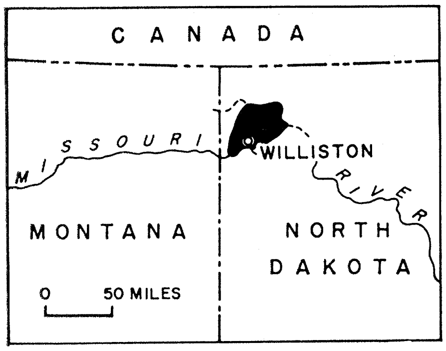

Fig. 2. Location of the pseudo superglacial till (shown in black) in northwestern North Dakota.

for the granitic rocks, and almost none for the metamorphic rocks. Whereas the upper till has only half the quantity of limestone and dolomite contained in the lower till, it has $4\frac{1}{2}$ times the quantity of metamorphic foliate rocks, and nearly $\frac{3}{5}$ again as much granite. The contrasts are not due to different degrees of weathering because both tills are unaltered except for oxidation. The contrasts are apparently not due to different rates of attrition of various types of rock under different conditions of transport, because the abundance of pebbles is not related to expectable durability as inferred from the presence or absence of foliation, lineation, and fractures, and by the resistance to breaking under impact. For example, if breakup is assumed to be rapid during reworking of superglacial moraine prior to deposition, the decrease in the percentage of limestone-dolomite might be attributed to more rapid fragmentation of the granite and metamorphic pebbles. If, however, we turn to outwash as the closest analogy to such reworking, we find almost no difference in the relative proportions of the pebbles in outwash and its related till. If, on the other hand, it is assumed that breakup is more rapid in the subglacial transport that provides the clayey till, we are faced with the dilemma of explaining the relatively small content of the easily breakable metamorphic rocks. These same considerations make it seem unlikely that the silty till is the periglacially reworked upper part of the clayey till.

The upper till is largely restricted to a single drainage basin forming a broad south-trending lowland; the clayey till, however, is of regional distribution. The next drainage basin to the west, in Montana, is almost identical in configuration yet the silty till is absent. If the silty till is a superglacial facies of the clayey till, its restriction to a single lobate area presents a difficulty for which there is no ready explanation.

A later clayey till shows no stratification of superglacial and lodgement till even in topographic environments comparable to that in which the silty till occurs. This is true even in the northern part of the lowland in which the silty till is found.

A probable intervening soil was found in exposures in which the silty till overlies the clayey till. All seven members of a visiting party of soil scientists (*4*) were of the opinion that a soil was present, although they varied in their degree of conviction. The soil, where best exposed, seems to have an A-horizon about 1 foot (0.33 m) thick, and a gypsiferous B-horizon 2 to 3 feet (0.66 to 1 m) thick. For the most part, however, the A-horizon is missing.

At one locality, the silty till rests on a level surface truncating the clayey till which is contorted and displays clear evidence of slumping. The contact between the two tills appears to be a simple erosional unconformity, following slumping and crumpling of the lower till. A possible alternative explanation is that the deformation resulted from shoves beneath the ice and that the moving ice beveled the deformed till before deposition of an ablation moraine. The fractures, however, are relatively steep and comparable to those found in modern slumps. Furthermore, a short distance away the beveled surface is underlain by the probable intervening soil mentioned above.

In some areas the upper till is a typical boulder-clay. This argument against a superglacial origin is not stressed, however, because it has not yet been demonstrated that ablation moraine may not, under favored circumstances, accumulate with preservation of most of the fine fraction. It is worthy of mention, however, that there are no significant differences in the pebble analyses of the clay-poor and clay-rich facies of the silty till.

ARTHUR D. HOWARD
Department of Geology, Stanford University, Stanford, California

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4. The visiting soil scientists included James Thorp, then regional director of the Division of Soil Survey, Department of Agriculture, and the following Canadian specialists: F. Bentley, W. E. Bowser, J. Clayton, W. Jensen, H. C. Moss, and W. Odynsky.

26 April 1965

Glass-Coated Tungsten Microelectrodes

Abstract. *Unusually rugged microelectrodes for recording the activity of single nerve cells or fibers can be constructed from tapered tungsten wire on which a glass capillary is collapsed and surface bonded. Tip diameter in the range between 1 and 5 microns provides relatively low impedance detection of extracellular potentials.*

In an earlier paper (*1*) it was shown that extracellular spike potentials from nerve cells could best be observed by means of a metal-tipped microelectrode rather than a fluid-filled pipette since the admittance of the metal electrode increases with frequency. Various metal microelectrodes have been described (*2–4*), each with particular attributes such as ease of manufacture, reliability of insulating coat, and sturdiness. The best type of metal electrode for use by neurophysiologists would combine high insulation resistance, stiffness, and good adhesion of the electroplated metal at the fine tip. Such an electrode would allow observation of spike activity near a single nerve fiber with the highest ratio of signal to thermal noise for long periods of time.

The kind of metal which is coated with insulating material makes no difference, since the actual electrical contact is made through the material plated on the tip. Tungsten, as suggested by Hubel (*4*), seems to be at least as stiff as the platinum-iridium alloy or stainless steel used by other investigators. Glass is superior to Hubel's varnish, however, for several reasons: first, it can be examined under the microscope for continuity; and second, when fire-polished, it provides a smooth, hard surface for easy penetration of biological material.

Wolbarsht *et al.* (*5*) thought that Wilska's method (*2*) of collapsing a capillary of glass around the metal electrode was too delicate a technique, and they developed a procedure for pushing a pre-sharpened electrode through a meniscus of molten glass. We have found that under proper conditions the collapsing of a glass capillary tube into metal is relatively easy and the bond provided by glass in intimate contact with tungsten provides a greater rigidity than metal alone. Furthermore, tungsten can be sharpened quickly in the flame of a Bunsen burner, because it sublimates at the temperature of an ordinary gas flame. A tip of the order of 1 μ is formed according to laws similar to those that would apply to electrolytic etching. The taper, as well as surface regularity, of a flame-sharpened tungsten wire depends critically upon the temperature distribution along the length of the wire heated in the flame. Obviously, a greater temperature gradient produces more rapid tapering. Straight pieces of tungsten wire 3 inches (7.6 cm) in length and 0.005 inches (0.0127 cm) in diameter are convenient to use and can be obtained from various manufacturers (*6*).

A piece of this wire is held in the outer zone of a flame from a Bunsen burner, adjusted for maximum air intake, until the wire is seen to thin down in the heated region. Heating is continued for several minutes until a terminal piece of wire breaks off. The point may be inspected under a microscope and, if necessary, flame-etched repeatedly to produce the desired tip size and taper. It must not be permitted to let stand long enough to gather dust. The tapered tungsten wire is carefully dropped, butt end first, into a 10-cm length of Pyrex or Kimax glass tubing, 1 mm inner diameter and 2 mm outer diameter. The glass tube with the tungsten wire inside is then held horizontally in two pin-vise chucks that have been previously adjusted to be in axial alignment. One of the chucks is mounted on a track so that it may be moved some 5 to 10 cm along its axis in a pure translational movement. A heating coil of eight closely spaced turns of 0.020 inches (0.051 cm) nichrome wire lies between the pin-vise chucks, and is mounted coaxially with them. The outer diameter of this heating coil is about 1 cm. It is made by winding the wire around a 6/32 screw. Such a coil can be heated by the current provided from a 6-volt, 5-amp transformer connected to a variable transformer and a 115-volt a-c circuit. The variable transformer should be adjusted so that the glass tube is softened in less than a minute by the heat produced with the nichrome coil. As soon as the glass has softened, the end of the glass tube with the blunt end of the tungsten wire is pulled slowly and deliberately about 1 cm with the movable pin vise. Now the current in the heating coil is shut off and the glass is allowed to cool until it becomes rigid. If this operation is performed correctly, the glass will be collapsed around the tungsten wire about 3 cm from the tapered end of the wire. The glass is now replaced in the pin vise so that the constriction is centered in the heating coil. Heat is again applied and, when the glass is so soft that no pulling resistance is felt, the end of the glass tube containing the blunt end of the tungsten wire is pulled slowly and smoothly until the tip comes free from the molten glass. In this manner a smooth coat of glass is laid down on the tapered portion of the tungsten wire. When the tip is examined under the microscope, it should be noted that the glass is in intimate contact with the tungsten wire down to its very tip. Usually a small whisker of glass extends beyond the metal tip, and this is carefully broken off under the microscope so that the terminal portion of the glass insulation lies flush with or slightly behind the termination of the tungsten wire. The tip of the electrode is then exposed briefly in the periphery of the reducing flame of a Bunsen burner. (Such a flame should show no more than a reddish-orange color.) This firepolishing performs two functions. It retracts the glass to form a slight bulge at the very tip, as shown in Fig. 1, and it smooths the glass-metal union so as to prevent surface defects. The electrode can be stored in this form and plated before it is used. Contact with the blunt end of the wire is made by selecting a straight piece of copper wire of the proper diameter to wedge against the tungsten inside the glass tube. The pressure contact is of low resistance. If a potential is caused by contact of the wires it is steadily shorted out. If the resistance fluctuates slightly at the metal-metal contact, it is of little significance since the impedance of the electrode fluid contact is many times greater. While it is true that glass and tungsten generally have different coefficients of expansion, these electrodes do not break when cooled. Any metal wire less than 5 mils in diameter can be coated reliably. When a fracture does occur from bending the coated wire, the glass shatters only over a relatively small region. At these dimensions the surface energy of cohesion seems greater than the bulk stress.

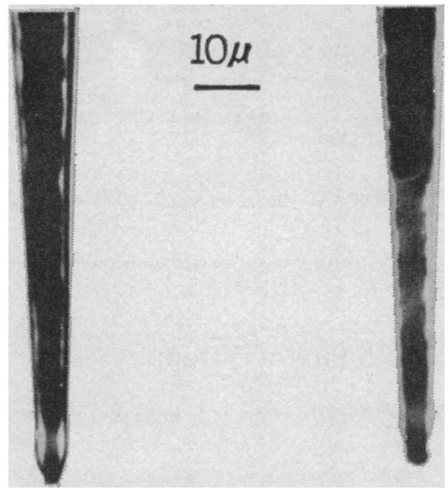

Fig. 1. A glass-coated tungsten electrode before and after plating of a precious-metal tip. (Left) Electrode showing thickening of the glass coat as a result of firepolishing. (Right) The same electrode, with slight photographic differences due to high magnification used, after a gold and platinum black tip is electroplated on the end of the tapered tungsten wire.

When the electrode is ready to be used, the tip is plated with gold. We have found a commercial preparation (*7*) of gold solution to be suitable, and have used a tip plating of balls 1 to 5 μ in diameter; they are strongly bonded to the tungsten. A second plating of platinum black from a chloroplatinic acid solution (*1*) is then put on just before use. The plating operation should be observed under a microscope.

We have used microelectrodes such as those described here to obtain 40- to 50-μv spikes in a noise background of 10 to 20 μv from the olfactory mucosa of the frog, where nerve processes are particularly fine, and from unmyelinated fibers of the optic nerve.

H. A. BALDWIN*
S. FRENK
J. Y. LETTVIN
Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge

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6. For example, Sylvania Electric Products, Woburn, Mass.
7. For example, Sifco Metachemical gold plating solution, Cleveland, Ohio.
8. This work was supported in part by the U.S. Army, Navy, and Air Force under contract DA 36-039-AMC-03200(E), and in part by the Bell Telephone Laboratories, Inc., the NSF (grant GP-2495), NIH (grant MH-04737-04), NASA (grant NsG-496), U.S. Air Force [ASD contract AF 33(615)-1747], and ONR [contract Nonr-4315(00)]. One of us (S.F.) is an Inter-American Guggenheim Fellow.
* Present address: Sensory Systems Laboratory, 2700 West Broadway, Tucson, Arizona.

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Holocene Submergence of the Eastern Shore of Virginia

Abstract. *Radiocarbon ages of basal peats 4500 years old or younger and the thickness of salt-marsh peat in the lagoon east of Wachapreague, Virginia, are nearly the same as those of equivalent samples from New Jersey and Cape Cod. This suggests that these coasts have had similar submergence histories. Data obtained from the coasts of Connecticut and northeastern Massachusetts indicate that the Atlantic coast of the United States has been differentially warped during the later Holocene.*

The tidal-marsh and lagoonal sediments in the area between Wachapreague and Wachapreague Inlet on the Atlantic coast of Virginia's Eastern Shore (Fig. 1) are in an area that is physiographically similar to most of the coast between Long Island and Cape Charles. The area is characterized by a series of barrier beaches that are separated from the upland by lagoons, bays, tidal marshes, mudflats, and anastomosing tidal channels. Subsurface samples of Holocene tidal-marsh, lagoonal, and swamp deposits were taken with a 1-m stroke piston sampler with an inside diameter of 4.75 cm. The Holocene sediments overlie an older surface ("basement") of compact silty sand, presumably of Pleistocene age (*1*); the sand is covered by a thin diachronous layer of freshwater-swamp and brackish-marsh peat evidently accumulated at the transgressing high-tide shoreline (*2*).

The maximum thickness of Holocene sediments in the area is 11 m (36 ft), measured from the surface of the high-salt marsh at about mean high water to the basement. Most of the Holocene sediment wedge consists of organic clayey silt containing a characteristic lagoonal microfauna; the silt is sandier adjacent to Wachapreague Inlet. The surface layer consists chiefly of organic silt containing rhizomes of salt-marsh grasses, particularly *Spartina* sp. Only locally, in protected areas adjacent to the upland, does the thickness of salt-marsh sediment exceed 1.8 m. The spring tidal range at Wachapreague is 1.45 m, suggesting that only recently has the salt marsh developed extensively.

All borings were initiated on the surface of the high (*S. patens*) salt marsh which was assumed to be at mean high water, the datum used for this investigation; work of other investigators in similar marshes indicate that this surface is within 30 cm of mean high water (*3*). Samples for radiocarbon dating were taken from the peat immediately above the basement surface. If the basal peat represents the level of the initial marine transgression (at a unique time and elevation below the surface of the high-tide marsh), and if consolidation and compaction of the basement have been negligible since the transgression, the ages and depths of these samples can be used to establish relative sea levels at different times and places. The ages of four samples, from four borings, were determined by radiocarbon analyses.

Samples ML-191 and ML-192 (*4*), from borings WC-1 and WC-2 at Bradford Bay (37°35′52″N, 75°41′13″W) and Wachapreague Channel (37°35′54″ N, 75°40′50″W), respectively, showed

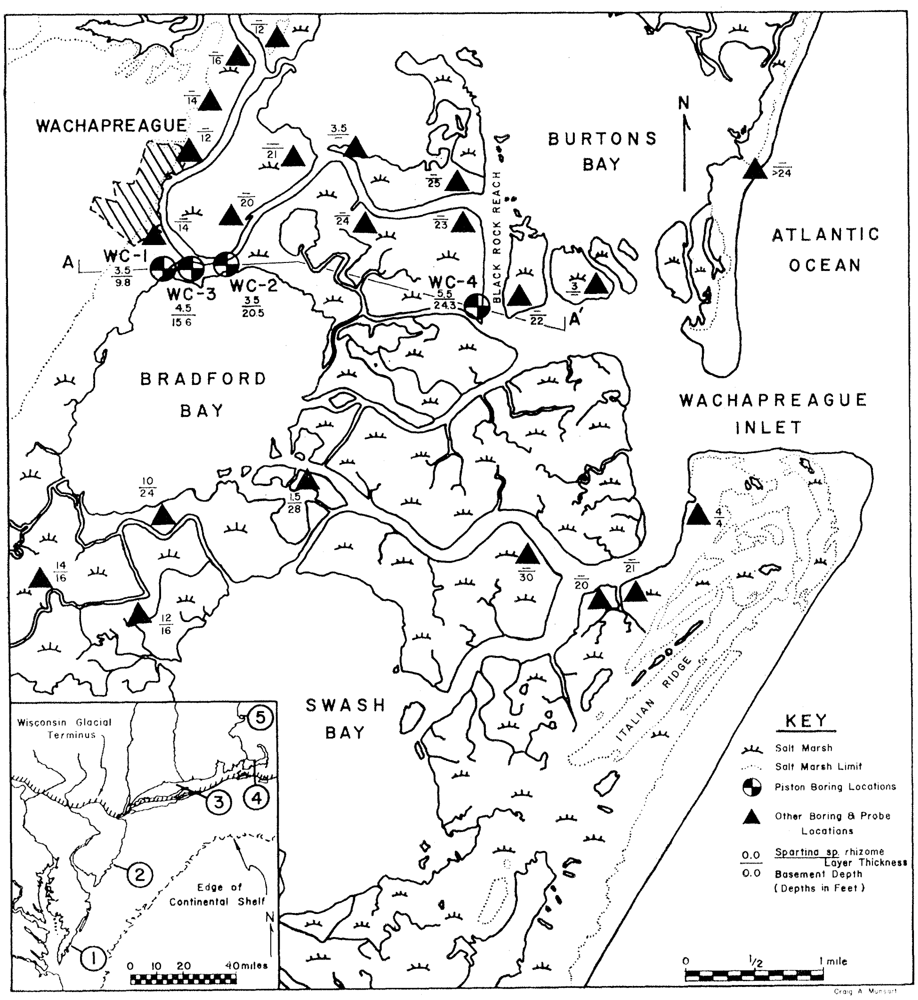

Fig. 1. Wachapreague and vicinity, Eastern Shore of Virginia. Lagoon and tidal marshes, showing bore locations and geographic distribution of environments. Insert locates: *1*, Wachapreague; *2*, Brigantine, New Jersey (*7*); *3*, Clinton, Connecticut (*2, 8*); *4*, Barnstable, Cape Cod (*9*); and *5*, Plum Point, Massachusetts (*10*).