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Map of Landslides in Coastal Plain Deposits of the Franconia Area, Fairfax County, Virginia

by

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INTRODUCTION

The map delineates the areal extent of landslides and creep deposits recognized in the unconsolidated Coastal Plain sediments of the Franconia area. Three categories of landslides were mapped, in decreasing order of certainty: Definite, Probable and Possible. Determination of the presence of a landslide is based primarily on topographic or geologic evidence; some reliance was placed on evidence of creep, but only in conjunction with topographic evidence. Geologic evidence was based on mapping recently completed by Force (1975). Coastal Plain sediments in the area identified by Force are Potomac Group deposits, Cenozoic Upland Gravels, Quaternary terraces and Alluvium, and artifically changed ground. A complete discussion of the nature and origin of these geologic materials is presented in the text to the Preliminary Geologic Map of the Coastal Plain in Fairfax County, Virginia (Force, 1975).

Planners and engineers interested in development and construction in the area can obtain useful information from the landslides map.

LANDSLIDE MAPPING PROGRAM

The landslides were mapped primarily on topographic evidence determined in the field. Airphotos (scale 1:12, 000) were used to identify potential landslide areas, but were useful only for locating large slides, having areal dimensions on the order of hundreds of feet. Topographic maps (scale 1:24, 000), 10-foot contour interval) were of limited use in locating some anamolous areas, but larger scale county topographic maps (1:6000, 5-foot contour interval) were of much greater value. The airphotos and the 1:24, 000 scale topographic maps were generally inadequate because of the limited areal extent of many slides, and the subtlety of the topographic evidence. Deeply eroded ravines occasionally presented an opportunity to view landslide features from a three-dimensional aspect, but such opportunities were rare.

Geologic evidence based on previous geologic mapping (Force, 1975) was also used to identify landslides. Both previously mapped geology and additional field observations of geology were used to identify the planar glide block type of landsliding, shown on the Explanation to the attached map.

An empirically-derived concept utilized in detecting landslides was that all long, undisturbed hill slopes in this area deriving their morphology from erosion have rather uniform slopes, from top to bottom. Any major irregularity is usually associated with one of three sources: stream erosion, the activity of man, or landsliding. Minor irregularities are associated with the presence of colluvial deposits and differences in composition of the underlying sediments.

The role of stream erosion on the land morphology was determined to some extent by observing the elevations of possible terraces. A possible terrace could frequently be distinguished from a landslide by comparing elevations of flat areas at nearby locations. Adjacent extensions of a given terrace are located at approximately the same elevation, whereas landslide deposits were at erratic and unpredictable elevations.

The activity of man by homesite development or by excavation of construction materials has drastically altered the landscape in much of the area mapped. The most widespread alteration has resulted from the removal of the Upland Gravels from the tops of the hills. In many areas the upper 10 to 30 feet of gravel cap has been removed. During excavation, some of the gravel was pushed over the top and down the hill. These operations frequently obscured natural landslides, and it was often difficult to distinguish hummocks of natural landslides from material dumped on the hillside. One criterion used to distinguish between true landslide hummocks and dumped material was the age of trees growing on the hillock. Hummocks from sliding could have old trees (older than approximately 40-50 years) growing on them, but recently dumped material could not. If only young trees were found on the hillocks, and the relief of the hillocks was only a few feet, the hillocks were considered as probably dumped material. It should be noted, however, that slides occurring on altered hillsides, including those in artifical fill and road-cuts, were included on the map.

In residential developments it was often difficult or impossible to determine the presence of previous landslides as landscaping has commonly obscured the original topography. Old trees predating the development were examined for evidence of creep, but this was not considered sufficient evidence to map a landslide.

Only slides longer than 100 feet were mapped, the length being the distance from the crown to the toe of the slide. It was considered unrealistic to map smaller slides at the 1:24,000 scale; this minimum length of mapped slides also has slope stability mechanics implications, as discussed later.

LANDSLIDE MAP UNIT CATEGORIES

Three categories of landslides were mapped, as well as areas that have experienced creep. In decreasing order of certainty the mapped categories of landslides are as follows: Definite, Probable and Possible Landslides.

Definite Landslides delineate areas where sliding has definitely taken place, based on topographic or geologic evidence verified in the field. Definite Landslides are more distinct than Probable or Possible Landslides but may not always be readily apparent to an untrained person. Typical field evidence for a Definite Landslide of the rotational type is a bulge (toe of slump) beneath a scarp (crown of slump), as shown on the Explanation; principal geologic evidence for a planar glide block is the displaced topographic position of Upland Gravel hillocks. Some hillocks appear to have moved downhill as glide blocks, maintaining their integrity as they moved. Evidence of creep, without the topographic or geologic evidence cited above, was not considered adequate to establish a Definite Landslide.

Areas mapped as Probable Landslides were mapped where topographic or geologic evidence was incomplete, but where features show sliding has probably taken place. The scarp at the crown may have been disturbed by gravel excavation or erosion, or the origin of a feature may have been in doubt. Topographic evidence for mapping an area as a Probable Landslide is the presence of a broad, slightly convex lower slope, combined with evidence that the adjacent upper steep slope had experienced creep, as evidenced by tilted or bent old trees. Additional evidence that in some cases indicated a toe of a slump at the base of a broad convex hummocky lower slope include a well-defined, short steep convex slope, possibly having tilted and bent large trees and gullying transverse to the slope. The gullying was an indication of a fairly rapid and recent change in topography or drainage patterns. Large trees growing in the gullies suggested that the gullying predates any activity of man which could have significantly altered the runoff characteristics of the uplands; thus these gullies probably resulted from erosion of the toes of slumps. Field examination by augering established that none of the areas interpreted as toes of slumps was composed of colluvium or alluvium. Evidence of creep aided in identification of a Probable Landslide, but only with other topographic evidence.

An area mapped as Possible Landslide had only one or a few characteristics of a well developed slide. Only a scarp or convex slope may be present, in addition to bent or tilted trees. Hummocky ground at the base of a slope was also used as evidence, if it seemed likely that the hummocks were not man-made. Evidence of creep was often used to support an interpretation as a Possible Landslide, but only with topographic evidence. Creep was mapped on the basis of tilting or bending of trees.

In many areas where creep or landslides were mapped, only the large trees were tilted or bent, with young trees growing vertically. Rapid creep may not be occurring at the present time in many of these areas, but has occurred within the past 50 or 100 years.

ORIGIN AND TYPES OF LANDSLIDES

Most of the unstable slopes are on the Potomac Group sediments, or at least originated through failure of these sediments. The predominant materials in the Potomac Group are clayey sand and sandy clay, with approximately equal percentages of both cropping out in the Franconia area. Montmorillonite is frequently the major constituent of strong, hard, unweathered clay; however, upon exposure and weathering near the surface, the montmorillonite will soften and with time may be altered to kaolinite. Soft clay is commonly encountered on natural slopes and immediately beneath the Upland Gravels, extending to a depth believed to be from a few inches to tens of feet.

Both topographic and geologic evidence demonstrate that at least three types of landslides have occurred on long slopes, (a long slope being defined as having a horizontal extent of at least 100 feet, from the toe to the crown of the slide). These three types are rotational slides (slumps), planar glide blocks slides and combinations of these two. Most of the slides are believed to be a combination of the two types, as the failure surfaces for most slides mapped, and especially for longer slides, were almost certainly approximately parallel to the initial ground surface throughout most of the length of the slide. It is also probable that much or even most of the initial failure surfaces of the naturally occurring slides passed through the weathered softened clay near the ground surface, irrespective of the type of slide. It is impossible to do more than hypothesize about the relation of the failure surface to the weathered kaolinite and softened montmorillonite at this stage.

There are many cases where the toe of a slump has moved a large distance, as though the soil had been nearly liquified. Typical distances that toes of large slides have moved are of the order of hundreds of feet.

The bases of planar glide blocks are invariably in Potomac Group sediments, indicating that the Potomac deposits were primarily responsible for this type of failure. In some cases bowl-shaped depressions are present uphill from the glide block, showing where the glide block was originally detached. Two glide blocks observed have undergone horizontal movements greater than 400 feet; many others have moved 200 feet or more.

The mechanics of the failure of undisturbed slopes in Potomac Group sediments is not well understood. Analysis of slope failure is further complicated by the geologic history of the Potomac Group sediments, as these sediments were originally much thicker; however, erosion has removed as much as several hundred feet of the Potomac sediments prior to subsequent deposition of Upland Gravel. As a consequence of this previous loading, the remaining unweathered Potomac clays are very stiff and may have high residual stresses, especially if not fractured. The stiffness and strength of the unweathered clays can deteriorate upon being placed in a different stress field, such as the field resulting from erosion or excavation of a slope. This deterioration results in loss of strength of the clay, and this loss of strength combined with the highly impermeable nature and high swelling pressures of the montmorillonite clays is believed to be largely responsible for landslides occurring many years after completion of construction projects.

The engineering analyses of undisturbed slopes in Potomac sediments is presently the subject of much debate. It is generally accepted that the use of a residual friction angle in drained shear results in a conservative design for long, undisturbed slopes. However, the use of drained or undrained cohesion and undrained shear strength parameters may also be realistic for some situations, such as analysis of previously failed slopes, and additional research utilizing field measurements is needed in this area. Furthermore, the mechanics of the failure of natural and man-made cut slopes may be quite different, especially if the man-made cut goes through unweathered clay.

Groundwater pore pressures are also normally involved in initiating slides in the area, as discussed in the section following.

LANDSLIDE SUSCEPTIBILITY OF POTOMAC GROUP SAND AND CLAY UNITS

The landslide mapping program afforded an opportunity to observe the relative landslide susceptibility of Potomac Group sand (Kps) versus Potomac Group clay (Kpc) units, as mapped by Force (1975). Units mapped as Kpc by Force have lenticular sand and silt beds comprising as much as 30 percent of the thickness of the map unit: stated another way, for a map unit thickness of 10 feet of Kpc, at least 7 feet will be composed of material that would be classified as clay by an engineer. Similarly, units mapped as Kps can have lenticular clay beds comprising as much as 30 percent of the thickness of the map unit. Both units exhibit abrupt lateral changes, and a given unit often changes to the other within some hundreds of feet. Both units tend to dip gently to the southeast at about 80 to 100 feet per mile.

The landslide susceptibility of a given unit is strongly affected by the pore water pressures in a slope. These pressures are controlled primarily by the material composition and the slope gradient and length. The influence of these factors is illustrated in Figure 1, which shows conceptual static water elevations in a northwest-southeast section through the Franconia area. Slopes in the section represent those along the major valleys and streams. The figure shows that the water table tends to be shallow in outcrops and subcrops of the Kpc unit, and deeper in areas underlain by Kps; furthermore, the water table gradient is steeper on slopes underlain by the Kpc unit than on slopes underlain by the Kps unit. This combination of factors often results in high pore water pressures in slopes underlain by the Kpc unit, causing them to be relatively unstable.

Figure 2 shows current (April, 1976) short-term static water table elevations in the southeastern portion of the Franconia area. Some of the elevations represent data from confined aquifers. Comparison of Figure 2 and the landslide map reveals there is a good correspondence between the areas of high pressure gradients and past landsliding, indicating strongly that the gradients are related to pore pressures in slope stability problems. It should also be anticipated that future landsliding is suspect in areas having high pressure gradients.

An attempt was made to determine whether long slopes underlain by the Kpc unit are more susceptible to sliding than the Kps unit irrespective of groundwater pressure considerations. Most long slopes underlain by Kps and Kpc units are much longer than 100 feet, averaging 300 to 400 feet. There are few areas where only one unit is encountered in going from the toe to the top of the slope, and most landslides pass through two or three layers of Kps and Kpc. However, in at least one area where the Kps unit is exposed on a long slope, no slumps were initiated at less than 12 degrees (20 percent), and few were initiated between 12 and 18 degrees (32 percent). Areas underlain only by the Kpc unit commonly had slides initiated on slopes exceeding 9 dégrees (16 percent). On slopes having more than one unit from the toe to top of slope, slides commonly are present on slopes greater than 10 degrees (18 percent), but on angles as low as 8 degrees (14 percent) in a few localities.

Creep is evident on slopes composed exclusively of the Kps unit at angles exceeding about 12 degrees (20 percent). Creep on slopes of the Kpc unit and mixed Kpc and Kps units is evident on slopes as low as 5 or 6 degrees (9 or 10 percent).

MAP UTILIZATION BY PLANNERS AND ENGINEERS

All areas mapped as having either landslides or creep require detailed examination by a qualified soils engineer before development is undertaken. Many slopes having Definite and Probable slides require careful engineering design and remedial solutions prior to development. Some slopes with Possible slumps and creep may also require expensive solutions. Groundwater is often instrumental in initiating slides in this area, and underdrains are used frequently to help stabilize slopes.

Plans should be such as to avoid diversion of surface storm-water onto or into slide susceptible slopes, or to alter the ground water characteristics in such a way that the water table or pore water pressures are raised in the vicinity of slide susceptible slopes. Steep slopes having high groundwater tables are especially susceptible to sliding wherever construction activity blocks natural internal drainage. This is especially important in areas where sliding has previously taken place, as many Potomac Group clays that have been sheared by previous sliding are probably considerably weaker than those in the undisturbed state.

Engineers can use the map as an aid to determine the areal locations and approximate depths where more detailed soils investigations are required. The map can also be used as an aid to backfigure shear strength parameters, and to determine the approximate depths of critical sliding surfaces of old slides.

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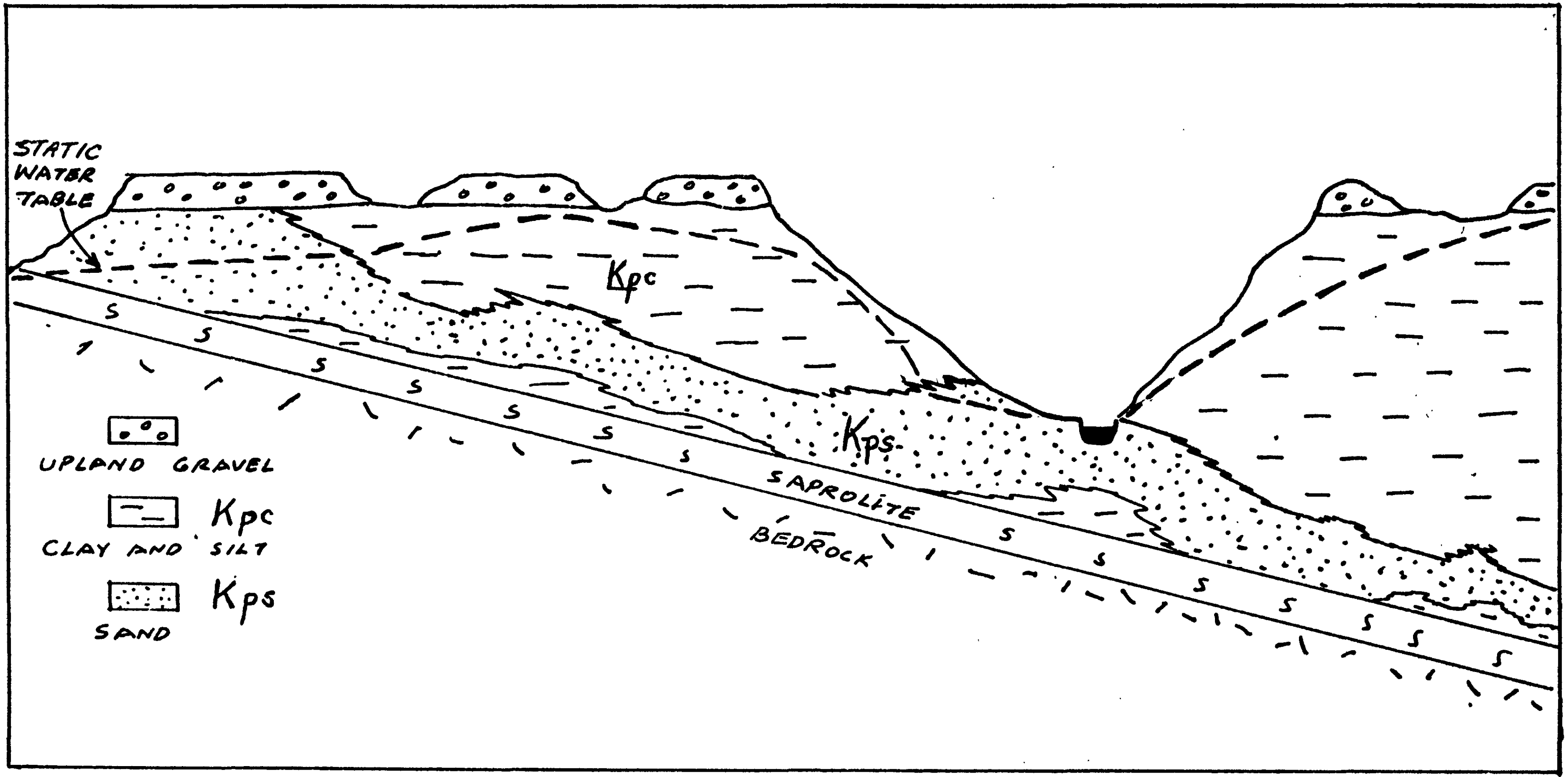

FIGURE I GENERALIZED HYDROGEOLOGIC SECTION THROUGH THE FRANCONIA AREA after Johnston & Larson, 1976

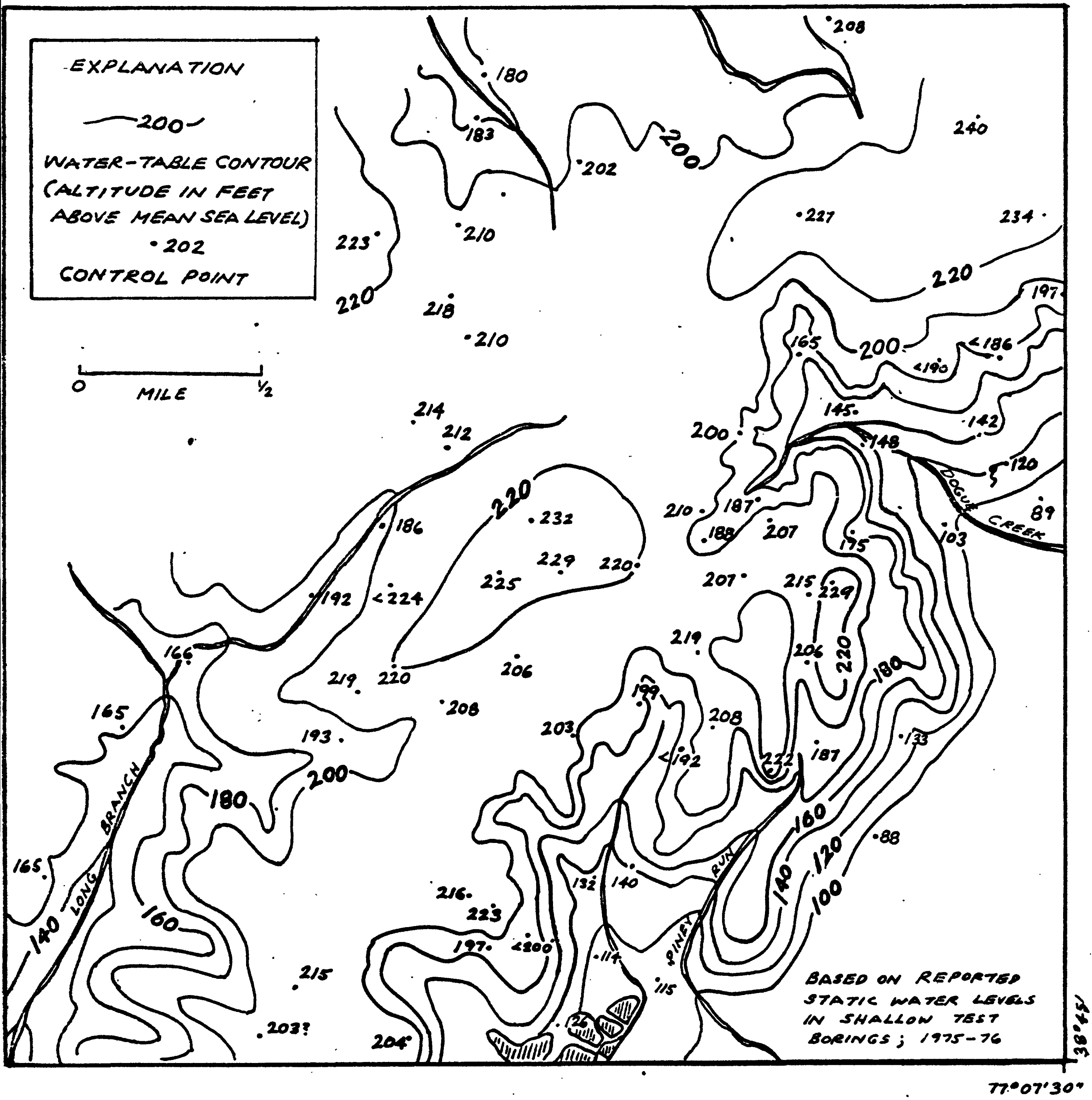

FIGURE 2 WATER-TABLE CONTOUR MAP OF THE SOUTH-EASTERN CORNER OF THE FRANCONIA AREA

Johnston & Larsen, 1976