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THE CAROLINA BAYS AND A PLEISTOCENE WEATHER MAP

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ABSTRACT. A winter mean pressure pattern for a glacial winter was constructed by assuming a mean 10,000 ft. pressure pattern like the modern one for the month of January, by drawing a temperature pattern parellel to the glacier margin, and by pressure-height extrapolation to sea level. The direction of the surface winds that result from the hypothetical surface pressure pattern coincide with the long axis of the Carolina Bays. The strong pressure gradient on the hypothetical map supports the idea that the orientation of the bays and the Pleistocene loess phenomena are a result of much higher mean winds in glacial times.

INTRODUCTION

THE elliptically shaped depressions that cover the Coastal Plain of eastern Georgia, South Carolina, and North Carolina have been the subject of much discussion and controversy during the last fifty years. These remarkable depressions are all oriented in roughly a northwesterly to southeasterly direction, and from aerial photographs a bay area resembles cookie dough after the cookies have been cut out. Most of these depressions, although once existing as lakes, are now filled with peat and support a thick swamp vegetation containing among other plants bay trees (*Persea*), from which these areas get their name. An aerial photograph of some bays is shown in plate 1.

The extensive discussions and observations regarding the origin of these structures are summarized by Johnson (1942) His book presents the theory that the depressions were formed by the combined action of ground water flow, artesian waters, solution, and the action of winds. Johnson also summarizes and discusses the rival theory of the origin due to a shower of meteorites as presented by Melton and Schriever (1933), Prouty (1935), and others. There is still no agreement as to the initial formation.

Including the theory of Grant (1945) that the bays were fish-spawning depressions, a review of the discussions indicates that regardless of the proposed cause of the original depression, the action of wind is considered by nearly all authors to be a factor in at least rounding the edges of these sand bordered "saucers" or determining orientation. Cooke's (1945 complex idea of the details of the vortex-producing action of the wind is probably incorrect in view of the observations in figure 3 and criticisms by Grant (1945).

The recent work on pollen stratigraphy and morphometry by Frey (1949, 1950, 1951) and Buell (1939, 1946) and the radioactive carbon dating by Arnold and Libby (1951) have indicated that the depressions are at least older than the last Pleistocene glaciation. The presence of endemic fish and mollusks also indicates their age (Hubbs and Raney, 1946). The stratum of blue-gray mud that is found in all the bays has been postulated to be loess (Deevey, personal communication, and Frey, 1951). The wind-oriented lakes in Alaska recently reported by Black and Barksdale (1949) have been compared to the bays. In the case of the Alaskan lakes the orientation is with the strongest winds which at times blow 100 miles per hour. South African pans have also been compared favorably (Shand, 1946).

If, as many authors think, the orientation as well as the rounded edges is due to prevailing wind direction, the bays represent a wind direction observation from the Pleistocene. With this observation it is possible to limit the possible patterns of wind flow and temperature distribution in the Pleistocene. The purpose of this communication is to construct a reasonable winter Pleistocene mean surface weather map for the eastern United States. If the wind flow across the Carolinas is compatible with the bay orientations the map may be considered to have some validity. Or if the temperature and upper air pressure assumptions seem reasonable for the Pleistocene, the role of the wind in determining the bays may be supported.

While the author was assisting David G. Frey on an investigation of some of these lakes in 1948, he had an opportunity to observe wave patterns under approximately 35 mph wind. The pattern of waves was as one should have expected for a shallow depression. The action of wind waves in lakes to reduce surface area has long been known (Johnson, 1919). The wave fronts, of course, turned parallel to shore as they approached, as in figure 3. The diverging wave fronts were undoubtedly associated with some underwater convergence and return flow due to some mass transport of the surface waters. The oval shape of the depressions is a sort of resultant wind rose summing the stresses.

The present strongest winds usually occur during strong

Plate 1. Composite aerial photograph of Bladen County, North Carolina, showing oriented Carolina bays. Photo courtesy of U. S. Dept. of Agriculture.

cold front passages from the northwest, but even under these conditions sustained winds rarely exceed 50 miles per hour. Although sufficient to keep the oval shapes somewhat oval in those bays still containing lakes, the winds do not seem capable of radically changing the initially different shape of a lake. However, it is very possible that during the Pleistocene, the winds were of a considerably greater order of magnitude. The phenomenon of Pleistocene loess has usually been attributed to bare exposures making possible more collection by the winds (Flint, 1947). However, the possibility of much stronger winds capable of bearing more matter is also very reasonable, as will be shown.

These ideas about the role of wind in the Pleistocene are qualitative and not at all new (Hobbs, 1926). Buell, for example, has compared Greenland winds to possible Pleistocene flow over the Bay Lakes (personal communication). However, by constructing a weather map, these old postulates are shown to be harmoniously related quantitatively by hydrostatic and geostrophic functions.

ASSUMPTIONS IN CONSTRUCTION OF THE PLEISTOCENE MAP

The basis for construction of the Pleistocene map is an assumed 10,000 ft. pressure field superimposed on an assumed mean temperature distribution for the layer of air between the surface and 10,000 ft. levels. The surface pressures are thus determined according to the familiar hydrostatic relationships. In practice the calculations were made with a Bellamy pressure height slide rule.

The temperature field was constructed by drawing two boundary mean isotherms and filling in the space between them with approximately equally spaced isotherms. The northern isotherm was drawn along the southern border of the Wisconsin Glaciation as taken from Flint (1947). Keeping in mind that air masses over snow and ice cover in source regions tend to have an isothermal or more stable lapse rate in the lower layers, the mean temperature was assumed to be similar to the surface temperature in the winter time around ice sheets in northern regions. Fortunately the thickness of ice can be neglected if an isothermal lapse rate exists. Thus a —20° C. isotherm seems reasonable. Greenland has a similar temperature distribution today. Over a snow cover the radiational heating from the ground is not great. Actually such temperatures occur at the same latitude today during cP outbreaks. Thus it is not unreasonable to expect —20° C. mean temperatures at lower latitudes in the layer over an ice sheet.

The southern boundary isotherm of +15° C. was determined by assuming that the land and sea surfaces in the areas south of Florida had similar temperatures then as now. It is probable that these areas which include Gulf Stream source were not much colder than at present since most of the modern theories of glaciation postulate only small if any change in equatorial temperatures. Thus, using the present sea surface temperatures and assuming a moist adiabatic lapse rate for

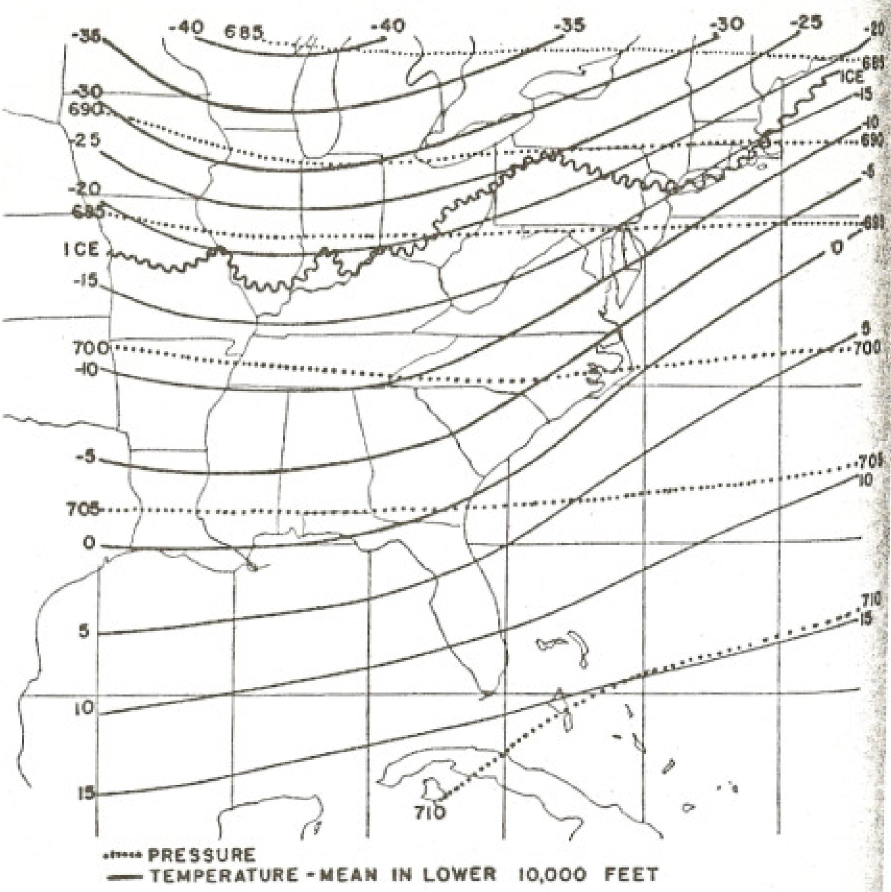

Fig. 1. Data used to construct Pleistocene surface pressure map. Pressures are the mean 10,000 ft. pressures for January from U. S. Weather Bureau Normal Monthly Pressure charts. Isotherms are drawn according to assumptions in the text.

maritime tropical air masses, a mean temperature isotherm of 15 degrees is drawn south of Florida. The isotherms drawn between the boundary isotherm were drawn so as to resemble present day patterns especially in paralleling the coast line and Gulf Stream position. Although approximate, these assumptions have the merit of objectivity and simplicity as a first approximation. The resulting temperature patterns are shown in figure 1. The surface temperatures would vary somewhat because of the steeper lapse rates expected in polar air moving southward over land which is warmer than the air in contrast to the more stable lapse rates over the ice and over the ocean.

The pressure pattern at 10,000 ft. was assumed to be the same as the present mean 10,000 ft. pattern of pressure for January. This is of course most certainly not exactly true since the whole world circulation is interconnected and changes as a whole when a part changes. However, it is to be expected that if the general features of the world circulation are unchanged, the presence of a dense cold layer of air due to cooling over a glacier will affect the weight of the air above 10,000 ft. far less than it does the surface pressure. To be sure, there will probably be some lowering of the tropopause and pressures aloft, but by and large the effect of the dense air in the lower layers will be to increase the surface pressures far more than to change the upper air. This is reasonable since this is the behavior of air masses over Greenland, over Canada and Siberia in winter. The presence of a cold dense air mass in a fairly low latitude so as to be under the weight of relatively high 10,000 ft. pressures associated with the horse latitudes will tend to create a much higher pressure over North America than exists today. The use of the 10,000 ft. pressures as they are today in winter is probably the best approximation that can be made at present without being arbitrary. The map that will be constructed thus becomes the map that will exist if a cold permanent air mass were inserted in North America under the present overall general circulation.

Although the map being constructed is a mean map fo a Pleistocene winter, the existence of the ice sheet will tenc to reduce the variability by eliminating many of the fronta systems. This is what has been observed to happen on a smal scale in Greenland. There is a correlation between the amoun of ice in the Greenland sea and the frontal systems that reach this far north (Schell, 1940). Similarly the pressure patterns in the winter over Siberia, Antarctica, and Greenland tend to be less variable. If this point is correct, the mean map for the Pleistocene should actually represent the flow on a good number of days.

THE MAP

Figure 2 is the result of the pressure height calculations based on the mean temperature and 10,000 ft. pressure fields in figure 1. Superficially it resembles eastern Asia in the wintertime. The pressures are quite high and the pressure gradients very strong. Again this pattern resembles that of Greenland and Antarctica where glaciers are in close juxtaposition to the sea. In general the eastern United States was probably

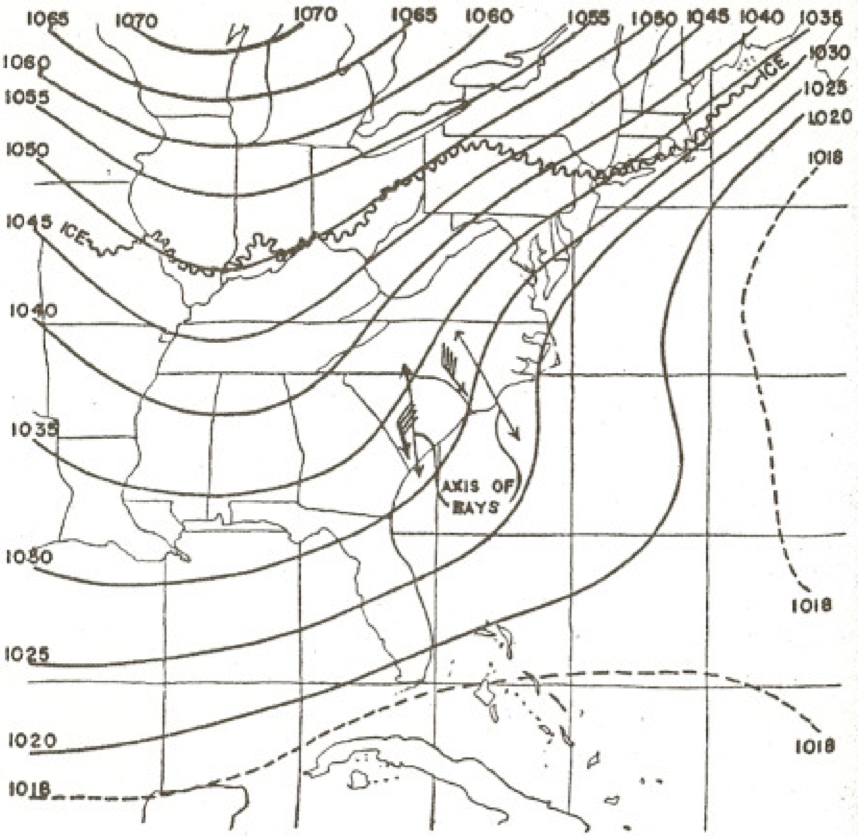

Fig. 2. Pleistocene mean sea level pressures in winter.

dominated by anticyclonic conditions and a frontogenetic trough off the coast.

These interpretations do not contradict most of the interpretations of Pleistocene climate as summarized in Brooks (1949), but they provide an objective synoptic picture to supplement the climatic indications which are more a function of precipitation and temperature means.

If the Pleistocene map is somewhat near the correct answer, many deductions can be made about Pleistocene climate. Steep lapse rates, turbulent lower layers, low relative humidities and unstable type clouds in the lower layer must have been characteristic of much of the continent. Precipitation was possibly less, mostly of frontal type due to overrunning from cyclones off the coast, except south of the polar trough over Puerto Rico. With high winds, the possibility of spruce pollen being blown great distances suggests caution in the interpretation of conifer distribution from pollen analyses.

In figure 2 the winds that result from the calculated pressure pattern are drawn across the isobars at an angle of about 40 degrees. Although winds above 2000 ft. blow along the isobars, the friction at the surface causes the winds to blow across the isobars toward low pressure at an angle (Byers, 1944). Thus the surface wind direction seems to correspond roughly with the axes of the Carolina Bays. The frictional action also decreases the surface wind velocity below that which would result in free air from the map's strong pressure gradient and anticyclonic curvature.

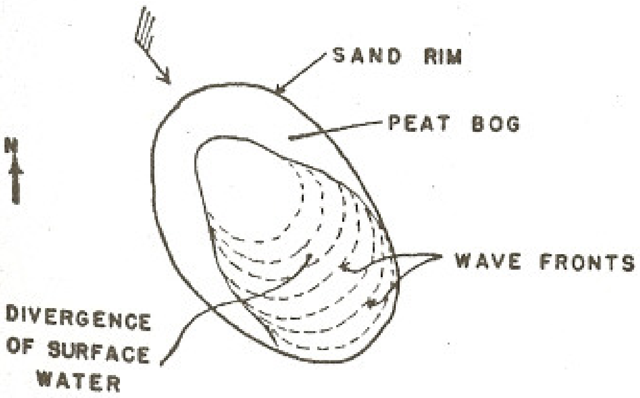

Fig. 3. Waves on Singletary Lake, North Carolina.

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