5 % of the variance in sediment yield values of the three combined data sets at a probability level of <0.001 and an F-statistic of 15.114 (Table 8.5). Drainage area explained the largest portion of variance (24 %), followed by the percent of non-forested land (15 %),

Table 8.5 Multiple linear regression model explaining 52.5 % of the variation in annual sediment yield of Blue Ridge Mountains streams

Variable	Coefficient	*t*-test value of coefficient validity or significance	Probability (ratio) that coefficient is invalid or not significant	Proportion of variation explained (partial R^2)
Y-intercept	−77.903	−2.911	0.006	Not applicable
x1: drainage basin size or area, DA (km^2)	0.0187	2.926	0.006	0.241
x2: percent of basin that is not forested	1.891	3.6	<0.001	0.15
x3: annual average daily runoff from entire basin (m^3/s)	8.425	3.971	<0.001	0.134
			Total explained (total R^2) =	0.525

Model equation: Sediment yield (tonnes/km^2/year) = −77.903 + (0.0187 * DA (km^2)) + (1.891 * % Non-forest) + (8.425 * Runoff (m^3/s))
Number of samples in the regression model = 43
F-statistic of overall model strength = 15.114
Standard error of estimate = 31.131 (t/km^2/year)
Shapiro-Wilk normality test score (which passed) = 0.624

and then average runoff or wetness (13 %). The fact that drainage area was such a strong predictor is consistent with the observation above concerning the distributed sediment budget, because the dependent variable of sediment yield (tonnes per km^2 per year) is already normalized for contributing drainage area. Overall, the results indicate that the climatic 'dummy variable' is essentially as good a predictor as the percent of nonforest cover and reinforce the idea that subtle variations in climate can have a significant influence on sediment yield. This is consistent with Knox's (1993) observation that modest changes in climate can have a significant influence on flood magnitude and frequency.

Little to no evidence of pre-settlement erosional forest disturbance can be discerned from the 12 stratigraphic sites identified in this paper. There are some minor variations in sedimentation rates at individual sites, but it is impossible to determine whether those were driven by intrinsic mechanisms of the fluvial system or by extrinsic mechanisms, such as climate change. This result stems from the fact that it is very difficult to obtain the spatial and temporal resolution from long-term average sedimentation rates that allows discrimination of the ultimate drivers of natural forest disturbance. Also, it is apparent from pollen records (Delcourt et al. 1986; Delcourt and Delcourt 1988) that forest cover has persisted throughout the Holocene (mostly deciduous with evergreens at high elevation), so that vegetation (and probably climate) did not vary enough to favor big changes in sediment yield and runoff. However, temporally continuous pollen records for the entire Holocene are lacking for the SBRM. Indeed, other places where large geomorphic variations have been noted are within ecotonal zones where pronounced shifts from grassland to forest have occurred (e.g., Knox 1983).

In summary, paleoclimatic changes in rainfall delivery that lead to increased soil wetness make hillslopes more susceptible to erosion (especially by mass wasting) and are agents that theoretically should be reflected in the stratigraphic record. However, in practice the scale of observation in the stratigraphic record, along with the medium to large watershed scale that derives sediment from many different tributaries, is generally too coarse to resolve climatically-driven disturbances. Only the most pronounced variations in sediment yield (driven largely by mass-wasting) are crudely discernable in the pre-settlement stratigraphic record.

8.6 Were Prehistoric Native Americans Agents of Hillslope Erosion?

There is recent interest about the extent to which prehistoric Native Americans altered natural vegetation and environmental conditions. Abrams and Nowacki (2008) contend that indigenous land management affected vegetation 'ubiquitously.' In contrast it has been argued that indigenous impact varied widely with some regions exhibiting no discernable human impacts (Vale 2002). Most recently, Munoz et al. (2014) document the spatial pattern of the late prehistoric human impacts to be 'localized and heterogeneous' for eastern North America, and they challenge the idea that the prehistoric Native American's impact on vegetation was widespread and ubiquitous. Instead, they argue that indigenous land use was patchy, including spatially varied niches of 'undomesticated woodland management' and agricultural land. Furthermore, they stress the idea that human impacts were temporally dynamic.

Delcourt and Delcourt (1988, 1997, 1998, 2004) and Delcourt et al. (1986, 1998) advanced the idea that prehistoric Native American impacts on southern Appalachia were significant, primarily in terms of managed silviculture that involved burning the understory of nut-bearing trees (American chestnut (*Castanea dentata*), oak (*Quercus* spp.), hickory (*Carya* spp.)) and by cultivation of maize, squash and gourds (*Cucurbita* spp.), beans (*Phaseolus* spp.), and other crops. Forests are thought to have been disturbed and managed by Native Americans for edible mast as early as 4,000–5,000 years BP (Delcourt and Delcourt 2004). Cultivation of squash and gourds is known to have occurred as early as 5,200 years BP (Delcourt and Delcourt 2004), and widespread domestication and cultivation of goosefoot (*Chenopodium* spp.) is known to have occurred by 3,500 years BP in eastern North America (Smith and Cowan 1987). Later, cultivation of maize is documented in the Little Tennessee River valley by 1,700 years BP, but it did not become a mainstay of the diet until 1,000 years BP (Delcourt and Delcourt 2004). Beans were introduced into the lower Little Tennessee valley at about 600 years BP (Delcourt and Delcourt 2004). In summary, indigenous silvicultural and agricultural activities in the Little Tennessee valley were established by at least 4,000–5,000 years BP and these activities progressively increased though the late Holocene, culminating with widespread dependence on agriculture during the Mississippian cultural period circa 1,000–500 years BP.

The question is not whether indigenous people were managing and altering the ecosystem and vegetation patterns of the SBRM, but whether or not their use of the land was erosive enough to register 'legacy sediment' in stratigraphic sections. James (2011) provides a nice summary of indigenous land use patterns in the eastern USA, and he concludes that indigenous practices were minimally destructive to soil and slope stability, as no mechanized methods were practiced (no plows, wheels, or metal tools) and agriculture was focused on flat alluvial bottomlands. In stark contrast, Stinchcomb et al. (2011) promote the idea that indigenous people caused significant erosion and bottomland sedimentation circa 1100–1600 AD and registered the first 'legacy sediment' (sensu James 2013). They extrapolated their example of 'pre-Colonial sediment' from a tributary of the Delaware River valley to all of eastern North America, while acknowledging that "future research efforts should focus on mapping the chronological and geographic range."

Six of the 12 geochronologies presented above contain at least three age control points spanning 2,500 years BP to 80 years BP (1870 AD) that facilitate evaluation of the question of acceleration of sedimentation rates by indigenous people in the SBRM (Fig. 8.10; Table 8.3). The past 2,500 years encompasses the Middle Woodland, Late Woodland, Mississippian, and Cherokee prehistoric cultural phases,

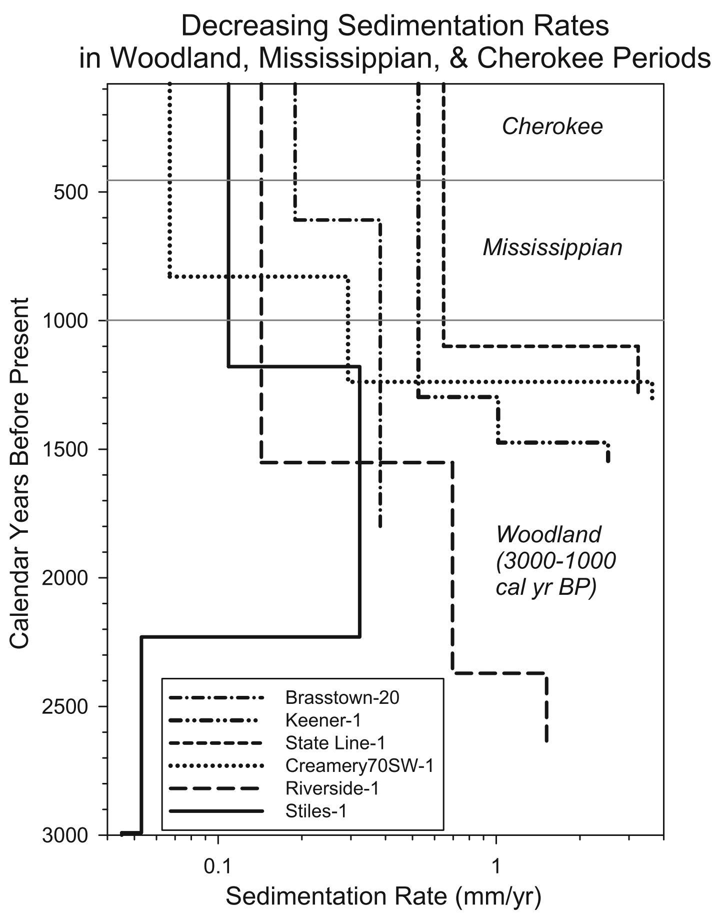

Fig. 8.10 Sedimentation rate plots that have two or more age control points between 2,500 years BP and 80 years BP (1870 AD) that enable evaluation of whether indigenous people caused increased sedimentation rates during the Woodland, Mississippian, and Cherokee cultural periods

and during this time agricultural expansion is known to have occurred (Delcourt and Delcourt 2004), with maximum pre-settlement extent of cropland occurring during the Mississippian and Cherokee phases. Furthermore, the Upper Little Tennessee River valley is known to have been a hub of the prehistoric Cherokee culture (Hudson 2002). Results show that all six stratigraphic sections fail to indicate any increase in sedimentation rates during the Mississippian or Cherokee phases; in contrast, all six sections show a pronounced *decrease* in sedimentation rates from the Middle Woodland through Cherokee phases. Although the resolution of the dating on these six sections is somewhat coarse, all six fail to support the idea that Mississippian or Cherokee peoples accelerated bottomland sedimentation rates. While lack of support does not mean that indigenous human-induced erosion and accelerated sedimentation did not happen anywhere, it does indicate that it was not prevalent enough to be commonly observed in the stratigraphic record like the post-settlement stratum.

The Stiles site shows an interesting increase in sedimentation rates at 2,230–1,179 years BP during the Middle Woodland period (Fig. 8.10; Table 8.3), but thereafter a decrease is apparent. This Middle Woodland increase may be attributed to human agency, but on the other hand it is quite possible that it simply results from intrinsic shifting of the Upper Little Tennessee River. That is, the Stiles meander scar sedimentation site may have been far away from the active channel until 2,230 years BP when the active channel avulsed and shifted its position closer to the site (near it present position), thus automatically increasing the delivery of overbank sediments. The current position of the modern channel, and the fact that sedimentation rates at the Stiles site *decrease* after 2,230 years BP, are consistent with this intrinsic mechanism. Also, it seems that if it were attributed to human agency, then the higher Middle Woodland sedimentation rates would have persisted into Mississippian and Cherokee periods.

The above example of intrinsic mechanisms causing change in fluvial systems raises the point that, in addition to human agencies, there are other important drivers that can cause changes in fluvial sedimentation rates, namely intrinsic channel shifting and climate change. Climate change is particularly germane to the discourse about indigenous land use influences on erosion and sedimentation. The Medieval Climate Anomaly (MCA, circa 800–1300 AD) and the Little Ice Age (LIA circa 1400–1800 AD) exhibited significant shifts from relatively warm to cold climate conditions, respectively (Bradley and Jones 1995; Cronin et al. 2003; Grove and Switsur 1994), at exactly the time when indigenous agricultural land use was rapidly expanding. Although such MCA temperature shifts have not been documented in the southeastern USA, Wang and Leigh (2012) noted significant evidence (coarser sand sedimentology) of increased flood magnitudes in the Blue Ridge Mountains at the beginning and end of the MCA, but no changes in sedimentation rates were observed. They concluded that the Upper Little Tennessee valley may have been influenced by a relatively wet climate and large floods at the beginning and end of the MCA, circa 1,150–1,350 years BP and 650–900 years BP. Stinchcomb et al. (2011) acknowledged that global climate change associated with the transition from the MCA to the LIA could have played a role in depositing their ‘pre-Colonial sediment,’ but they discounted that explanation and favored the interpretation of indigenous human-induced erosion.

In summary, no compelling evidence has been recovered in the SBRM to indicate that indigenous people caused accelerated erosion and increased alluvial sedimentation rates. Of course, there might be some localized areas of accelerated prehistoric bottomland sedimentation rates that were proximal to agricultural fields (which have yet to be found), but preliminary evidence suggests that relatively slow, or ‘natural,’ rates of sedimentation were normally occurring on river and stream bottomlands, despite significant disturbance of the native forest in support of mast harvest, hunting, and agriculture during pre-settlement time. It is likely that most of the pre-settlement agricultural disturbance of the forest occurred in relatively low-gradient alluvial bottomlands where sediment erosion and transport was physically improbable. Furthermore, indigenous population densities probably were small enough to negate the need to expand agricultural fields on to steep hillslopes. Delcourt and Delcourt (2004) estimated (based on Baden’s 1987 model) that Mississippian population densities in the lower Little Tennessee River valley were 16–17 persons per km^2 for entire watersheds and 52–56 persons per km^2 if concentrated over cultivated alluvial bottomlands. However, values of 16–17 persons per km^2 equates to the 1983 AD population density in Macon County, North Carolina, which suggests the Delcourt’s estimates for the Mississippian period may be high. Baden’s (1987) model indicated that minimum caloric needs for food required 0.1–0.6 ha per person. Using those values, even if 56 persons per km^2 of alluvial bottomland is assumed, then that equates to 1.8 ha of bottomland available per person (100 ha divided by 56 persons = 1.8 ha per person) or at least three times Baden’s (1987) presumed bottomland requirement for subsistence. Thus, one could contend that available bottomland was not a limiting factor for indigenous Mississippian and Cherokee agriculture, so they did not need to deforest and cultivate steep erosive hillslopes. Baden (1987) assumed that nutrient depletion was a key factor in the progressively decreasing productivity of agricultural lands, which ultimately limited and depleted the soil resource. However, it is not clear whether he was considering nutrient replenishment from annual floods, weathering, and additions by humans. Indeed, Bartram speaks of the bottomlands in the Upper Little Tennessee River valley as appearing very fertile in 1775 AD.

8.7 Past Fires and Charcoal Records in Alluvium

Like many parts of the USA, suppression of human-ignited fires has been the norm for the SBRM during the past century (see Grissino-Mayer Chap. 6). However, fire routinely was used to clear land by early settlers during the 1700s and 1800s (Jurgelski 2008) and by Native Americans during pre-settlement times (Delcourt and Delcourt 2004) (also see Grissino-Mayer Chap. 6; Greenberg et al. Chap. 12). Bartram’s 1775 travels (Van Doren 1928) through the SBRM describe many grassy meadows and open grassy understories in woodlands indicative of frequent low-intensity fires. Paleoecological studies have shown that fires were an important component of the pre-settlement landscape (Delcourt and Delcourt 2004). Delcourt and Delcourt (2004), as well as Delcourt and Delcourt (2004), assert that human use of fire caused distinct changes in forest composition and structure after 3,000 years BP, which favored fire-adapted mast-bearing trees such as oaks, chestnuts, hickories, and walnuts (*Juglans* spp.), as well as a patchwork of meadows and clearings initiated by fire. Fesenmyer and Christensen (2010) radiocarbon dated 83 samples from 18 separate soil pits (0–30 cm depth) on hillslopes bounding the upper Nantahala River valley in Macon County, North Carolina in an effort to construct a pre-settlement stand-level fire history. They found that "fires were frequent over the past 4,000 years, and their frequency appears to have increased significantly about 1,200 years before present (YBP), coinciding with the advent of the Mississippian Native American culture."

With respect to sediment yield, fires can greatly increase surface erosion by removal of the protective vegetation cover and in some cases by producing a hydrophobic surface that reduces infiltration and enhances overland flow (Stine 2013). However, low-severity and prescribed fires generally produce small effects on erosion and sedimentation (Committee on Hydrologic Impacts of Forest Management 2008). Indeed, Elliot and Vose (2005) found no significant increase in total suspended solids following prescribed restoration fires in the Conasauga watershed of northwest Georgia and southeast Tennessee, and noted that several other studies in the southeastern USA report little to no soil erosion following light- to moderate-intensity fires. Neary and Currier (1982) measured the total suspended solids derived from watersheds that were intensively burned in April 1978 during an 'abnormally hot' wildfire in the SBRM of South Carolina, and observed no significant difference between the forested 'control' watershed and burned watersheds. Thus, there is no compelling evidence to indicate that intentional pre-settlement use of fire for removal of understory and for garden clearings would have increased sediment yield and be reflected in the stratigraphic record. Recall that the six stratigraphic sections noted above that have sufficient chronologies to evaluate sedimentation rates after 2,500 years BP generally show decreasing sedimentation rates. Thus, it is not possible to infer that increased use of fire by Native Americans led to increased rates of pre-settlement erosion and sedimentation.

One of the 12 stratigraphic sections noted above, the Stiles site, has a continuous sedimentary history for the entire Holocene (11,244 years BP basal age of vertical accretion). Charcoal fragments larger than 125 μm were sieved and counted from a continuous column of closely spaced samples representing a time series of charcoal frequency or the CHAR metric of Higuera et al. (2009). The CHAR metric relies on the long-term sedimentation chronology derived from radiocarbon dates and the age-depth model (CLAM) described above. The results (Fig. 8.11) show a very pronounced increase in charcoal concentrations at about 2,400 years BP, whereas the majority of the record prior to then exhibits little to moderate evidence of fire except for the earliest Holocene (circa 11,244–10,900 years BP). This increase in charcoal concentrations after 2,400 years BP is consistent with the assertion that

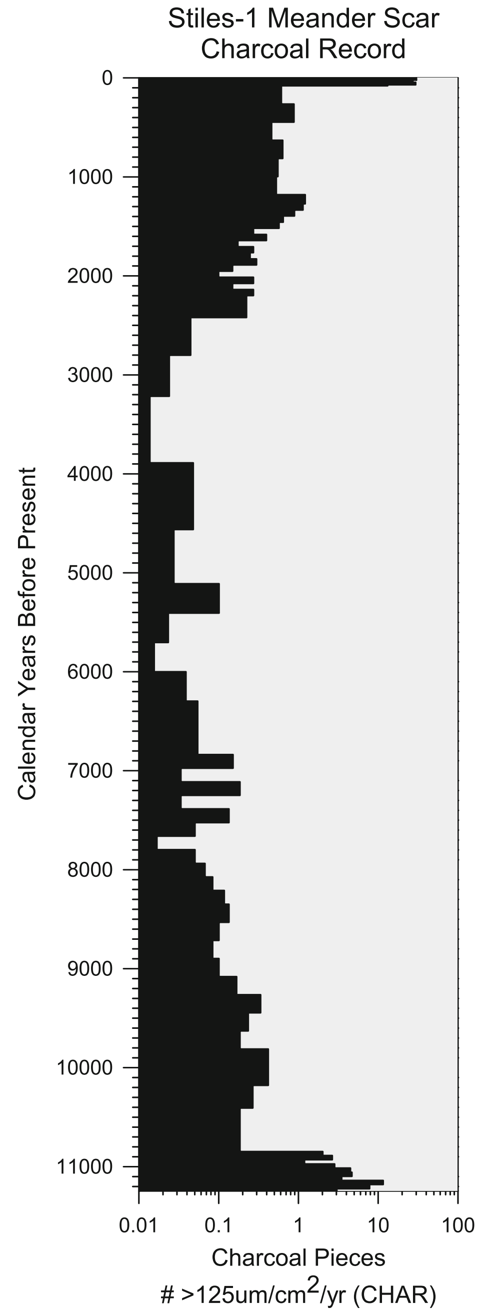

Fig. 8.11 Charcoal accumulation rate (pieces >125 μm per cm^2 per year) versus age (years BP) for the entire Holocene at the Stiles site, which is a cutoff meander scar between Otto and Franklin, North Carolina in the Upper Little Tennessee River valley

human-ignited fires became increasingly more prevalent after 3,000 years BP (Delcourt and Delcourt 2004, p. 85), as there is no known paleoclimate change at 2,000–3,000 years BP in the southeastern USA to entertain as an alternative explanation involving lightning ignitions. The high frequency of charcoal at the very beginning of the Holocene is more difficult to reconcile, although it is a known period of rapid climate change that may have involved frequent lightning ignitions. Unfortunately, there currently are insufficient data to support either lightning- or human-ignitions in the earliest Holocene.

In summary, pre-settlement and post-settlement fires have not been demonstrated to register distinct changes in sedimentation rates in the SBRM, and modern prescribed low-intensity burns do not appear to be erosive. The Stiles stratigraphic section confirms that fire was a definite component of the pre-settlement landscape, though unevenly through time, and it strongly suggests that fires became much more frequent in association with expansion of agriculture during the Woodland and later prehistoric cultural periods as suggested by others. The charcoal record from the Stiles site reinforces the idea that stratigraphic chronologies of past fire provide valuable insight about the importance of fire in pre-settlement forests of the SBRM. However, when coupled with sedimentation rate analysis there is no indication that forest fires caused any significant changes in hillslope erosion and bottomland sedimentation rates.

8.8 Conclusions

In the SBRM, vertical accretion alluvium provides a coarse-resolution proxy for past erosional forest disturbance that clearly discriminates the end members of fully forested to approximately 30 % regional deforestation, as illustrated by pre-settlement versus post-settlement alluvial stratigraphic records. Post-settlement sedimentation rates are about one order of magnitude greater than pre-settlement rates (typically ranging from 1.0–10 mm per year versus 0.1–1.0 mm per year, respectively), and this is consistent with post- versus pre-settlement stratigraphy recognized nationally (Knox 2006) and even globally (Wilkinson and McElroy 2007). Clearly, the stratigraphy and sedimentation rates of the post-settlement alluvium provide a geologic and stratigraphic record in support of the newly proposed Anthropocene epoch (Crutzen 2002; Zalasiewicz et al. 2010). Under 'natural' conditions that are not mediated by humans, only the most pronounced variations in sediment yield (driven largely by mass-wasting) are crudely discerned in the pre-settlement stratigraphic record. Indigenous human impacts of soil erosion and changes in bottomland sedimentation rates are *not* recognizable in the pre-settlement stratigraphic record of the SBRM. However, the use of fire for forest management and agricultural activities by Woodland, Mississippian, and Cherokee prehistoric cultures is apparent in the fluvial stratigraphic record via charcoal preserved in the stratigraphic sections.

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