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GEOLOGICAL AND NATURAL HISTORY SURVEY
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SLOPE STABILITY, DOUGLAS COUNTY RED CLAY DISTRICT, WISCONSIN

by

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Joseph T. Mengel

Prepared in cooperation with:
Department of Geosciences, University of Wisconsin - Superior
Wisconsin Department of Transportation, District 8
Office of Superior - Douglas County Planning and Development

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INTRODUCTION

This report presents the results of an investigation of slope stability conditions in the Douglas County, Wisconsin red clay district made by the Wisconsin Geological and Natural History Survey in cooperation with the Geosciences Department, University of Wisconsin-Superior, The Wisconsin Department of Transportation, District 8, and the Office of Superior-Douglas County Planning and Development. The area of investigation (Figure 1) includes all of the Wisconsin portion of the following U. S. Geological Survey 7 1/2 minute topographic map quadrangles: West Duluth, Superior, Parkland, Poplar N.E., Cloverland and parts of the Esko, Frogner, Borea, Sunnyside, South Range, Poplar, Lake Nebagamon, Foxboro, and Patzau quadrangles, and also part of the Brule 15 minute quadrangle.

The purpose of the investigation was (1) to determine the stratigraphy of the Quaternary sediments as it is related to slope stability problems, (2) to summarize available State file data on the mechanical properties of these sediments, and (3) to establish the types of slope failure processes operative within the Douglas County red clay district in order to provide the geologic background information necessary for development of slope stability criteria for constructed slopes and for control and management of development generally.

Subsurface stratigraphic interpretation is based on the lithologic logs of several hundred bore holes which penetrate the Quaternary sedimentary rocks, supplemented by field observation of natural and man-made cuts. Aerial photographs and air photo map interpretation, surface site investigation of about 100 localities and construction of over 200 slope profiles or slope

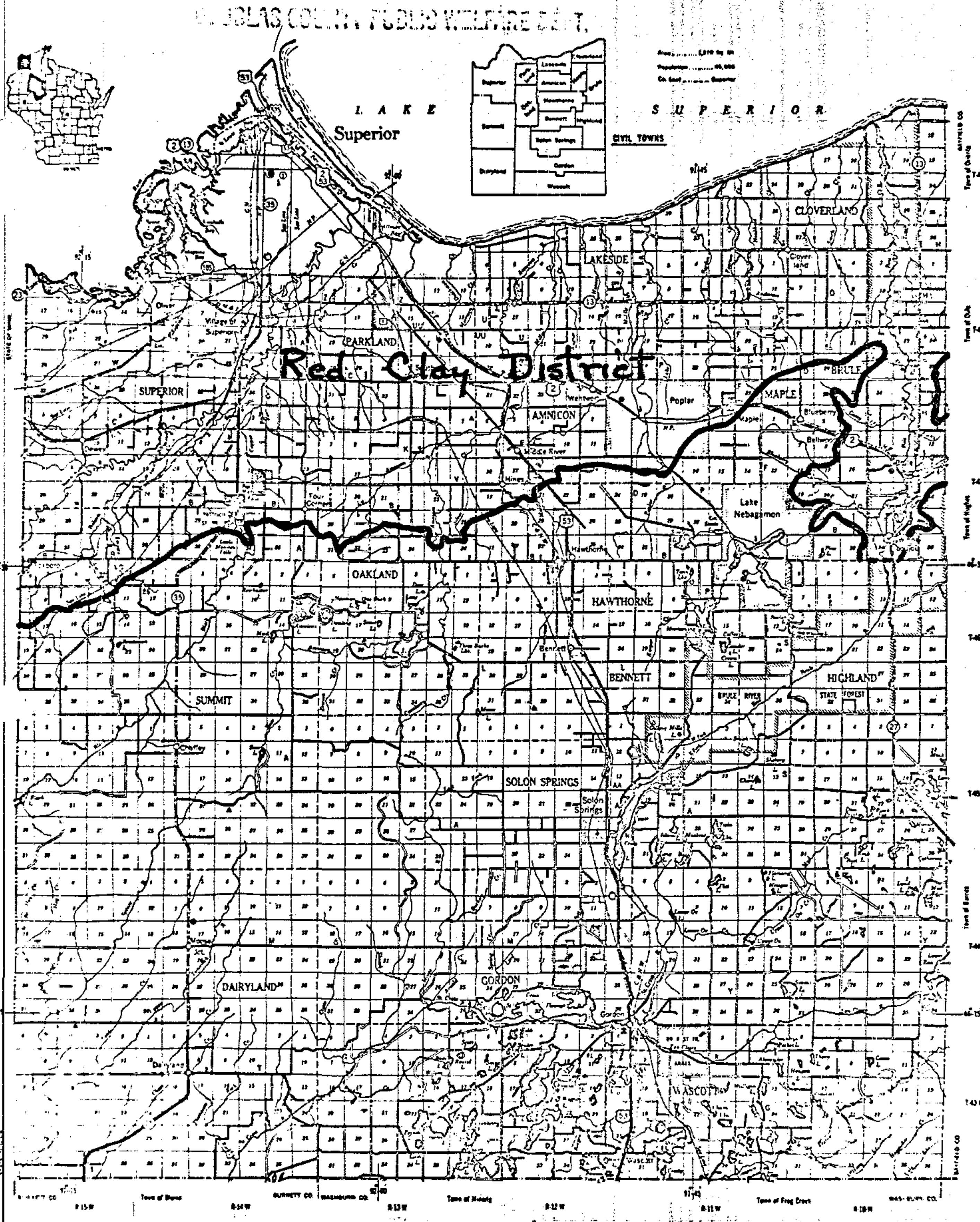


Figure 1. Index map showing Douglas County red clay district.

angles from maps were used to determine bank failure processes and to develop construction set-back criteria. The distribution of primary control is shown on Plate 1.

This investigation could not have been conducted without the generous cooperation of the following persons who, as representatives of governmental agencies, or as individuals, provided information and helped in other ways.

Mr. George Howell, Director of City-County Planning and Development, who initiated the project through a request for technical aid and provided service support throughout its life.

Mr. Emil Meitzner, Wisconsin Department of Transportation, District 8, who acted as a co-director of the study.

Mr. Thomas Meierotto, Wisconsin Department of Transportation, District 8, who directed slope profile surveys.

Mr. James Kumbera, Superior-Douglas County Planning and Development Office and University of Wisconsin-Superior, who directed field surveys and graphic work.

Mr. Frank Meyer, Physics Department, University of Wisconsin-Superior, who interpreted mathematical theory underlying models of hill-slope evolution.

GEOLOGY

GENERAL STATEMENT

The Douglas County red clay district is part of a lowland plain which borders the southwestern side of Lake Superior and lies entirely within the rectangle bounded by the 91°33' and 92°17'30" meridians, west longitude, and the parallels 46°30' and 46°45', north latitude. The altitude of the land surface in the district ranges from about 625 feet above mean sea level along the Lake to 1100 feet along the South Range which is the south boundary of the lake-deposited red clay area. The surface of the plain is underlain by a thick layer of glacially derived red clay and associated sandy sediments which rest on a layer of glacial till and bedrock of Late Precambrian age. The Quaternary age sedimentary rocks accumulated during a period about 9000 to 12000 years before present while glacial ice was retreating but still filled the eastern portion of the Lake Superior basin, causing high lake levels along the west arm (Farrand, 1969).

The gently north or east sloping clay surface of the Superior plain, the floor of the former high level lakes, is now being dissected by a youthful stream system which has cut valleys which are typically 25 to 125 feet deep. Post-glacial rebound of the eastern outlet of the lake basin and relative subsidence of the southwestern side of the lake (Moore, 1948; Clark and Personage, 1970) has caused flooding of the lower courses of all major drainages in the district. Subsidence is proceeding at a rate which may be as much as one foot in 100 years.

Wave attack on the Quaternary sediment sequence, caused by this relative rise in Lake level, has cut bluffs 25 to 75 feet high. Severe bank over-steepening has led to landsliding accompanied by creep and flow of bank materials along virtually the entire coastline. Only from the air is it possible to fully assess the high degree of bank failure along the coast, which is perhaps the most prominent part of the "red clay problem" in the Douglas County red clay district. Far less accelerated slope failure is occurring inland along stream valley walls. Although slope failure is most evident and troublesome along the coast, and to a lesser degree in the deeply intrenched drainages in Lakeside, Cloverland, and adjacent parts of Brule townships, it is also severe in the nearly inaccessible northwest portion of Superior township (Plate 1).

CONSOLIDATED ROCKS

Consolidated rocks underlie the entire extent of the Douglas County red clay district. A reddish colored sandstone sequence, the Bayfield Group ("Lake Superior Sandstone") of late Precambrian age underlies the northerly part of the district and a sequence of fissure-type basaltic lava flows also of late Precambrian (Keweenawan) age underlies the southerly part of the district. Separating the two types of bedrock is the east-west trending Douglas fault zone, which dips steeply (55 degrees) toward the south, and along which the lavas have been raised to a higher stratigraphic position, overriding the sandstones. Both rock types and the fault are well displayed in Pattison and Amnicon Falls State Parks and along the Middle River in 24 and 25-48N-12W (cf. Grant, 1900; Thwaites, 1912, Tyler, et al, 1940; and Dutton and Bradley, 1970).

The surface of the bedrock slopes generally northward. Its most prominent feature is the North Shore Depression, a northeasterly trending low area about a mile wide which parallels the northerly shore of the Lake, and which reaches depths greater than 600 feet below present lake level along the Minnesota-Wisconsin state line at Superior. About 25 to 50 feet of local relief is present on the bedrock surface flanking the depression. There is no consistent relation between the configuration of the bedrock surface and that of the present land surface; some high places on the bedrock underlie hills, especially in these parts of the district south of the 900 foot contour, but others have no surface expression. The Brule River flows in a "pre-glacial" valley where it crosses the South Range and it is probable that the North Shore Depression also originated through agencies other than ice scour.

Because of their substantial bearing strength (cf. Buckley, 1898) and small area of exposure neither the sandstones nor the lavas present a public problem in regard to slope stability. Failure will take place along weak zones and care should be exercised in siting structures close to steep bedrock slopes which exhibit thin layering and/or closely-spaced fractures, especially in locations where undercutting by streams may take place.

QUATERNARY DEPOSITS

The unconsolidated deposits which cover the bedrock in the Douglas County red clay district were laid down during and after the advance of the last Pleistocene age ice sheet over the area. The deposits include till laid down by the glacial ice, red clay and sandy deposits accumulated during high lake stages during the melting back of the ice, deposits formed by modification of the till and other sediments, and materials laid down later as the lake approached its present level. Figure 2 is an idealized section which illustrates the probable range of stratigraphic and outcrop relationships among the unconsolidated deposits and their general relationship to elevation above sea level.

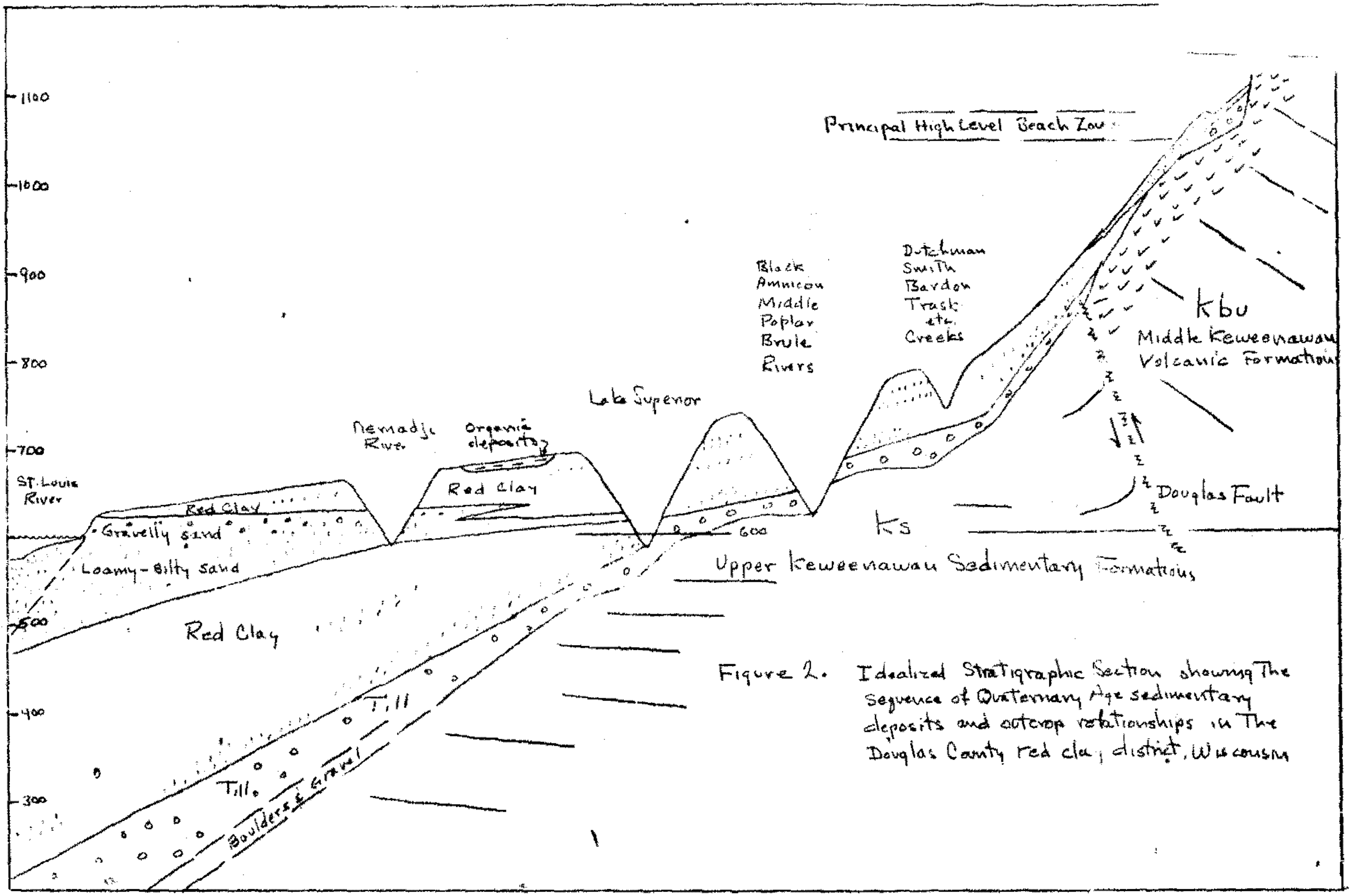


Figure 2. Idealized Stratigraphic Section showing The Sequence of Quaternary Age sedimentary deposits and outcrop relationships in The Douglas County red clay district, Wisconsin

Glacial Till

Glacial till, known to well drillers as "hardpan" crops out or is under a thin, moving blanket of colluvial clay along the lower valley walls of the Black, Amnicon, Middle, Poplar, and Brule Rivers; is at or near lake level along most of the Superior shore line; and is in present above bedrock in boreholes throughout the district except in the northerly part of 47N-13W. Borehole records report "hardpan" at the surface in NW 1/4 of 48N-15W, the SW 1/4 of 47N-15W and the center of 47N-15W.

The till is an unstratified mixed deposit of clay, silt, sand and stones having a variable resistance to penetration. In the vicinity of the city of Superior the till sheet contains interbedded layers of sandy or gravelly material up to several feet thick. Little is known of these layers but they apparently are of limited extent and more or less completely enclosed in the till and are a possible source of ground water. Reported till ("hardpan") thicknesses vary irregularly over the district but in the range 20-50 feet, with a tendency for thicker deposits to be found at lower elevations. Up to about 150 feet of till is estimated to occur at depth in the bottom of the North Shore Depression (Figure 3). No rock strength determinations have been made on the till. However, because of its limited near surface occurrence it does not exert an obvious influence on bank failure conditions.

Granular Materials

Sandy materials located stratigraphically above the glacial till and below the red clay section are reported in several boreholes along the Brule valley and are exposed along the Lake between the east County line and the city of Superior. These deposits are more or less stratigraphically equivalent

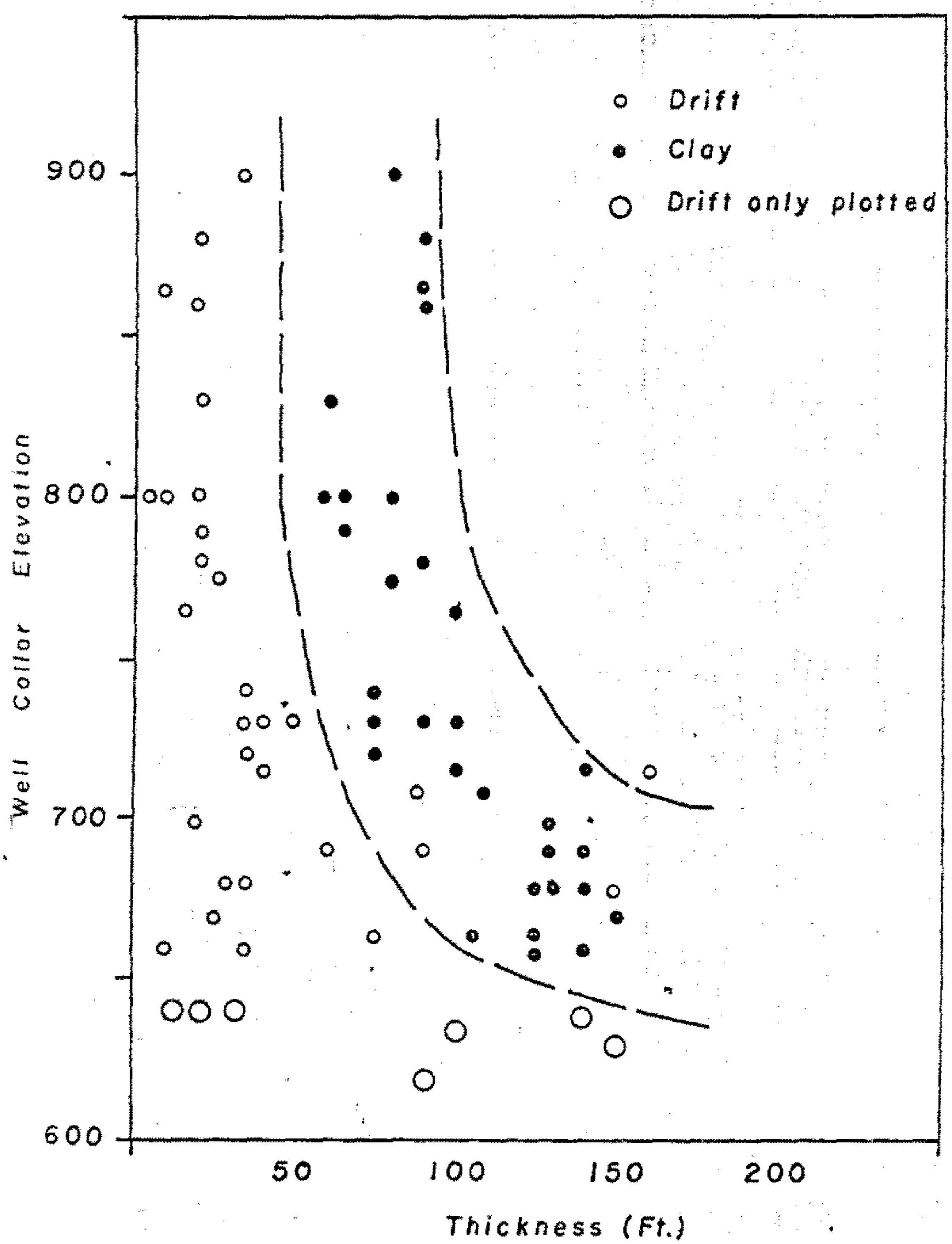


Figure 3. Quaternary sediment Thickness relationships to Topographic elevation.

to, but not necessarily continuous with, the sandy materials which underlie East End Superior at a depth of about 55-65 feet (i.e., below the level of influence on surface slopes in this area). In West Superior and Billings Park sandy materials occur at depths of less than 40 feet and crop out extensively along the St. Louis River banks where the sands are beneath an upland clay cover no more than about 15 feet thick. Sands crop out southwestward along the St. Louis drainage into 47N and 48N-15W where granular deposits are a predominant part of the near-surface Quaternary stratigraphic section in the Red River tributary drainage. Sands occur beneath red clay along the Nemadji River in 1 and 12-48N-14W and elsewhere in Superior township.

A maximum thickness of about 200 feet of sandy materials occurs along the axis of the North Shore Depression. The lower part of the sequence is silty or clayey, but the upper part, especially from about river level to the bottom surface of the younger red clay is moderately well sorted fine to coarse sand, and, in the vicinity of Oliver contains up to perhaps 20% pebbly material. The general grain size distribution characteristics of the upper part of the sandy sequence is shown in Figure 4. No strength determinations have been made on these slightly consolidated sands, whose cohesion is dependent mainly on their clay and/or moisture content.

Sandy materials a few inches to a few feet thick or more are inter-layered with red clay and/or overlie less than 50 feet of red clay in most areas south of the 900 foot topographic contour line (Plate 1), especially in the lava outcrop belt south of the Douglas fault zone. Fine examples of such deposits can be seen in the Borea 7 1/2 minute quadrangle from Pattison Park (28-47N-14W) southwestward into the adjacent Patzau 7 1/2 minute quadrangle.

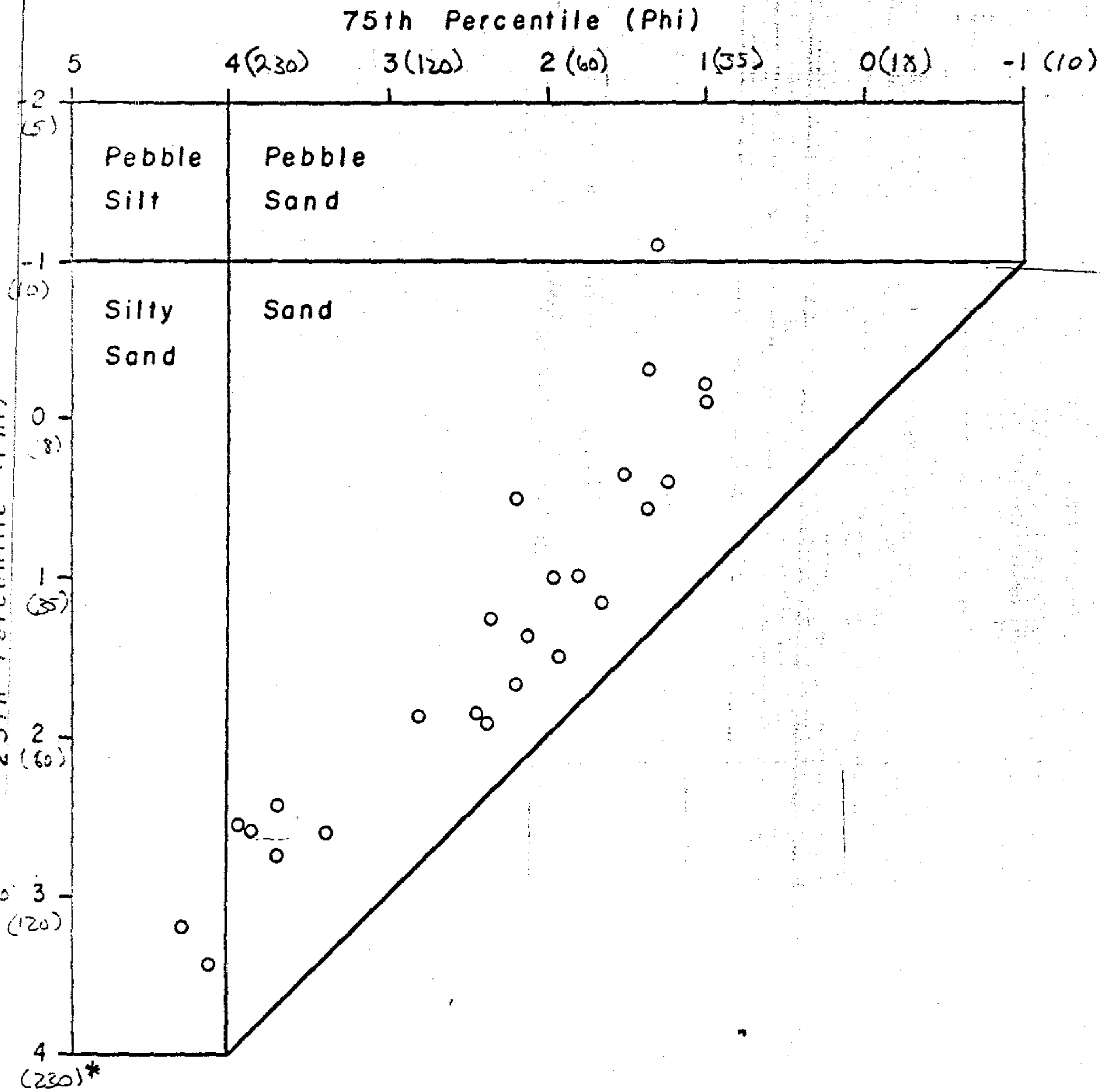


Figure 4. Grain-size characteristics of granular deposits of Quaternary age in St. Louis River banks between Oliver and Billings Park.

* U.S Standard Sieve Mesh Number

Bean and Thompson (1945) describe relationships in the Brule River basin where, south of about the 900 foot contour the Quaternary deposits are mainly bouldery morainal material and sandy outwash more or less reworked by the outflow of high level Lake Duluth and the ancestors of the modern river. They note sand and gravel terraces along the sides of the outflow valley, which, near the source of the river in 34-46N-11W, occur at elevations of 1180, 1160, and 1120 feet above sea level, corresponding roughly to the highest reported lake levels.

Throughout the remainder of the red clay district sandy deposits are concentrated primarily between elevations of about 1050 and 1080, the principal high-level beach zone. At lower elevations sands occur as locally developed beach lines and/or as an irregularly developed surficial layer of material a few inches to a few feet thick. Such surficial sandy materials may be of sufficient thickness and extent to cause soil types to be different from the principal bank forming material beneath the surface zone. Conversely, soil creep carries clay over sand-controlled slopes whenever erosion is not proceeding rapidly, and may mask sand occurrence.

A. W. Farrand (1969) notes a beach level at about 1010, and Bean and Thompson (1945) note another one at about 980 on which the town of Poplar is built. Below this level to the lake shore the surface of the plain is dominantly red clay. However, from general considerations in the Lake Superior basin Farrand believes these to be subsequent beach developments at elevations of about 860, 710, 650, and 610 feet. Other data is supplied by Leverett (1929). Wilson (1931) and Farrand note the existence of lake levels below modern ones. These low water levels have significantly influenced topographic evolution, especially along the St. Louis River.

Red Clay

The 1100 foot topographic contour marks the approximate south limit of the high-level lake deposits of red clay. In the zone between the 1100 and the 900 foot contour the clay is seldom reported to be as much as 50 feet thick. Below an elevation of 900 feet red clay is 75 to 100 feet thick beneath the surface of the Superior plain although it is considerably reduced in thickness along major drainages and is removed entirely along parts of the Brule, Poplar, Middle, Amnicon, and Black River drainages. In Superior township well records record 200 feet or more red clay in the northerly half of 47N-15W and adjacent areas. Hence, throughout the district, red clay is the principal slope forming material, except along the St. Louis River (cf. Plate 1)

The "clay" is actually a vaguely stratified, variable mixture consisting, in representative instances, of perhaps 70-90% clay-size fraction material, together with up to 15 or 20% silt, and up to 5 or 10% sand size grains, together with a variable, but usually small number of ice rafted pebbles, cobbles, and even boulders. The composition of some strata differ markedly from these proportions and a complex history is indicated for the red clay stratigraphic unit.

Limited x-ray data suggests that a small percentage of the clay-size fraction material present is kaolinite, up to a third of the remainder is illite, and the bulk is montmorillonite-vermiculite. Calcite and/or dolomite is also an important constituent of the clay and may be concentrated in small irregular concretionary bodies at and near the surface of the clay. Several percent of hematitic material, derived mainly from the bedrock red sandstone sequence, supplemented by materials from the lava sequence and regional occurrences of iron formation is responsible for the prevailing red or red brown color of the clay. Since the clay is actually a glacially derived rock flour it includes a great variety of other mineral matter as well.

Where exceptionally rapid erosion has exposed native clay as can presently (1974) be observed in NE 34-49N-12W and SW 21-49N-11W, the clay is seen to be very stiff and to be cut by several, usually about 4-6 sets of major high-angle joints. Joint surfaces are usually gray in color owing to reduction of ferric iron in the presence of organic matter. Such joint surfaces are probably the principal routes by which precipitation enters the red clay. They are supplemented, at the surface, by moisture-related shrinkage cracks.

Data on plasticity index and liquid limit of red clay currently available in Survey and Department of Transportation files, is summarized in Figure 5.

Undrained triaxial shear tests run at a slow rate (6 hours to obtain failure) on three sets of three core samples taken in NE 36-49N-14W are perhaps the best data currently available from which values of internal friction angles (ø angles) and cohesion can be obtained.

TABLE 1

Depth	ø	ø	c = c̄
12-14	12.5	17	.05 kg/cm^2
32-34	9	14	.20 kg/cm^2
80-82	8.5	9.5	.35 kg/cm^2

ø = angle of internal friction: Total Stress

ø = angle of internal friction: Effective Stress

c = c̄ Cohesion

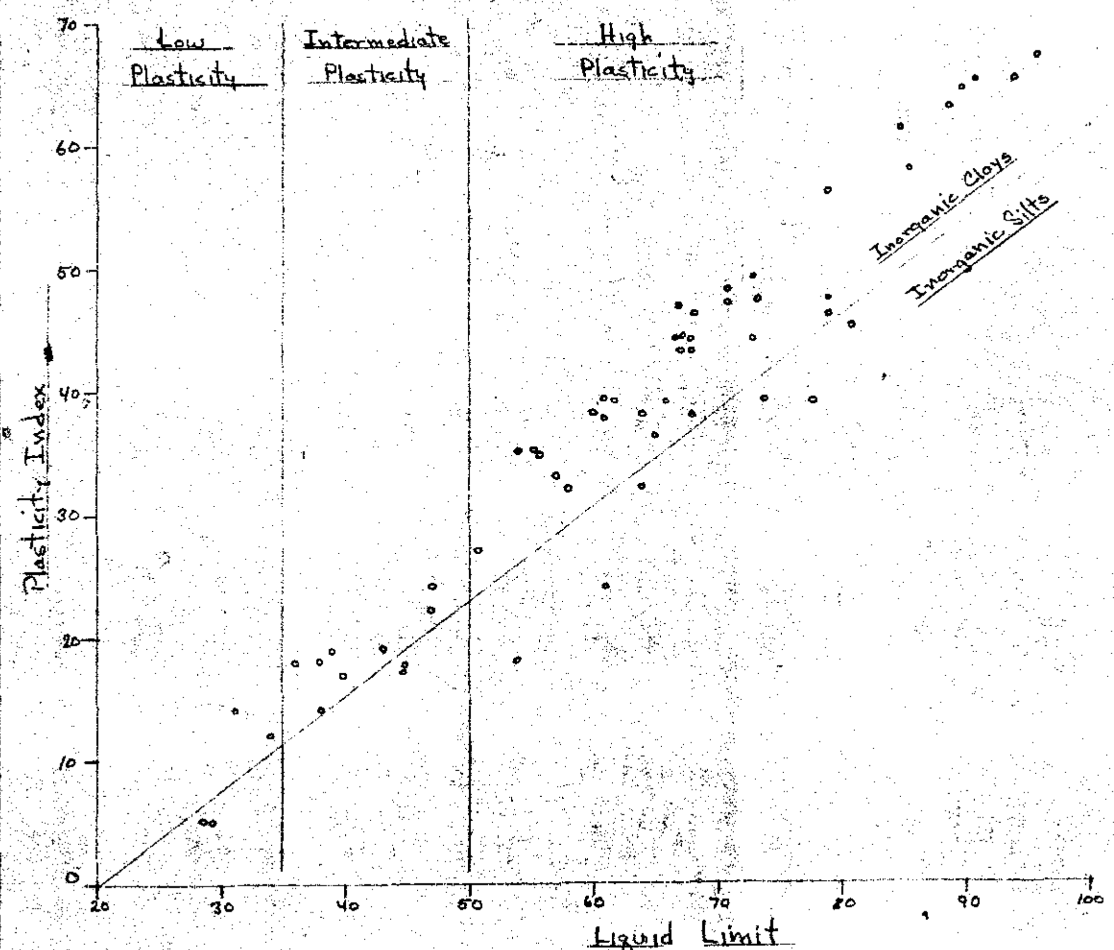


Figure 5. Red Clay Plasticity

The present study indicates that a ϕ angle in the order of about 10 degrees is preferred, although construction site test data give ϕ angles ranging from a low of 11 degrees to a high of 32 degrees, determined by various techniques. In long term slope stability studies of clays cohesion is often disregarded, i.e., considered to be zero. Construction site data typically show bearing strengths in the range 0.5 to 1.5 tons per square foot.

Department of Transportation studies suggest that the dry weight of the clay is typically about 90 lb/cu ft, and that below about a 5 foot deep surface zone, the natural moisture content is about 35%, giving the clay a weight of about 120 lb/cu ft in the native state in well-drained areas being considered as possible borrow sites. Other data obtained from core samples at depths from 12 to 80 feet taken in NE 36-49N-14W give a dry density of about 75 lb/cu ft and a water content of about 50% for materials at greater depth below a nearly flat marshy upland surface.

No free-water table exists in the red clay within the depth zone of primary concern with regard to slope stability, although sand interlayers contain small volumes of water wherever they are encountered, and water may be produced from the till, and/or from the upper portion of the bedrock. Reported natural water levels in wells range from surface flows to depths as great as 100 feet below surface. Most wells are semi-artesian in character, with water rising higher than the top of the aquifer in which it is encountered. Boreholes have encountered strong artesian flow from sands beneath 50 feet or more of red clay in 6-48N-14W, and it is probable that such conditions will be encountered elsewhere in Superior township, and along the South Range. Weidman and Schultz (1915, p. 316) report flowing wells in various parts of Superior, in 22, 27, and 28-47N-14W, and in 24-47N-13W.

During the late part of the 19th Century the sandy unit along the St. Louis River was the principal source of domestic water in the Billings Park community. Wells were sunk to depths of about 40 feet beneath the upland surface (about 640 foot elevation). Indications are that the water table lies only slightly above Bay or River level (about 600 foot elevation) and the part of the sandy sequence above this level is nearly dry owning to the comparative impermeability of the overlying red clay stratum.

Wetlands occur on undeveloped portions of the red clay upland, especially below an elevation of 700 feet in Superior township. These wetlands occupy shallow basins in which undecayed organic matter has accumulated. The maximum known thickness of these organic deposits is in the order of 10 feet, although accumulations more than 2 feet thick are unusual. Below this irregular surface accumulation, organic material rarely can be identified in cuts or boreholes. The poor drainage of the shallow, organic filled basins, also serves to regulate runoff. "Improvement" of drainage for agricultural purposes in Lakeside and Cloverland townships and in urbanized areas of the city of Superior has tended to reduce retention of water, thereby altering the existing natural equilibrium conditions, and locally contributing to bank failure through gully development.

SLOPE STABILITY

GENERAL PRINCIPLES

Under natural conditions in the Douglas County red clay district slope stability is established by erosion processes which gradually lengthen and flatten slopes originally cut by stream or lake activity. The resulting slope surfaces eventually approach equilibrium with climatic and vegetational conditions but are never static since they are surfaces along which loose materials are transferred down slope to the water body which will carry them away. Among other things, cyclic climatic change, natural or artificial modification of vegetation (through fire, clear cutting, or overgrazing), or natural or artificial removal of material from the toe of any slope disturbs the previously established conditions and is apt to accelerate downslope movement until a new approach to equilibrium can be established. Experience with highway embankments indicates that a period of months to as much as about 10 years may pass before the acceleration in downslope movement becomes dangerously evident.

In every slope gravity-produced shearing stresses exist which increase with slope inclination and height, and with the unit weight of the slope-forming material, which in the present instance is considered to be clay. The processes of heating and cooling, freezing and thawing, and of wetting and drying produce additional shearing stresses. The response of the slope to the sum of these stresses is determined by the resistance of the slope-forming material. Very slow downslope movement (creep) takes place wherever and whenever a critical stress level is exceeded and plastic deformation can be initiated. A total imposed stress approaches the shear strength of the red clay the rate of creep increases until some form of relatively rapid slope failure takes place, to which the term landslide is applied. Creep involves only the uppermost few feet of the slope surface and clay which is experiencing creep grades downward into stable material at depth. Landsliding involves more rapid movement along one or more closely spaced shear surfaces which separate the moving rocks from the underlying bank material. Landslides do not necessarily have sharp boundaries but may grade laterally into stable ground across a zone of creeping material. The rate of movement of gravity transported slope material ranges from several miles an hour in the case of mudflows and some deep landslides to rates of a few inches or a few feet per month for some shallow landslides, and fractions of an inch per year for most creep movements.

Mean annual precipitation in the red clay district is about 29 inches but varies considerably over long time intervals (U.S. Army Corps of Eng., 1973, p. 35). Longer periods of higher than average rainfall are times when the clays are less resistant to shear stress owing to the internal effects of moisture on their structure and grain arrangement. The weight of the water (62.5 lb./cu. ft.) also increases shear stresses. These are the same times during which stream and lake levels are higher than average, beaches are flooded, and erosion rates are correspondingly higher. Exceptional climatic events, occurring once in 100 or 1000 years may produce more erosion than that which occurs during all the time intervening between such events. Recognition that weather records for the red clay district cover only about the past century is a clear warning that plans for construction setback, and design generally, should not depend entirely on "means" or even "extremes" for such a short period of record but should err somewhat on the side of conservatism if safety and usefulness is to be insured for structures designed to last for several generations.

Coastal structures should also be designed with allowances made for the relative regional subsidence of about one foot per century as previously noted. Although flooded stream mouths and the estuarine character of the lower St. Louis River valley leave no doubt that relative subsidence is occurring in the red clay district. There is no clear cut evidence as to whether subsidence takes place continuously or episodically. If the latter is the case, as seems probable, the present high rate of coastal retreat is due primarily to a pulse of subsidence which took place within the past half century. The activities of man which affect both the coast line and stream valley banks have also accelerated natural decay to an increasing degree over about the past century.

The profound nature of the impact of long-term lake erosional activity can best be appreciated by examining 35 and 36-49N-13W (Parkland 7 1/2 minute quadrangle) where upwards of half mile of bank retreat can be observed to have taken place since the establishment of Wisconsin Point within the last two or three millenia.

SLOPE FAILURE PROCESSES

In the red clay district a variety of slopes are to be observed, ranging from ones which are undergoing intense modifications to those which are approaching equilibrium. An equilibrium slope is the most nearly stable slope attainable under a given set of material and environmental circumstances. These slopes exhibit the lowest degree of inclination and are found under full natural plant cover in situations relatively protected from geologic and human description. In the red clay district such slopes leave inclinations of about 6 to 10 degrees and typically are about 8 degrees. They occur along stream reaches protected by wide flood plains and along shore stretches well protected by beaches. At the other end of the stability spectrum are banks subject to current and/or wave attack along the coast line or on the outer side of meander curves where active erosion of the slope toe is occurring.

General slope conditions are easily identifiable on U. S. Geological Survey 7 1/2 minute topographic map quadrangles although the scale of the maps is not suitable for making precise slope angle determinations or for most types of construction site evaluation. Slope features such as degree of inclination, profile shape, and smoothness are indicators of the particular processes which are active. Lake Superior coast line slopes locally exceed 60 degrees although typical slopes are no more than about 30 degrees. These slopes are highly irregular in detail and exhibit a clearly spaced, irregular contour patterns on topographic maps. In Lakeside and Cloverland townships, and generally throughout the district below the 900 foot topographic contour the inclination of stream valley walls rarely exceeds 20 degrees and most slopes range between 12 and 17 degrees, measured rise over run, toe to crest

(Figure 6). Most such slopes are convex in profile and exhibit regular topographic contour patterns. In Superior township detailed maps exhibit many slope irregularities, characteristic of slopes on which sliding is taking place.

In theory (Kirkby, 1971; and Carson and Kirkby, 1972) slope flattening depends on the transporting capacity of the most active erosion agents and bears a functional relationship to bank inclination. The present investigation clearly indicated that on most natural clay slopes of less than 15 degrees creep is the principal erosion agent, and that on steeper slopes landsliding coupled with creep, mud flows, and occasional clay block slides or falls are the principal agents. Creep is particularly prominent everywhere because of the great depth (5-8 feet) of frost penetration results in heave of as much as several inches and because of moisture-related expansion and contraction of the montmorillonite-rich clay.

A gradational spectrum of land slide types may be observed. On slopes of about 15 to 18 degrees shallow translational slides - slides where materials move as a thin sheet nearly parallel to the slope surface - may originate on any part of the slope. Such slides can be seen in 8 18, and 20-48N-12W. Translational movements affect only a layer of slope surface perhaps no greater than 4-6 feet deep. Within this layer, during dry weather, penetrometer-indicated bearing strength is usually over 4.5 tons per square foot (TSF) at the surface. Strength values decline to less than 0.5 TSF at depths of 2-3 feet and then rise to values over 1.0 TSF as depth increases. The surface layer is also penetrated by a mat of roots which further serve to give it cohesion. Such root systems of grass, shrubs, and canopy trees are limited to no more than about the uppermost 3-4 feet. This is the approximate depth to which moisture-related shrinkage cracks develop and permit water entry.

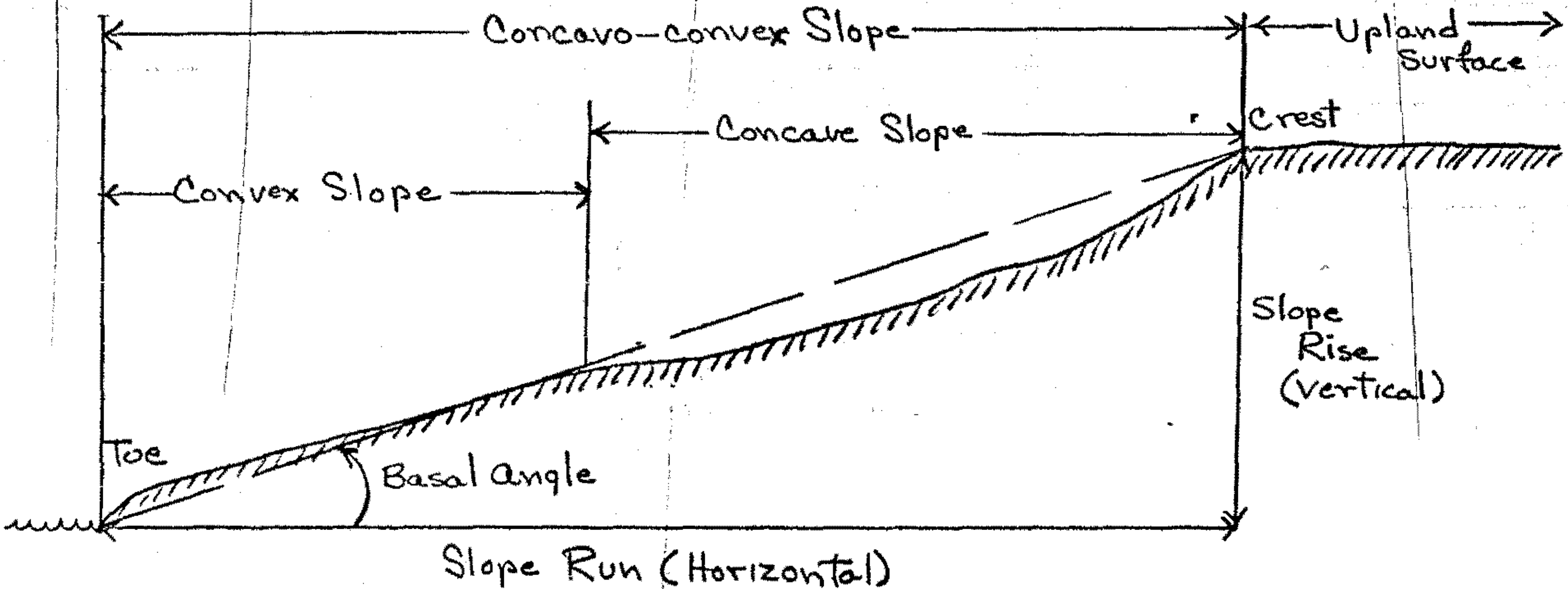


Figure 6. Slope Terminology

Sliding takes place along shear surfaces at the base of this coherent upper crust. It is doubtless promoted by crack development which in turn is related to modification of the surface vegetation. Natural jointing in the clay doubtless also contributes to the development of open fissures.

Slope failure can be initiated through undercutting of the slope toe by stream or lake action. First evidence of failure along the toe are high angle slips which allow blocks of material only a foot or so thick to slide down steep fractures into the water body. Failures migrate up slope where translatory and/or rotational sliding along shallow shear surfaces initiates one or several small, steep curving escarpments perhaps 2 to 4 feet high and 25 to 150 feet wide across the slope. Water entry into fissures opened by the sliding promotes movement as does water supplied from granular horizons within the clay unit.

If very rapid toe erosion takes place as it may on the outer side of some stream meanders and commonly does along the lake, rotational failure occurs along steeper, deeper and broader arcs and bank failure is potentially more descriptive and dangerous. Once sliding takes place there is a tendency for very removal of the badly cracked and remoulded toe materials and erosion rates are higher than they would be for undisturbed native clay. More or less rotational failures related to stream activity can be observed in NWNW 33-48N-12W and in Superior where U. S. Highways 2 and 53 cross Bear Creek; and lake related rotational slides can be seen along most of the coast. These latter are best observed from the air. In Superior township failures are influenced by the presence of sand layers and probably also by artesian water conditions, or by water pressures within isolated sand bodies. A portion of County Trunk Highway A was permanently destroyed and the flow of the Nemadji River temporarily obstructed by such a slide which occurred during 1966 in SE 1-48N-14W. Similar serious rotational slippage also obstructed the Nemadji during 1973 in NE 21-47N-15W and a number of other such failures have taken place elsewhere in the Nemadji and in both of the Pokegama river drainages.

In Superior township failure can, and frequently does take place on slopes of less than 15 degrees and some slopes with as gentle as 6 degree inclination are still not in equilibrium. In all parts of the red clay district bank height does not necessarily determine sliding and disruptive failures can take place on slopes no more than 10-15 feet high. Accordingly all slopes should be viewed as potentially dangerous to construction works if their inclinations exceed suggested equilibrium angles. The likelyhood of sliding increases with each added degree of inclination and probably no clay slopes in the district will long remain free from sliding if their inclination exceeds 15 degrees. Since natural slopes in the red clay district evolve concurrently with a plant cover (cf. Wilson, 1938), and plants regulate moisture content, cracking, and soil removal, it is probable that constructed slopes will fail at 15 degree inclinations unless measures are taken to protect them as quickly as possible. Vegetation on all slopes should be protected from serious disruption if natural equilibrium conditions are to be maintained. Thompson (1945) notes the value of willows in protecting stream banks from erosion along the Brule River, and such protection is amply evident along the Amnicon River as well. Since toe erosion is particularly apt to trigger bank failure willow growth should be encouraged where feasible.

Along the St. Louis River and elsewhere, especially in Superior township, where sandy layers are major slope-forming materials, bank inclinations are typically steeper than 30 degrees and may be nearly vertical locally. Failure takes place in sandy materials through individual grain movements at the surface, which are aided by strong winds in Winter, Spring, and Fall, through very shallow translatory sliding, and through mass movements controlled by incipient high angle fracture surfaces. Rill development is also a factor in sand slope decay.

CONSTRUCTION SET-BACK CRITERIA

Prediction of bank stability can be made for various conditions using Chart 1 and Chart 2. Chart 1 and its descriptive text is used in evaluating stream banks; Chart 2 and its descriptive text is used in evaluating lake banks. These charts are based on average conditions and local exceptions may occur. Evaluation aid may be obtained from the Superior representative of the Wisconsin Geological and Natural History Survey, Department of Geosciences, University of Wisconsin-Superior, 715-392-8101, Extension 261.

Chart 1 - Stream Banks

Lakeside and Cloverland Townships South to 900 Foot Topographic Contour.

Prediction of bank stability is made using the basal angle (cf. Figure 6). To determine the basal angle of a slope two points must be established: the crest, where the land first becomes relatively level, and the toe, where the land becomes relatively level on the inner margin of floodplain or at the edge of stream (or beach). The two points must lie along a line whose bearing coincides with the steepest slope at the place where the determination is made. The steepest slope for any condition will be at right angles to the average compass trend direction of the slope. After the two points have been established the vertical angle formed by a straight-line joining the points is measured directly with an Abney Level, or other instrument designed for determination of vertical angles, and the vertical bank height determined with the hand level. In heavily wooded areas or where slope conditions preclude establishing a line of sight, the vertical height of the bank can be determined with the level in the usual manner and the slope distance with a tape. These quantities can then be plotted on graph paper and the basal angle measured from the plot.

Enter Chart 1 with this angle and knowledge of the measured bank height to determine set-back distance for individual structures. If desired for more thorough planning of large scale development, the upland surface adjacent to the bank can be zones by the method demonstrated in Figure 7.

Slopes of 8 degrees are about as gentle as any which occur in the red clay region and have the highest degree of stability under natural weathering, erosion and vegetation conditions. Slopes with basal angles from 8 to 15 degrees look deceptively stable, but are subject to soil creep, and at angles close to 15 degrees may experience minor translatory slides. In this regard it is well, as noted above, to recognize that there may be no obvious down-slope movement for years while materials are loosened and prepared for transport by the erosion agents and that then the net erosion of decades may take place in days, hours or seconds (Verhoogen, et al, pp. 327-328).

Slopes having basal angles of more than 15 degrees are actively unstable and subject to periodic translatory sliding. Adjustments are probable within the life of a typical structure, here arbitrarily defined as 60 years (three generations), and no major structure should be built here or major modification of vegetation be undertaken.

Resurvey of slope basal angles should be made as necessary to assess changing natural conditions or changes proposed by man. Ordinarily the basal angle will be nearly constant for long periods because of the slow rate of growth in valley width, but the angle should be redetermined at the time of property sale in order that the purchaser may understand existing conditions and future outlook. In the event of drastic erosional changes in the toe area of a slope evaluation should be made using Chart 2a, described below.

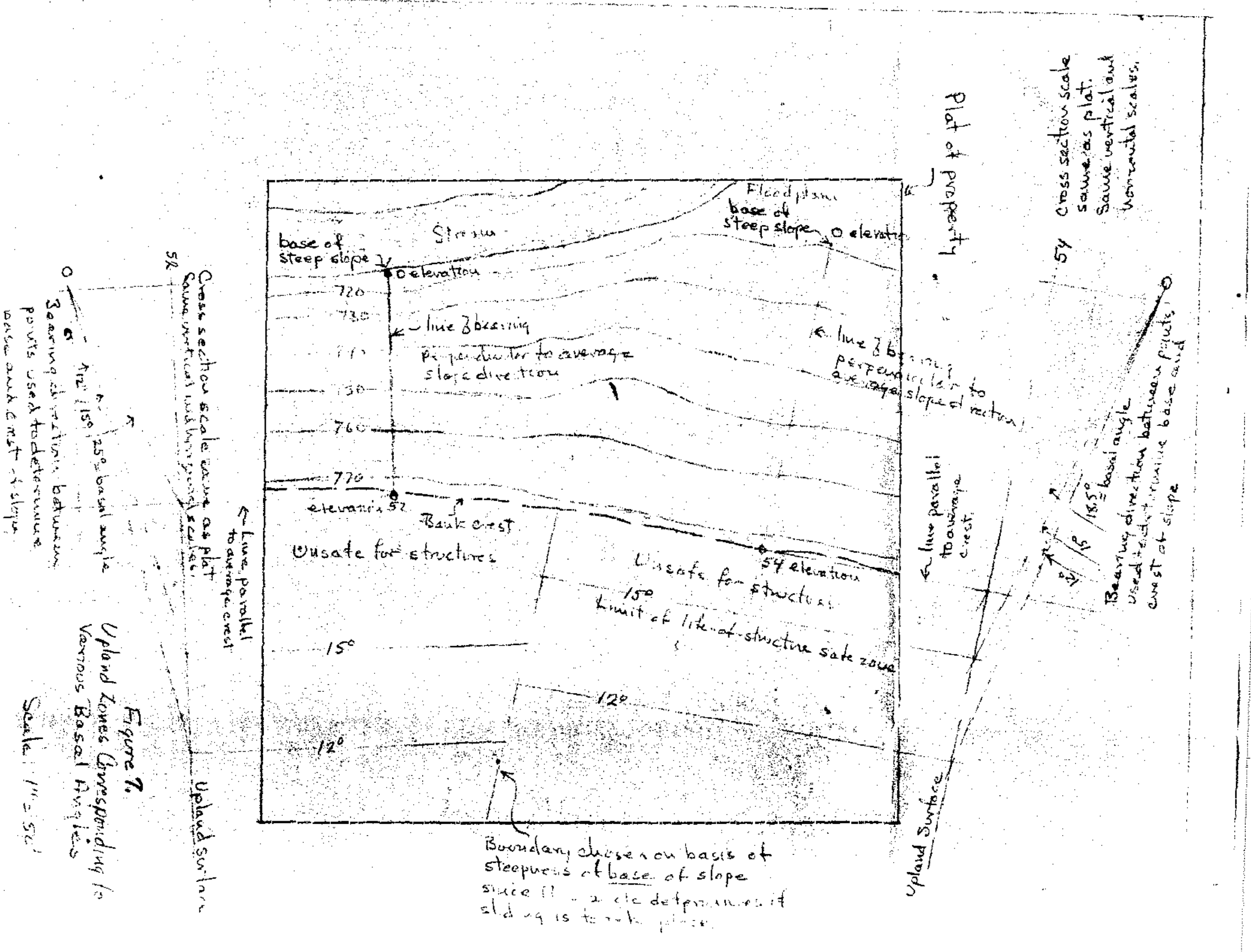


Figure 7. Upland Zones Corresponding to Various Basal Angles

Scale: 1" = 50'

Superior Township

Superior, Superior Township and South to the 900 Foot Topographic Contour.

Experience with severe rotational slips in 1-48N-14W on slopes with basal angles of about 10 degrees, the more frequent occurrence of concave and irregular slope profiles and widespread problems with railroad rights of way, indicate that use of the 15 degree basal angle set-back criterion in Superior Township should be made only with considerable knowledge of local conditions.

Granular materials - hardpan and/or sands - are an important or predominant part of the near surface stratigraphic section in the northwesterly corner of 48N-15W and in the northeasterly corner of Superior Township in the Nemadji and adjacent Pokegama River drainages. Strong undercutting by streams may trigger important rotational sliding along steep arcs in these areas and consideration should be given to use of a 12 degree angle or even an 8 degree angle setback, based on local experience, and observation of existing conditions.

Setbacks along the St. Louis River from Billings Park to Oliver (cf. Plate 1), where thick sands are present at water level can usually be established with the 15 degree basal angle criterion unless examination of the slope vegetation indicates rapid erosion, in which case of 12 degree basal angle setback criterion is preferable, or, in extreme cases at the ends of points undergoing rapid retreat use of Chart 2a would be preferable for expensive structures. Alternately, consideration should be given to riprap emplacement along the toe of the bank to protect it from further erosion.

Little or no subsurface data is available to assess stratigraphic conditions in the SE half of 48N-15W, but experience with continuing motion of railroad and highway structures on slopes much less than 15 degrees suggest use of the 8 degree setback criterion would be wise unless local conditions are clearly indicative of a more stable state. At present there is limited access to this area. Most of the area is swampy upland still as yet undrained by man. In this area and in the belt of thick red clays across the center of Superior township it is probable that sandy interbeds and intermixture with red clay is more common and mechanically important than in the remainder of the red clay district to the east.

In the belt of thick red clays in the north half of 47N-15W, in the Nemadji River drainage above State Highway 35 and along Black River and Copper Creek, use of the 12 or the 15 degree basal angle setback criterion can be determined from local knowledge of stability conditions or with the aid of the Wisconsin Geological Survey representative in Superior.

Chart 2 - Lake Banks

Lakeside and Cloverland Townships and Superior to Base of Wisconsin Point.

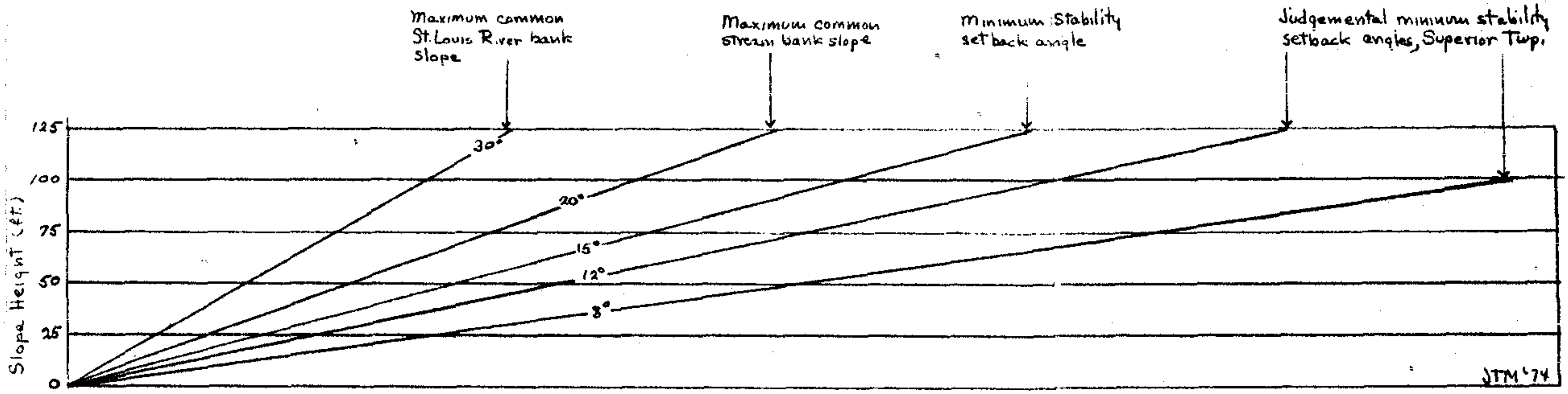
Shore line erosion on the western arm of Lake Superior was studied in detail by Hess (1973) in a private study made for the Reserve Mining Company. Air photographs, maps, and field checks were made of the entire Douglas County shore line and that of Bayfield County as far east as Park Point. Hess identified an average of 280 feet of shore retreat in the period 1852-1966, 133 feet of which took place in the 28 years 1938-1966. The average rate of bank retreat for the full 114 year period was 2.5 feet/year; and for the shorter period 4.8 feet/year. Hess correctly observed that such average rates have little relation to actual rates at any single locality because coastal processes are highly variable in their action from place to place and time to time and that climatic fluctuations influence both bank strength and lake level.

However, the shore line retreat rate averages are of a realistic order of magnitude and can be used for correcting the basal angle projections. Such corrections will tend to be conservative in character. Charts 2a and 2b show the basal angle projections necessary to meet the 15 degree angle criterion for differing life-of-structure projections and for the two differing erosion rate averages. Property closely adjacent to the mouth of a major stream where active beach building takes place should use Chart 2a, based on 2.5 feet/year retreat; property in other areas where erosion is evidently proceeding at a rapid rate should use Chart 2b, based on 5 feet per year retreat. It should be remembered that along the mouth of streams bank attack may also involve stream undercutting and property evaluation should include zone determination of conditions such as outlined in Figure .

Use of either Chart 2a or Chart 2b requires the same field data as for the use of Chart 1. Once the basal angle and slope height are known the setback requirements to meet the 15 minute criterion at various times in the future can be determined from Chart 2a or Chart 2b. In rare instances exceptions occur to setback suggestions given above. Such is true for example at the mouth of Bardon Creek in 21-49N-11W where a former point bar flat area is heavily protected by sands introduced by the creek and very little erosion has taken place over the past 35 years or more. Study of the age of trees growing undisturbed on the lake slope is a useful guide to slope stability and should be noted. Care should be taken to be certain that the trees observed have not been involved in down slope movements.

Chart 1 - Stream Valley Side Slopes

Setback Distances Corresponding to Various Bank Heights



Setback Distance (ft.)

Scale: 1" = 50 ft. vertical and horizontal

Enter chart by plotting measured bank basal angle at the zero position, Trace this angle to the measured bank height, measure foundation setback from bank crest by following measured bank height line to the right of the 15° basal angle line. In Superior Township and elsewhere judgement of local conditions may indicate use of 12° or 8° basal angle criterion to determine reasonable set back.

Chart 2 - Lake Shore Slopes

Setback Distances Corresponding to Various Bank Heights

Chart 2a - 2.5 ft/year bank erosion average rate

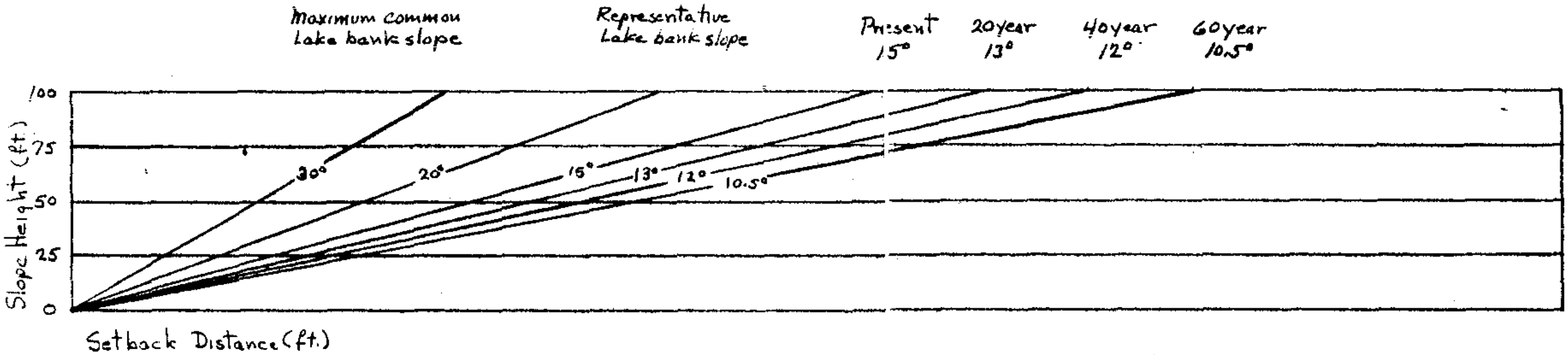
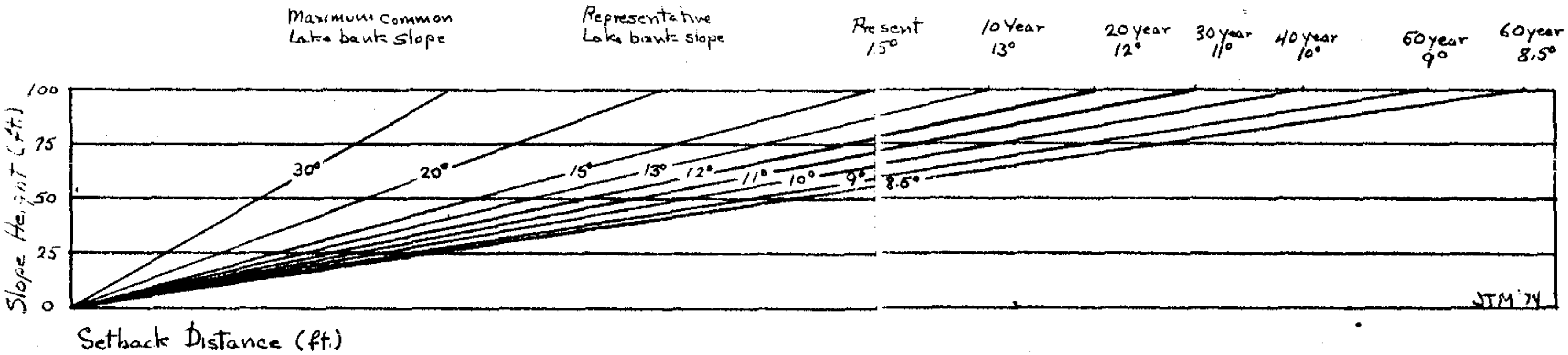


Chart 2b - 5.0 ft/year bank erosion average rate



Enter either Chart 2a or 2b by plotting measured bank basal angle at the zero position, trace this angle to measured bank height, measure foundation setback from bank crest by following measured bank height line to the right of the 15° basal angle line to estimated life of structure. Basal angles noted insure meeting the 15° basal angle criterion for lengths of time listed.

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