Reports

North American Pleistocene Stages Reconsidered in Light of Probable Pliocene-Pleistocene Continental Glaciation

Abstract. *Confusion due to the conceptual usage of classic North American Pleistocene stage terms indicates the need for a new or revised terminology. The Pliocene-Pleistocene boundary has tentatively been dated about 2.5 ± 0.1 × 10^6 years. Glacial deposits in the central United States older than about 2.2 × 10^6 years may span that boundary.*

A comparison of the usages of pre-Illinoian stage terms (Fig. 1) in the classic area of the Nebraskan-Aftonian-Kansan sequence in southwestern Iowa (*1*) with that in eastern Nebraska (*2*), the Gulf of Mexico (*3*), and the South Atlantic (*4*) shows that each of these stage terms, as well as Illinoian and Sangamonian, has been applied to sediments of various ages. The conceptual application of these terms undoubtedly accounts for the inconsistencies. At any given locality the oldest Pleistocene glacial cycle has been labeled "Nebraskan," the first interglacial cycle "Aftonian," the second glacial cycle "Kansan," and the succeeding interglacial "Yarmouthian." Figure 1 shows that this naming process has resulted in the following approximate overlapping time spans: "Nebraskan," 2.8 to 0.7 × 10^6 years (before the present); "Aftonian," 2.0 to 0.6 × 10^6 years; "Kansan," 1.7 to < 0.6 × 10^6 years; and "Yarmouthian," 1.3 to 0.5 × 10^6 years. Because this conceptual application of pre-Wisconsinan Pleistocene stage terms results in a serious communication problem among scholars, I advocate discontinuance of their conceptual use until they are redefined or until a new terminology is formulated.

Recent studies of till compositions, volcanic ash ages, and physical stratigraphy of Pleistocene deposits in eastern Nebraska, western Iowa, southwestern Kansas, and southeastern South Dakota (*5–9*) have provided a chronology for the Pleistocene stage terms for the two midcontinental sequences shown in Figs. 1 and 2. In conjunction with one of these projects (*5*), a test hole (Nebraska Geological Survey core hole 5-A-75) was drilled on the south slope of Twelvemile Creek, south of Afton, Iowa, in the classic area of the Nebraskan-Aftonian-Kansan sequence [Fig. 3, location 1 (*10*)]. This site is in one of the areas that Kay and Apfel (*1*) cited as typical examples of Nebraskan, Aftonian, and Kansan deposits. The sequence drilled was as follows: Kansan till (0.0 to 8.8 m), upper 4.3 m leached; Aftonian paleosol (8.8 to 11.9 m); Nebraskan till (11.9 to 46.9 m); nonglacial clay with paleosol development capped by a thin layer of silt containing volcanic ash (46.9 to 50.0 m); till (50.0 to 51.8 m), upper 0.3 m leached; and Pennsylvanian shale and limestone (51.8 m to the bottom of the test hole at 57.9 m) (see Fig. 2, column 2). The volcanic ash, the underlying silts and clays, and the underlying till are all pre-Nebraskan by definition because they directly underlie the classic Nebraskan-Aftonian-Kansan sequence.

A date of 2.2 × 10^6 years was obtained on glass shards from the ash-bearing silt by means of the fission-track method (Ft-glass) (*6, 7, 11–13*). Only enough ash was retrieved to make a single age determination. However, multiple-age determinations on other ashes of similar age (*6, 8, 11*) indicate that a precision of 5 to 10 percent (1 standard deviation) should be applied to that date.

Although the Aftonian paleosol penetrated by the test hole is slightly calcareous, Aftonian deposits separating the Nebraskan and Kansan tills in two nearby exposures [Fig. 3, locations 2 and 3 (*14*)] are deeply weathered clayey silts, contain scattered resistant silicate grains, and are leached of carbonate. This material is the Nebraskan gumbotil described by Kay and Apfel (*1*) and assigned an Aftonian age by Kay (*15*). Although the classic Nebraskan-Aftonian-Kansan sequence crops out at numerous localities in the Afton, Iowa, area, ex-

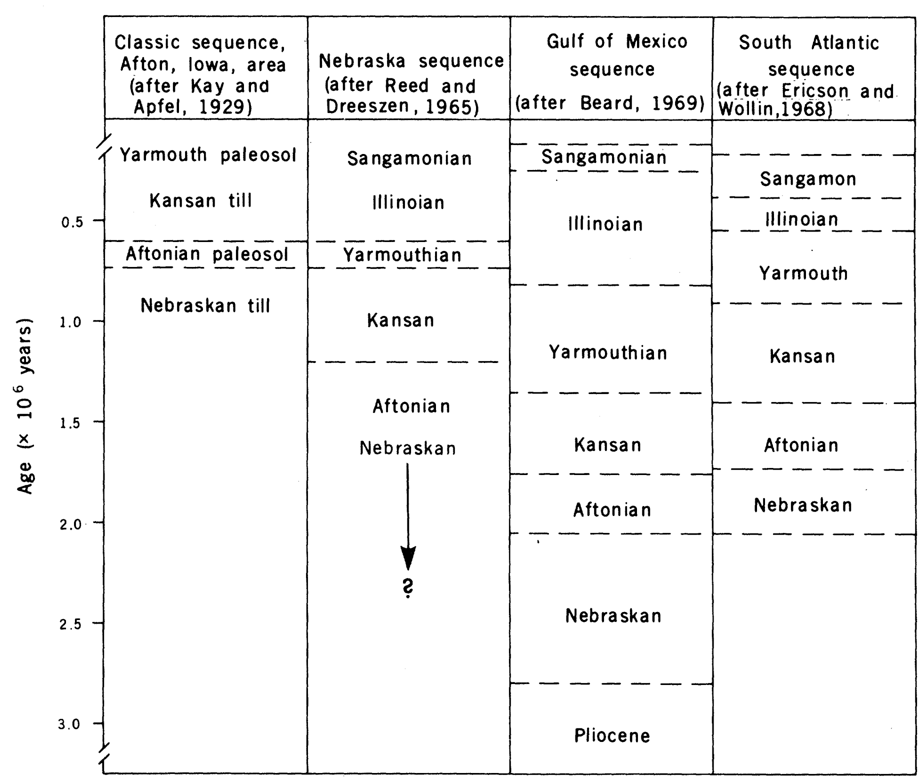

Fig. 1. Usages of pre-Wisconsinan stage terms. The chronology for the Iowa and Nebraska sequences are based on fission-track dating of volcanic glass shards. The chronology for the Gulf of Mexico and South Atlantic sequences are based on paleomagnetic dating.

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posures of the pre–2.2 × 10[6] year sequence penetrated in the test hole have not yet been found to crop out in this area.

The aforementioned studies of Pleistocene deposits in Nebraska and adjacent areas lead to the following conclusions. (i) There are three compositional types of tills, here merely labeled A, B, and C (Fig. 2, column 3). There are at least two type C tills, at least one type B till, and at least four type A tills. The oldest type A till exhibits reversed polarity. (ii) The classic Kansan till is the youngest of the type A tills and is younger than about 0.6 × 10[6] years. (iii) The classic Aftonian sequence contains two volcanic ashes—the Pearlette ash (restricted) and the Hartford ash, which have been repeatedly dated at about 0.6 × 10[6] and 0.7 × 10[6] years, respectively. Thus the duration of the Aftonian is at least on the order of 100,000 years. (iv) The classic Nebraskan till of Shimek (*16*) appears to be the oldest type A till and is somewhat older than the Hartford ash (≃ 0.7 × 10[6] years) and somewhat younger than the Coleridge ash (≃ 1.2 × 10[6] years). I estimate an age of about 1.0 × 10[6] years for the classic Nebraskan till. (v) The type C tills are older than about 2.2 × 10[6] years. The type C till near Afton, Iowa, predates the classic Nebraskan till by at least 1 × 10[6] years.

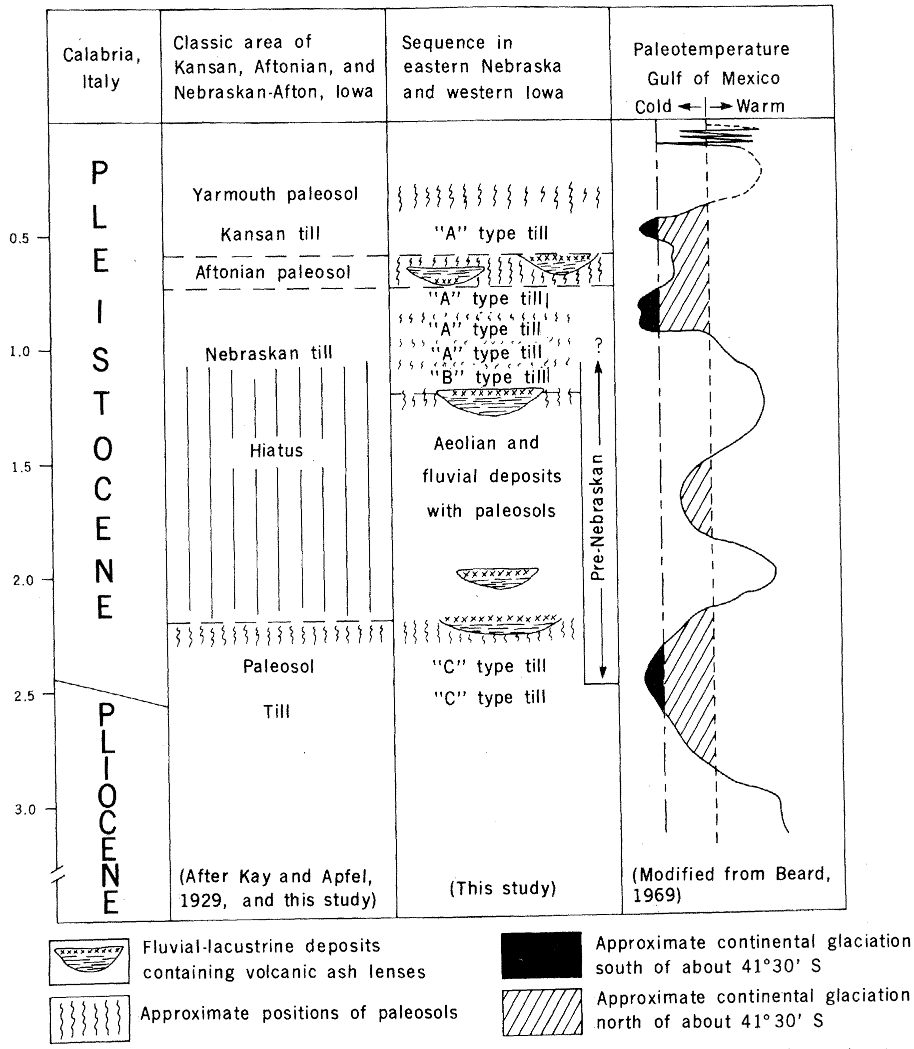

Fig. 2. Comparison of chronologies of some Pleistocene deposits from North America and Italy. The chronology of the Gulf of Mexico sequence is based on paleomagnetic dating. All other chronology is based on fission-track dating of volcanic ashes (glass). The line showing the approximate continental glaciation south of about 41°30′S is drawn at the maximum cold of the Wisconsinan, because the study area is just beyond the limit of Wisconsinan glaciation (Fig. 3).

The pre–2.2 × 10[6] year till near Afton, Iowa, probably correlates with the maximum of the first late Cenozoic cold cycle recorded in the Gulf of Mexico sequence (Fig. 2, columns 3 and 4) and, if so, is approximately 2.4 × 10[6] years old. The paleotemperature record of the Gulf of Mexico (*3*) suggests that the first late Cenozoic glacial cycle in North America commenced about 2.8 × 10[6] years ago, reached a maximum around 2.4 × 10[6] years ago, and ended about 2.2 × 10[6] years ago. Beard (*3*) labeled this cycle Nebraskan, again on a conceptual basis rather than on the basis of actual correlation with the classic Nebraskan. An age of about 2.4 × 10[6] years for the pre–2.2 × 10[6] year till seems reasonable, considering that some time must be allocated to glacial retreat, silt and clay deposition, and paleosol development between deposition of the till and the 2.2 × 10[6] year ash.

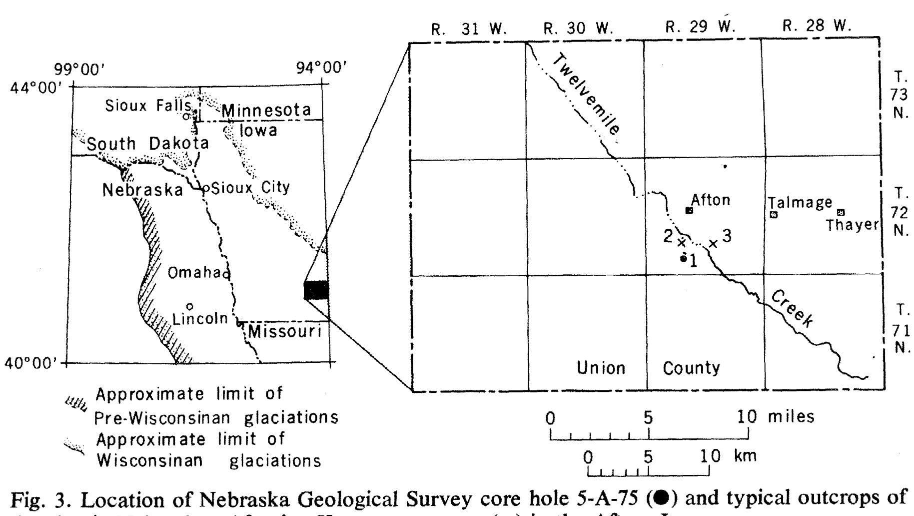

Fig. 3. Location of Nebraska Geological Survey core hole 5-A-75 (●) and typical outcrops of the classic Nebraskan-Aftonian-Kansan sequence (×) in the Afton, Iowa, area.

Glacial deposits dating between about 1.2 × 10[6] and 2.2 × 10[6] years have not been found in eastern Nebraska and western Iowa. Perhaps the cold period recorded in the Gulf of Mexico record between about 1.5 × 10[6] and 1.9 × 10[6] years ago was not of sufficient intensity to permit continental glaciers to reach eastern Nebraska and western Iowa.

In earlier papers based on indirect evidence, I proposed a date of about 2.0 × 10[6] years for the "climatically defined Pliocene-Pleistocene boundary" in the midcontinent (*6–8*, *11*, *17*). The date of 2.2 × 10[6] years (± ≃ 0.2 × 10[6] years estimated) for the ash overlying the paleosol and till sequence in the test hole near Afton, Iowa, provides the first direct evidence that the "climatically defined

Pliocene-Pleistocene boundary" in the midcontinental United States is at least on the order of 2.2×10^6 years old.

The final chronologic placement of the Pliocene-Pleistocene boundary in its stratotype area (in Calabria, Italy) will dictate whether the first late Cenozoic glaciation in North America is to be considered Pliocene, Pleistocene, or spanning the Pliocene-Pleistocene boundary.

The working group of the International Geological Correlation Program (IGCP) Project N 41, "The Boundary Between the Neogene and Quaternary," and the Subcommission on the Plio-Pleistocene Boundary of the International Union on the Study of the Quaternary (INQUA) are considering a section near Vrica, about 4 km south of Crotone, Italy, as a potential stratotype for the Pliocene-Pleistocene boundary (*18*). Furthermore, these groups stated (*19*): "This boundary can be defined by the appearance of cold-water North Atlantic immigrants in the Plio-Pleistocene sequence of Calabria."

A layer of volcanic ash occurs near the middle of a sequence 60 m thick between definite Pliocene and definite Pleistocene sediments in the Vrica section and about 30 m above the recommended Pliocene-Pleistocene boundary as defined by the first appearance of cold-water forms. The presence of this ash makes the Vrica section extremely attractive as a stratotype for the Pliocene-Pleistocene boundary because the age of the ash provides a tool for recognizing the boundary in both marine and continental sequences elsewhere.

The Vrica ash has yielded dates of $2.5 \pm 0.1 \times 10^6$ years [Ft-glass (*20*)], $2.1 \pm 0.3 \times 10^6$ years [Ft-glass (*18*)], and $2.2 \pm 0.2 \times 10^6$ years [K/Ar glass (*18*)]. The date of $2.5 \pm 0.1 \times 10^6$ years is the age ash used herein for the Vrica ash and for the Pliocene-Pleistocene boundary (Fig. 2, column 1) because the sample yielding this date, as well as ash samples from the midcontinental United States on which Figs. 1 and 2 are based, were dated along with the Borchers ash, which is used as an intralaboratory standard (*13*). Thus, the age relationships of the Vrica and midcontinental United States ashes, as well as interpretations based on these ages, are more likely to be sound than those based on radiometric dates which are not tied together by an intralaboratory standard.

If the date of $2.5 \pm 0.1 \times 10^6$ years is valid for the Pliocene-Pleistocene boundary, at least half of the time span of the North American Pleistocene is pre-Nebraskan in age and the oldest known late Cenzoic continental glaciation of North America probably spans the Pliocene-Pleistocene boundary. However, glacial deposits in eastern Nebraska and southwestern Iowa probably represent the maximum of this glaciation and may be Pleistocene.

As shown in Figs. 1 and 2, all of the currently used North American Pleistocene stage terms, except perhaps for the Wisconsinan, are in need of redefinition or revision. Such redefinition or revision is beyond the scope of this report. However, some alternatives are the following: (i) the establishment of chronozones based on radiometric dates, paleomagnetics, and paleontology for their recognition; (ii) the formulation of a revised stage terminology based on the chronology of major climatic changes and utilizing both the midcontinental United States and Gulf of Mexico records; and (iii) a system incorporating both chronozones and stages (*21*).

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14. The legal description of the exposure at location 2 (Fig. 3) is $SW^1/_4NW^1/_4$ section 28, T. 72 N., R. 29 W., Union County, Iowa. The legal description of the exposure at location 3 (Fig. 3) is Cen. $W^1/_2$ section 27, T. 72 N., R. 29 W., Union County, Iowa.
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Condensation of Nonequilibrium Phases of Refractory Silicates from the Vapor

Abstract. *Silicon monoxide solid was evaporated in a bell jar containing reducing, neutral, or oxidizing atmospheres at pressures of a few torr. The vapor invariably condensed as smoke-sized particles of silicon sesquioxide,* Si_2O_3. *The condensation of a solid whose composition differs from that of the parent gas and is apparently the least stable of the three solid species illustrates the importance of specific nucleation effects in the condensation process. This result has significant implications for theories of formation of grains in space.*

Fine grains occur in the interstellar medium, circumstellar dust shells, expanding nova shells, the primordial solar nebula, and comets (*1*). The grains have dimensions in the range from below 100 Å to a few micrometers. The origin of these particles has not yet been satisfactorily explained, although there appears to be a consensus that they condensed in a dense cloud (number of hydrogen atoms $> 10^5$ per cubic centimeter).

Some of the problems of particle formation arising from the characteristics of astronomical clouds as opposed to laboratory systems have been considered by Czyzak and Santiago (*2*) and Donn (*3*). Extensive laboratory experiments on the condensation of fine grains of many metals as well as some oxides, carbon, and silicon carbide have been carried out (*4*). Reference to recent Japanese work in this field may be found in Kamijo *et al.* (*5*). There are several significant differences between condensation processes in the laboratory and in space (*3*). The most important one for the present purpose is that particles observed in space are generally believed to be compounds of refractory oxides and silicates which do not exist in the gas phase.

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