Sea Level and Climate of the Past Century

Abstract. *During the past century global temperatures increased until about 1940, after which there was a decrease. Precipitation trends show a decrease from 1900 to 1940, and a definite global increase thereafter. Sea level trends for the eastern coast of the United States are parallel to, and presumably related to, the climatological changes.*

A correlation can be made between sea level trends obtained from published sea level observations for coastal stations of the eastern United States and trends in global climate of the past century. The correlation will gain considerably in significance if it can be shown to occur also for world-wide sea level.

In 1950 Willett (*1*) presented global annual mean temperature statistics from about 1845 to 1939. More recently, Mitchell (*2*) combined Willett's data with new information from 1939 to 1959. Mitchell weighted the temperature means by the area between parallels of latitude, thereby reducing the amplitude of the trends shown by Willett's temperature curves.

According to Mitchell's reductions, as shown in modified form in Fig. 1, a global annual warming occurred from 1880 to about 1940, amounting to 0.8°F (0.4°C); the global winter warming was 1.2°F (0.6°C). The lower curves in Fig. 1 show a warming in latitudes 40°N to 70°N of higher magnitude: an annual warming of 1.6°F (0.9°C) and a winter warming of 2.4°F (1.3°C).

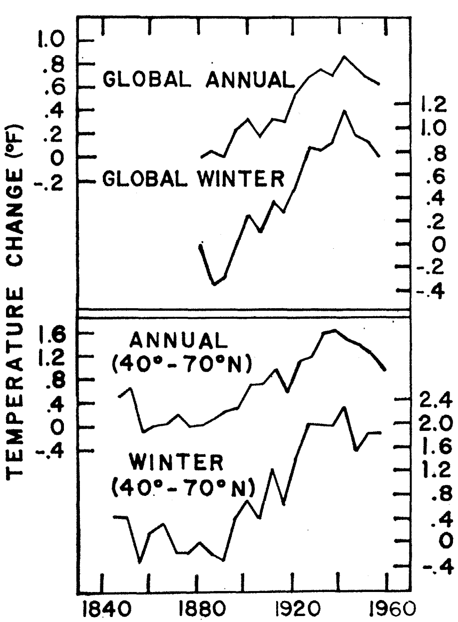

Fig. 1. Temperature trends for about the past century (after Mitchell, *2*). (Top) Global trends; (bottom) trends for latitude 40° to 70°N.

After the early 1940's a clear reversal in the trend of temperature occurred. The moderate cooling has so far removed about 30 percent of the temperature increase between 1880 and 1940.

A similar effect occurred in at least one other important climatologic parameter. In a study of the physical aspects of climate change, Kraus (*3*) demonstrated a decrease in precipitation during the first 40 years of the 20th century. This was reversed to a precipitation increase after 1940.

Figure 2 was constructed by combining the sea level data of Disney (*4*), up to 1953, with those of Harris (*5*), to 1960. In order more readily to note any sea level trends correlated with the rather striking climatic changes, we treated the data for sea level as two sets of results, one from the beginning of the data to 1939, and the other from 1940 to 1960, and fitted least-squares straight lines to each set, for each station. All stations except Portland show a rising trend to about 1940. Since 1940, all stations except Portland, Charleston, and Galveston show a definite decrease in the rate of rise of sea level, although some rise continues at all nine stations.

Portland, which is the only station distinctly north of the glacial hinge line (*6*), seems to be anomalous, in showing practically no change in sea level prior to 1940. Clearly the trends are not identical in the other eight cases, but this is expected in view of the natural and occasionally artificial factors known to affect local sea level. For example, the Charleston curve is not completely valid, because early in 1942 the South Carolina Public Service Authority added an additional flow of 10^9 gallons of water per day to Charleston harbor (*7*). This increase, with concurrent additional silting, probably accounts for the straight-line rise in sea level from 1941 to 1943. Continued annual fluctuations are thus about a new, higher mean.

Leaving aside Portland and Charleston (the latter affecting only the second decimal place, not given here), the average rise of sea level at the other seven stations prior to 1940 is 0.7 ft (21 cm) per 50 years. From 1940 to 1960 the average rise is at the rate of 0.4 ft (12 cm) per 50 years, representing a 40-percent decrease in the rising trend. The thermal expansion of the mixing layer of the ocean (taken as 400 m) can account for only about a centimeter of these observed changes. Disney (*4*) ascribed the increase in level to ice melting in the high latitudes. Although this seems reasonable in view of the more pronounced warming in high latitudes prior to 1940 (Fig. 1), the values of the trends given here are not typical of world sea level, so we cannot attribute all of these changes to the melting of ice. Continuing Disney's reasoning, the temperature decrease since 1940 would thus have slowed the rate of ice melting, and this seems a reasonable explanation of the concurrent decrease in the rate of rise of sea level.

The sea level observations from tide gauges can also be documented by interesting visual observation of coastal shore changes. For example, McDonald (*7*) has noted a 1300-ft (400-m) encroachment of tidal marshes into the dry land in the past 57 years in the Charleston area.

Disney's data also include stations on the western coast of the United States. He notes that the average rate of rise of sea level is about half that for the eastern coast, which empha-

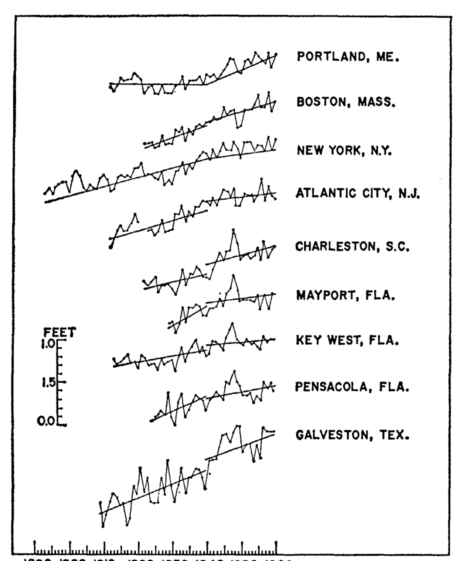

Fig. 2. Sea level trends for the eastern coast of the United States, based on the data of Disney (*4*) and Harris (*5*).

sizes that we cannot consider the absolute values of sea level trends of our eastern coast to be typical of global changes in sea level. Although we do not have immediately available an adequate continuity of data to compare trends to 1960 for the Pacific and Atlantic coasts, we can anticipate that equivalent trends exist, in view of the climatological causes.

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References and Notes

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2. M. Mitchell, *Ann. N.Y. Acad. Sci.*, **95** (1), 235 (1961).
3. E. Kraus, *ibid.*, p. 225.
4. L. P. Disney, *Proc. Am. Soc. Civil Engrs.* **81**, 666 (1955).
5. D. L. Harris, *U.S. Weather Bur. Tech. Paper No. 48* (1963).
6. The line northward of which the continent has been upwarped from glacial unloading.
7. J. E. McDonald (U.S. Soil Conservation Service), personal communication.
8. Supported by grants from the National Science Foundation (NSF-GP-550) and the U.S. Steel Foundation to the Lamont Geological Observatory. This is Lamont Geological Observatory (Columbia University) Contribution No. 663.

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Paleontologic Investigations at Big Bone Lick State Park, Kentucky: A Preliminary Report

Abstract. *The Big Bone Lick area in Kentucky, the first widely known collecting locality for vertebrate fossils in North America, is being investigated for further faunal and geologic evidence. Mammal bones, ranging in age from Wisconsin (Tazewell?) to Recent, were recovered in 1962 from four different faunal zones in two terrace fills.*

Big Bone Lick, a swampy area surrounding salt and sulfur springs, is located at the confluence of Big Bone Creek and Gum Branch in Boone County, Kentucky, about 20 miles (32 km) southwest of Cincinnati, Ohio, and 2 miles (3.2 km) east of the Ohio River. This famous locality, the first widely known collecting area for vertebrate fossils in America, is now in part Big Bone Lick State Park. The first white man to have visited Big Bone Lick appears to have been Major Charles LeMoyne de Longueuil, who was in command of French and Indian troops from Canada. In 1739, Longueuil found many big bones and teeth at the edge of a marshy area, and made a small collection of the fossils. These specimens were later sent to France for preservation and study. During the ensuing two centuries several large and many small collections of late Pleistocene to modern bones have been made here.

Osborn (*1*), Jillson (*2*), and Simpson (*3*) have recounted the history of early collecting at Big Bone Lick. Although thousands of bones were collected in the early days, few found before 1807 have survived. In that year President Thomas Jefferson sent a collecting expedition to Big Bone Lick at his own expense. William Clark, the leader, had had experience in fossil collecting on the Lewis and Clark Expedition to the West. In September and October 1807, Clark, with the aid of ten assistants, made a large collection which was shipped to President Jefferson. For several months after its arrival in Washington the collection was "spread in a large room" in the White House, where it was examined by Caspar Wistar, probably the foremost American anatomist of that time (*4*). The collection was divided into three parts: one for the American Philosophical Society in Philadelphia, one for the Museum d'Histoire Naturelle de France in Paris, and a smaller one for the President's personal collection.

The Clark-Jefferson bone collection, and a few exceptionally good specimens collected and preserved by others during the early years of the 19th century, have provided the basis for most studies of the Big Bone Lick fauna. Seventeen species of large mammals of Pleistocene and Recent age have been recovered there. Type specimens of three important species of Pleistocene mammals, *Bootherium bombifrons* (Harlan), *Bison antiquus* Leidy, and *Cervalces scotti* (Lydekker), were found at Big Bone Lick, and the type specimens of two other species, *Mylodon harlani* Owen and *Tapirus haysii* Leidy, may have come from there, although data on their original localities are conflicting.

It should be noted that the type specimen of *Bison latifrons* (Harlan) did not come from Big Bone Lick, as many writers have reported, but was found at a nearby locality "in the bed of a creek falling into the Ohio River, a dozen or more miles north of Big-bone-lick, Kentucky" (*5*). Apparently it was derived from Pleistocene deposits in the vicinity of Woolper Creek, Boone County, Kentucky. No identifiable remains of *B. latifrons* have been found at Big Bone Lick, and most specimens from there that have been attributed to this species appear to be *Bison antiquus*.

Since the time of Jefferson, the largest collection made at Big Bone Lick was that of N. S. Shaler in 1868 for the Museum of Comparative Zoology at Harvard College. Shaler tried to determine a stratigraphic succession at the site and at one place he thought he had unraveled it, but no description by him has been found. In any event, it appears that his excavations reached a depth of only 8 ft (2½ m). In studying the bison in Shaler's collection, Allen (*6*) found that most bones were of the modern species, *Bison bison*. Hay (*7*) aptly summarized the work that had been done at Big Bone Lick when he reported: "Notwithstanding the amount done at Big Bone Lick, the geology of the locality and especially of the bone-bearing levels is not well known. Most persons who have labored there were interested almost wholly in getting as many bones as possible and then in getting away."

Since 1934 we have spent several brief periods there assessing the site. The lack of stratigraphic control at such an important collecting locality prompted us to collect fossils and study the stratigraphy of the area. We spent 6 weeks at Big Bone Lick in July and August 1962 (*8*), and it is anticipated that field studies of the site will be completed by the fall of 1966. In addition to investigating the stratigraphy and paleoecology of the site, and collecting stratigraphically located topotypes of species described from there, we hope to determine the horizons from which specimens in the older collections were recovered.

The history of the Big Bone Lick deposits, before modification by human activities during the past two centuries, corresponds to that of the nearby Ohio River, to which Big Bone Creek is a tributary. Although glacial tills of Kansan and Illinoian age crop out near the