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G. A. Rosenfeld
Iowa State College

K. M. Hussey
Iowa State College

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By G. A. Rosenfeld and K. M. Hussey*

Introduction

The problem of oriented lakes has been a subject of controversy in North America as well as other parts of the world. Much has been written on why lakes are oriented, but for the most part no suitable theories have been proposed that satisfactorily explain some of the observed facts associated with orientation. The two most famous examples in North America are the Carolina Bays, located on the Atlantic Coastal plain in the Carolina region, and the Oriented Lakes of Northern Alaska. For both of these areas, several widely differing theories on cause of orientation have been proposed. Some workers have attempted to compare the two areas and have proposed the same origin for both. The writers have worked primarily with the Alaskan lakes and necessarily are more familiar with that area. However, the discussion to follow may be applicable to the Carolina Bays or other areas of oriented lakes. This paper will not offer a final solution to the problem. Its purpose is to point out some discrepancies in proposed causes of orientation, and to present some different hypotheses in light of new information.

Description

Black and Barksdale (1949) adequately describe the oriented lakes of Alaska and the associated terrain. Briefly, these lakes occur in an area of some 25,000 square miles adjacent to the Arctic Ocean. They tend to be elliptical in shape, and are oriented slightly to the west of north, the range for the whole area is 9 degrees to 21 degrees west of north. In any one area the orientation does not deviate more than 3 or 4 degrees. The average near Barrow is N 13 degrees west.

The lakes occur in a region of permanently frozen ground, and most owe their origin to local thawing and subsequent collapse of the ground. Others originate as uplifted lagoons. This is an area in which thermal contraction has produced a ground pattern known as "polygonal ground," a pattern similar to that produced by dessication of fine mud. The fractures become occupied and enlarged by ground ice-wedge growth. Large quantities of ice are found in the ground in the following forms: nearly vertical ice wedges; irregular ice

*Research Assistant and Professor of Geology, respectively, Iowa State College, Ames, Iowa.

masses; small grains; crystals; stringer; irregular particle; and films of ice as cement. The greatest amounts are found in the wedges.

The coastal plain is a relatively young area of low relief, being a recently elevated segment of the continental shelf. The oriented lakes occur in that portion of the area nearest the ocean. To the south, many of the lakes are not oriented. Many of those which are in this area, exhibit a broad shelf, or shallow underwater bench, surrounding a deeper central portion.

The oriented lakes range in size from some that are over nine miles long and three miles wide, down to those small ponds a few tens of feet in length. The average length to width ratio is $2\frac{1}{2}:1$ to $3\frac{1}{2}:1$. The lakes are remarkably shallow, some only 2 feet deep and rarely are they over 20 feet deep. The average depth is about 6 or 7 feet.

Origin By Wind

Only two hypotheses have been proposed for the cause of orientation of the Alaskan lakes, and both draw their source from the wind.

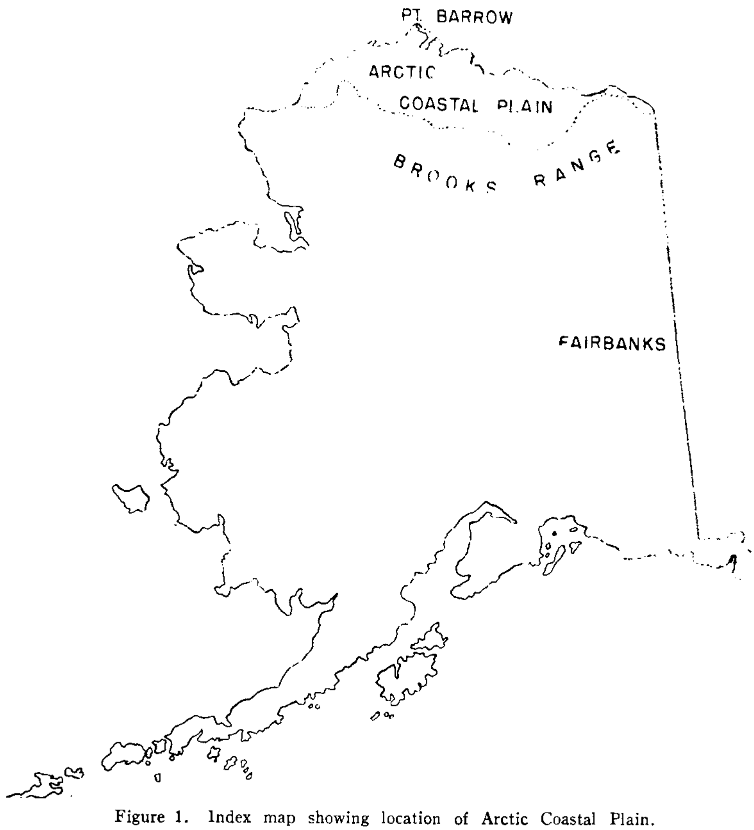

Figure 1. Index map showing location of Arctic Coastal Plain.

Cabot (1947) and Black and Barksdale (1949) postulate that a former prevailing wind in the direction of the long axis is the cause of orientation. Livingston (1954) and Rex (1958) postulate that prevailing winds in a direction normal to the long axis is sufficient cause for orientation. It is evident then that these two differing wind hypotheses can be resolved by answering the question, "are the lakes being oriented today?" The prevailing wind now is approximately at right-angles to the axis of orientation.

Field evidence and evidence from aerial photographs indicate that the lakes are still being oriented. Shorelines change very rapidly under the influence of summer storms. Livingston (1954) after observing shoreline retreat at East Oumalik Lake proposed a figure of one meter a year for shoreline advance of these lakes. At such a rate, it would not take the lakes more than a few centuries to completely change their direction in response to a change in prevailing wind. That the prevailing wind would change by almost 90 degrees

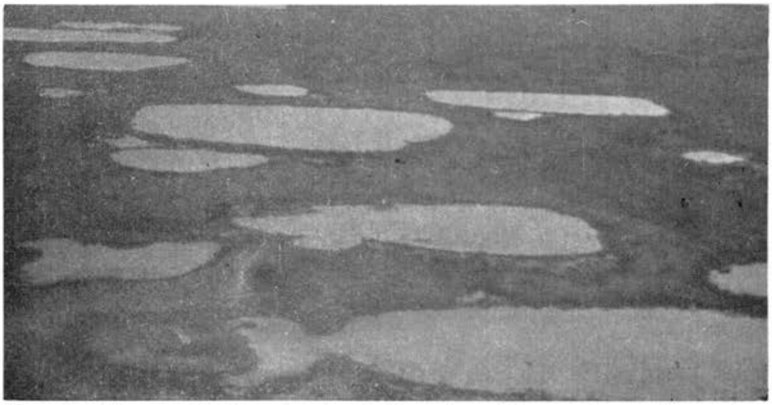

Figure 2. Oblique aerial view of oriented lakes. Large lakes in foreground are about three-fourths mile in length.

in such a short time is unlikely. In fact, there is no known evidence of a former NNW-SSE prevailing wind. Old, stabilized sand dunes in the direction of the prevailing wind of today indicate the ENE-WSW wind has been in effect for some time. The surface at Barrow is relatively young. Black estimates an age of only 4,000 - 5,000 years, based on observed ice wedge growth. There should be some evidence preserved of the NNW-SSE wind, if there was one.

An area of very small, evidently young, lakes occurs in the Kuparuk Sagavanirktok River area (Figure 3). All these are small compared with the other lakes, many are only 25 feet long by 5 feet wide and only about 2 feet deep, and are perfectly oriented. These young lakes evidently were oriented under prevailing wind conditions normal to their long axis. It is evident, then, that orientation is continuing.

Figure 3. Vertical aerial view of very small lakes located along the Kuparuk River. Top of photo is north. Largest oriented lakes are about one-fourth mile in length. Smaller lakes are a few tens of feet long.

Livingston (1954) postulates that prevailing winds normal to the long axis produce a horizontal circulation system (longshore currents) that scours out the ends of the lakes at a greater rate than the downwind shore is reduced. A circular lake will then gradually become elliptical with its long axis at right-angles to the prevailing wind. He supposes that the motion is all horizontal, and that a constant wind stress imposes a constant acceleration V on the water in the direction of the wind. If the radius of the lake is r and x is measured from the diameter normal to the wind direction, he tries to show that the acceleration producing a longshore gradient current at any point X, $(r^2 - x^2)^{1/2}$ on the lee shore is given by

$$\dot{V}' = g \left[\dot{V} \frac{(r^2 - x^2)}{x^3} \right]^{1/2} - \dot{V} \left(\frac{r^2 - x^2}{r^2} \right)^{1/2}$$

From this, it is evident that at the midpoint of the windward shore where $x = r$, $\dot{V}' = O$, and at the points where the X axis cuts the shore and $X = O$, $V = \infty$.

Rex (1958) says deposition occurs on the downwind shore because the current there is not strong enough to transport the sand, silt, and peat that is eroded by wave action. At the ends of the lake, the current reaches a maximum and, hence, no deposition in these areas. Thus, he explains the shelf-like nature of the lakes; i.e., broader shelf along the sides, and very narrow at the ends. These are, then, depositional features instead of erosional remnants, he postulates.

According to these two theories, the wind blowing normal to the long axis is the cause of orientation. There is some merit in these wind theories. For instance, it is common to find a smooth, even, wave action bench and shoreline on the west side of the lakes, while, on the eastern side, more irregular shorelines and benches are the case. This is what to expect, according to the theories, from a prevailing NNE wind: on the downwind shore, erosion and wave action, along with the longshore currents, produces the smooth shoreline; while, on the upwind sides, deposition in a series of eddies, produces the irregular effect. It is evident that the wind is altering the lakes, but whether or not it is the cause of orientation is another matter.

Livingston admits his theory is a first approximation only. He has not taken into account several important considerations. He assumes a circular beginning, and neglects such important factors as eddy viscosity, depth of water, variations of wind force, and fails to state whether the shore is perfectly elastic, perfectly resistant, or neither. The writers believe circulation in lakes cannot be resolved by a formula such as this. There are too many other complex drifts and currents at work. Livingston says that lakes are seldom longer than 1,500 yards, and he implies this is to be expected according to his circulation formula. Actually, there are hundreds of lakes, perfectly oriented, three, four, and five miles in length.

Rex's idea that underwater benches are depositional is not in agreement with observed field evidence. O'Sullivan (personal communication) reports that along the Meade River, in a recently drained lake where a trench was cut from the central basin, through the bench to the river, contorted peat layers occur that can be traced from the offshore tundra, and through the bench, which dip under the central basin. Overlying this is a thin 2″ layer of fine sand. The break between bench and central basin is very sharp. It seems improbable that these benches are depositional features, for if such were the case, a smooth profile from center to edge of lake would be expected; and certainly a peat layer traced from outside the lake into the center is not to be expected.

Rex takes a figure of 5,000 feet as an average width of a lake, and working from a lake of this size, he arrives at his conclusions.

The calculations of Livingston and Rex possibly are applicable to lakes of medium-size, though discrepancies do occur. Much more work has to be done, such as actual current measurements in these lakes, to substantiate the hypotheses. However, when considering oriented lakes of the size found in the Kuparuk-Sagavanirktok River area, some as small as 15 feet by 3 feet, it is difficult to visualize a current system operating here as proposed for larger lakes. Wind must have a negligible effect blowing across only three feet of water surface. Certainly these are not large enough bodies of water to produce the effect hypothesized for larger lakes.

Figure 4. Oblique aerial view of polygonal ground, showing coalescing ponds. Eventually these small ponds will form a larger lake.

Figure 5. Small polygons and lakes on old river bar showing ice wedge control by the river.

Other Theories

Meteoric air shock waves are postulated by Prouty (1952) as the orienting factor for the Carolina Bays. Geophysical and magnetometer surveys have not revealed any deposits of meteorites in the Arctic coastal plain, and the shape of the lakes and absence of rims do not conform to such a theory for orientation of the Alaskan Lakes (Black, 1954).

Johnson's (1942) hypothesis that the Carolina Bays were produced by artesian springs, operating in part by solution, is not applicable to the Alaskan Lakes because of the confining permafrost.

Russell (1936) explains the faint orientation of round lakes in the Gulf Coast Region as due to the pattern of natural levees, with the direction always the strike of the levees. Again, this cannot be applied to the Alaskan Lakes because lakes are not associated with rivers, being ubiquitous throughout the plain. Also, no levees have been reported for northern Alaskan rivers.

In the immediate Barrow area, ancient beach ridges are located at varying intervals from the coast—a feature associated with the emergence of the coastal plain. These ridges are underlain by coarse material, since they are beach deposits, mostly gravel and sands, compared with other adjacent areas. The cliffs southwest of Barrow are higher than those on the southeast, and there is a parallel effect of beach ridges (some trending north). These observations seem to point to the fact that the emerging land is tilting to the east. Thus, an uneven cover of sediments could be deposited: coarser where there are beach deposits, and finer for the adjacent non-beach deposits. This pattern of distribution of sediments, if it exists throughout the area, would produce a pattern in differential thermal conductivity, the gravels compared with the sands and silts. This could produce preferred orientation of ice wedges parallel to the ancient beach ridges. However, many more data are needed on thermal conductivity of coarse versus fine materials, and on the pattern of distribution of sediments, before this theory could be put into practice. It is possible that the lakes are influencd by these beach or bar deposits.

Structural Control

It is not at all unlikely that there is a structural control on these lakes. In any event, there is strong evidence that points to some sort of structural trend in the area. Examination of a controlled aerial photo mosaic of the area south of Barrow, and construction of a drainage map of the same area, revealed a definite pattern in the drainage. A lineation, which includes ice wedges, edges of lakes, edges of polygons, streams, and small lakes, can be traced continuously for many miles, in some instances for nearly 15 miles. These lineaments have the same NNW trend as the oriented lakes. One example of this occurs near Ikroavik Lake, just south of Barrow. Here, a stream near the ocean begins the lineation. It can be traced south along the west edge of Ikroavik, along the west edges of two more lakes, obscured by a larger lake, picked up again along the west edge of another lake, traced through a polygonal trend, through a stream, and finally off the photo. This particular lineation can thus be traced for many miles. This type of association can be seen throughout the whole area.

It was discovered from the drainage map that the majority of the streams, large and small, are oriented in the NNW direction. There is also a faint, but definite, trend of lineation in the ENE direction nearly at right-angles to the major trend. This ENE direction is very faint, expressed in larger streams, by right-angle turns of streams, in small drainages between lakes, and even by small lakes. The Ikpikpuk River, which exhibits several right-angle turns, expresses this pattern.

From all this, it is inferred that there is some sort of regional pattern exhibited, with a major direction NNW-SSE and a minor one in the ENE-WSW direction.

This relationship could be likened to a joint system with modifications produced by the permafrost. This is an area of Recent tectonic activity (Payne, et al, 1951). Before freezing, the young unconsolidated sediments at the surface would respond to the developing stresses as incompetent materials and would absorb the effects of diastrophism. It is possible that upon becoming frozen the permafrost layer would be fractured. These same sediments would respond competently to the diastrophic forces and a master fracture pattern could thus have been established in a NNW-SSE direction, with a minor set in a ENE-WSW direction. Ice wedges would reach their maximum development in these fractures. Thus, the major ice wedges would be trending in the NNW-SSE direction, with a minor development to the ENE-WSW.

We know the permafrost thaws; i.e., beneath lakes, etc. This surface thaw would, in most cases, have destroyed the surface expression of the original ice wedges. However, in subsurface the original ice wedges may still be present. The lakes and streams would then conform to this deeper control. It can be shown that developing ice wedges conform to lake shores and to bars controlled by streams. Thus, in most places, new sets of polygons have formed at the surface which are not related to those which formed with the original development of the permafrost. Today we have a random pattern of polygons and ice wedges controlled by modern surface features. There is, however, still an indication of this original orientation of the wedges, which could control the distribution and shape of the lakes.

Research should be done in the Carolina Bay region to see if there are any structural relationships that could produce the orientation of the bays. Fault and joint patterns control so many surface features that certainly the geologic structure should be one of the first factors to consider in seeking an answer to the problem of such features as the oriented lakes.

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DEPARTMENT OF GEOLOGY
IOWA STATE COLLEGE
AMES, IOWA