AN EVALUATION OF SITE QUALITY FROM AERIAL PHOTOGRAPHS OF THE UNIVERSITY OF BRITISH COLUMBIA RESEARCH FOREST, HANEY, B. C.

by

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1958

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF FORESTRY

in the Department

of

FORESTRY

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April, 1960

ABSTRACT

Classification of site of forest land is possible on aerial photographs. This classification can be based on topographic features, physiographic features, forest cover types, or on their combinations.

Aerial photographs of the University Research Forest were typed using the following topographic features: exposure, percentage of slope, shape in profile, and shape in contour. Data on topographic and physiographic features were collected on 238 sample plots within topographic types in 30-year-old stands, on 83 permanent sample plots in 70-year-old stands, and on 26 sample plots in old-growth stands.

Both graphical and mathematical analyses were carried out to determine relationships among site index and thirteen site factors. Simple correlation coefficients for site index of each of 320 plots were highly significant for each of local and general position on slope, per cent of slope, elevation, soil depth, moisture regime, permeability, soil texture, and thickness of A_2 layer. Shape in profile was significantly associated with site index. Aspect, shape in contour, and thickness of the humus layer were not significantly associated with site index. The best of the single factors was moisture regime, but use of this by itself could only account for 20 per cent of the variation in plot site indices. Linear multiple-regression equations were computed to estimate site index from various combinations of topographic and physiographic variables. These equations were not used further in this study for determination of site index because of their relatively high standard error of estimate; however, several potentially useful equations were recognized. The best multiple-regression equation was highly significant statistically but accounted for only 31 per cent of the variation in plot site index. It included aspect, local and general position on slope, per cent of slope, shape in profile, elevation, and moisture regime.

A procedure was developed to estimate site indices directly from aerial photographs by stereoscopic examination. Photo-estimation of site index was much more accurate than the computed equations based on all data collected in the field. Standard errors of estimate were reduced from 23 feet to 16 feet by direct estimation of site index.

Regression equations were developed for conversion of site index of Douglas fir, western hemlock, and western red cedar from one species to another and to the average of all three species.

Site maps were prepared for the 30-year-old stands which had not been mapped in the 1950 inventory of the University Research Forest. Preliminary site and forest cover types were recognized and general stand and stock tables were developed to describe these 30-year-old stands.

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ACKNOWLEDGEMENT

The writer of this thesis wishes to express his sincere thanks to Dr. J.H.G. Smith, assistant professor of Faculty of Forestry at the University of British Columbia for his suggestions, guidance, and encouragement.

Financial assistance received from the Faculty of Forestry (University President's Committee) and from the National Research Council is gratefully acknowledged by the writer.

Acknowledgement also is due to D. Little (now deceased) and to Mr. R. Dobell graduated student and staff member of the Computing Centre of University of British Columbia for their guidance and assistance in using the ALWAC III-E electronic computer. Staff members of the Computing Centre are hereby thanked for their kindness and assistance in the computation.

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Introduction

The forest provides man with its products which are indispensable in the life of any society. Human needs have multiplied with the progress of society to the present time. With the development of industry the forest business became more important. Its base is the stored raw material in the forest which can be utilized. This does not include directly the small timber, the growth of this small timber, and the soil, but man is particularly interested in the forest as a continuous source of wood. The quality or value of the timber crop and the time required for the trees to reach this quality in a forest are most important in planning a forest business. The quality of a forest crop and the rotation time depend on the existing tree species, on the soil and climate, and on man's treatment of the forest. The quantity and quality of wood that forest land can produce in a given period of time vary with the site quality of that land. Since site quality determines the growth of forest crops, site classification has great importance in forest management and in forestry practice. Site classification is also required in forest research work.

The beginning of forest-site classification reaches back to the nineteenth century. A site-classification method was originated in Germany (1888) which used trees to express the site quality of forest areas. Another method, chiefly ecological or biological, was developed in Russia and Finland at the same time. This method used all vegetation in addition to soil, climate and topography to express site quality of forest land. Modifications of these two approaches are the base of current site-classification methods.

Site quality of forest land can be expressed by tree heights at a certain age, by indicator plants, or by pertinent physiographic factors. Thus different approaches can be used for forest-site classifications. In North America the most commonly used measure of site quality is the average height of dominant and codominant trees, usually at 100 years of age. However, soil sites and indicator plants are also used to describe the quality of forest land.

Site classification can be done by ground sampling, by evaluation from aerial photographs, or by a combined approach. Site classification from aerial photographs has certain limitations but is cheaper than any ground method. Since a most important factor, tree age cannot be determined from aerial photographs, direct calculation of site index is impossible from data measured only on aerial photographs. Therefore, site classification from aerial photographs must be based on the photomeasurable site factors such as topography, soil, and geological formations, and vegetation.

There is at least one method of evaluating site quality directly in mathematical terms from aerial photographs. This is the "Height/crown-diameter ratio" method. Tree height and crown width can be measured on aerial photographs, and their ratio will, under certain conditions, provide a measure of site quality (Spurr, 1948). This method is not used often because of the fact that tree-crown diameter varies not only with site quality but also with stand density. Crown diameter, like other biological characteristics of a tree species, also changes from place to place.

After consideration of the possible methods of site classification from aerial photographs, the topographic approach, with addition of soil characteristics, was applied to evaluate site quality in this study. However, there is an unusual additional feature of this study. In one analysis site quality was expressed by site index not computed from data, but estimated directly from aerial photographs through evaluation of topographic and soil factors.

A brief explanation of site factors is given in the first part of this study for better understanding of the results of the analyses. Three kinds of forest areas were analysed, young stands (30 years old), second-growth stands (80 years old), and old-growth stands (more than 300 years old). Site maps were prepared only for young stands because the second-growth and old-growth area had been mapped in 1950.

SURVEY OF LITERATURE

Introduction

The use of aerial photographs for forest-site classification is not new. Various methods have been developed based on the photo-recognizable variables of site quality, such as physiographic site classification, topographic site classification, direct estimation of site index using topographic variables, and site classification by forest associations. This is the first comprehensive test of site mapping from aerial photographs in British Columbia.

(1) Physiographic-site classification

Hills (1950) developed a system for classifying soil sites from aerial photographs in Ontario. His system was based on soil nutrients, moisture regimes, and ecoclimate. For basic forest-site classification he used the soil moisture regime, permeability of soil materials, temperature, and relative humidity of the local atmosphere (ecoclimate). The natural patterns of these basic soil sites are the geological patterns which can be called "land-types" or "site patterns". These land types indicate the soil moisture, soil permeability, ecoclimate, and other features of site. Since the possible number of soil sites may be over one hundred in each region, Hills grouped them into eleven classes from very hot and wet sites to very cold and dry sites. These basic soil sites were mapped on aerial photographs and described by symbols.

The Federal Forest Research Division applied the basic soil-site system for forest-site classification of Jack pine cover types in Quebec in 1953. Eleven soil-moisture regimes and permeability classes were used. Their combinations were grouped into 14 yield-site types. In addition nine land-types were recognized and described for mapping purposes. The basic site boundaries were marked on aerial photographs.

Burger (1956) used aerial photographs for identification of forest soils in Ontario. Parent material, soil moisture regime, and soil depth to the bedrock were estimated from aerial photographs by stereoscopic examination of the three major components of stereoscopic image, relief, vegetation, and land use. The interpretation was based on the combination of these components rather than on any single one.

Brown (1956) developed a method using aerial photographs for forest-road location through the interpretation of landforms on aerial photographs. A landform indicates a certain parent soil material, pattern of topography, depth to bedrock, drainage, and soil profile. A landform is a taxonomic soil unit. Brown used landtypes for mapping units which may include more than one landform. This method can be used for site classification since specific topographic positions on a given landform, within a given landtype, are characterized by differences in drainage. Topographic positions are the landtype components or sites. Landtypes can be interpreted on aerial photographs through the identification of features of vegetation, topographic forms, soil parent material, drainage, and profile development. Recognition of geological materials is the major factor in segregation of landtypes.

Davidson (1957) investigated the possibility of applying Hills' system to the University of British Columbia Research Forest. He stated that there would be little value to using the original system, but it would be possible to derive a system of site classification based on the soil-moisture regime, available nutrients, and their biological effects.

Hellum (1959) investigated various measures of site within the area of the University of British Columbia Research Forest. He found that soil depth and soil-moisture conditions are the major factors influencing site. Hellum also studied the interpretation of geologic and physiographic details from aerial photographs. He concluded that site study on the basis of landform and geomorphological principles is a very good approach since the study of surface expressions of physiographic forms gives information about landforms, history of formation, conditions of climate, and parent material.

Lacate (1959) applied Brown's system for a tentative physiographic site mapping from aerial photographs for a part of the University of British Columbia Research Forest. The following major landtypes were separated: (1) Deep glacio-fluvial deposits (outwash sands and gravels and related water sorted deposits). (2) Till-capped, shallow to bedrock, hilly to strongly rolling uplands. Granite, granodiorite or quartz diorite are main bedrock types. (3) Lacustrine or glacio-marine, stony to stone-free, sandy clay to silt loam deposits, deep and shallow to granitic-type bedrock. These major landtypes were divided into major landforms, which are the following:

Inclusions within landtype (1)

(a) till, shallow-to-bedrock,

(b) exposed bedrock knolls,

(c) shallow organic-type soils overlying bedrock,

(d) washed till in draws and gullies and at lower slope positions,

(e) till, moderately deep to bedrock.

Inclusions within landtype (2)

(a) deep water-laid sorted to semi-sorted sand and gravels, sometimes slightly loamy,

(b) water-laid material shallow-to-bedrock,

(c) water-washed till (finer fraction removed); usually coarser textured than dumped till mentioned above,

(d) exposed bedrock knolls.

Inclusions within landtype (3)

(a) clayey soils, moderately deep,

(b) clayey soils, shallow to bedrock,

(c) water-washed till or roughly sorted materials,

(d) bedrock knolls.

The following major sites were delineated within landforms:

1. Most common sites on glacio-fluvial materials in major valleys,

(a) excessively drained and well-drained sands and gravels (deep),

(b) excessively drained and well-drained sands and gravels shallow-to-bedrock,

(c) moderately well-drained to imperfectly drained sands and gravel deposits,

(d) poorly drained muck and poorly drained sand and gravel at foot of steep slopes or in bedrock-controlled depressions (not extensive in area).

2. Most common sites on till-capped bedrock hills,

(a) exposed bedrock and excessively drained loamy sand to sandy loam till sites (topography usually broken, or moderately steep),

(b) well-drained to moderately well-drained till, shallow-to-bedrock sites on mid- and lower-slope positions,

(c) imperfectly drained sites (dumped and washed till) in draws, gullies and depressions controlled by bedrock underlying thin soil mantle,

(d) moderately well-drained (pockets and lower slopes), moderately deep till (bedrock deep enough to not act as control on seepage water within rooting zone),

(e) imperfectly drained to poorly drained till and muck sites (not extensive in area) at foot of slopes and in bedrock depressions.

3. Most common sites on glacio-lacustrine (marine) sites,

(a) well-drained to moderately well-drained sandy clay moderately deep,

(b) well-drained sandy clay shallow-to-bedrock (not extensive),

(c) imperfectly drained to poorly drained sandy clay to loam on flats, lower long slopes and depressional topography.

Each landform was described by the following physiographic factors:

(a) Topography: gentle slope, moderate slope, steep slope, flat, draw or gully, depressed flat or depression, undulating (micro relief), ridge, and knoll.

(b) Soil drainage: very excessively drained, excessively drained, well-drained, moderately well-drained, imperfectly drained, very imperfectly drained, somewhat poorly drained, poorly drained, and saturated.

(c) Parent material: bedrock, granite types - granodiorite, quartz diorite, etc.; dumped till, unsorted, sandy loam, moderately compact in C-horizon; water-washed till, unsorted to roughly sorted, gravelly loamy sand to sandy loam; waterlaid, sorted sands and gravels (loamy sand in texture in places); sandy to silty clay, stone-free to stony waterlaid, glacier-lacustrine or glacier-marine deposits (restricted elevationally in southwest and west portions of Forest); organic muck; roughly sorted sand and gravels (alluvial fan-type deposits), (included in this type of parent material are colluvial deposits at base of steep bedrock slopes).

(d) Soil texture: sand, gravel, loamy sand, sandy loam, clay loam, and silt loam.

A method of land classification was applied on more than 8 million acres of national forest land in the state of Washington (Washington Agricultural Experiment Station, 1955). This method was established for evaluating and mapping mountain land features for forest management purposes. The appraisal and mapping constituted the delineation of soil material, quality and quantity, and topographic variance as landform units. Both field and stereophoto appraisal were carried out. The field delineation of soil types was corrected by stereophoto interpretation. New delineations were also made on aerial photographs by applying field notes to the physiography seen on the photographs. The landforms were mapped by field appraisal and checked and refined on aerial photographs by stereoscopic examination. New landform areas were delineated by reference to field notes. This method was found satisfactory for soil classification and mapping of a vast forest area.

Lutz and Caporaso (1957) investigated vegetation and topographic situations by using aerial photographs in the Alaska Interior. This method was used for classification of burned lands into broad productivity classes. They used tree species and topographic situations for recognition of forest land classes. The following tree species were found to be useful indicators of land classes: white spruce, black spruce, paper birch, quaking aspen, balsam poplar, and willows. Aspect had a powerful influence on soil conditions, especially on drainage and depth to permafrost, and forest vegetation. South facing slopes were most favorable for forest growth. Degree of slope was also an important factor when the slope percentage was less than 10 per cent and more than 60 per cent. Soil drainage was impeded and the ground was frozen on gentle slopes and steep slopes were too dry for normal forest growth. The natural boundaries of vegetation types were used in judging and delineating site conditions.

(2) Topographic site classifications

Losee (1942) used the topography and visible characteristics of vegetation for mapping forest-site from aerial photographs at Petawawa. The topographic situation of a specific area interpreted with knowledge of the geology and soil was used to evaluate site quality. He delineated the following series of site types: (a) Ridge series, (b) Dry series, (c) Moist series, and (d) Swamp series. These series were divided into forest associations or forest site types. This method was also applied in Saskatchewan and to two areas in Quebec. The following six sites were described in Saskatchewan in order from the best to the poorest site: (a) Fluvial (b) Lacustrine, (c) Glacial slope, (d) Delta, (e) Plateau, and (f) Lowland. Under Losee's supervision a similar method was used to map site on aerial photographs in Eastern Canada in 1955. Nine to thirteen different sites were determined, which were varied by regions. The following sites were recorded for the Port Arthur Division: (a) Wet flat, (b) Dry flat, (c) Lower slope, (d) Upper slope, and (e) Ridge.

Moessner conducted a study of photo classification of forest sites at the Central States Forest Experiment Station, U.S.A., in 1948. He indicated that forest site variations are largely caused by basic differences in topography and soil. Moessner pointed out that forest site classification from aerial photographs can be based on topographic position and soil groups.

He recognized three classes: (a) Upper slopes, (b) Lower slopes, and (c) Bottom land, considering aspect and position on slope. For areas where more than one broad soil group occurs, site classification should be based on soil group or landform, in addition to topography.

Land and soil characteristics have been classified by the Northeastern Experiment Station, U.S.A., during the past thirteen years. They found, working in West Virginia, that the site index of red oak is correlated with aspect, slope per cent, position on slope, and depth of soil. The Station classified only the first three factors on aerial photographs.

(3) Determination of site index from aerial photographs.

Johnson (1957) applied a method for evaluation of site quality for longleaf pine using aerial photographic evidence in the Southeastern United States. He used the following variables as independent variables to determine site index: total tree height, visible crown diameter, stand density in terms of per cent normal basal area, degree of slope, aspect, slope position, length of growing season, amount of rainfall during six warmest months of the year, number of dominant and codominant trees per acre, and the ratio of total height to visible crown diameter. He found that total height is strongly correlated with site index. Height is also correlated with age of tree. He stated that the height crown-diameter ratio is subject to considerable variation. No correlation existed between slope position and site quality. Only average tree height, percentage of slope, and number of trees per acre were found usable for site index prediction. He also applied a topographic site classification. The following topographic site classes were used: (a) High flats (under cultivation), (b) Bottomland flats, (c) Broad benches, (d) Upper slopes, (e) Lower slopes, (f) Narrow ridge tops, (g) Savannahs, and (h) Heavily gullied areas.

Choate and Pope (1958) investigated the possibility of developing a technique for estimating site index of Douglas fir in the Pacific Northwest using aerial photographs and topographic maps. Seven topographic variables were selected as independent variables: elevation, latitude, aspect, slope per cent, shape in profile, shape in contour, and soil depth. The multiple-regression analysis showed that two variables, aspect-plus-slope and aspect-plus-slope to the second power, were not significant. Seven other variables were highly significant, namely elevation, elevation to the second power, latitude, latitude to the second power, elevation-times-latitude, profile-plus-contour, and soil depth. Equations using topographic features were found useful for estimating site index as the dependent variable by a double-sampling procedure.

Tarrant (1948) conducted a ground soil survey for the Voight Creek Experimental Forest near Orting, Washington. He found that the relationship between types of topography and site class of Douglas fir was statistically significant. Two soil types, Barneston gravelly sandy loam and Indianola fine sandy loam were found within the experimental forest. The topography was classified by the terms convex and concave. The topographic units were used for soil mapping. This method could be used for site classification from aerial photographs since these topographic units are recognizable on aerial photographs.

(4) Site classification by forest associations.

Eis, Lesko, and Orloci (Krajina, 1960) carried out an ecological classification of the Coastal Western Hemlock Zone in British Columbia. They based their classification on forest communities. Each community was broken down into forest association types, these forest association types represented different site types. Each type occurs on certain topographic positions, therefore should be recognizable on aerial photographs. This method might be applied for site classification from aerial photographs as a useful supplement to physiographic site classification.

DEFINITION OF SITE QUALITY

The forest is a symbiosis of ligneous plants in an interconnection with the environment; this interconnection is changing as a result of mutual influences and of effects exerted in its external shape and in its inner structure (Morozov, 1922). A natural forest is the outcome of an evolution reaching back over centuries, but its present-day appearance depends on both earlier and more recent influences of climate and soil. The forest is not an independent creation, which submits itself to any kind of treatment, but a living community reaching far into its environment. The trees occupy a bit of both air space and ground space where many vital factors operate. No one can isolate these factors from each other and look separately at them. However, because we cannot comprehend a living space as a whole and describe it intelligibly, the forest environment which represents a complex condition and the nature of its influence, can be understood and interpreted only by factoring the environment into its components. The combination of these factors determines the productivity of an area.

There must be a classification by productivity in practical forestry. This classification concerns the potential productivity of an area, in which case the capacity of the soil and the climate to produce timber are the essential factors involved. The productivity of a forest area is commonly expressed by the term "site". Site is used in forestry in two senses, as an area or locality that supports tree growth, and as the capacity of that area to support tree growth (Spurr 1952). The scientific term "site" is applied to the combination of climatic and soil conditions affecting a plant. From the standpoint of silvics, site may be considered as including everything relating to the factors operating in a geographically definite locality so far as these factors influence forest vegetation (Toumey, 1937)

Site quality is a term used to indicate the productive capacity of an area of forest land usually for a given species or a combination of species (Spurr, 1952).

The definition of site given by the Committee on Forest Terminology of the Society of American Foresters (1950) is:

"An area considered as to its ecological factors with reference to its ability to produce forests or vegetation; the combination of biotic, climatic and soil conditions of an area".

Hills (1952) defined the "total site" term as follows:

"Site is the integrated environmental complex of all the features of a prescribed area, and, as such, is a specific unit".

Absolute site quality is measured by the maximum amount of wood that can be grown upon a forest area. To estimate site quality in practice it is necessary to find a measure which is easy to obtain, accurate, and relatively independent of stand density. Assessment of site is very complex even when applied to areas in which all environmental conditions are essentially uniform.

For classifying the site we may choose as reference points any combination of features which appear significant. Site includes all features, but it can be reduced to those combinations of features which are significant under specific circumstances (Hills, 1952). However, we always have to view the whole when we classify by parts.

FACTORS WHICH INFLUENCE SITE QUALITY

All sites depend upon certain essential components which are termed site factors. The relative intensities and duration of action of these factors determine the differences in site. Site factors may influence directly or indirectly the nature of the site. Trees and other kinds of vegetation differ on different sites. These differences exist not only in vegetation but also in climate, soil, and in other factors. The following site factors will be discussed here: climatic factors edaphic factors, physiographic factors, and biotic factors.

Climatic Factors

Climatic factors include all those influencing plant life that are associated with the atmosphere. They have the greatest importance in determining the vegetation of a large area. The extent of their influence may be regional or local. Climatic factors refer to conditions delimiting climatic regions when their influence is regional. They refer to conditions modifying regional climate mainly by topographic variations and interrelations of lands and water within a given climatic region. Climate is not exactly the same at any two places because the regional climatic factors are modified by local conditions.

Rhythmic and progressive changes in climate exist everywhere (Toumey, 1947). The rhythmic changes are recurrent alternations from day to night, and from season to season. The progressive changes are progressive alterations such as increase or decrease of temperature or aridity occasioned by changes in climate over longer periods of time. These progressive changes are slow, therefore the climate of any particular place is essentially stable in its effects on vegetation.

Temperature, moisture and light are the most important conditions determining regional and local climate. The factors which determine these conditions are: Solar radiation, air temperature, atmospheric humidity, precipitation, and wind.

(1) Solar Radiation

The chief energy is solar radiation for green plants and all life which depends upon them. The arrangement of forest vegetation in vertical layers or zones is controlled by intensity, quality, and duration of the light that reaches each layer (Toumey, 1947). Intensity and quality of solar radiation, which reaches the surface of the earth, varies with latitude, altitude, season of the year and time of day (Kimball, 1936)*. Solar

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*Cited by Toumey, 1947.

radiation may be modified also by local topographic features, vegetation, and by the atmospheric conditions resulting in scattering and absorption of light. Solar energy is altered by the atmosphere. Clouds greatly decrease the quantity of light and change its quality also by absorbing the longer wave lengths. A tree growing under a canopy is exposed to an increased percentage of reflected and transmitted light. An open-growing tree is exposed to the highest degree of unfiltered light. Under higher light intensities some plants increase their rate of growth much more than others, but in all species when the light intensity under a canopy is very low and other factors are not more significant, the rate of growth is directly proportional to the intensity of light. Height growth is also related to the intensity of radiant energy. Reduction in light intensity reduces photosynthesis and may cause an increase in height growth (Toumey, 1947).

(2) Air Temperature

Temperature of the air has no significant effect on the form and structure of trees; however, it is a fundamental factor. The action of heat is visible only in its final consequences as in increased retardation or complete cessation of physiological processes. The temperature of trees is approximately the same as the temperature of air which surrounds them. When a tree is colder it absorbs heat from the air and when a tree is warmer, it gives off heat to the air. A tree obtains its heat mostly from the sun through the atmosphere. The temperature of a tree is seldom exactly the same as the temperature of the air because of the slow heat conductivity of plant tissues. A tree with deeper tissues is cooler than the air during the day, and warmer at night. Open-grown trees begin cambial activity earlier than those growing in stands. An unfavorable temperature causes unhealthy development and death of the trees through disease. Trees suffer direct damage from frost. The loss of reproduction from frost is great.

Air temperature directly affects growth. Solar radiation modifies the air-temperature requirement of a given species; a tree growing in the open requires lower air temperature than the same species growing under shade. The air temperature determines the limits beyond which particular species and particular communities can not extend (Merriam, 1898).*

(3) Precipitation

Precipitation may occur in the form of rain, snow, sleet, hail or dew. Precipitation is the chief source of water for trees. When the air is cooled to the dew-point, or to the point of saturation, it cannot hold all the water in a vaporous state and the water is deposited in the form of mist (clouds), rain or dew. Precipitation influences forest growth both indirectly through its mechanical action on the trees and on the soil. Mist absorbs the light and retards heating of the soil. Precipitation influences the distribution of forests by its variation in geographical distribution. The character of a

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*Cited by Toumey, 1947.

forest depends in part upon the seasonal distribution of rainfall. Precipitation during the winter is not so effective as summer rainfall. A very low precipitation during the growing season may cause deficiencies in soil moisture such that the trees die. (Hursh and Haasis, 1931, Shirley, 1934, Toumey, 1947).

Snow is generally beneficial for forest vegetation during the winter, but it may be destructive to reproduction and young growth. Avalanches are very destructive to forests in high mountains.

(4) Atmospheric Humidity

Atmospheric moisture is in the form of vapor. It is the immediate source of supply for precipitation. The amount of moisture in the air is a main factor influencing forests. Water is a factor fundamental to the vital processes of trees. The chief factors which influence the distribution, occurrence and development of forest are precipitation, atmospheric humidity, and evaporation. Environmental conditions reduce the atmospheric humidity within certain limits, such as high air temperature, high winds, and intense solar radiation. Atmospheric humidity is commonly expressed as relative humidity, which is the percentage of saturation of the air. The amount of water in the atmosphere determines its absolute humidity. When the temperature is decreasing, the relative humidity is increasing without increasing absolute humidity.

The combined effect of atmospheric humidity, atmospheric pressure, temperature, solar radiation, and wind is evaporation. The evaporation rate has an influence on transpirational water loss from trees and also on reduction of water content of the soil.

(5) Wind

Wind influences both the form of trees and their distribution. Its direct influence is its mechanical action on trees. Wind indirectly affects trees through its influence on humidity, soil moisture, evaporation, transpiration, and distribution of atmospheric precipitation.

Edaphic Factors

Edaphic factors relate to soil conditions. These factors are: soil composition, soil moisture and permeability, and soil temperature. Forest soil is a portion of the earth's surface which serves for the sustenance of forest vegetation. It consists of mineral and organic matter, permeated by varying amounts of water and air (Wilde, 1946). Soil is differentiated into horizons, usually unconsolidated and its depth is variable. It differs from its parent material in composition, physical and chemical properties, and biological characteristics.

Trees and other plants obtain from the soil water and nutrients, which are necessary for the physiological processes associated with growth. The soil also provides trees and plants with space for root growth and development. The nature of soil and parent material influences the kind and the distribution of vegetation. The climate also is an important determinant of the range of species, but the condition of the soil often is responsible for limiting its occurrence (Toumey, 1947). Soil influences the rate of growth, yield, form,quality of wood, tolerance and reproduction of trees. The influence of soil is apparent in the local distribution of trees. If climatic conditions are similar, the quality of a site is determined by the character of the soil and its topographic position (Toumey, 1947). The climate, parent material, topographic position, and vegetation are the important factors concerned in the development of a soil.

(1) Soil Texture

Soil material may be divided into two fractions: (a) coarse fraction- larger than 0.05 mm in diameter: stones, gravel and sand-, and (b) a fine fraction- smaller than 0.05 mm in diameter: silt, and clay. The relative amounts of the coarse and fine fractions of a soil determine the soil texture. The coarse soil material supports plants. The fine soil fractions are the active portions of the soil. They fulfill many ecological functions through their absorptive and nutritive properties. The ability of soil to retain water depends upon the amounts of silt and clay present. The higher the amount, the greater is the soil moisture. The soil pores are filled with water or air, therefore an increase in the soil material and subsequent increase in soil moisture often leads to decreased soil aeration (Wilde, 1946). The fine fractions are the chief source of soluble substances. These effects of the textural properties of soils are reflected in the composition and the rate of growth of forest vegetation (Wilde, 1946).

(2) Soil Depth

Depth of the entire soil and the thickness of various horizons are important for tree growth, largely because of water stored in the soil. The soil depth varies from a few inches to many feet and it determines the penetration of tree roots. The lower limit of the forest soil is often delineated by an impermeable layer of soil or bedrock.

(3) Soil Moisture and Permeability

Vegetation obtains water, which is needed for transpiration and growth, by absorption through roots from the soil. The amount of water reaching the soil is determined directly by the amount of precipitation. It varies from one climatic region to another and it may show great seasonal and yearly variation within a region.

Water is present in the soil both in liquid and vapor forms. The various forms of water in the soil can be classified as follows, according to their movement or retention in the soil: (a) gravitational water; (b) capillary water; (1) interstitial,

(2) absorbed; and (c) water of hydration. Gravitational water is free to move under the force of gravity. It remains in the soil only a short time, therefore it is of little use to plants. Film forces hold the water in the interstitial spaces between soil practicles. It is used by plants because its movement is extremely slow and uninfluenced by gravity. This movement is determined by the size of interstitial openings, the viscosity of water, and the combined forces of adhesion and cohesion which cause water to wet the surfaces of soil particles and still maintain a continuous film (Toumey, 1947). Water of hydration is in chemical combination with the secondary soil minerals and is unavailable to plants.

Every tree species has a certain soil-moisture requirement under which it has optimum growth. There is a wide range of optimum soil moisture for different species. The growth and vigor of a given tree depends upon how nearly the soil conditions conform to the maximum soil-moisture requirements for the species. Each species is adjusted in form and structure to its normal water requirements in nature. External factors, which determine absorption and loss of water, may change the form and structure of tree species. These changes very largely determine the character and form of forest growth.

(4) Soil Temperature

The functional activity of tree roots depends on soil temperature and increases with increase of soil temperature up to the optimum. A too low soil temperature may kill a plant. The heat of the soil depends upon duration of sunlight and the angle of incidence of the sun's rays. The specific heat of soil varies with its composition; quartz sand heats quickly, peat heats slowly. The amount of water in soil significantly influences the soil temperature; dry soil heats quickly, wet soil heats slowly. Dark soils are rapidly heated by the sun's rays because they have greater absortive power. However the dark soils cool more rapidly than light soils, because they lose heat through greater radiation. Loose soils conduct heat slowly because of the larger air space.

The effect of soil temperature is uncertain on the form assumed by trees. High soil temperature gives rise to an abundance of sap and to short and thick roots, stems, and leaves (Wesque, 1878).* Vegetation is more subject to injury from spring frost in warm soils.

Physiographic Factors

The physiographic factors include the conditions which determine form and structure of a land surface and the progressive and rhythmic changes in these conditions. The topographic factors such as altitude, slope, exposure, position on slope, shape in profile and contour, and surface conditions indirectly affect forest vegetation through their effect on the direct factors. Their effects are expressed in the differences in forest vegetation on upper slopes as compared with lower

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*Cited by Toumey, 1947.

slopes, etc. The progressive changes are brought about through erosion and deposition. They have a great influence on forest vegetation. Cyclic changes in physiography are expressed in seasonal changes in water level; they are important in silviculture.

The physiographic factors largely determine the local or micro-climate. These factors affect particularly soil nutrients, soil moisture, and soil temperature (Russel, 1932).* The existing relation between the physiography of a region and the grouping of its flora determine the effect of physiography upon the water content and composition of the soil.

(1) Exposure

Exposure is the direction of the slope of the land. It determines the amount of sunlight received by a slope. Exposure modifies the moisture content and the temperature of the soil and air. A slope exposed to the sun and wind has different vegetation depending on the extent of exposure. Vertical sun rays cause greater heating in the soil than those striking the soil at an oblique angle. Trees grow at lower altitudes than their normal range on the cooler, northerly exposures, and above their normal range on the warmer southern slopes in mountainous regions. The effect of exposure is also influenced by the steepness of the slope and by the action of air circulation. North slopes have a maximum amount of atmospheric and soil moisture, because they are protected from the sun during

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*Cited by Toumey, 1947.

most of the day.

An easterly slope is protected from the sun during the hottest part of the day. It is a favorable slope for tree growth and usually has dense stands with good rates of growth (Toumey, 1947). There is the danger of too rapid thawing after frost on east slopes because it has early sun.

South slopes are warm and dry. The soil dries out quickly on these slopes. West slopes are also dry and warm.

(2) Slope and Position on Slope

Slope indicates the relation of the surface of the land to the horizon. It controls, through runoff and drainage, the water content of the soil. Slope modifies the intensity of insolation. When other conditions are similar, the gradient of the slope directly influences the depth of soil and its water content. Soil is deepest on level situations and roots are able to develop freely. However the soil may be poorly drained and tend to swampiness. The soil is fairly deep on gentle slopes and its moisture supply is plentiful. Steep slopes have shallow soil, especially on very steep slopes with rock outcrops. Vegetation on the steep slopes is exposed to heavy rainfall which may cause floods and landslides.

(3) Earth Configuration

The configuration of topographic relief has a great climatic significance. Rock formation determines the local water supply of the soil and the location of springs. Many soil characteristics are closely related to the shape of the land. Convex topography includes ridges, hilltops, and upper slopes. The effect of convex topography on the site is through the fact that soil loses its fine material, humus, and mineral salts through erosion, and loses moisture through drainage. Concave situations include the lower slopes, valleys, and basins. The effect of concave topography on the site is to build soil by deposition of fine material, soluble salts, and moisture from higher lands (Tarrant, 1950).

The horizontal shape - shape in contour - of a land is also important because it affects the duration and the frequency of exposure of land to the wind and sun. It also influences drainage. Soil of a depression is usually more moist than soil on a spur or on the end of ridge. A depression is relatively sheltered from the drying effects of wind and sun. Frequently a stream is located in a depression.

(4) Altitude

Altitude modifies the climate very much. The higher parts of a region are more subject to lightning. Solar radiation is more intense during clear weather at higher elevation than at lower elevations. Temperature of soil and air decreases with an increase of elevation. Decrease of air temperature greatly influences the amount of precipitation on the windward side of mountains, ridges, or hills (Toumey, 1947). Each tree species grows best at a certain altitude in any mountainous region. As a mountain is ascended, from the plain to the mountain top, a series of zones of vegetation is passed through. Each zone has one or more characteristic species as dominants. (Toumey, 1947).

(5) Latitude

Latitude influences the growth habits of a tree species. Seed from more northerly latitude starts later and completes growth earlier than the native seeds. Trees from warmer regions planted in cooler localities start growth later.

(6) Surface Conditions

The surface of forest land often shows irregularities such as rock outcrops and depressions. These irregularities can be described as even or uneven surfaces, a description which includes both the living and non-living soil cover. Surface condition affects all the direct soil factors.

Biotic Factors

The biotic factors are the plant and animal agencies, including man, which have a great influence on forest vegetation either directly or indirectly. These factors may change, arrest, or more or less completely interrupt the development of forest vegetation. Such actions of biotic factor are of great importance in a forest. The complex relationship between plants and between plants and animals profoundly affects forest vegetation as a whole (Toumey, 1947). The effect of community life is imprinted on forest vegetation and on the site itself.

(1) Vegetation

The interrelationships between forest plants are various and numerous. Competition occurs where trees grow close together forming a forest stand. Weaker trees are overtopped, suppressed, and crowded out by the more vigorous and more aggressive individuals as the result of competition. The relative aggressiveness of dominant species determines the composition of a mixed forest. This aggressiveness depends upon the ease and rapidity of reproduction of a species, and on its growth and its light, moisture, and soil requirements (Toumey, 1947). Stand composition is determined largely by the relative capacity of various species to occupy a site permanently.

Every forest community is changing from time to time. The forest arises, develops, and matures under the influence of the site factors. The series of these changes are called succession. The progressive changes in development of vegetation are the most important. On the same site one community replaces another which is different in growth form.

Vegetation moves forward from one stage to another in succession. Large areas of vegetation are never in complete equilibrium with the site; it is never free from small disturbed areas.

(2) Animals

The presence of animals in a forest has great importance to forest life. The interdependence between animals and plants is more obligatory than between plants alone or between animals alone (Taylor, 1935).* The effect of animals on the forest may be constructive or destructive. The forest provides the animals food, shelter from inclement weather, and protection from enemies.

(3) Man

Man is the most powerful and persistent contributing factor in deforestation or in disturbance of natural conditions in forests. Man is primarily interested in products of the forest which satisfy human needs. The original balance of nature has been disturbed and changed by man through clearing of forest land, cutting of timber, burning of forest land, elimination of native plants, and introduction of plants and animals. Man has modified and is modifying the condition and economic importance of natural forest areas.

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*Cited by Toumey, 1947.

RECOGNITION OF SITE FACTORS ON AERIAL PHOTOGRAPHS

Site factors were discussed in the previous chapter. Interpretation of these on aerial photographs is limited because climatic factors, soil composition, and soil temperature are not recognizable on the photos. Interpretation of edaphic factors and of biotic factors is possible to a limited degree. Recognition of physiographic factors is relatively easy and accurate. Since local climate is controlled by local physiographic conditions part of the climatic factors is determinable through study of physiographic factors.

Physiographic Interpretation

The basis of physiographic interpretation is analysis of topography, and study of its origin, so far as possible. Physiographic development is studied in reverse order, from the more evident to the less evident. The most important evidence is the external form, i.e., surface form, which is recognizable on aerial photographs. Surface form includes the morphology of individual features and the pattern, form, and drainage of the topography as a whole (Smith, 1943).

All kinds of aerial photographs are suitable for physiographic interpretation with the aid of a stereoscope. The interpreter must have an elementary knowledge of principles of physiography and geology, and skill in photo-interpretation.

(a) Development of Topography

Topography of an area is the product of the following factors: (i) Initial form, (ii) Internal lithology and structure, (iii) Climate, (iv) Modification processes, and (v) Stage of development.

Initial form determines the disposition of landforms; upland and lowland, and direction of stream flow. Initial forms are subjected to progressive modifications, determined by the other factors. The current form in a cycle is determined by the previous processes of erosion and deposition. When the initial forms are subjected to erosion, the effect of internal lithology and structure exist. The effect of erosion causes valleys and hollows on weak rock. Resistant rocks constitutes ridges, ledges, and higher parts of the landscape. The distribution of ridges and valleys determines streamflows and drainage patterns, and influences the nature of topography.

The influence of internal lithology and structure is more important in the maturity of the erosional cycle (Smith, 1943). Resistant and weak rocks are reduced and the effect of erosion is minimized with increased age of topography.

Climate influences the processes of deposition and erosion. It controls glaciation, stream erosion, wind action, and decomposition or weathering of rock.

The type of sequential landforms is determined by surficial processes which include: weathering, mass movement, stream action, glaciation, wind action, subsurface solution, and work of waves. Interrelations between stream action, mass movement and weathering are very important. Erosional and depositional landforms are the two main types produced by the surficial processes. Different processes result in many kind of landscapes.

The stage of development of a topography refers to the degree of a definite cycle. Stages of erosional development are described in the terms youth, maturity and old age. Distribution, orientation and interrelation of landforms have great significance in the analysis of erosion and deposition (Smith, 1943).

(b) Classification and Description of Geographic Units

Landforms may be considered as geographic units. They are the result of the effects of erosional and crustal movement forces on bedrock. The character of landforms indicates the kind of bedrock material and the erosional forces. Landform has a close relationship to the geologic materials upon which they were formed, and to the vegetation which grows on these materials.

It has been mentioned above that the two basic landforms are the most important, the erosional landform, and the depositional landform. Erosional landforms include combinations and variations of plains, valleys, slopes, ridges, and uplands. Floodplain deposits and valley fill, alluvial fans, basin deposits and deltas are the major depositional landforms as the results of stream action. These two major landforms can be divided and described by origin, for example: Landforms of volcanic and tectonic origin, landforms produced by mass movement, landform of eolian origin, etc. More information can be obtained from Smith (1943), and Lveder (1959).

(c) Recognition of Hydrographic Features

The subsurface water has a great influence on the process of geological change, and on the life of vegetation. The distribution and quantity of subsurface water control the flow of rivers, the levels of lakes and the location of swamps, thus the surface water is closely correlated with the subsurface water. Hydrographic features as a term includes all forms of surface water.

Streams

Streams are the most common form of hydrographic features. Recognition of streams is relatively easy on aerial photographs, because of uniform texture and color of the water surface, and characteristic winding and branching. Dry stream beds can be recognized by the light color and texture of sand or rocks. The characteristic of individual streams which may vary widely, are determined by the topography and parent material. Stream systems form the drainage pattern. They are extremely important in the determination of geologic structure and of character of the topography. Stream patterns may occur in many combinations. More information can be obtained on this subject from Smith (1943) and textbooks on glacial geology and geomorphology.

Ponds and small lakes

Ponds and small lakes can be determined by their appearance, texture and color. The form of appearance of a lake may be rounded, elongated, curved, or irregular. The bottom of a lake, when dry, is recognizable but is less uniform than the water.

Large lakes and seas

The extent of a water body can be recognized easily on photos. The edge of lakes or seas is distinct.

Swamps

Swamps appear in dark tones on aerial photographs, their texture generally is fine and frequently is mossy. Sometimes stunted trees are present in swamps. The form of swamps is sprawling and irregular. Swamps occur in poorly drained areas.

(d) Recognition of Topographic Factors

Recognition of topographic features on aerial photographs is the most accurate. A given topography appears in a three dimensional view under steroscopic examination. A topography can be described as a whole, for example: mountainous topography, badland terrain, and flat plains topography, or by its individual elements. Elements of topography greatly influence the distribution and growth of vegetation, therefore these elements are very important in site classification.

Aspect

Recognition of exposure of a hillside or valley is easy on aerial photographs if the direction of flight is known. Aspect can be recorded by cardinal points or azimuth readings generally. Recordings can be made to the nearest 45 degrees of azimuth reading or by eight cardinal points when detailed information is necessary.

Sites which are level, or nearly level with less than 5 per cent slopes, are exposed in all directions; these sites can be recorded as level situations.

Percent of slope

Percentage of slope can be determined with parallax bar or height finder and sterescope from aerial photographs. One has to select points on the top and bottom of the slope.

These points should be on a line which is parallel with the principal direction of the slope. To determine the slope percentage we have to measure and calculate the parallax difference and ground distance between the two points. Parallax difference can be measured by height finder, and converted to difference in elevation in feet. The distance between the two points can be determined by any kind of scale, then converted to ground distance in feet. The formula is the following:

$$\text{Slope per cent} = \frac{\text{Parallax difference converted to feet}}{\text{Ground distance in feet}} \times 100$$

Recording can be made in 10 or larger per cent classes.

Shape in profile

Shape in profile relates to the curvature of the slope. It can be recorded as concave, straight, and convex (Figure 1).

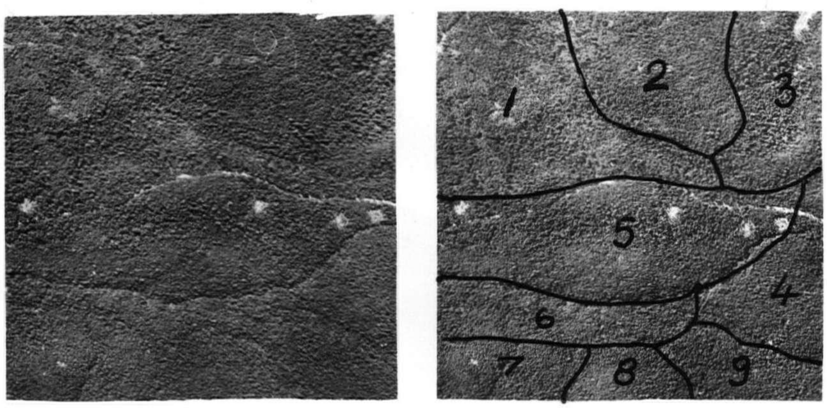


Figure 1. Stereogram illustrating shape in profile and contour.

(i) Concave: Relief is concave in profile (type 1). It is associated with lower slopes, basins and valley floors.

(ii) Straight: Slopes, which are neither convex or concave, are called straight. These are usually midslopes (type 2).

(iii) Convex: Slopes are convex in profile (type 5). Convex situations are characteristic of upper slopes, hills, and tops of ridges. They include plateaus which are level, or nearly level (less than 5 per cent slope), and which do not receive seepage water from above.

Level situations can be classified as concave or convex, concave if in a valley and receiving runoff or underground drainage from above, convex when found on the top of hills and losing moisture.

Shape in contour

Shape in contour relates to the horizontal shape of the land. The end of a ridge or a protuberance of a ridge will be convex; a draw or a cave would be concave.

Terms concave, straight, and convex are used also in the description of the horizontal shape of the land.

(i) Concave: Relief is concave in contour (type 1). It is represented mostly by draws or minor valleys on hillsides.

(ii) Straight: Slopes are straight without significant curvature in contour (type 6). This also includes level situations and slopes with less than 5 per cent.

(iii) Convex: Relief is convex in contour (type 5) such as the rounded ends or protuberances of ridges or hills.

Position on slope

Site characteristics vary along the slope. Determination and description of the slope is easy. Position on slope can be recorded as a level situation, low slope, middle slope, upper slope, and ridge, or hilltop. Position on slope may be described as local or general. A hillside can be divided into upper slope, middle slope, and low slope. A narrow bench on an otherwise middle slope, can represent low slope if we consider its relative location on the middle slope.

Elevation

Elevation can be obtained from a contour map or directly from aerial photographs by measurement of parallax and solution of the formula:

$$h = \frac{HxdP}{P+dP}$$

where <u>h</u> is the elevation difference between two points in feet, <u>H</u> is the flying height in feet, <u>dP</u> is the parallax difference of the two points in inches and <u>P</u> is the distance between the principal point and the conjugate principal point on the photos in inches.

Recognition of Soil Factors

The following three major components are used to identify forest soil characteristics: (1) Relief, (2) Natural vegetation, (3) Land use.

Soil development is closely related to the physiography and relief of a certain site. Relief can be divided into macrorelief such as hills, ridges, valleys, terraces, plains, rivers, lakes, etc. and to microrelief such as small bedrock outcrops, minor depressions, lake shores, small streams, etc.

The topography determines the direction of stream flow and the relative content of soil moisture, the soil depth to the ground water table, and distribution of organic matter.

Natural vegetation indicates many soil characteristics. Examination of tree species distribution, stand density and tree height gives reasonable information for identification of soil. However, many species of trees occur on soils which vary greatly in their texture and drainage.

Land uses such as roads, railroads, excavations and cut-over areas are often good indicators of soil characteristics. However, these do not occur generally in natural forest.

(a) Parent material

Parent material has a great effect on soil development.

All soil originates from a parent material. The effect of parent rocks on the growth of trees is obvious in the mountains, where erosion rejuvenates the surface of soil.

Parent material is determined mainly by the occurrence of and distribution, shape, and size of hills, ridges, valleys, and plains, and by their position in the microrelief. Landforms give good information on parent material. Interpretation of parent material requires a knowledge of local glacial geology and local ecology.

(b) Soil material

Interpretation of soil material is very difficult on aerial photographs. General information can be obtained by examination of erosional and depositional patterns, stream flows and land use.

Bedrock

Its appearance depends upon the type of bedrock and conditions under which it is exposed. Bedrock appears in a bare and rough form generally. Sometimes bedrock forms rocky knobs and cliffs.

Loose rocks

The appearance of loose rocks depends on their size, spacing, and color. Black rocks appear in dark tone. Light-colored rocks look almost white. The texture of loose rocks depends on their continuity.

Sand

Bare sand can be found along beaches, and in dry beds of rivers and creeks. The tone of sand is light, and its texture is smooth.

Excavations sometimes indicate the soil material. Excavations can be recognized by texture, color, and their unnatural appearance. Interpreters can infer the purpose and material of excavation from its appearance and form. For example: sand, gravel, or clay pits are irregular in form and depth, and frequently show scalloped edges. Glacial till is often used for road building.

(c) Soil depth

Soil depth can be determined from aerial photographs with a moderate degree of success. Microrelief is closely related to soil depth. Ridges, hills and steep slopes have shallow soils. Bottoms of hills and gentle slopes may indicate deep till deposits.

Soil depth can be determined also by observing changes in stand composition. Changes in stand composition over a short distance often indicate shallow soil on a level relief. Douglas fir stands show good developmemt on deep loamy soil at lower elevation. Scrubby growth indicates dry thin soil on hill tops or excessive moisture in bogs.

Excavations are also good indicators of soil depth. Estimation of soil depth is relatively easy on cut-over areas because the surface of the ground can be examined directly.

(d) Moisture regime and permeability

Soil moisture regime refers to the available moisture content of soil for plants during a complete vegetation cycle (Hills, 1952). Soil moisture depends greatly on soil texture, which determines the movement and retention of moisture in the soil. However, a general relationship exists between moisture regime, permeability and slope percentage. This relationship depends upon the climatic factors, the actual amount and distribution of rainfall, and evaporation.

The extremes of moisture regime can be determined easily from aerial photographs. A muck or peat site will be very wet, whereas a ridge or hilltop with thin soil will be very dry. The position of the slope is a good indicator of the moisture regime. However, the parent material, soil material and soil depth should be known during interpretation of soil moisture regime. A sandy soil on flat relief or a narrow hilltop will be dry. A level situation or low slope with deep loamy soil will be fresh (normal). A swamp, or a valley bottom, can be described as wet.

When the relief cannot be used to identify moisture regime the forest vegetation is very useful for this purpose.

Species distribution is closely related to the moisture regime. Different species indicate different soil moisture. Thus species identification helps to identify moisture regime. Douglas fir is dominant only in well-drained portions of the lower and middle elevations. Western red cedar indicates moist soil on flat sites and banks of rivers. Red alder occurs on lowlands, river valleys and moist mountain slopes.

Permeability of soil refers to the capabilities of soil for retention and movement of soil water. Size and percentage of soil materials and their combination determine the movement of water in the soil. In permeable material water moves in any form, therefore either pervious or porous material may be permeable. Permeability can be interpreted by consideration of the parent material, soil texture, position on slope and slope percentage. Recognition of soil permeability on aerial photographs is uncertain.

Vegetation

The occurrence of a given tree or groups of trees on a given topographic site often is sufficient to permit the recognition and classification of the forest site quality. Distribution of species, with respect to the site as the characteristic habitat of a species, can usually be recognized on aerial photographs.

Individual trees can be recognized on aerial photographs by their image factors: shape, tone, shadow pattern, size, and texture. Crown form of the tree which is the most important factor in species identification, may be pyramidal, conical, spire-like, etc. These crown forms are distinctive for various species. Identification of tree species in pure stands is relatively easy. The percentage of tree species in mixed stands also is recognizable because of their tonal differences and characteristic appearance. (Bajzak, 1959).

Different forest communities indicate different site qualities. Recognition of forest types is possible on aerial photographs, by tree species identification, evaluation of water supply, relative size of vegetation and altitude. For example; the Douglas fir - salal forest type occurs on a shallow podsol developed from glacial till and rock outcrops, mostly on hill tops, ridges or on upper slopes. Excessive drainage makes the soil dry for most of the growing season. Douglas fir is the dominant species of this forest type. Western red cedar and western hemlock constitute the second layer of the stand. The site index range of this forest type is 70-110 feet.

The western red cedar - deer fern forest type is located on gentle slopes and on flat land on ground water podsol soils, which were derived mainly from glacial till. Excessive or very good water supply are characteristic of these soils.

Western red cedar is the dominant species. Some western hemlock and amabilis fir also occur in this forest type. The site index of this forest type is about 180 feet. These forest types exist in the coastal western hemlock zone on the mainland of British Columbia (Krajina, 1960).

COLLECTION OF FIELD DATA

THE UNIVERSITY OF BRITISH COLUMBIA RESEARCH FOREST, HANEY

Location

The U. B. C. Research Forest comprises about 10,000 acres, which are situated within the Coastal Mountains, 30 miles from Vancouver, British Columbia. The Forest is roughly rectangular and is bounded by Garibaldi Park, Pitt Lake, and Pitt Meadows (Griffith, 1960).

Geological History

The general region of the Forest consists of rugged mountains rising up to 7,000 feet above sea level. These mountains are separated by deep U-shaped valleys. The area was subjected to at least four glaciations. During each glaciation the land was depressed relative to the sea, and the ice rested on the sea floor. Then the ice thinned and floated, and glacio-marine stony clay deposits were laid down below elevations of

500 feet. Above elevations of 500 feet, outwash was deposited. After that the ice melted and the land rose above the sea (Armstrong, 1957).

Most of the rock on the Forest area is quartz diorite, granodiorite, or diorite. Some granite outcrops occur around Loon Lake. Volcanic rock occurs east of Marion Lake, and glacial drift can be found between Marion and Katherine Lakes.

Topography

The elevation range of the Forest is 100 - 2,600 feet above sea level. The center of the Forest contains three parallel north-south valleys. The eastern valley is formed by Marion Lake and the west fork of the North Alouette River. Blaney Creek flows from Placid Lake to Blaney Lake in the central valley. The western valley contains Loon Lake which is about one mile long, and 120 acres in area. The ridges contain numerous rock outcrops and vary in steepness. The central ridge forms a semi-circle running to the northeast until it reaches 2,600 feet elevation. Then it continues as a high ridge to the north boundary of the Forest. The northwest slope is rocky, very steep and drops abruptly from the ridge top down to the Pitt Lake. Scrubby trees grow on this slope. The southern portion of the Forest has a south exposure and is lower in elevation. Slopes have numerous rock outcrops and bluffs, and vary greatly in steepness.

The North Alouette River in the east and Blaney Creek in the west provide the major drainage of the Forest. The North Alouette River cuts a deep channel across the southeast corner of the area.

Climate

The climate of the Forest is considerably influenced by the Pacific Ocean and by the Coast Mountains. The general characteristics of the climate are mild, wet winters and relatively warm, dry summers.

Precipitation

Precipitation of the Forest follows the general pattern of the southern coastal region of British Columbia. The average annual precipitation is approximately 90 inches. The period from October to March is very wet with approximately 70 inches of precipitation as snow and rain for these six months. The other six-month period is dry with only 20 inches of precipitation. The annual average snowfall is about 60 inches. Precipitation is highest in December and January and lowest in July and August.

The lower part of the Forest represents a warmer and drier zone with precipitation of 70-80 inches per year; the higher part is cooler and wetter with precipitation over 100 inches per year.

Temperature and Hours of Bright Sunshine

Temperature is mild during the winter months, approximately 30°F, and cool in the summer approximately 60°F. The average annual temperature is about 50°F. The average length of frost-free period is about 190 days per year. The total number of hours of bright sunshine is about 1,300. Hours of sunshine are lowest in December, approximately 30 hours, and highest in July, about 200 hours.

Soil

The following five main soil types are distributed on the Forest area: (1) Alluvial soils. (2) Organic soils. (3) Hydromorphic soils, (4) Dry edaphic soils, and (5) Climax or zonal soils.

(1) Alluvial soils

These soils occur on flood plains and occupy relatively small areas, however, their economic importance is high because of their excellent productivity and good accessibility.

(a) Well-drained immature alluvial soil. The surface of the soil is well above the average water level of the river. The soil profile is immature. Parent material is sandy river deposits. The humus content of the soil is generally low. Soil depth is about 3-7 feet.

(b) Poorly drained immature alluvial soil. The water table is just below the soil surface. Parent material is stratified alluvial sand. This soil is also immature, but it contains organic matter. Water content of this soil is higher than that of the former.

(2) Organic soils

These soils are developed on former swamps and on muskegs. Parent material is organic. The depth of the water table is 7-10 inches below the soil surface; however, it sometimes is above the soil surface. This soil type is not significant.

(3) Hydromorphic soils

These soils have importance because of their great productivity. Their productivity and distribution are determined by the amount, type, and depth of the seepage water. The seepage water is usually highly nutritive for the plants.

(a) Black muck (α-gley) soil. This soil occurs on river terraces and concave slopes, where the seepage approaches the surface of the soil. Parent material is glacial till or alluvial deposit. The <u>A</u> layer is very rich in organic material. This soil is poorly aerated. The mineral soil is usually compacted and it is usually sandy loam which is 1-2 feet deep.

(b) Excessively drained high-seepage soil. Rapidly moving spring water characterizes this soil type. This rapidly moving seepage water prevents the accumulation of organic matter on the surface of the soil. Parent material is usually very coarse glacial till. If the soil particles are fine the steepness of the slope causes rapid water flow. This soil is shallow and stony. It is very rare, even on concave slopes.

(c) Ground water podzol soil. It occurs mostly on gentle slopes in the lower third of a hill side. Parent material is mostly glacial till. Excessive or very good water supply is the characteristic of this soil. Active seepage exists throughout the year in most cases. This podzolic soil is associated with a cool micro-climate. Soil depth is 4-7 feet. This soil type is the most abundant on the upper part of the Forest (in the wetter subzone).

(d) Red-brown podzolic soil. This soil occurs on concave lower slopes of varying steepness. Parent material is mostly glacial till. The soil is 3-6 feet deep, well drained and relatively coarse. It has drainage and favorable water supply. Seepage water is always present. The soil profile is well developed. It is an important soil type in the drier subzone (lower part of the Forest).

(4) Dry edaphic soils

These soils are dry and shallow.

(a) Shallow podzol soil. This soil was developed from glacial till or rock outcrops. It occurs on hilltops, ridges, and upper slopes. Soil depth is about 1-2 feet.

(b) Very shallow dry podzol soil. This soil is very shallow, and occurs on dry outcrops, with excessive drainage.

The mineral part of the soil is an ashy gray layer. Soil depth is 5-10 inches.

(5) Zonal soils

These soils are relatively deep and their water-holding capacity is high.

(a) Brown podzolic soil. This was derived from glacial till. Seepage water is rare. The soil profile is well developed and 4-6 feet deep. This is a relatively dry soil. It is not found on extreme topographic situations. Brown podzolic soil is common in the lower part of the Forest.

(b) Brown podzolic soil at higher elevations (above 2,000 feet). This soil has fine texture. Temporary seepage water is quite common, and in most cases water is supplied in abundance by increased precipitation at higher elevations within the Forest. This soil type is most abundant in the wet subzone of the western hemlock forest zone (Krajina, 1960).

Forest History

Two main factors, fire and logging, determined the development of the present condition of the Forest. About 1840 a fire burned over most of the Pitt Lake slope. All of the area, which supports second-growth stands at the present time, was burned over by a large fire in 1868. In 1925 a fire, which started near the southeast corner of the present U.B.C. Forest, burned 1,560 acres of slash. This fire was very severe and left only a thin covering of soil in a few places. A second major fire occurred in 1931 in slash on the east side of the Forest. It burned for 48 days on much of what is now called the A. and L. part of the Forest.

The east part of the forest was logged from 1921 to 1931, and supports a 30-year old immature stand at the present time.

Forest Types

The following four main forest types are found in the Forest: (1) Old-growth, (2) Scattered old-growth, (3) Second-growth, and (4) Immature (reproduction)(See forest-cover map, Appendix B).

(1) Old-growth

The total old-growth area remaining in the Forest is about 800 acres. About 80 per cent of this area comprises almost the entire east slope of the north central ridge. The stands consist of over-mature cedar-hemlock-fir with scattered white pine and balsam (Scientific names are listed in Appendix A). The three major species vary considerably in different stands. The cedar constitutes the major part of the volume, but varies greatly in size and quality. About one-half of the cedar is of poor quality with dead tops, especially the larger trees. Hemlock trees vary considerably in age and are a third less in total volume than the cedar. The best hemlock occurs on the area with a northerly aspect. The volume of Douglas fir is one-half of the volume of hemlock. Many firs have broken or dead tops, and numerous fir snags occur. The volume of other species is small. A few yellow cedars occur at the higher elevation on the poorer sites. A few small patches of old-growth which occur throughout the rest of the Forest survived the fire. The age of the old-growth stands is about 300 years.

(2) Scattered old-growth

This type occurs throughout the western portion of the Forest on about 1,000 acres. Douglas fir is the major species in the scattered old-growth stands. Old-growth Douglas fir trees occurs in groups, or singly. Within this type one-half of the old-growth volume consists of dead cedars, very scattered.

(3) Second-growth

Twenty per cent of the Forest area (2,030 acres) is occupied by second-growth stands, which are about 80 years old. The older second-growth stands are found on the Pitt Lake slope and along the southern boundary of the Forest.

Douglas fir is the major species in the second-growth stands. Sometimes it occurs in pure stands or is mixed with hemlock and cedar. The trees are reasonably well pruned and thrifty on the better sites. Hemlock forms a few small pure stands; it has the second largest volume in the second-growth stands. Cedar is a secondary species. Balsam grows in small patches mixed with hemlock through this type. A few white pine and yellow cedar occur in bogs and higher elevations.

(4) Immature stands

Reproduction occupies 45 percent (3,770 acres) of the stocked productive area of the Forest. The area logged in the 1920's one mile wide and six miles long, has various stages of reproduction. Thirty year-old dense stands cover the southeast part of the Forest. In other places reproduction was killed by the fire of 1931. Along the timber edge, stocking is good. The entire ridge west of Marion Lake is poorly stocked, but no large area is without natural reproduction within the Forest.

Douglas fir is uniformly distributed through the area. It constitutes about 30 percent of the number of trees where the stocking is poor, and a much lower percentage where the stocking is good. The number of hemlock and cedar trees increases with the degree of stocking. With a few exceptions hemlock is more numerous than cedar. Scattered white pine and yew occur in some poorly stocked areas. The age of the reproduction varies from about 12 to 32 years.

Some small patches of alder type occur in the Forest, with some second-growth Douglas fir, hemlock and cedar.

GENERAL PROCEDURE

The productive capacity, or site quality, of an area can be evaluated through the site factors. These factors and their effects on tree growth are greatly variable. Each factor has a different influence on site quality; some of them are more important than others. Some factors can be measured only with difficulty, and their measurement would be expensive. Use of aerial photographs for the evaluation of site quality should be cheaper than any ground method but this method eliminates those site factors which are unrecognizable on aerial photographs. Determination of several site factors used in this study is uncertain or impossible from aerial photographs.

The most valuable expression of site quality is site index. Site index is based on the height reached by a forest stand at a given stage in its development. Since site index involves the measurement of the average height of dominant and codominant trees at a specific age, it cannot readily be determined directly from aerial photographs. However, it can be calculated from regression equations using different site factors as independent variables; or it can be estimated by the photo-interpreter directly from aerial photographs.

In this study the following site factors were used as independent variables: (a) topographic factors inclusing aspect, local position on slope, general position on slope, percentage of slope, shape in profile, shape in contour, and elevation;

(b) soil factors including pore pattern, soil depth, moisture regime, texture of soil, portion in rock, thickness of humus layer and thickness of $\underline{A}_2$ layer.

The University Research Forest is relatively homogeneous with respect to the climate and soil, therefore most of the forest was used to evaluate site quality. The Forest was divided into types based on topographic features. The types were established on aerial photographs and transfered by Kail Plotter to a base map. These types provided a reference for collection and analysis of data. Each type was located by stereoscopic examination of aerial photographs and was described by the code of topographic features.

The correlation between site index and the variables was calculated from ground data collected on a sample plot within numerous types. Usually a tenth-acre circular sample plot was established on a representative portion of each type. Two summer months were spent collecting the field data.

Two kinds of analysis of field data were carried out to find the correlation between variables, a graphical analysis and a linear multiple regression analysis computed on the ALWAC III E electronic computer. These analyses indicated the significance of variables for estimation of site index. The electronic computer was used to find many equations for site index as the dependent variable and site factors as independent variables.

However, these equations were not adequate to compute the site index directly from the independent variables. Therefore determination of site indices for different types, was based on the equations and field experience as a guide to the judgement and estimation of the photo-interpreter. Finally a site map was drawn up. The previously established topographic types were used as the base for the site map. Those types which had similar site indices were joined.

PRELIMINARY WORK

In the fall of 1958 the University Research Forest was typed on aerial photographs. Delineation of the types was based on the following topographic features: aspect, percentage of slope, shape in profile, and shape in contour. Sixteen aerial photographs in two flight lines were used for the typing. These aerial photographs were taken in 1955 at a flying height of 15,900 feet A.S.L. A 12-inch-focal-length camera was used, thus the scale of the photograph was about 1 inch to 20 chains. Interpretation was done using an Abrams 2-4x stereoscope, Model CB-I. Four hundred and eighty-five types were established on the A. and L. portion of the Forest. These types were relatively small, about 5 acres in size, because of the rough, steep, and variable topography. There were 211 types on the second and old-growth area. The types on these area were generally large in size; average size of these types was about 20 acres because of the relatively uniform topography.

After interpretation each type was described by the code of aspect, percentage of slope, shape in profile, shape in contour, general position on slope, and elevation. Except for elevation, these topographic features were determined by stereoscopic examination of aerial photo-pairs. Elevation was read from a contour map.

The types were transfered to a base map using a radial planimetric plotter. The base map was made by Multiplex planimetry by Photographic Surveys (Western) Ltd., with a scale of 1 inch equal to 1,000 feet (Appendix C).

During the fall of 1958 three days were spent in the University Research Forest checking the photo classification. The checking was done with Kare Hellum as part of his directed studies. His work indicated that the description of the types from aerial photographs was in close agreement with the actual topographic features.

A preliminary graphical analysis was carried out between site index as the dependent variable and topographic features as independent variables for the second-growth and old-growth portions of the Forest. Site index was determined from a site map which was made by ground survey in 1950. In that survey strips had been run through the Forest at 10-or 20-chain intervals. Dominant and codominant trees were measured every 5 chains along the strips and site index was calculated from these data. The independent variables were obtained from the type classification. A separate graph was drawn up for site index on each independent variable. The results of the preliminary analysis were similar to those from graphical analysis of data collected in 1959 and described in following section. The order of classes within each variable was in decreasing order of site index. The crosses on the graphs represent the average site indices for the corresponding classes; the numbers represent the number of types in each class (Figures 2 to 7).

Figure 2 presents the relationship between site index and aspect. Types with south aspects had the highest average site index. Average site index for types with western exposure is about the same as for types with north exposure. Reference to the graph shows a decreasing order of exposure with a decrease in site index: South (S.I.122), West (S.I.120), Level situation (S.I.III), East (S.I.109), North (S.I.105), and Ridge (S.I.96).

In Figure 3 the slope range of 5 per cent to 34 per cent had the highest average site index (S.I.121), and with increase in slope, percentage site index decreased. The level situation had a relatively low site index (S.I.III).

No important differences were found between shape in profile, and shape in contour. However, concave-shaped topography indicated better site quality than the straight or convex topography (Figures 4 and 5).

To follow page 64

S. I. on ASPECT.

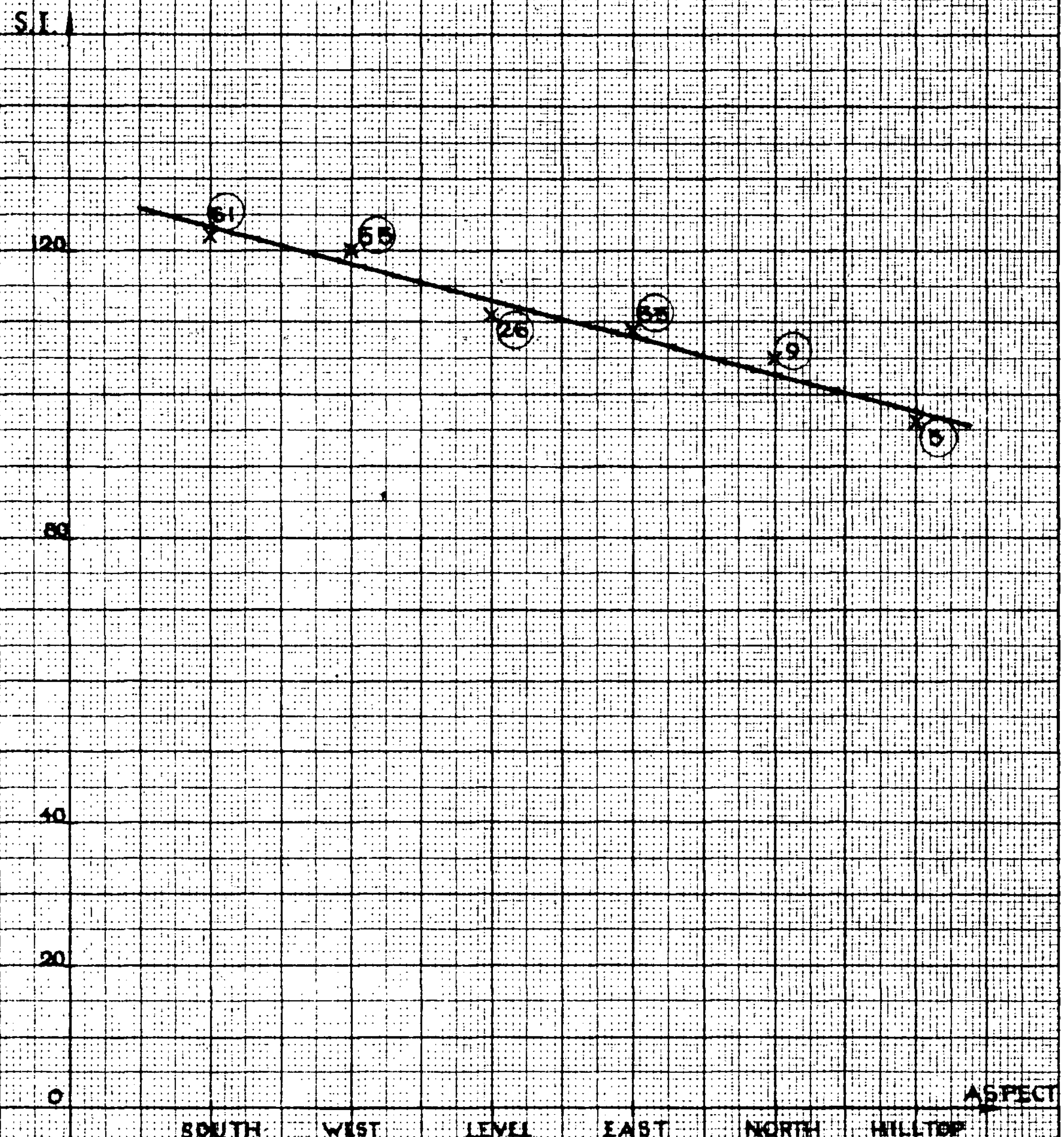


Figure 2.

S.I. on % of SLOPE.

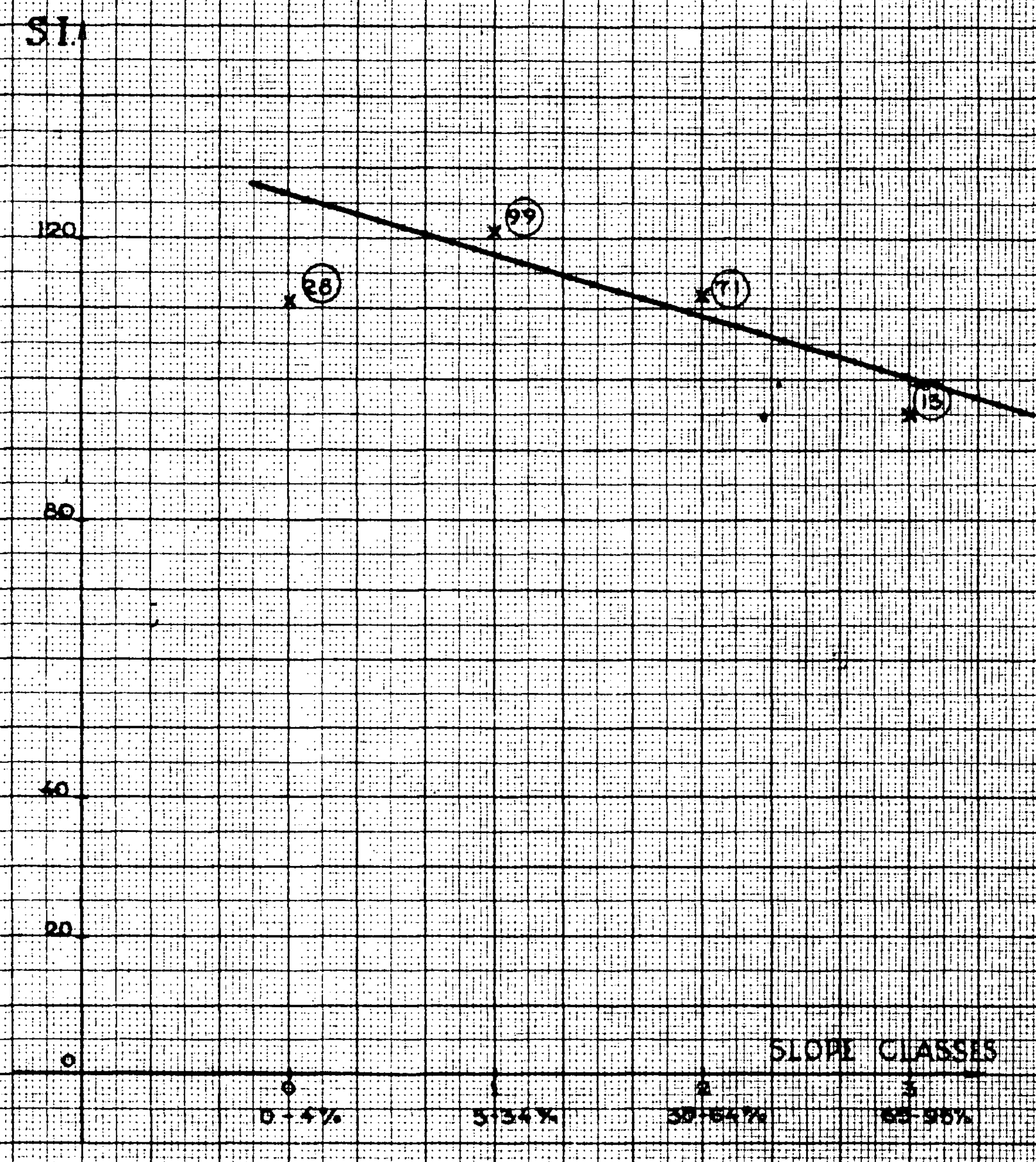


Figure 3.

S.I. on SHAPE in PROFILE.

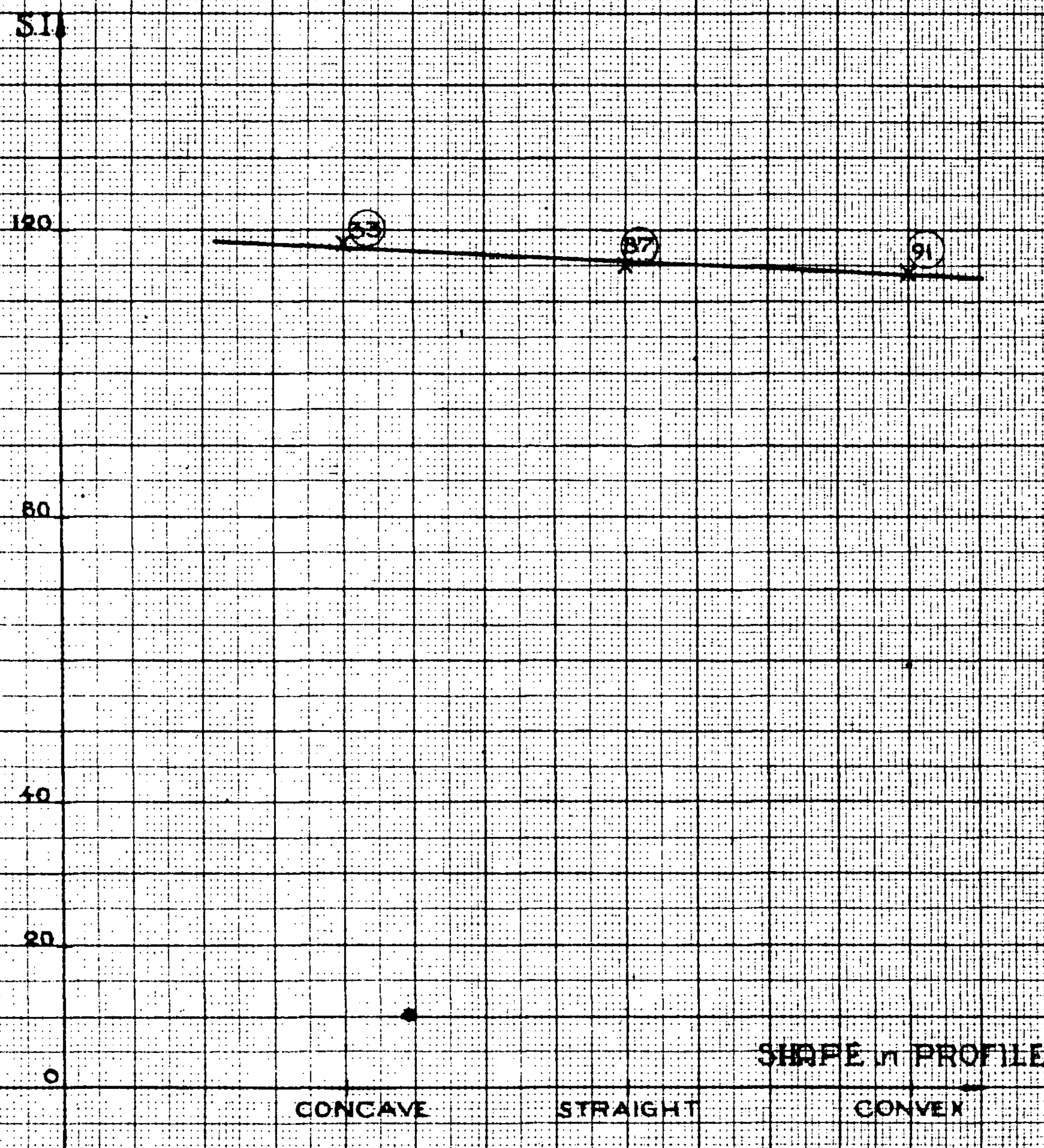
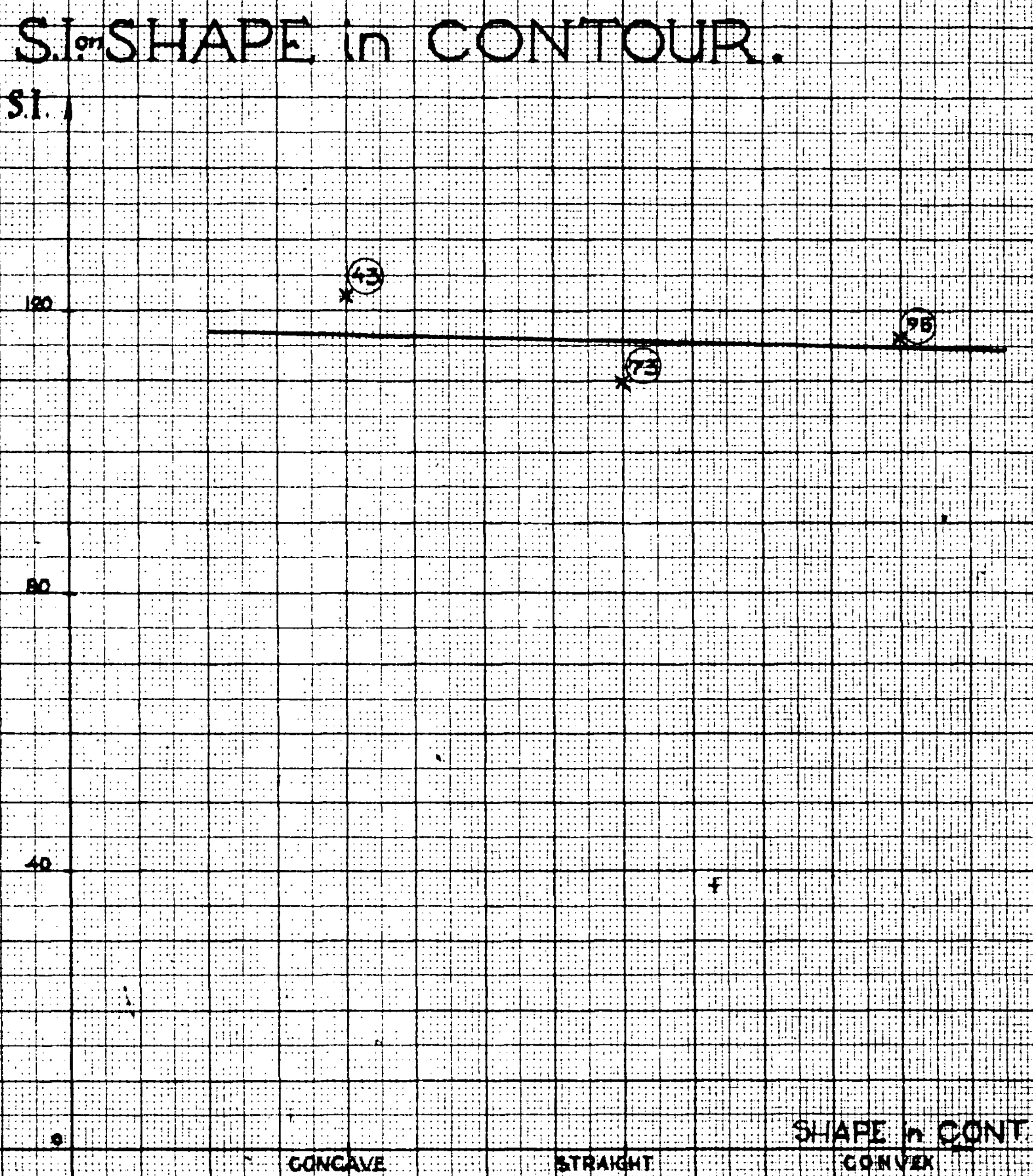


Figure 4.



S.I. on SHAPE in CONTOUR.
S.I.
120
80
40
0
43
73
95
SHAPE in CONT.
CONCAVE
STRAIGHT
CONVEX

Figure 5.

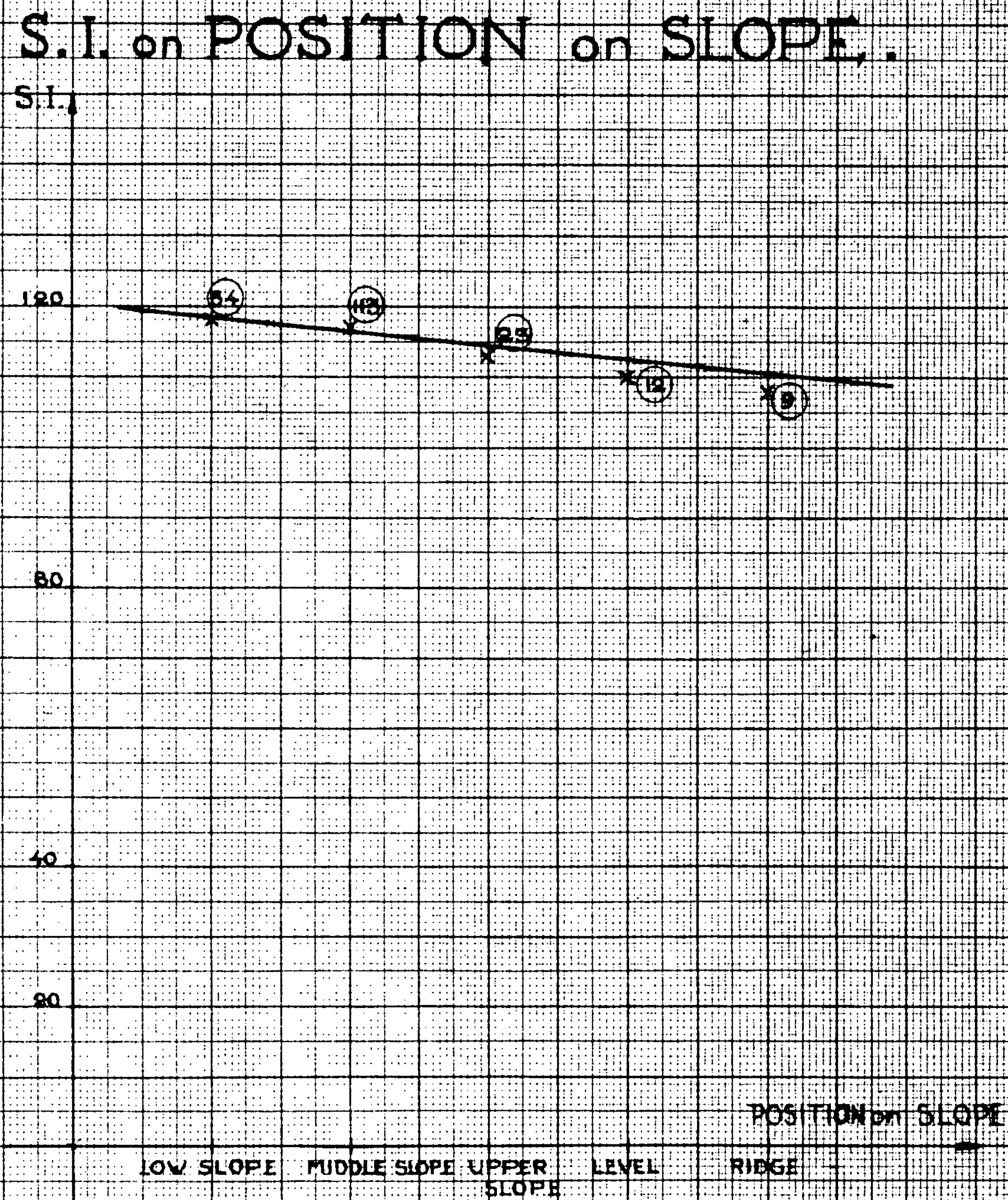

S.I. on POSITION on SLOPE.
S.I.
120
80
40
20
54
118
25
12
9
POSITION on SLOPE
LOW SLOPE
MIDDLE SLOPE
UPPER SLOPE
LEVEL
RIDGE

Figure 6

S.I. on ELEVATION.

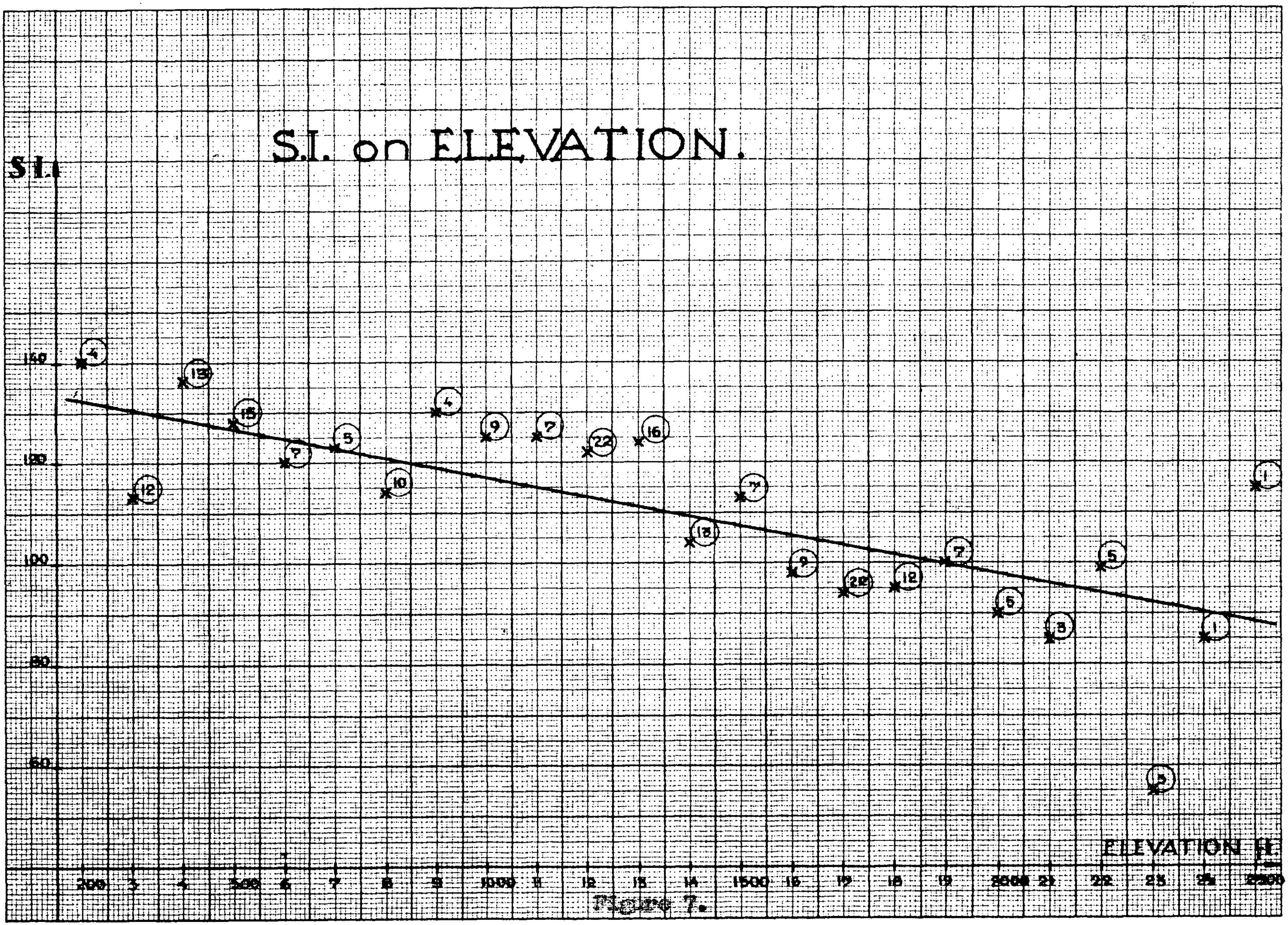


Figure 7.

The influence of position on slope on site index was important (Figure 6). Low slope and middle slope position had the highest average site indices (S.I.118 and S.I.117). Site indices were lower on upper slopes and on ridges.

Site index decreased with increase in elevation (Figure 7). However, the variation was broad. A better regression line could be established if the data were divided into two groups, the first group from 200 to 1,300 feet elevation, and the second group from 1,400 to 2,500 feet. The rate of decrease in site index with increase of elevation in the first group was not as large as in the second group.

These graphical analyses indicated that aspect, percentage of slope, position on slope, and elevation are usable variables for the estimation of site quality from aerial photographs.

COLLECTION OF FIELD DATA

During the summer of 1959, the months of May and July were spent in collection of field data.

After considering the site factors used by Hills (1950), and Choate (1958), the following variables were chosen for study: (A) Items required to confirm the photo classification, (B) Soil factors for correlation with photo classification, (C) Yield factors for correlation with photo classification, (D) Stocking, and (E) Cruise data. Different classes were set up for each variable, and these classes were coded to facilitate recording and analysis of data.

(A) Items required to confirm photo classification

		Code
(1) Aspect:	In azimuth reading.	1^{o}-360^{o}
	Level situation (less than 5 per cent in slope).	L
(2) Local position on slope:		
	Level situation.	-
	Low slope.	L
	Middle slope.	M
	Upper slope (Hill).	H
	Ridge	R
	Low seepage	LS
	Middle seepage.	MS
	Swamp.	Sw
(3) General position on slope:		
	Level situation	-
	Low slope.	L
	Middle slope.	M
	Upper slope.	H
	Ridge.	R
	Swamp.	Sw
	Rock	Rock

		Code
(4) Per cent of slope: In percentage		0-100%
(5) Shape in profile:		
	Convex.	C
	Straight.	S
	Concave	Co
(6) Shape in contour:		
	Convex.	C
	Straight.	S
	Concave.	Co

(7) Elevation: In hundred's of feet.

(8) Distance to the nearest creek:

In hundred's of feet.

(B) Soil factors for correlation with photo classification.

(1) Soil depth: In inches.

(2) Moisture regime (after Hills, 1950):

Extremely dry: Soil is always dry. Available moisture is extremely low. Soil profile is featureless. Generally this site is found on drifting sand, extremely steep eroding loam or clay banks, on bare bedrock, or on ridges without soil. e

Dry: Soil dries out over long periods. Available moisture is low. Soil development is better than at the former class. Generally these sites can be found on very steep slopes of rapidly permeable sand, on steep banks of more slowly permeable clays and

Code

loams, and on very shallow material over convex bedrock. 0

Somewhat dry: Soil dries out temporarily. Available moisture supply is moderate. This site is commonly found on moderately permeable materials with a water table below the tree roots. 1

Optimum (normal): Available moisture supply of the soil is adequate. The influence of micro-climate is normal on both soil development and plant growth. These are the sites of the normal or zonal soils. This moisture regime is generally found on moderately permeable material. A water table is available. Optimum moisture regime is not the average for a climatic region; it is the optimum moisture which is required for the development of zonal soils and climax vegetation. 2

Somewhat moist: Moisture supply is more than adequate for a small portion of the growing season. Below the B horizon the soil is dry. This site is found on slowly permeable clay loams, and in shallow sand over a somewhat impermeable layer. 3

Moist: Moisture supply is more than adequate for part of the year. This moisture regime can be identified by development of a glei layer or a shallow layer of organic matter. These gleisolic mineral soils are found on rapidly permeable soils with a high fluctuating water table, or a slowly permeable soil with a seasonal water table. Excess moisture causes cool soil and poor root-

Code

ing below two and a half feet. 4

Somewhat wet: These sites are saturated with water six to twenty inches from the surface of the mineral soil for most of the year. The soil is generally covered by a thick layer of organic matter. Excess moisture causes cold soil and poor rooting below one and a half feet. 5

Wet: Soil is saturated with water close to the surface (a few inches). Excess moisture causes cold soil and poor rooting below one foot. 6

Very wet: There is a continuous saturation of the surface of the mineral soil. This prevents decomposition of the organic matter which constitutes peat or muck. This peat is usually three-four feet deep. Excess moisture limits rooting to accumulated organic matter. 7

Extremely wet: Water table exists almost to the surface of organic matter. 8

Saturated: Saturated sites may or may not have an organic matter layer. They comprise marsh and deep bogs. Water table exists at the surface all year.. 9

(3) Permeability (after Hills, 1950): The following permeability classes may occur either on mineral or organic materials.

Code

Instantaneous: There are no fine soil particles which stop the movement of water. Mineral material is commonly gravel and large stones without soil Organic material, which belongs to the permeability class, is peat. This peat is commonly so dry that the water, passing through the soil, does not wet it. Θ

Extremely rapid: Extremely rapid permeability is characteristic of coarse sands and loose medium sand soils. The water only moves rapidly downward but water vapour can rapidly evaporate into the atmosphere. This permeability class occurs on sphagnum peat organic soil. 0

Very rapid: This permeability class is characteristic of very previous soils, such as the loosely packed fine sands, fairly compact medium and coarse sands, and gravelly or bouldery sands. Poorly decomposed peat moss of organic soils represents this permeability class. The water moves rapidly downward and water vapour can pass fairly rapidly upward in these soils. 1

Rapid: Water movement is rapid in the loamy sands soils. The rapid permeability class occurs on moss and woody peat organic soil with some decomposition. Gravity water moves freely downward and water vapour freely upward. 2

Code

Moderately rapid: Largely compact fine sand, somewhat compacted loamy sand, silty sand and sandy loam soil have this permeability class. Organic materials of this permeability class are muck and peat with some sedge. 3

Moderate: This permeability class is the characteristic of moderately previous soils such as the sandy loam mineral soils, or the muck and peat, and sedge and muck organic soils. Gravity water moves slowly downward and water vapour slowly upward. 4

Moderately slow: Gravity water moves slowly through the soils which have this permeability class. Normal moisture regimes are commonly found on mineral soils of this permeability class. Mineral soils of this class are channelled silt and clay loams. Medium textured, fairly well decomposed peats and mucks of organic soils belong to this permeability class. 5

Slow: Slow permeability class is the characteristic of moderately well-channelled, impervious soils, such as massive clay and silt loam. Fine textured mucks belong to this permeability class of organic soil. 6

Very slow: Impervious silt loams, clay loams, and clays of mineral soils which are poorly channelled, belong to this permeability class. Gravity water moves through the channels, but these channels are small and

Code

infrequent. The organic soils of this permeability class are mucks and peats with a moderate percentage of sapropël (organic ooze). 7

Fractured impermeable: Various types of channelled bedrock; usually sedimentary limestones, sandstones, and shales; represent this permeability class. Fractured impermeable class may also include many hard-pans of both geologic or pedologic origin. 8

Impermeable: Impermeable bedrocks, generally granite, gneiss and other igneous rocks, belong to this permeability class. However, massive methamorphic and sedimentary rocks may also belong to this class. 9

(4) Texture of soil:

Loamy sand	LS
Clay - Loam	CL
Loam	L
Sandy loam	SL
Sand	S
Silty loam	SiL
Silt	Si
Clay	C
Sandy gravel	SG
Gravel	G
Peat	P

(5) Portion in rock: In percent

(6) Humus layer thickness: In inches

(7) A_2 layer thickness: In inches

(C) Yield factors for correlation with photo classification (by species).

(1) Total height: In feet.

(2) Age at breast height: In years.

(3) Total age: In years.

(4) Site index: In feet.

(5) Growth in diameter inside bark at breast height from one to five years ago: In millimeters.

(6) Growth in diameter inside bark at breast height from six to ten years ago: In millimeters.

(7) Double-bark thickness at breast height: In millimeters.

(8) Diameter outside bark at breast height: In inches.

(9) Most prominant lesser vegetation.

(D) Stocking

Good stocking: Sample plot is 0.05-acre (radius 26.3 feet).

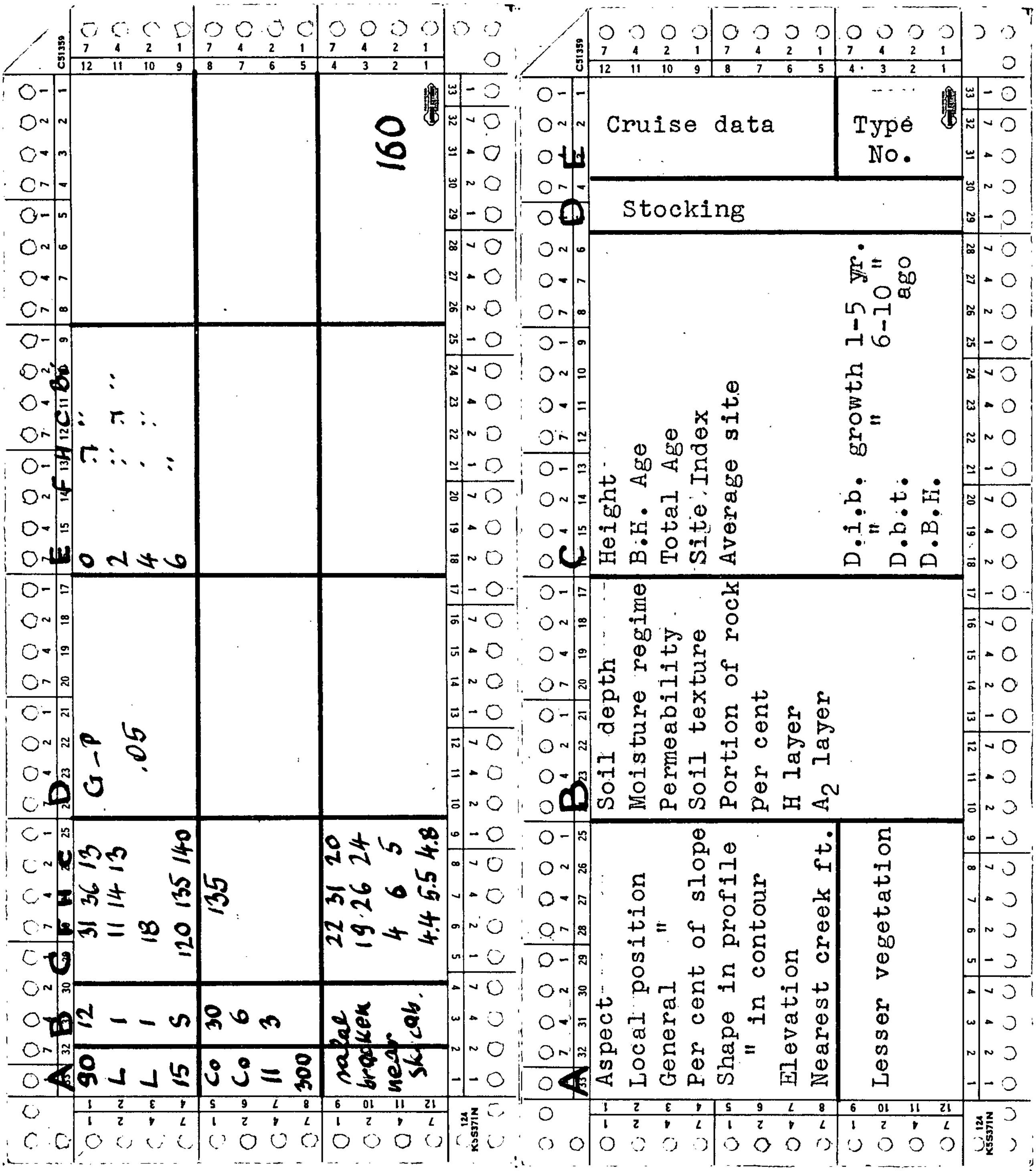
Medium stocking: Sample plot is 0.1-acre (radius 37.2 feet).

Poor stocking: Sample plot is 0.20-acre (radius 52.7 feet).

(E) Cruise data (by species and two-inch d.b.h. classes).

Two hundred and thirty-eight sample plots were established by the author and Dr. J.H.G. Smith within the types on the A. and L. portion of the Forest. The centers of the sample plots were marked on the aerial photographs, and transfered to the base map (Appendix C). Types sampled were well distributed over the area. One plot was established per type by random selection in a representative position within each type sampled. McBee punch cards, form C51359, were used for collection of field data. The variable classes were described by their code numbers or code letters on these cards (See Figure 8, on following page). On the sample plots, all topographic variables were estimated with the exception of slope, aspect, and elevation. A hand compass was used to determine the degree of exposure. A Haga height-finder was used to check on slope per cent. Soil data were measured or estimated from a small soil pit, which was established in the center of each plot. One dominant or codominant tree was chosen for each major species present in the plot as close as possible to the center of the plot to measure the yield factors and determine the site index. Tree height was measured with a Haga height-finder. Sample trees were measured with a diameter tape and bored with an increment borer to determine size, age, and growth at breast height. Years-to-reach-breast-height was estimated by counting rodes, where possible.

To follow page 74



160
0
2
4
6
G-P
.05
31 36 13
11 14 13
18
120 135 140
135
22 31 20
19 26 24
4 6 5
4.4 5.5 4.8
12
1
1
5
30
6
3
90
L
L
15
Co
Co
11
300
Cruise data
Type No.
Stocking
Height
B.H. Age
Total Age
Site Index
Average site
D.i.b. growth 1-5 yr.
" " 6-10 " ago
D.b.t.
D.B.H.
Soil depth
Moisture regime
Permeability
Soil texture
Portion of rock
per cent
H layer
A2 layer
Aspect
Local position
General "
Per cent of slope
Shape in profile
" in contour
Elevation
Nearest creek ft.
Lesser vegetation
A
B
C
D
E

Figure 8

The size of the sample plot was chosen depending on the degree of stocking within the plot. For well stocked plots, 0.05 acres was used, for medium and poorly stocked plots, 0.10 and 0.20 acres respectively were used. The most prominant species of lesser vegetation were also recorded for each plot.

For collecting field data on the second-growth area of the Forest, eighty-three permanent sample plots and thinning plots were used. Only the topographic and soil data were collected on these plots. Some of these plots were systematically located, others were randomly selected. Due to the lack of time and transportation facilities, only 26 plots were established over the old-growth and scattered old-growth areas. Some soil and vegetation data were collected along every road within the Forest at 10-chain intervals.

The site indices of all plots were based on expected average total height of dominant and codominant trees at age one-hundred years. For the old-growth stands, site index curves were used to determine the site indices. Site indices for the permanent sample plots and thinning plots were available from previous mensurational work (Smith and Ker, 1959).

A stand table was prepared for the A. and L. portion of the Forest, showing the number of trees per acre by species, d.b.h. classes and stocking (Table 2). Area distribution of forest cover types by species, age, stocking and site for the same area is presented in Table 1.

TABLE I

Area distribution of forest cover types on A. and L. portion of the Forest by species, age, stocking, and site

1. Species Composition	2 Age	Stock-ing 3	S.I. 80	110	140	170	200	Total
			(Area in Acres)					
FHC	1	G	-	9.9	-	-	-	9.9
		M	31.1	3.8	8.4	-	-	43.3
		D	15.2	11.7	-	-	-	26.9
	2	G	11.1	28.9	70.8	19.5	-	130.3
		M	30.7	57.2	38.8	24.4	-	151.1
		D	14.1	8.9	-	-	-	23.0
HCF	1	G	3.9	32.0	-	-	-	35.9
		M	6.5	-	-	-	-	6.5
		P	2.7	18.3	-	-	-	21.0
	2	G	8.6	198.6	173.9	26.5	-	407.6
		M	41.3	18.5	42.8	-	-	102.6
		P	2.1	24.2	-	-	-	26.3
HC	1	G	-	41.0	8.4	-	26.9	76.3
		M	22.6	21.1	58.0	16.6		118.3
		P	19.9	20.6	-	6.6	-	47.1
	2	G	96.0	184.6	357.7	88.9	-	727.2
		M	87.0	87.2	49.5	19.7	-	243.4
		P	10.6	9.8	-	-	-	20.4
CH	1	G	8.8	36.1	14.7	-	-	59.6
		M	19.3	14.4	34.7	-	-	68.4
		P	45.3	27.4	22.8	-	-	95.5
	2	G	87.9	169.7	204.7	56.1	-	518.4
		M	58.4	149.5	38.3	20.4	-	266.6
		P	34.3	36.8	3.2	-	-	74.3
HF	1	G	3.8	-	-	4.5	-	8.3
		M	3.2	11.3	4.1	-	-	18.6
		P	5.0	8.1	-	7.9	-	21.0
	2	G	2.5	3.6	40.3	8.2	-	54.6
		M	42.3	27.7	32.1	-	-	102.1
		P	8.7	5.9	-	-	-	14.6
Total			722.9	1,266.8	1,203.2	299.3	26.9	3,631.4

1. Species- Douglas fir, F; western hemlock, H; western red cedar, C.
2. Age- under 20 years, 1; over 20 years, 2.
3. Area of stocking classes (in acres):

Stocking:			
	Good:	2,102.2	(S.I.130)
	Medium:	1,133.1	(S.I.120)
	Poor:	395.1	(S.I.80)
	Total	3,631.4	acres

TABLE 2.

Number of trees per acre by species, d.b.h. classes and stocking

d.b.h Classes (Inches)	Douglas fir Poor	Douglas fir Medium	Douglas fir Good	Douglas fir Very good	Western hemlock Poor	Western hemlock Medium	Western hemlock Good	Western hemlock Very good	Western red cedar Poor	Western red cedar Medium	Western red cedar Good	Western red cedar Very good
	(Number of trees)											
0	0.83	4.47	2.69	3.64	25.83	68.48	49.90	145.00	10.42	37.37	66.00	171.00
2	3.75	8.95	7.38	10.30	23.75	47.63	75.60	306.00	20.00	41.05	91.80	284.00
4	4.17	7.05	7.11	29.10	11.25	21.59	63.40	302.00	9.58	14.74	56.40	106.00
6	2.92	5.00	5.24	10.90	4.17	2.90	29.30	109.00	4.58	2.63	21.90	37.70
8	2.08	0.79	3.09	10.90	0.42	2.30	13.60	29.10	1.25	0.80	7.11	-
10	0.42	1.05	2.55	3.64	-	-	6.04	7.21	1.25	0.53	2.95	-
12	0.42	0.26	2.01	7.27	-	-	1.61	-	-	-	0.94	-
14	-	0.26	0.81	-	-	-	0.81	-			0.40	-
16	-	-	0.13	-	-	-	0.13	-	-	-	0.27	-
18	-	-	0.13	-	-	-	0.13	-	-	-	-	-
20	-	-	0.13	-	-	-	-	-	-	-	-	-
No. of trees per Acre	14.58	27.83	31.28	76.35	65.42	143.44	240.52	898.31	47.08	97.12	247.77	593.70

TABLE 2. (cont'd)

Number of trees per acre by species, d.b.h. classes and stocking

d.b.h. Classes	White pine			Yew				Sitka spruce		Bal-sam	Western cherry			
	Poor	Med-ium	Good	Poor	Med-ium	Good	Very good	Med-ium	Good	Good	Poor	Med ium	Good	Very good
0		0.80	0.54	1.67	4.21	2.55	10.90	0.16	-	-	-	3.16	1.88	-
2	0.42	0.53	0.13	1.67	2.37	1.21	-	0.48	0.13	0.27	-	6.32	6.44	-
4	0.42	-	0.13	-	0.26	-	-	-	-	0.27	0.42	2.11	3.76	3.64
6	-	-	0.13	-	-	-	-	-	-	0.67	-	-	1.75	-
8	-	-	-	-	-	-	-	0.16	-	0.67	-	-	0.27	-
10	-	-	-	-	-	-	-	-	-	0.54	-	-	-	-
12	-	-	-	-	-	-	-	-	-	0.27	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	0.13				
No. of trees per Acre	0.84	1.33	0.93	3.34	6.84	3.76	10.90	0.80	0.13	2.82	0.42	11.59	14.10	3.64

TABLE 2. (cont'd)

Number of trees per acre by species, d.b.h. classes and stocking

d.b.h. Classes	Red alder Poor	Red alder Medium	Red alder Good	Black cottonwood Poor	Black cottonwood Medium	Black cottonwood Good	Aspen Poor	Aspen Medium	Aspen Good	Western white birch Poor	Western white birch Medium	Western white birch Good
0	1.67	2.11	0.67	-	1.58	0.13	1.67	0.26	0.13	0.42	8.68	4.16
2	2.50	0.80	4.03	1.67	2.63	1.07	-	0.53	0.13	2.92	8.68	6.44
4	1.67	2.11	5.91	0.42	0.80	0.40	0.42	-	0.13	1.25	3.42	4.56
6	-	1.05	4.70	-	0.26	1.61	-	-	0.13	-	1.58	2.69
8	-	-	3.49	-	-	0.13	-	-	-	-	-	0.81
10	-	-	2.01	-	-	0.13	-	-	-	-	-	0.13
12	-	-	0.94	0.42	-	0.27	-	-	-	-	-	-
14	-	-	0.13	-	-	0.40	-	-	-	-	-	0.13
16	-	-	0.13	-	-	-	-	-	-	-	-	0.13
No. of trees per Acre	5.84	6.07	22.01	2.51	5.27	4.14	2.09	0.79	0.52	4.59	22.36	19.05

d.b.h. Classes	Broad leaf maple Good	Lodge-pole pine Good	Other deciduous Good
0	-	-	-
2	0.13	0.13	-
4	-	-	0.27
6	0.13	-	-
No. of trees per Acre	0.26	0.13	0.27

Totals:	Poor	Medium	Good	Very good
No. of trees per acre	146.71	319.94	587.76	1,582.9
Acres sampled	2.40	3.80	7.45	.28

SUMMARY AND ANALYSES OF DATA

The following thirteen independent variables were used for the analyses: Aspect, XI; Local position on slope, X2; General position on slope, X3; Per cent of slope, X4; Shape in profile, X5; Shape in contour, X6; Elevation, X7; Soil depth, X8: Moisture regime, X9; Permeability, X10; Soil texture, X11: Humus-layer thickness, X12; A_2-layer thickness, X13. The average site index for Douglas fir, western hemlock, and western red cedar trees measured at each sampling point expressed as total height in feet at 100 years, was the dependent variable. Variables one to ten are the photo-identifiable variables.

Tabular analysis

The following tabulation of field data of A. and L. portion of the Forest was set up:

	Average site index:	Number of plots:
(1) Aspects:		
North	125	13
East	120	55
South	116	78
West	123	86
Flat	108	2
All	120	234

	Average site index:	Number of plots:
(2) Local position on slope:		
Level	118	16
Low	121	33
Middle	120	53
High	104	17
Ridge	105	27
Low seepage	131	47
Middle seepage	136	29
Swamp	81	12
All	119	234
(3) General position on slope:		
Level	133	11
Low	129	73
Middle	126	73
High	113	16
Ridge	105	36
Swamp	88	16
Rock	76	8
All	118	233
(4) Per cent of slope:		
0- 4	106	11
0- 4	128*	6
5-10	124	70
5-10	126*	65
11-20	124	66

	Average site index:	Number of plots:
(4) Per cent of slope: (cont'd)		
21-30	117	28
31-40	119	25
41-50	100	9
51-60	110	2
61-70	78	2
71-80	83	2
81-90	75	2
All	120	217
*Excluding swamp types		
(5) Shape in profile:		
Convex	114	92
Straight	117	63
Concave	126	80
All	118	231
(6) Shape in contour:		
Convex	114	92
Straight	119	80
Concave	125	59
All	119	231
(7) Elevation:		
0- 400	133	2
500- 600	124	22
700- 800	128	15
900-1000	136	36

	Average site index:	Number of plots:
(7) Elevation: (cont'd)		
1100-1200	135	38
1300-1400	110	29
1500-1600	110	28
1700-1800	108	34
1900-	94	9
All	121	213
(8) Soil depth:		
0-10	107	22
11-20	116	105
21-30	125	79
31-	128	9
All	119	215
Also summarized by 1-inch classes		
(9) Moisture regime:		
Dry	91	27
Somewhat dry	118	121
Normal (optimum)	140	48
Somewhat moist	140	5
Moist	117	6
Somewhat wet	111	7
Wet	89	6
Extremely wet	50	1
All	119	221

	Average site index:	Number of plots
(10) Pore pattern:		
Extremely rapid	90	6
Very rapid	118	176
Rapid	132	29
Moderately rapid	123	6
Moderate	88	2
Moderately slow	125	1
Slow	65	1
All	119	221
(11) Soil texture:		
Sand	118	147
Clay loam	140	2
Loam	130	2
Sandy loam	130	44
Loamy sand	145	9
Sandy gravel	100	8
Peat	82	6
All	120	218
(12) Depth of humus layer; in inches:		
- 0	105	1
1- 2	115	15
3- 4	118	61
5- 6	119	56
7- 8	125	41
9-10	123	28

	Average site index:	Number of plots:
(12) Depth of humus layer: in inches (cont'd)		
11-12	115	14
13-14	167	3
15-16	123	5
17-	95	6
All	120	230
(13) Depth of A_2 layer: in inches:		
0	123	139
1	122	41
2	111	28
3	104	12
4	110	10
5	98	2
6	125	1
7	100	2
8	70	1
All	119	236

The numbers of plots were not the same for each variable because some plots were incomplete. From this tabulation of data separate graphs were drawn for site index on each variable. The following graphs illustrate the linear regression existing between the site index and variables: Figure 9 to Figure 21.

To follow page 85

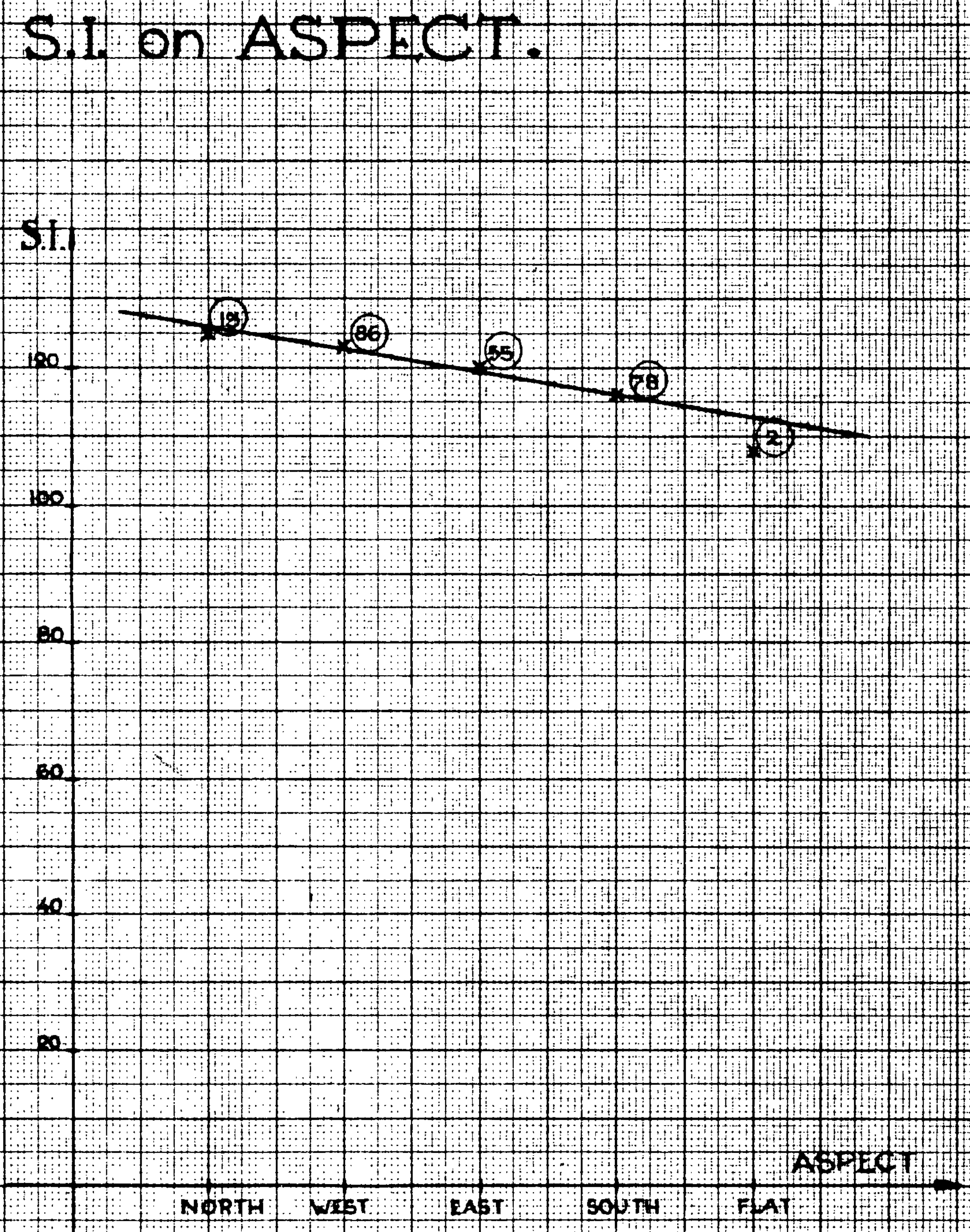

S.I. on ASPECT.
S.I.
120
100
80
60
40
20
ASPECT
NORTH
WEST
EAST
SOUTH
FLAT
13
86
55
78
2

Figure 9.

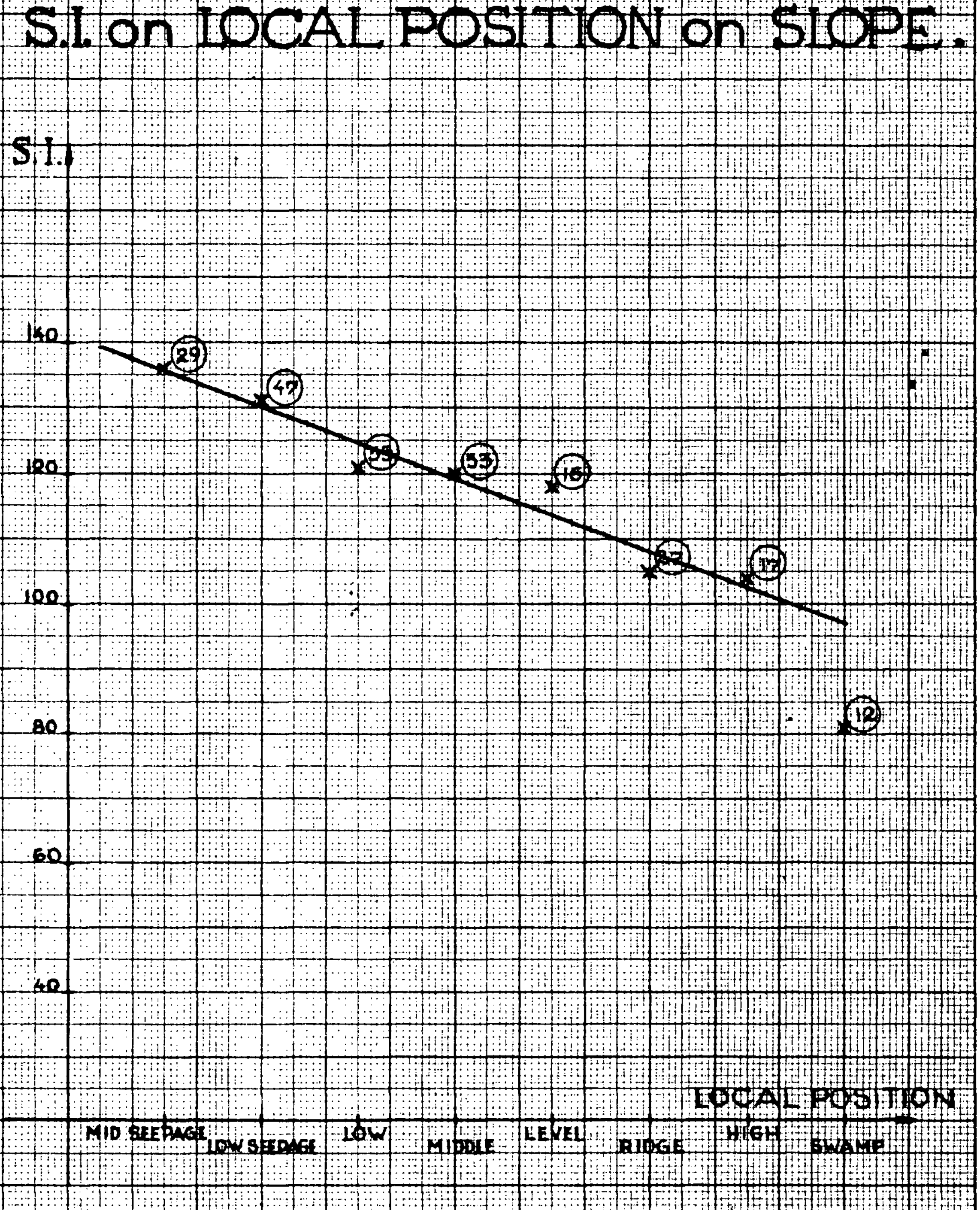

S.I. on LOCAL POSITION on SLOPE.
S.I.
140
120
100
80
60
40
29
47
53
16
12
LOCAL POSITION
MID SEEPAGE
LOW SEEPAGE
LOW
MIDDLE
LEVEL
RIDGE
HIGH
SWAMP

Figure 10.

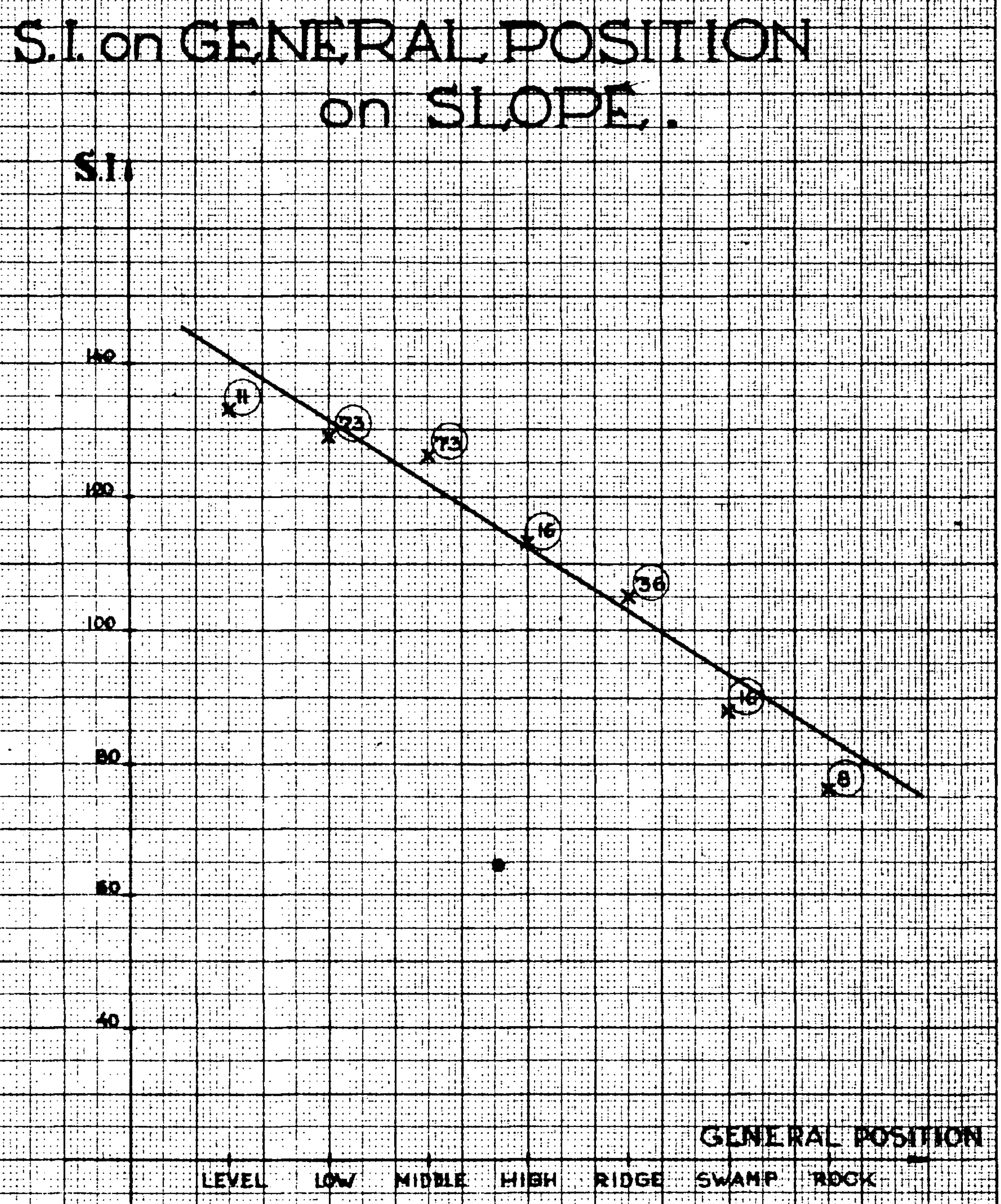

S.I. on GENERAL POSITION on SLOPE.
S.I.
140
120
100
80
60
40
11
23
73
16
36
16
8
GENERAL POSITION
LEVEL
LOW
MIDDLE
HIGH
RIDGE
SWAMP
ROCK

Figure 11.

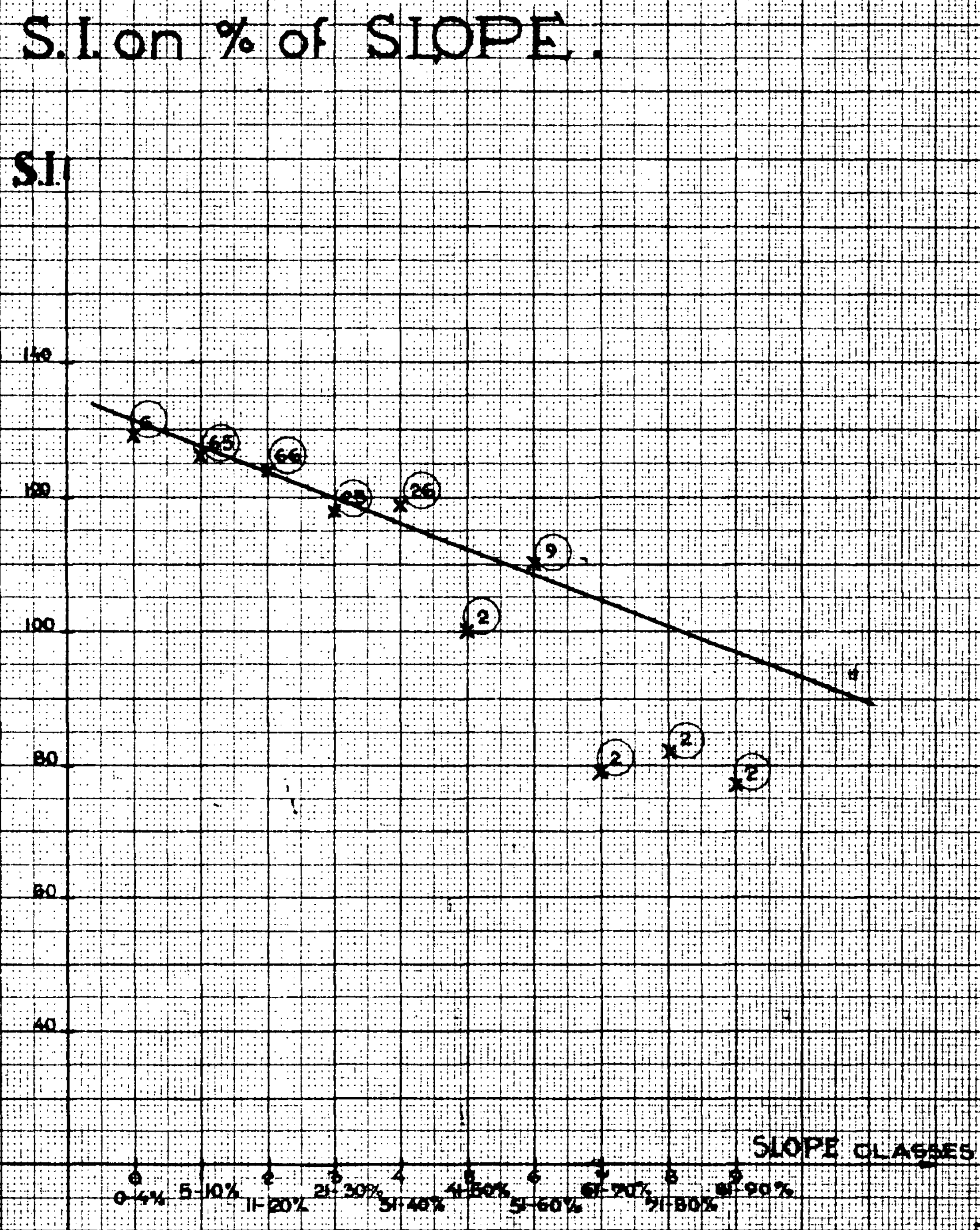

S.I. on % of SLOPE.
S.I.
140
120
100
80
60
40
SLOPE CLASSES
0-4%
5-10%
11-20%
21-30%
31-40%
41-50%
51-60%
61-70%
71-80%
81-90%

Figure 12.

S.I. on SHAPE in PROFILE.

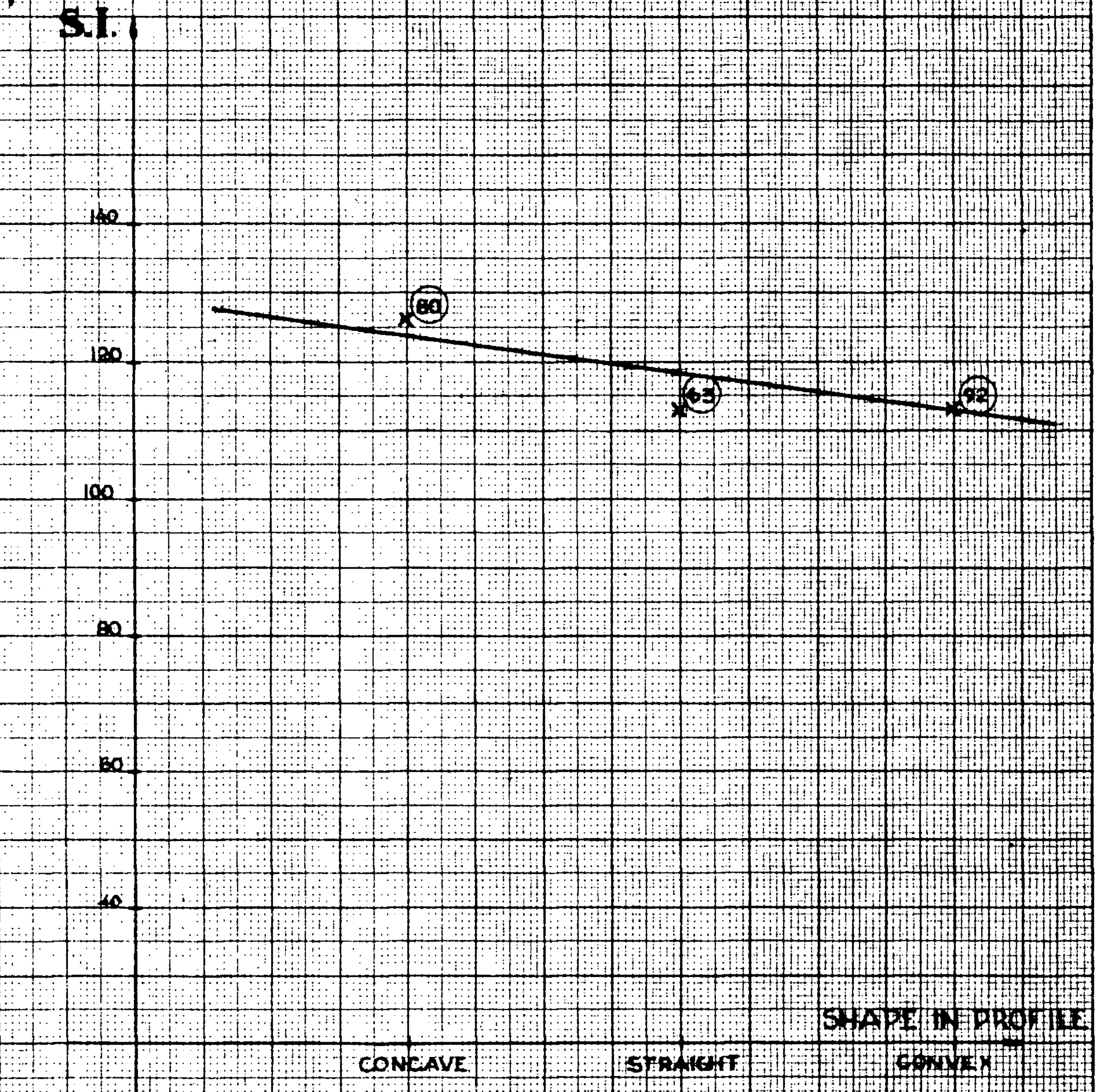


Figure 13.

S.I. on SHAPE in CONTOUR.

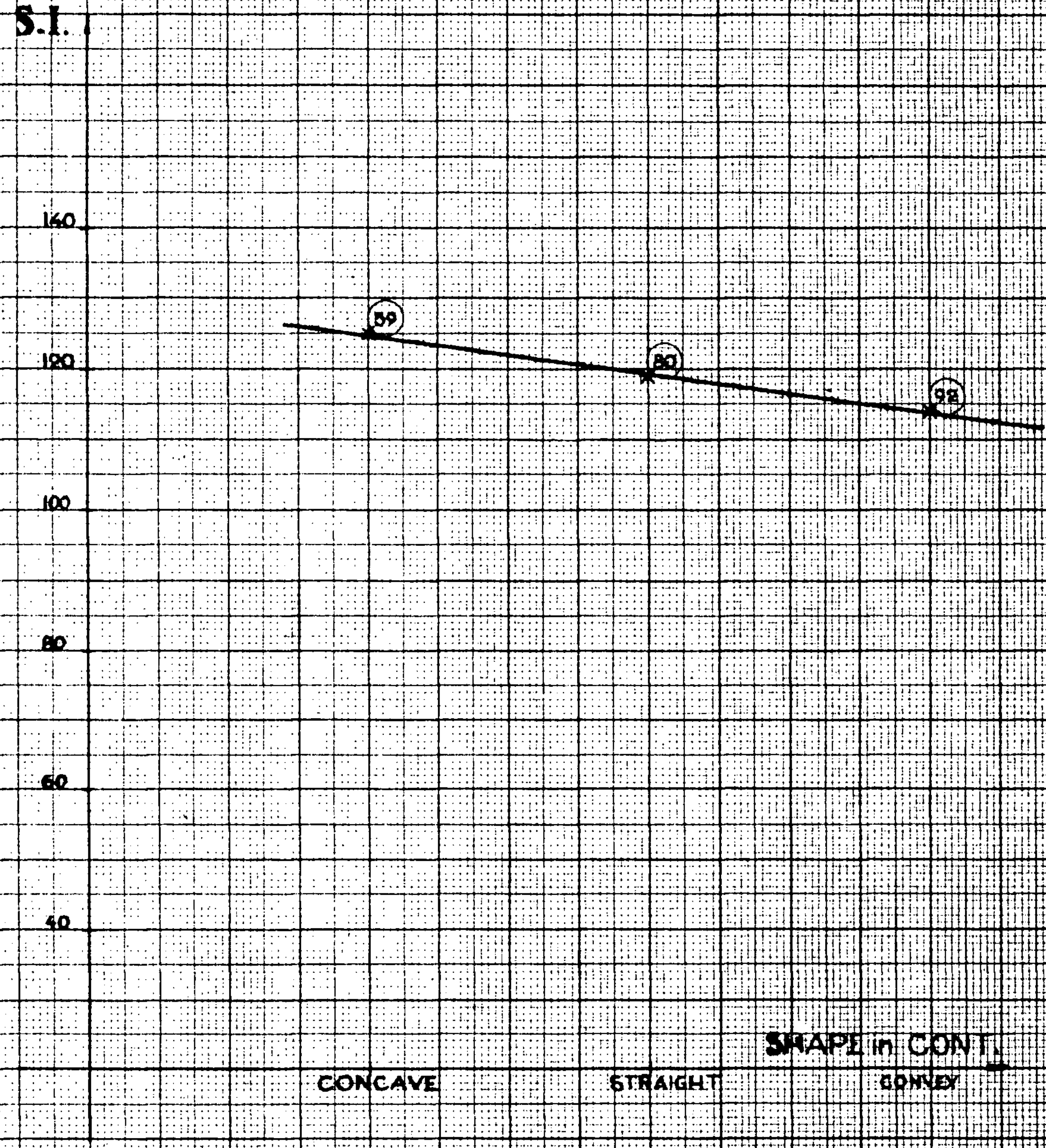


Figure 14.

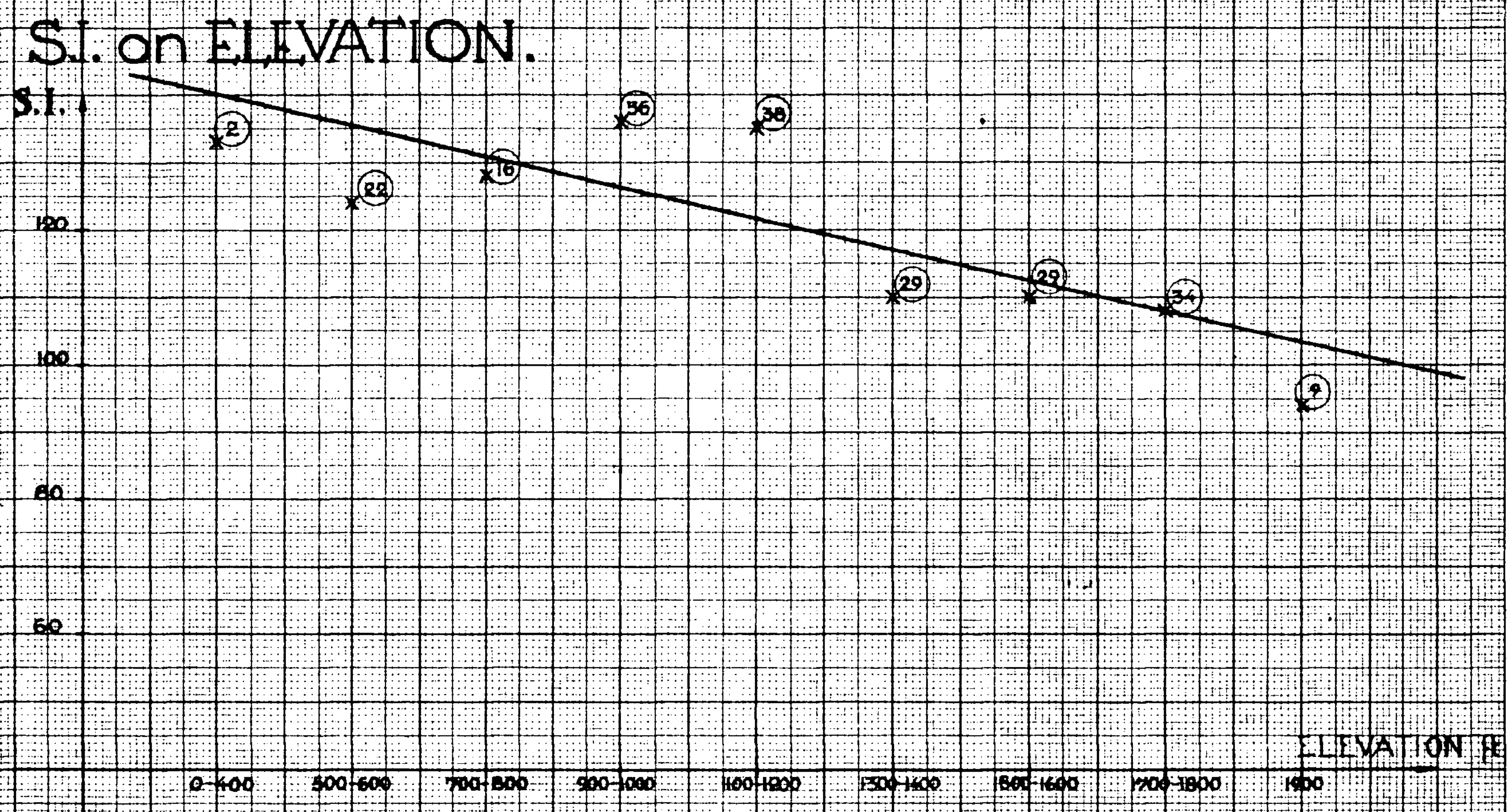

S.I. on ELEVATION.
S.I.
120
100
80
60
2
22
16
36
38
29
29
34
9
0-400
500-600
700-800
900-1000
1100-1200
1300-1400
1500-1600
1700-1800
1900
ELEVATION

Figure 15.

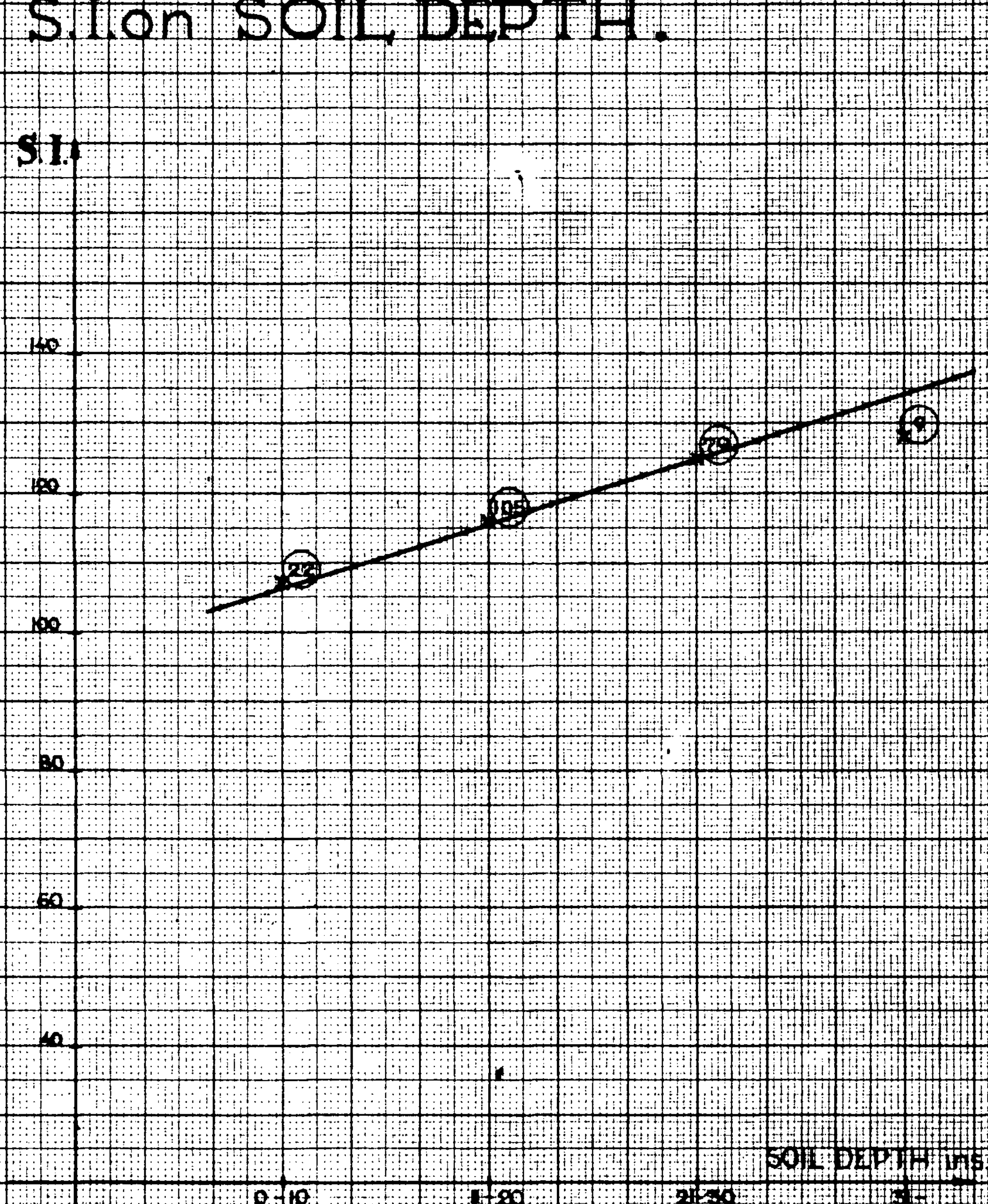

S.I. on SOIL DEPTH.
S.I.
140
120
100
80
60
40
105
SOIL DEPTH ins
0 - 10
11 - 20
21 - 30
31 -

Figure 16.

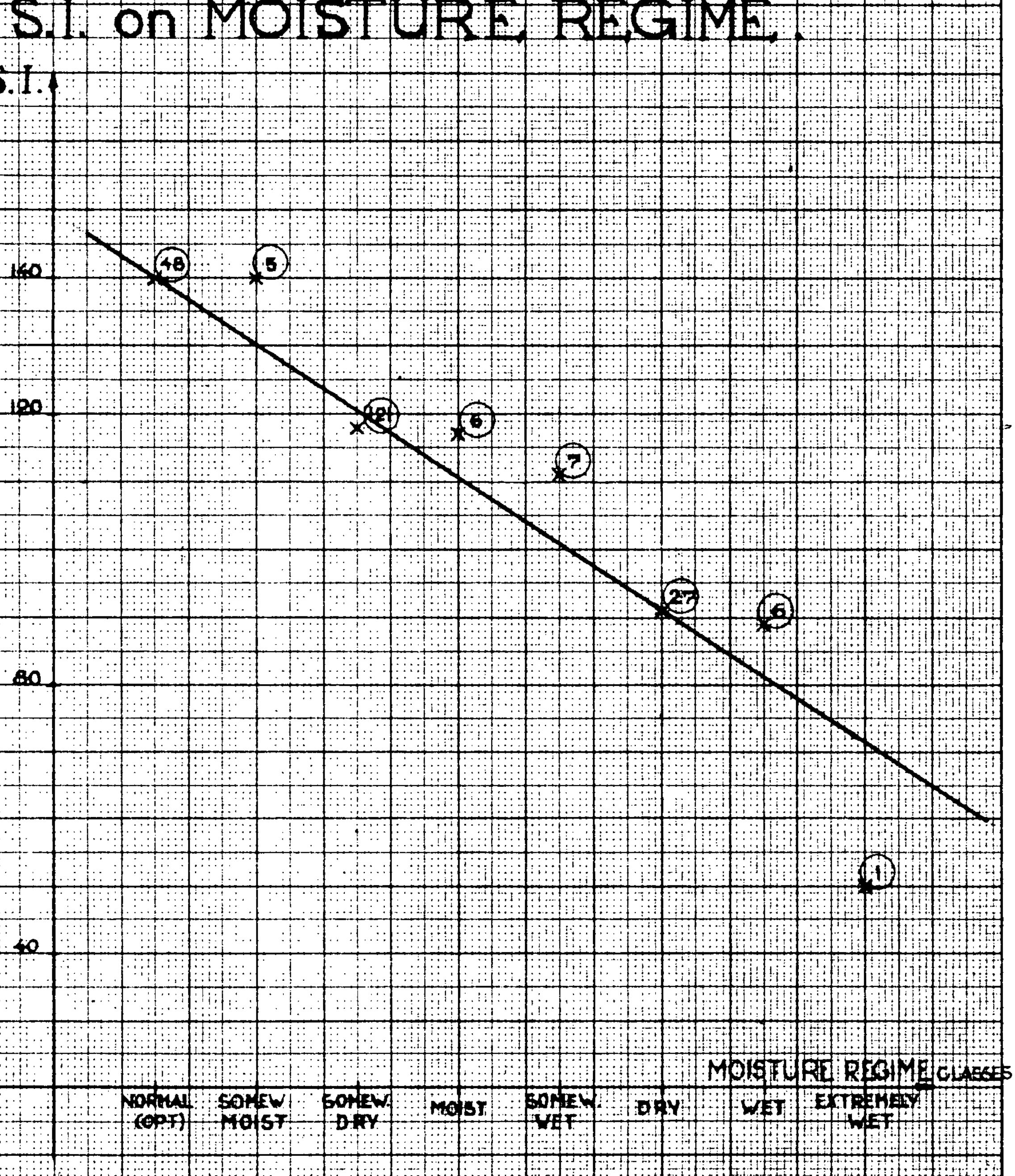

S.I. on MOISTURE REGIME.
S.I.
160
120
80
40
48
5
121
6
7
27
6
1
MOISTURE REGIME CLASSES
NORMAL (OPT)
SOMEW MOIST
SOMEW. DRY
MOIST
SOMEW. WET
DRY
WET
EXTREMELY WET

Figure 17.

S.I. on PORE PATTERN.

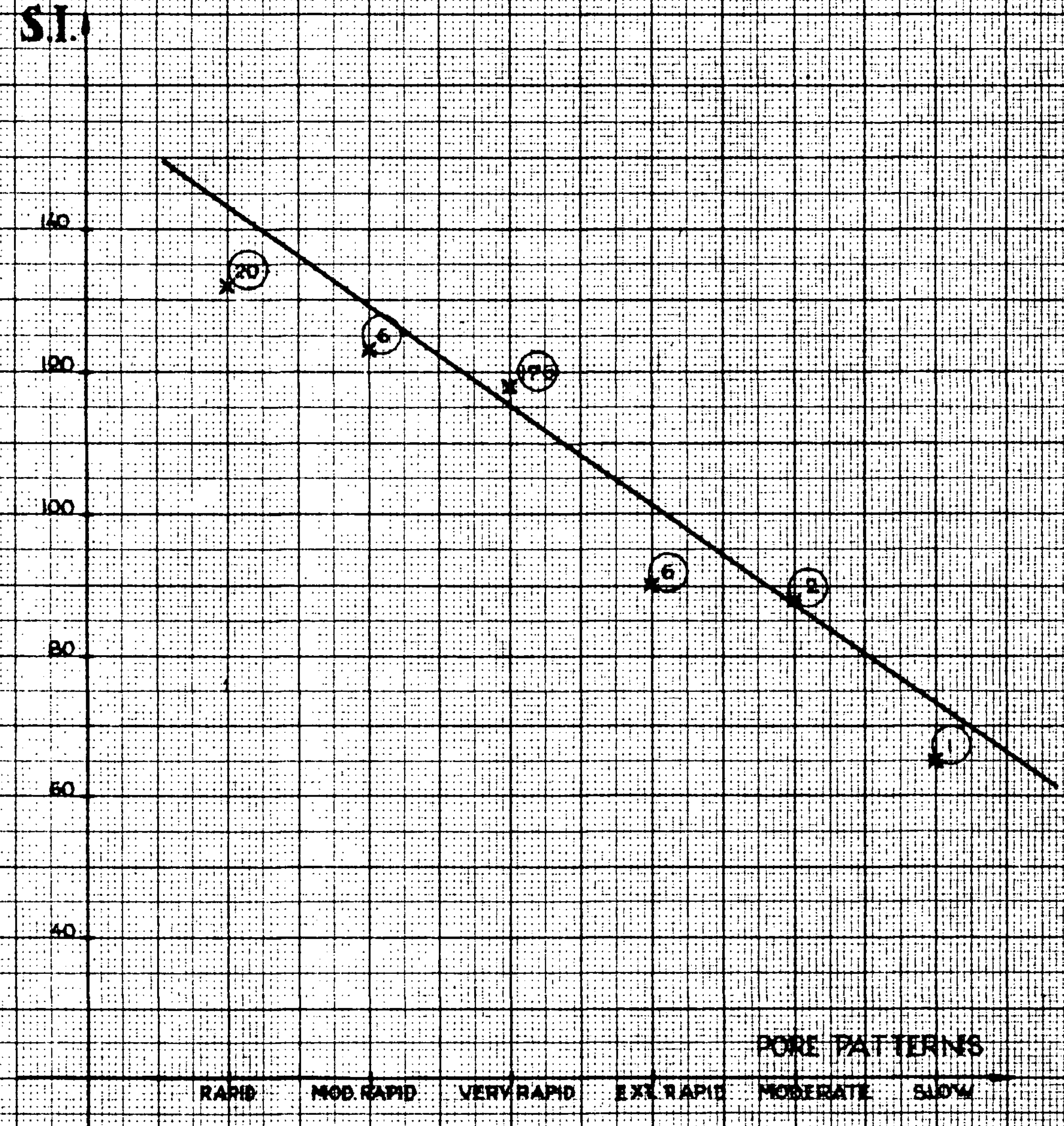


Figure 10.

S.I. on TEXTURE.

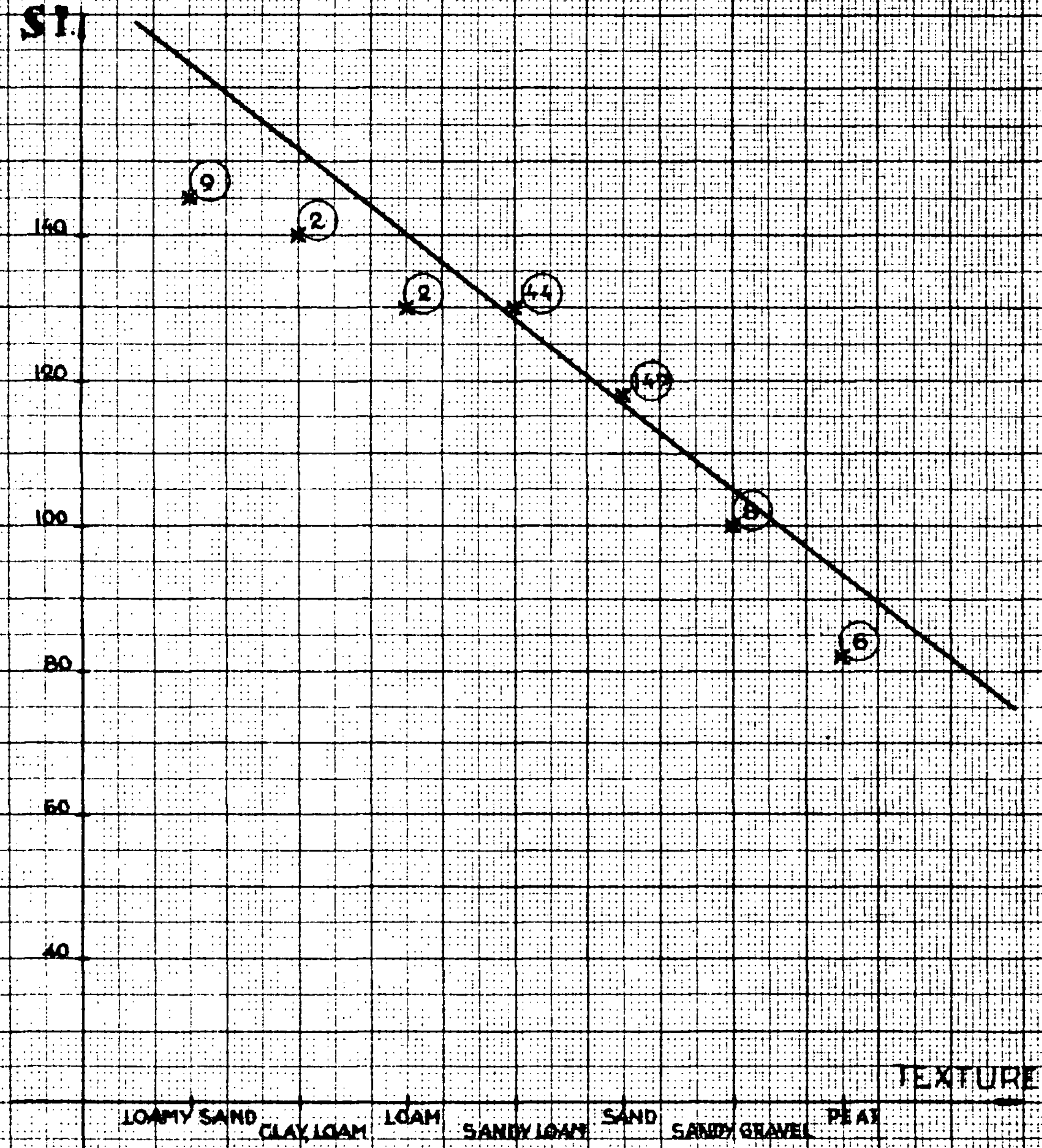


Figure 19.

S.I. on "H" LAYER.

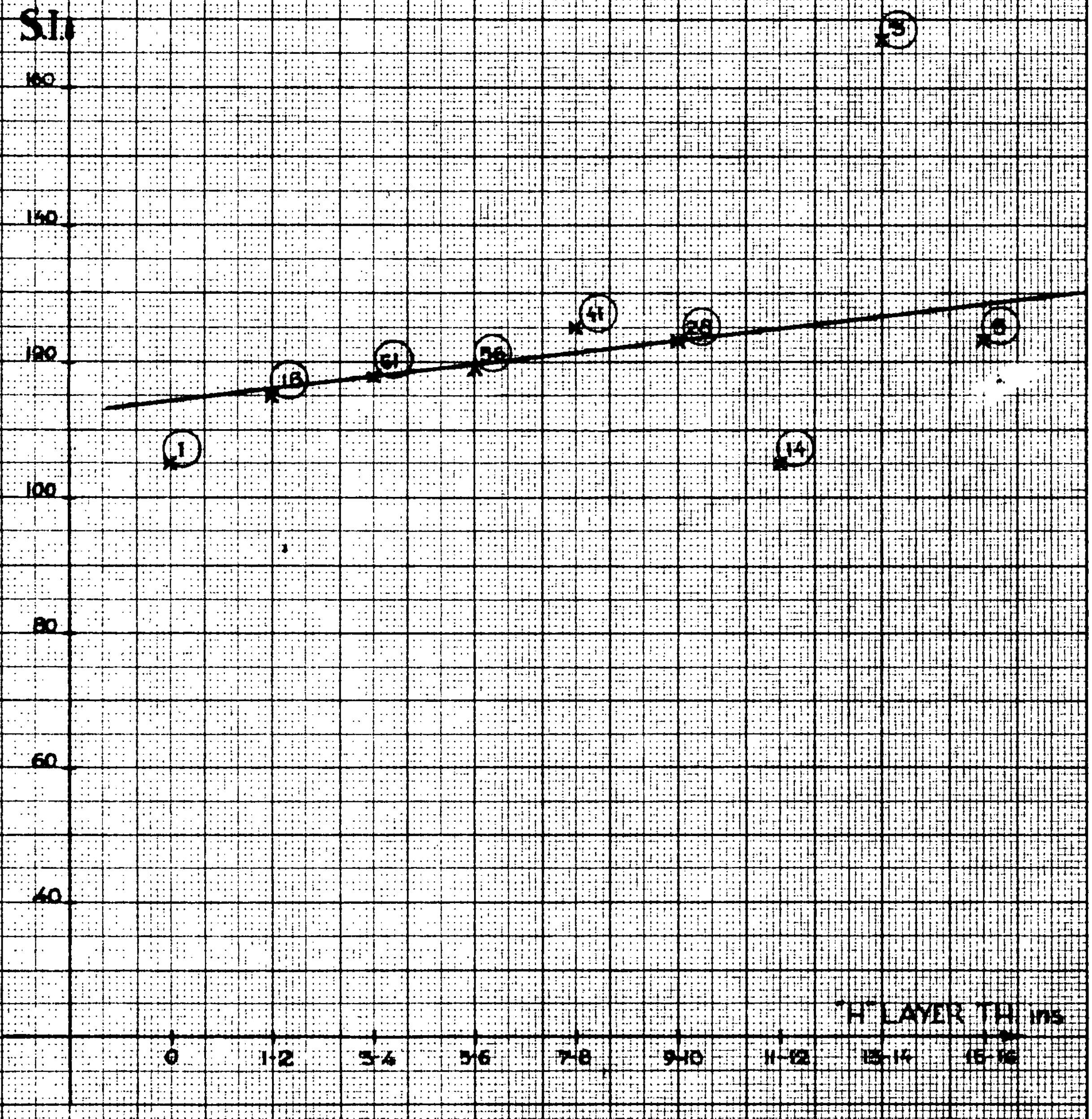


Figure 20.

S.I. on A_2 LAYER.

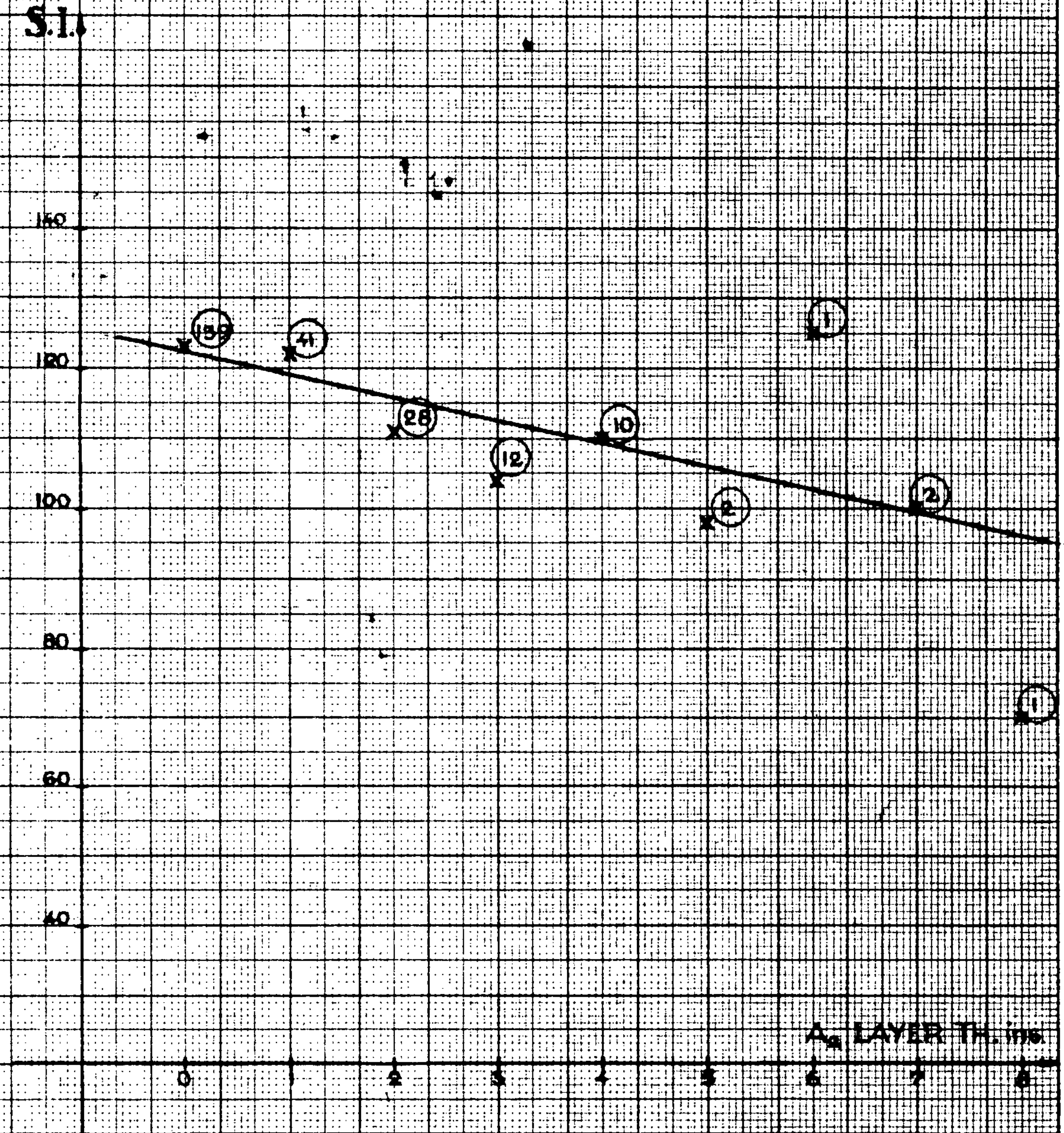


Figure 21.

Statistical Analysis

The S7 program for the ALWAC III E electronic computer was used for the analysis of field data. This statistical program provides for the computation of means, covariances, standard deviations, correlation coefficients, and regression coefficients. Four separate linear multiple-regression analyses were carried out; one for the A. and L. portion of the Forest, one for the second-growth area, one for the old-growth area, and one for the combination of these areas. Data of 211 complete sample plots from the A. and L. portion of the Forest were used for the computation. The number of plots in the second-growth area was 83, and 26 in the old-growth area.

Some variables had no actual value, therefore, a code value was given for these variable classes. The highest number in the scale corresponded to that class which had the highest site index, and the lowest number was used for the class with poorest site (based on the graphical analysis). The following code values were given for the variable classes:

Aspect, XI: South-1: East-2; West-3; North-4.

Local position on slope, X2: Swamp-1; Ridge-2; Upper slope-3; Flat-4; Middle slope-5; Low slope-6; Low and middle slopes with seepage-water-7.

General position on slope, X3: Rock-1; Swamp-2; Ridge-3; Upper slope-4; Middle slope-5; Low slope-6; Flat-7.

Per cent of slope, X4: Over 81 per cent-0; 71-80 per cent-1; 61-70 per cent-2; 51-60 per cent-3; 41-50 per cent-4; 31-40 per cent-5; 21-30 per cent-6; 11-20 per cent-7; 5-10 per cent-8; 0-4 per cent-9.

Shape in profile, X5: Convex-1; Straight-2; Concave-3.

Shape in contour, X6: Convex-1; Straight-2; Concave-3.

Elevation, X7: Over 1,900 feet-1; 1,700-1,800 feet-2; 1,500-1,600 feet-3; 1,300-1,400 feet-4; 1,100-1,200 feet-5; 900-1,000 feet-6; 700-800 feet-7; 500-600 feet-8; 0-400 feet-9.

Soil depth, X8: 0-10 inches-1; 11-20 inches-2; 21-30 inches-3; over 31 inches-4.

Moisture regime, X9: Wet-0; Dry-1; Somewhat wet-2; Moist-3; Somewhat dry-4; Somewhat moist-5; Normal (optimum)-6.

Permeability, X10: Moderate-0; Extremely rapid-1; Very rapid-2; Moderately rapid-3; Rapid-4.

Soil texture, X11: Peat-1; Sandy gravel-2; Sand-3; Loam-4; Sandy loam-5; Loamy clay-6; Loamy sand-7.

Humus layer thickness, X12: 1-2 inches-1; 3-4 inches -2; 5-6 inches-3; 7-8 inches-4; over 9 inches-5.

A_2 layer thickness, X13: Zero inch-0; 1 inch-1; 2 inches-2; 3 inches-3; 4 inches-4; over 5 inches-5.

Site index, Y: Estimate of average height of fir, hemlock, and cedar at age 100 based on one tree of major species per plot.

The results of the analyses are presented in Tables 3, 4, 5, and 6. Table 7 contains the multiple-regression constants for Y on X1-13. Regression equations were computed using the photo-measurable variables (X1 to X9), then eliminating the least important variable in turn. Constants and regression coefficients of these equations, correlation coefficients, and standard errors of estimate are presented in Table 8. Finally, regression equations were computed for estimating site index from photo-measurable variables applying several possibly useful combinations of variables. Variables used in these combinations had the highest correlation coefficients in the analysis using all variables. Table 9 contains the constants of these equations, correlation coefficients, and standard errors of estimate. The last two analyses were carried out only for the combined data. Discussion of observations follows the tables.

TABLE 3

Statistics of variables on A. and L. portion of the Forest

Statistics	Variables						
	XI	X2	X3	X4	X5	X6	X7
Means	2.15	5.12	4.90	6.70	1.98	1.88	4.65
Standard dev.	0.94	1.89	1.29	1.73	0.85	0.80	2.04
Minimum	1	1	1	0	1	1	1
Maximum	4	7	7	9	3	3	9
Correlation coefficients	.098	.425**	.359**	.164*	.199**	.148*	.316**

Statistics	Variables						
	X8	X9	X10	X11	X12	X13	Y
Means	2.41	3.92	2.24	3.47	3.31	0.91	118.96
Standard dev.	0.74	1.63	0.75	1.19	1.31	1.33	28.08
Minimum	1	0	0	1	1	0	60
Maximum	4	6	4	7	5	5	205
Correlation coefficients	.190**	.537**	.190**	.328**	.055	.249**	1.000

Age 30
No. plots 211
*Significant
**Highly significant

TABLE 4

Statistics of variables on second-growth area

Statistics	Variables X1	X2	X3	X4	X5	X6	X7
Means	2.13	5.10	5.47	7.58	1.64	1.71	5.53
Standard dev.	1.18	1.08	0.70	1.01	0.76	0.89	1.43
Minimum	1	1	3	4	1	1	3
Maximum	4	7	7	9	3	3	9
Correlation coefficients	.073	.331**	.328**	.150	.190	.012	.143

Statistics	Variables X8	X9	X10	X11	X12	X13	Y
Means	2.45	5.13	3.33	5.37	2.41	1.41	131.51
Standard dev.	0.77	1.06	0.95	1.63	1.31	1.22	26.74
Minumum	1	0	0	1	1	0	80
Maximum	4	6	4	7	5	5	190
Correlation coefficients	.163	.107	.307**	.137	.087	.043	1.000

Age 70
No. of plots 83
**Highly significant

TABLE 5

Statistics of variables on old-growth area

Statistics	Variables						
	X1	X2	X3	X4	X5	X6	X7
Means	2.04	5.19	5.31	5.89	1.73	1.96	3.27
Standard dev.	1.04	0.85	0.47	2.34	0.92	0.96	1.37
Minimum	1	3	5	1	1	1	1
Maximum	4	6	6	9	3	3	5
Correlation coefficients	.159	.092	.062	.162	.063	.284	.587**

Statistics	Variables						
	X8	X9	X10	X11	X12	X13	Y
Means	2.23	4.73	2.77	5.73	2.31	1.12	105.00
Standard dev.	0.82	1.04	0.91	1.28	1.09	1.48	20.59
Minimum	1	2	2	3	1	0	60
Maximum	4	6	4	7	5	5	140
Correlation coefficients	.119	.112	.405*	.265	.089	.355	1.000

Age 300
No. of plots 26
*Significant
**Highly significant

TABLE 6

Statistics of variables for the combined data

Statistics	Variables X1	X2	X3	X4	X5	X6	X7
Means	2.13	5.12	5.08	6.86	1.87	1.84	4.77
Standard dev.	1.02	1.64	1.15	1.70	0.84	0.84	1.94
Minimum	1	1	1	0	1	1	1
Maximum	4	7	7	9	3	3	9
Correlation coefficients	.075	.368**	.349**	.191**	.152*	.088	.346**

Statistics	Variables X8	X9	X10	X11	X12	X13	Y
Means	2.40	4.30	2.57	4.14	2.99	1.06	121.08
Standard dev.	0.75	1.55	0.94	1.63	1.36	1.33	28.08
Minimum	1	0	0	1	1	0	60
Maximum	4	6	4	7	5	5	205
Correlation coefficients	.187**	.444**	.238**	.252**	.030	.168**	1.000

No. of plots 320

*Significant
**Highly significant

TABLE 17.

Multiple regression constants for Y on X 1 - 13

	No.	a	b_1	b_2	b_3	b_4	b_5	b_6	b_7
Young stand	211	58.85	1.33	1.85	2.09	1.12	2.03	-1.87	1.99
Second-growth	83	17.33	2.92	5.33	4.05	1.33	4.86	-2.52	-0.26
Old-growth stand	26	-58.89	-4.46	-2.95	20.55	-.98	-10.25	9.60	10.36
All	320	43.53	1.72	2.42	2.50	1.13	2.41	-1.25	2.75

	b_8	b_9	b_{10}	b_{11}	b_{12}	b_{13}	R^2	R	SE_E
Young stand	-2.06	6.64	-3.22	1.22	1.18	-1.89	.1624	.4029**	±26.54
Second-growth	5.77	0.81	6.58	0.65	0.69	0.68	.2566	.5065**	±24.96
Old-growth stand	0.06	6.02	0.11	1.40	5.76	-0.22	.6857	.8281**	±16.01
All	-0.40	5.02	-0.32	.55	1.54	-1.03	.3162	.5623**	±23.67

**Highly significant

TABLE 8.

Regression equations for estimating site index from photo-measurable variables used in study, eliminating least important variables in turn (320 plots)

Variables	Constant (a)			
	44.53	44.12	45.11	49.68
	Regression coefficients (b)			
X1 Aspects	1.83	1.83	1.83	
X2 Local position	2.69	2.67	2.67	2.77
X3 General position	2.33	2.32	2.29	2.07
X4 Percent of slope	1.12	1.13	1.14	1.06
X5 Shape in profile	2.34	2.04	2.08	2.12
X6 Shape in contour	-0.54			
X7 Elevation	2.83	2.85	2.91	2.80
X8 Soil depth	0.66	0.67		
X9 Moisture regime	4.88	4.86	4.93	5.15
R^2 or r^2	.309	.308	.308	.304
R or r	.555**	.555**	.555**	.551**
SE_E S.I.	±23.58	±23.58	±23.58	±23.65

Variables	Constant (a)				
	52.16	58.22	63.04	73.87	86.55
	Regression coefficients (b)				
X1					
X2	3.17	3.04	3.54		
X3	1.83	1.91			
X4	1.16				
X5					
X6					
X7	2.87	3.24	3.55	3.66	
X8					
X9	5.06	5.14	5.35	6.93	8.04
R^2 or r^2	.300	.296	.292	.257	.197
R or r	.548**	.544**	.540**	.507**	.443**
SE_E S.I.	±23.70	±23.68	±23.74	±24.32	±25.28

**Highly significant

TABLE 9.

Regression equations for estimating site index from photo-measurable variables, applying several possibly useful combinations (320 plots)

Variables	Constant (a)						
	54.17	58.84	62.66	65.91	66.31	63.04	71.79
	Regression coefficients (b)						
X2 Local position	3.37	5.49	5.53	6.13	6.30	3.54	5.58
X3 General position							
X4 Per cent of slope	1.12	1.40	1.76	3.14	3.19		
X5 Shape in profile	1.77	0.88	1.00	1.21			
X6 Shape in contour							
X7 Elevation	3.07	3.56	3.82			3.55	4.35
X8 Soil depth	0.54	2.48					
X9 Moisture regime	5.30					5.35	
R^2 or r^2	.299	.235	.232	.172	.173	.292	.224
R or r	.547**	.485**	.481**	.417**	.416**	.540**	.473**
SE_E S.I.	±23.73	±24.79	±24.73	±25.65	±25.66	±23.74	±24.85

**Highly significant

TABLE 9. (cont'd)

Regression equations for estimating site index from photo-measurable variables, applying several possible useful combinations (320 plots)

Variables	Constant (a)						
	74.80	73.87	62.79	55.42	70.13	60.48	91.34
	Regression coefficients (b)						
X2 Local position	3.71		0.66	2.63	4.46		
X3 General position			5.22	2.20	5.53	6.31	
X4 Percent of slope						0.97	1.13
X5 Shape in profile				2.66			
X6 Shape in contour				-0.66			
X7 Elevation		3.66		3.10		2.95	4.62
X8 Soil depth						3.25	
X9 Moisture regime	6.35	6.93	6.60	5.24			
R^2 or r^2	.235	.257	.250	.301	.175	.188	.123
R or r	.485**	.507**	.500**	.548**	.418**	.433**	.351**
SE_E S.I.	±24.67	±24.32	±24.43	±23.71	±25.63	±25.55	±26.42

**Highly significant

TABLE 9. (cont'd)

Regression equations for estimating site index from photo-measurable variables applying several possibly useful combinations (320 plots)

Variables	Constant (a)					
	87.51	111.45	86.82	71.50	91.09	66.19
	Regression coefficients (b)					
X2 Local position	6.07		6.03			
X3 General position				6.33		5.22
X4 Per cent of slope						
X5 Shape in profile	2.38	5.00	1.82			
X6 Shape in contour	-1.05	.16				
X7 Elevation				3.66	4.60	
X8 Soil depth					3.35	
X9 Moisture regime						6.60
R^2 or r^2	.139	.023	.138	.177	.127	.236
R or r	.373**	.152	.372**	.421**	.356**	.486**
SE_E S.I.	±26.18	±27.88	±26.19	±25.59	±26.37	±24.66

**Highly significant

Discussion of Observations

The graphical analysis of data illustrates the relationship between the variables. The mathematical analysis provides us with the equations of these relationships, and informs about the statistical significance of these equations. The results of graphical and mathematical analyses will be discussed together in the following section.

Influence of topographic variables on site index.

(1) Aspect

According to Figure 9 the following trend of aspect was observed with the decrease of site index: North (S.I.125), West (S.I.123), East (S.I.120), South (S.I.116), and flat situation (S.I.108). The numbers represent the average site indices for the corresponding aspects. The graph indicates a well fitted linear relationship between the site index and aspects, but the data represent averages and the variation of individual observations around the line is large; this relationship is statistically non significant (r0.075). However, the site quality probably is higher on the North, East and West slopes than on the South slopes because the South slopes are subject to the drying effect of sun.

(2) Local and general position on the slope.

Local position on the slope is an important factor influencing site quality. According to Figure 10 site index decreases with the following order of local position classes:

Middle seepage (S.I.136), Low seepage (S.I.131), Lower slope (S.I.121), Middle slope (S.I.120), Level situation (S.I.118), Ridge (S.I.105), High slope (S.I.104), and Swamp (S.I.81). Where seepage is occurring the site quality is high. The correlation coefficient "r" for this variable was 0.37, highly significant. This trend of local position classes is expectable; however, the site quality of level situation is too low. This variable is correlated also with moisture regime (r0.43).

Figure II illustrates the relationship between site index and general position on slope. The effect of general position on site quality is about same as the effect of local position with exception of level situation, which has the highest average site index (S.I.133). The correlation coefficient was highly significant (r0.35).

(3) Percentage of slope.

It is obvious that site index decreases with increase in per cent of slope (Figure 12). Decrease of site index is slow on slopes from zero to 20 per cent. On slopes over 20 per cent the site index decreases rapidly with increase in slope percentage. The correlation coefficient (r0.20) indicates that this relationship is statistically significant, however, this value is low, and variation of data around the line is broad.

(4) Shape in profile and contour.

Figure 13 and Figure 14 illustrate these relationships. However, these average values of site indices do not represent adequately the individual data, therefore these relationships are non significant. It can be stated that only the concave curvature in profile and contour represents better site quality.

(5) Elevation.

Site index decreases with increase in elevation (Figure 15). Site index decreases slowly with increase in elevation from 100 feet to 800 feet. A small increase of site index occurs at 1,000 feet elevation, then site index rapidly decreases with increase in elevation. The correlation coefficient for this relation was highly significant (r0.35).

Influence of Soil Factors on site index.

(1) Soil depth.

Figure 16 illustrates the relationship between site index and soil depth. Site index increases with increase in soil depth to 30 inches. Over 30 inches, the soil depth does not influence the site quality.

(2) Moisture regime.

Mositure regime is the most important factor determining the site quality of an area. Figure 17 illustrates this relationship. This regression is highly significant (r0.44). The optimum moisture regime indicates the highest average site index (S.I.140). Extremely wet soil represents the lowest site quality (S.I.50).

(3) Permeability.

The trend of permeability classes with decrease in site index is presented by Figure 18. Soil with rapid permeability represents the highest site quality (S.I.132). Soil with slow permeability represents the lower site quality (S.I.65). The correlation coefficient of this relationship was (r0.24), highly significant.

(4) Soil texture.

Soil texture significantly influences site quality. Site index is higher on loamy sand, clay loam and loamy soils than on the sandy, gravelly and peat soils (Figure 19).

(5) Humus layer thickness.

Humus layer thickness on the soil does not influence significantly the site quality. However, site index is lower on soil with a thin humus layer (from zero to 2 inches) than on soil with thicker humus layers (Figure 20).

(6) A_2 layer thickness.

Site quality is correlated with A_2-layer thickness (r0.17). Site index decreases with increase in A_2-layer thickness (Figure 21).

Estimation of Average Site Index, and Estimation by Species.

Graphical and mathematical analyses provide us with good information about the relationships which exists among the variables. However, the mathematical equations, which were computed, were not accurate enough to estimate site indices. The standard errors of estimate of these equations are very high, over $\pm$ 22 feet in each case with the exception of the equation for old-growth stand using thirteen variables (Table 7).

The computed equations represent general relationships between the variables. However, the natural condition of a forest cannot be expressed completely by a mathematical formula. It could happen that the site quality of a particular forest type is better although having otherwise worse site factors than the site quality of other types having the same or better site factors. Sometimes many variables would indicate a good site quality for a certain type but one variable determines a low site quality. Therefore, for a good estimation of site quality one needs the judgement of the photo-interpreter in each case. In this the following method was developed and applied to estimate the site quality from aerial photographs.

It was supposed that the site quality of a topographic type is the same within the type. Generally this is true because the topographic factors determine the site quality through their influence on microclimate, soil and moisture conditions of a particular place. As the first step the interpreter collected and analysed the field data. It is very important that the photo-interpreter collects the field data because he had to know the working area. After analysis the photo-interpreter decided which variables were the most important for correlating with the site quality. Then the interpreter, knowing the actual field relationships among the variables, examined many topographic types, on which the ground data were collected, stereoscopically on aerial photographs.

In the second step the photo-interpreter estimated site indices from the aerial photographs for numerous types and checked those on the ground. If the estimation of site indices was accurate enough the interpreter estimated the site indices for the rest of the types. The site estimation of the writer after training in the field, was highly significant having (r=0.65). The standard error of estimate was ± 16.4 feet, which is about the same as the standard error of estimate found from the determination of type site index from the individual tree data on each plot.

The average site index was estimated first by five-foot classes, then the site indices for Douglas fir, western hemlock, western red cedar, and red alder were estimated separately. Estimation of site index for individual species from aerial photographs is more difficult than the estimation of average site index. Before the estimation of site index for individual species the photo-interpreter must study the ecological characteristics of the local species and their topographic location on the working area. The estimation of site indices for individual species was based on the following observations within the University Research Forest area. Site index of Douglas fir is greater than the site index of western hemlock and of western red cedar on better sites, particularly where seepage surface running water is found on lower and middle slopes. Site index of Douglas fir is lower on upper slopes. Site index for the three species is about the same on low site. Site index of western hemlock is greater than the other two species on upper slopes and dryer middle slopes where the humus layer is thicker. Site index of red alder and black cottonwood varies between 90 and 130 feet. Red alder has a lower site index than the black cottonwood.

The average site index for Douglas fir is 120 feet, for western hemlock 122 feet, for western red cedar 113, and the average for the three species 119 feet. A good correlation was found between the individual and average site indices. This correlation was significant at the two per cent probability level (t=2.058, degrees of freedom=152) (Table 10). Table 10 presents the statistics and regression equation for the average site index and site indices of Douglas fir, western hemlock, and western red cedar. Table II contains the constants and Standard Errors of estimate of linear regression equations for conversion of site index of Douglas fir, western hemlock, and western red cedar from one species to another.

Preparation of Site Maps.

In preparing site maps the problem is to choose adequate mapping units. It is difficult to determine the borders of different site types on the ground. The big advantage of aerial photographs is that a photo-interpreter, with a good forestry background, can easily determine type boundaries on aerial photographs by stereoscopic examination. The basic mapping unit for site maps may be forest cover types, soil types, physiographic types or topographic types, depending on the method which was used for the evaluation of site quality. Topographic types were the basic mapping units in this study. Site indices for each topographic type were determined from the field data or were estimated from aerial photographs. Then those types were combined which had site indices within 20-foot classes.

Two site maps were prepared for the A. and L. portion of the Forest; (1) average site map, and (2) site map for Douglas fir (Appendix D and E). A site map was prepared for the second-growth and old-growth area of the Forest in 1950 by ground survey. This site map is presented on same map with the average site map for A. and L. portion of the Forest (Appendix D).

TABLE 10

Statistics and regression equation for the average site index and site indices of Douglas fir, western hemlock, and western red cedar

Statistics		S.I. of Douglas fir	S.I. Western hemlock	S.I. Western red cedar	S.I. Average
Means		119.5	122.1	112.5	119.2
Standard deviations		27.0	32.0	31.9	25.7
Minimum		65	50	40	60
Maximum		205	200	200	175
Correlation coefficients		.734**	.896**	.780**	1.000
No. of plots	152 t	2.058**			
		b_1	b_2	b_3	a
Constants		.276	.413	.286	3.616

TABLE II

Linear regression equations for conversion of site index of Douglas fir, western hemlock, and western red cedar from one species to another

Y	X	a	b	CC	SE_E
Fir	Hemlock	59.60	0.49	0.58**	± 21.98
Fir	Cedar	80.91	0.37	0.40**	± 24.72
Hemlock	Cedar	48.87	0.60	0.60**	± 25.67
Hemlock	Fir	39.63	0.69	0.58**	± 26.06
Cedar	Fir	55.57	0.48	0.40**	± 29.14
Cedar	Hemlock	40.16	0.59	0.60**	± 25.58

**Highly significant

SUMMARY AND CONCLUSION

The site quality of the University of British Columbia Research Forest area was evaluated on aerial photographs. The method used was based on a combination of Choate's (1958) and Hills' (1950) systems. A significant correlation was found between site index as the dependent variable and some topographic and soil factors as independent variables. Linear multiple-regression equations were calculated by a ALWAC III-E electronic computer determine site index from the various topographic and soil variables. Because these equations had high standard errors of estimate for computation of site index (SE_E 25 feet) site index was estimated directly from photos for different topographic types by the author. This estimation by a photo-interpreter was more valuable (SE_E 17 feet) than use of the computed equations. One site map was prepared to illustrate the site quality of part of the U.B.C. Forest by averaging the site indices of Douglas fir, western hemlock, and western red cedar; another site map was prepared for Douglas fir alone. Regression equations were developed for conversion of site index of Douglas fir, western hemlock, and western red cedar to each other species and the average of all species.

This study confirms the utility of aerial photographs for evaluating site quality. Although, applied at Haney on a relatively small area, the method could be used for evaluation of site quality of larger areas. This method is more accurate on deforested (logged) or on young stand areas because the topographic and soil factors can be observed there more easily by stereoscopic examination. However, the application of this method for second-growth and old-growth forests was also successful.

This method of evaluation of site quality from aerial photographs is not an ideal method but does offer many advantages. It is likely that the accuracy of photo-estimation of site index can be increased by more experience in photo-interpretation and by more observation in the field.

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APPENDICES

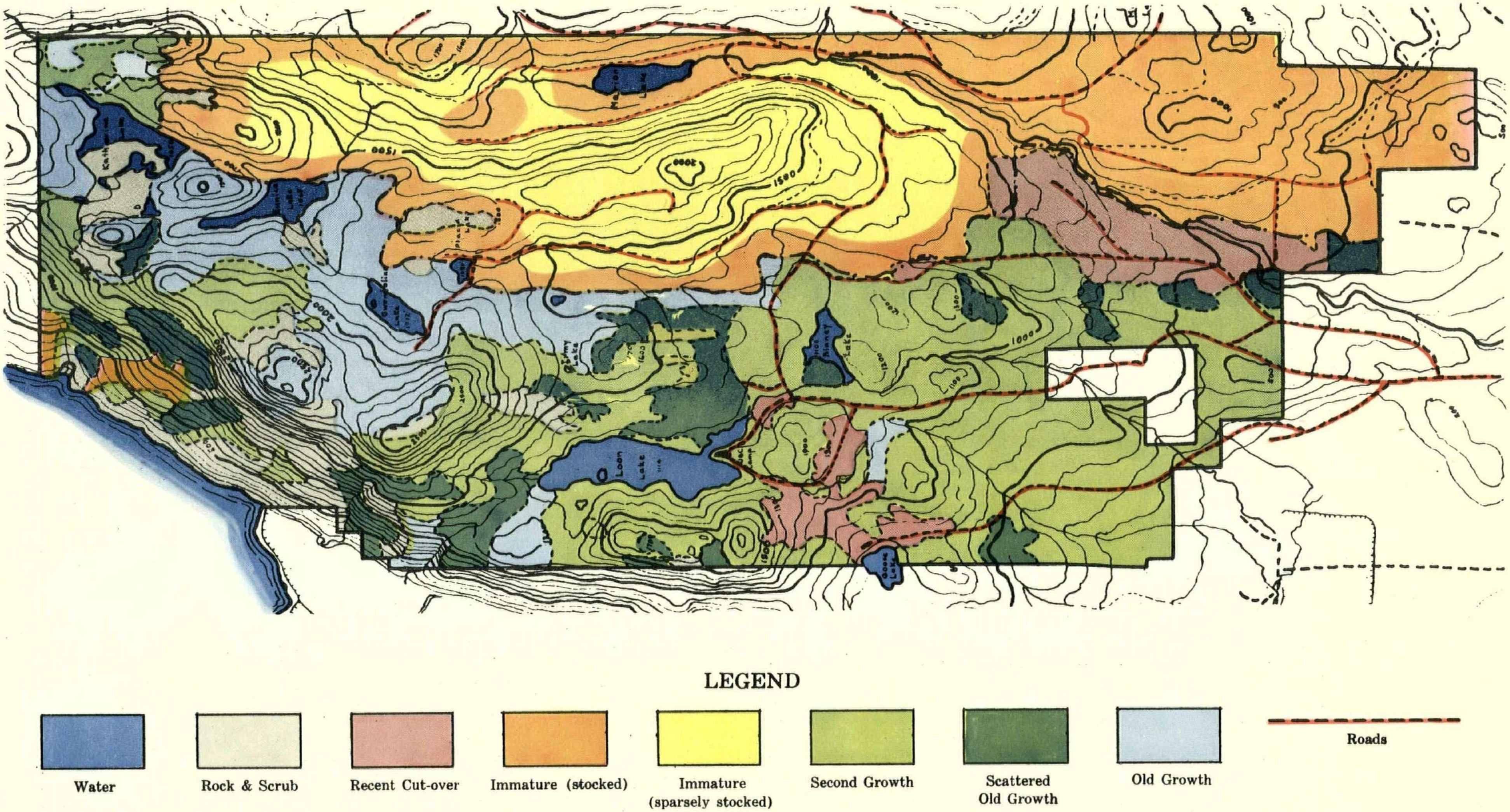
APPENDIX A

COMMON AND SCIENTIFIC NAMES OF SPECIES

University Forest Tree Species

a. Coniferous Species	Common name
Abies amabilis (Dougl.) Forb.	Amabilis Fir
Chamaecyparis nootkatensis (D.Don) Spach	Yellow cedar
Picea sitchensis (Bong) Carr.	Sitka spruce
Pinus contorta Dougl.	Lodgepole pine
Pinus monticola Dougl.	Western white pine
Pseudotsuga taxifolia (Poir.) Britton	Douglas fir
Taxus brevifolia Nutt.	Western yew
Thuja plicata Donn.	Western red cedar
Tsuga heterophylla (Raf.) Sarg.	Western hemlock

b. Broad-leaved Species	
Acer circinatum Pursh.	Vine maple
Acer macrophyllum Pursh.	Broadleaf maple
Alnus rubra Bong (oregona)	Red alder
Betula papyrifera Marsh	
Var. commutata (Regel) Fern	Western white birch
Cornus Nuttalli Audubon	Western dogwood
Crataegus Douglasii Lindl.	Black Hawthorn
Malus fusca (Raf.) Schneid	Pacific crabapple
Populus trichocarpa Torr. & Gray	Black cottonwood
Prunus emarginata (Doug.) D. Dietr.	Wild cherry
Rhamnus Purshiana DC.	Cascara



Appendix B. Forest Cover Map

Western red cedar is the dominant species. Some western hemlock and amabilis fir also occur in this forest type. The site index of this forest type is about 180 feet. These forest types exist in the coastal western hemlock zone on the mainland of British Columbia (Krajina, 1960).

COLLECTION OF FIELD DATA

THE UNIVERSITY OF BRITISH COLUMBIA RESEARCH FOREST, HANEY

Location

The U. B. C. Research Forest comprises about 10,000 acres, which are situated within the Coastal Mountains, 30 miles from Vancouver, British Columbia. The Forest is roughly rectangular and is bounded by Garibaldi Park, Pitt Lake, and Pitt Meadows (Griffith, 1960).

Geological History

The general region of the Forest consists of rugged mountains rising up to 7,000 feet above sea level. These mountains are separated by deep U-shaped valleys. The area was subjected to at least four glaciations. During each glaciation the land was depressed relative to the sea, and the ice rested on the sea floor. Then the ice thinned and floated, and glacio-marine stony clay deposits were laid down below elevations of

500 feet. Above elevations of 500 feet, outwash was deposited. After that the ice melted and the land rose above the sea (Armstrong, 1957).

Most of the rock on the Forest area is quartz diorite, granodiorite, or diorite. Some granite outcrops occur around Loon Lake. Volcanic rock occurs east of Marion Lake, and glacial drift can be found between Marion and Katherine Lakes.

Topography

The elevation range of the Forest is 100 - 2,600 feet above sea level. The center of the Forest contains three parallel north-south valleys. The eastern valley is formed by Marion Lake and the west fork of the North Alouette River. Blaney Creek flows from Placid Lake to Blaney Lake in the central valley. The western valley contains Loon Lake which is about one mile long, and 120 acres in area. The ridges contain numerous rock outcrops and vary in steepness. The central ridge forms a semi-circle running to the northeast until it reaches 2,600 feet elevation. Then it continues as a high ridge to the north boundary of the Forest. The northwest slope is rocky, very steep and drops abruptly from the ridge top down to the Pitt Lake. Scrubby trees grow on this slope. The southern portion of the Forest has a south exposure and is lower in elevation. Slopes have numerous rock outcrops and bluffs, and vary greatly in steepness.

APPENDICES

F1, F2, F3, F4.

APPENDIX F, I

Sterogram illustrating sites southwest of Marion Lake

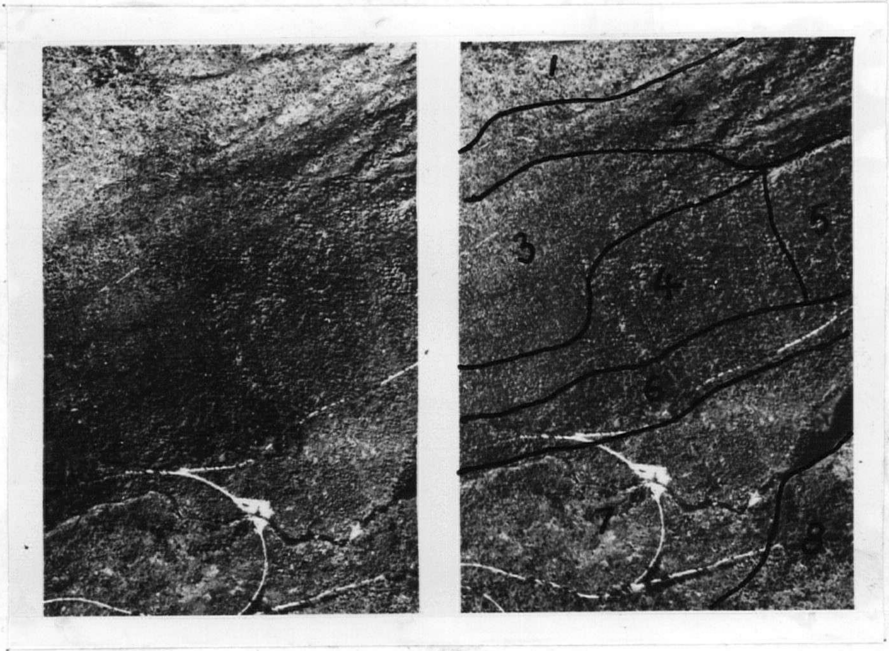


Figure 22

Description of types by codes of photo-measurable variables which were used in this study.

Type Number	Aspect	Local position	General position	Per cent of slope	Shape of profile
1	270	H	H	50	S
2	90	R	R	60	C
3	90	H	H	40	S
4	90	M	M	45	S
5	90	M	M	50	S
6	90	L	L	30	Co
7	L	Sw	Sw	-	C
8	270	L	L	5	S

Shape in contour	Elevation	Soil depth	Moisture regime	Average site index
S	20	10	0	80
S	19	10	1	80
S	17	15	1	110
S	14	20	1	140
S	14	20	1	130
C	12	25	2	160
C	10	20	1	80
S	10	20	1	140

APPENDIX F, 2

Sterogram illustrating sites southwest of Mike Lake

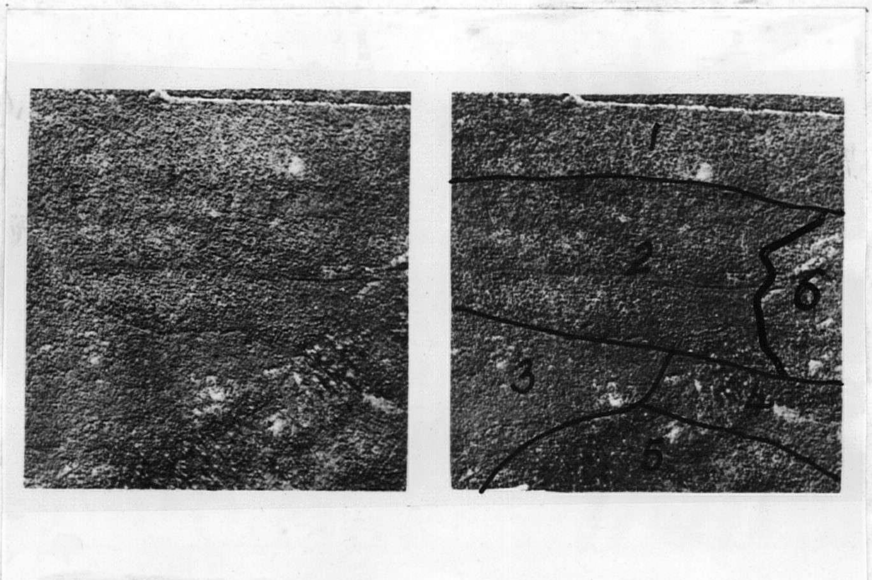


Figure 23

Description of types by codes of photo-measurable variables which were used in this study.

Type Number	Aspect	Local position	General position	Per cent of slope	Shape of profile
1	270	L	L	5	S
2	180	LS	L	10	S
3	270	M	L	20	S
4	270	L	L	10	S
5	30	M	M	15	S
6	270	R	Rock	20	C

Shape in contour	Elevation	Soil depth	Moisture regime	Average site index
S	7	20	1	140
C_o	8	20	2	150
C	9	15	1	120
S	9	15	1	120
S	9	20	2	130
C	10	10	1	90

APPENDIX F, 3

Sterogram illustrating sites of Blaney Lake area.

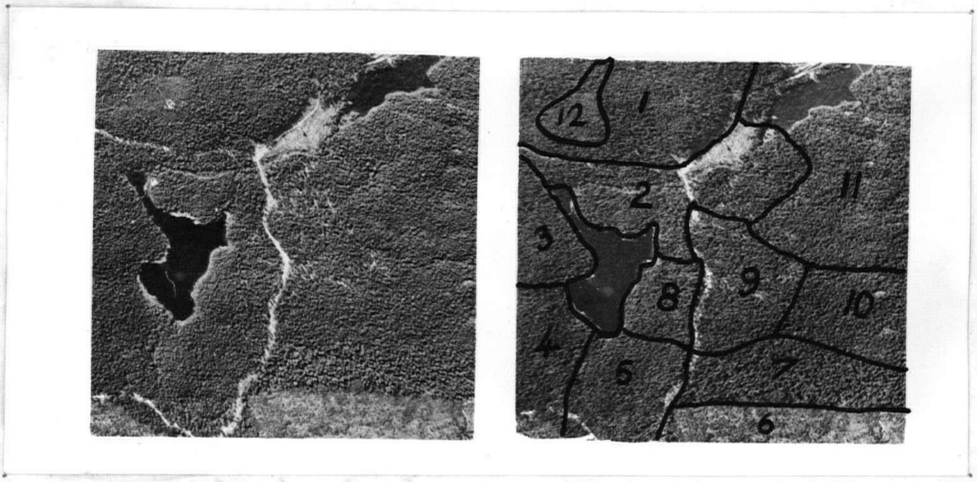


Figure 24

Type Number	Aspect	Local position	General position	Per cent of slope	Shape in profile
1	90	M	M	40	C
2	180	L	L	8	C_o
3	0	L	L	20	S
4	0	L	L	15	S
5	270	L	L	20	C
6	180	M	M	20	S
7	180	LS	L	15	S
8	180	M	L	20	C
9	180	M	M	25	C
10	90	L	M	15	S
11	270	M	M	30	S
12	180	M	M	35	C

Shape in contour	Elevation	Soil depth	Moisture regime	Average site index
C	13	20	1	135
C_o	11	30	2	135
C	12	20	1	130
C_o	12	15	2	125
C	12	20	1	125
S	12	15	1	120
C_o	12	25	2	140
C	12	20	1	130
S	13	20	2	130
S	13	25	2	135
S	14	20	1	120
C	14	15	1	80

APPENDIX F, 4

Sterogramm illustrating sites west of Blaney Lake.

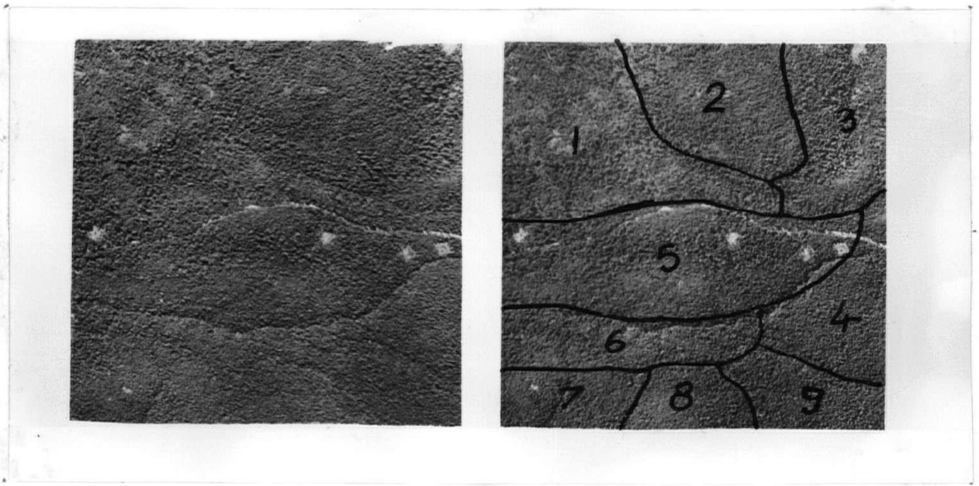


Figure 25

Description of types by codes of photo-measurable variables which were used in the study.

Type Number	Aspect	Local position	General position	Per cent of slope	Shape of profile
1	270	M	M	30	C_o
2	180	M	M	40	S
3	L	LS	L	4	C_o
4	180	M	M	25	S
5	270	L	M	15	S
6	270	LS	M	20	S
7	180	R	H	15	C
8	270	H	H	30	S
9	270	LS	M	25	S

Shape in Contour	Elevation	Soil depth	Moisture regime	Average Site index
C_o	7	20	2	110
S	10	10	1	100
C_o	10	25	2	150
C	12	20	1	130
C	10	20	1	120
S	11	20	2	130
C	12	10	1	110
C	12	20	1	100
C_o	11	25	2	140

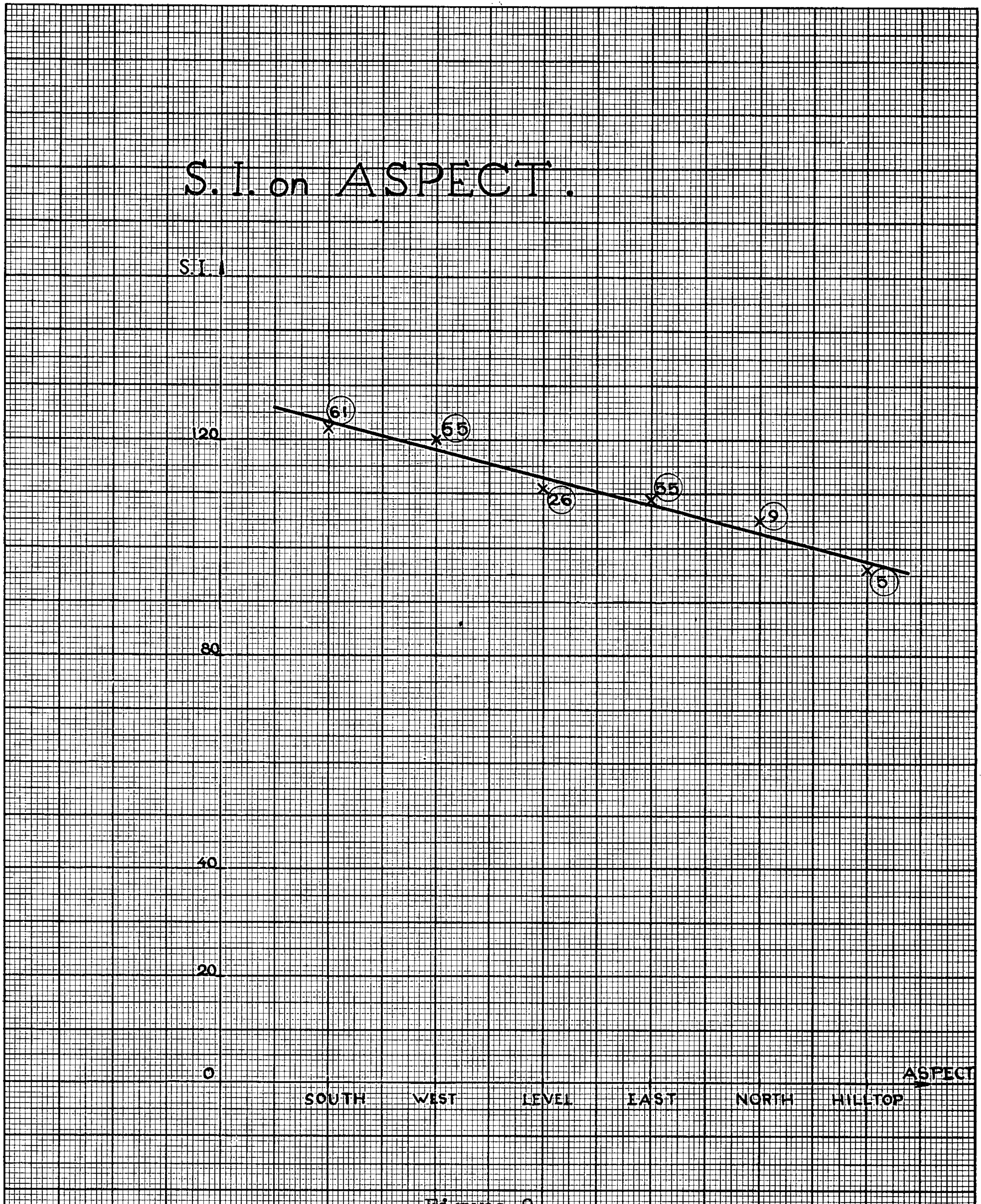

S.I. on ASPECT.
S.I.
120
80
40
20
0
61
55
26
55
9
5
SOUTH
WEST
LEVEL
EAST
NORTH
HILLTOP
ASPECT

Figure 2.

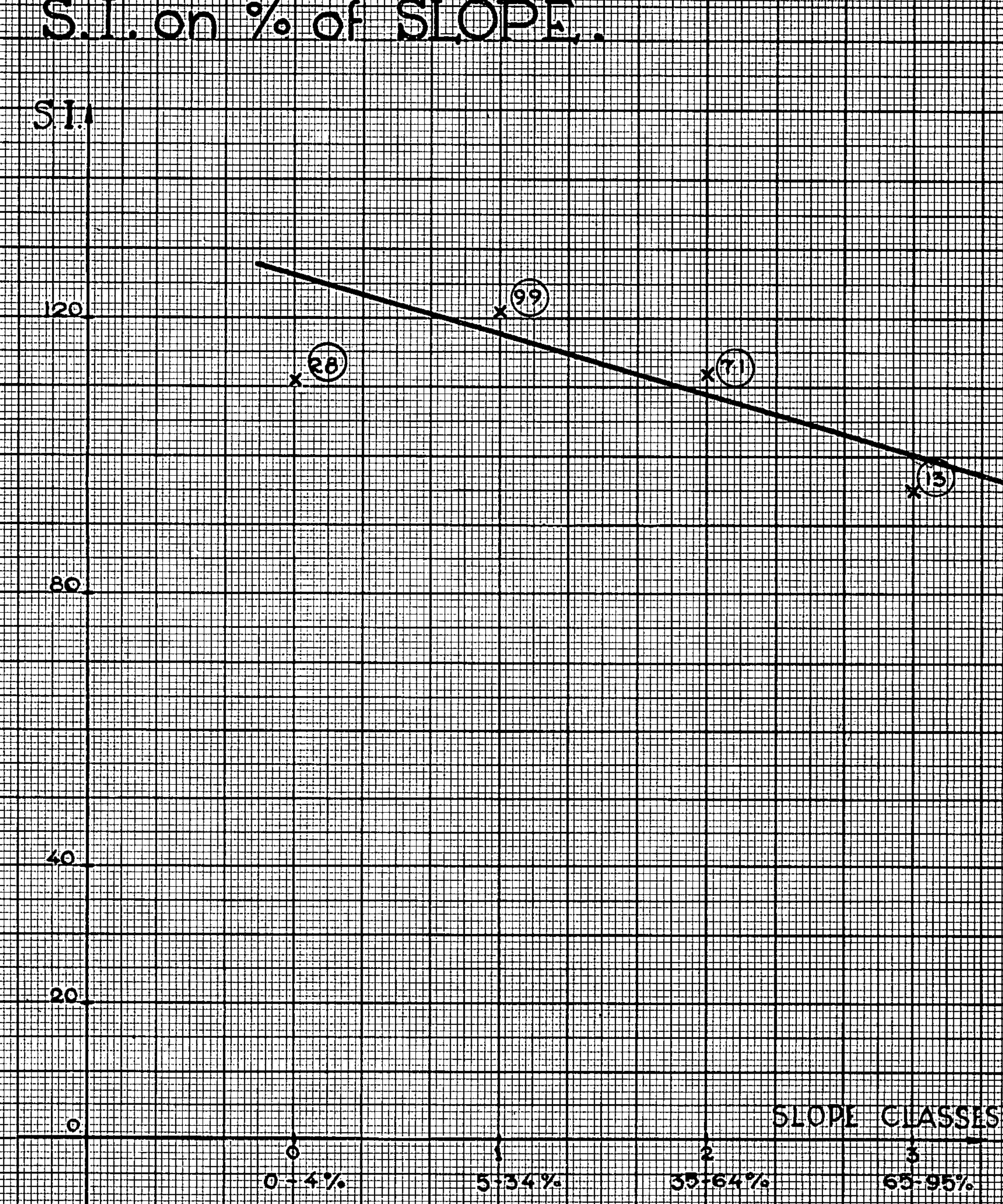

S.I. on % of SLOPE.
S.I.
120
80
40
20
0
28
99
71
13
SLOPE CLASSES
0
1
2
3
0 - 4%
5-34%
35-64%
65-95%

Figure 3.

S.I. on SHAPE in PROFILE.

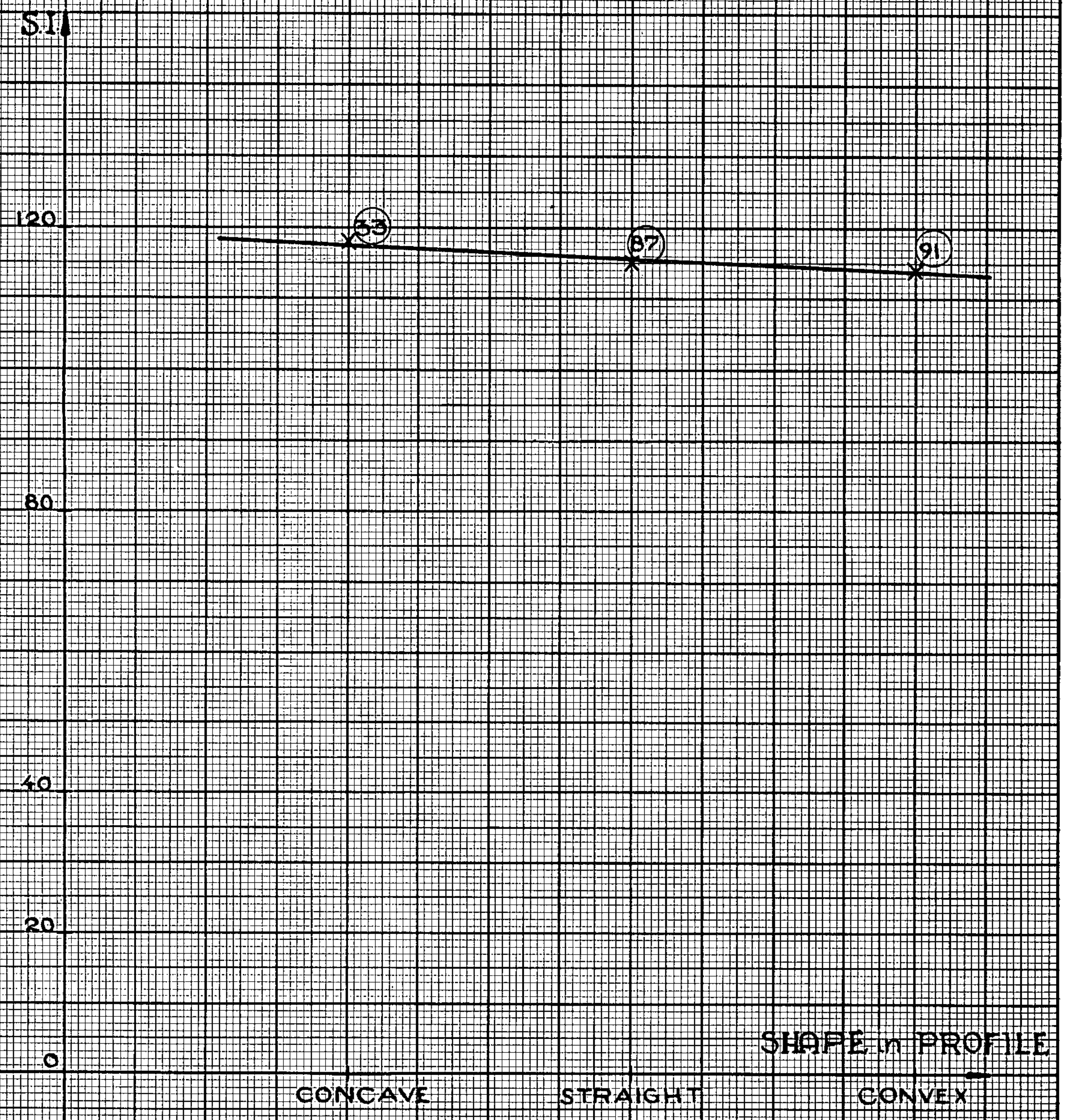


Figure 4.

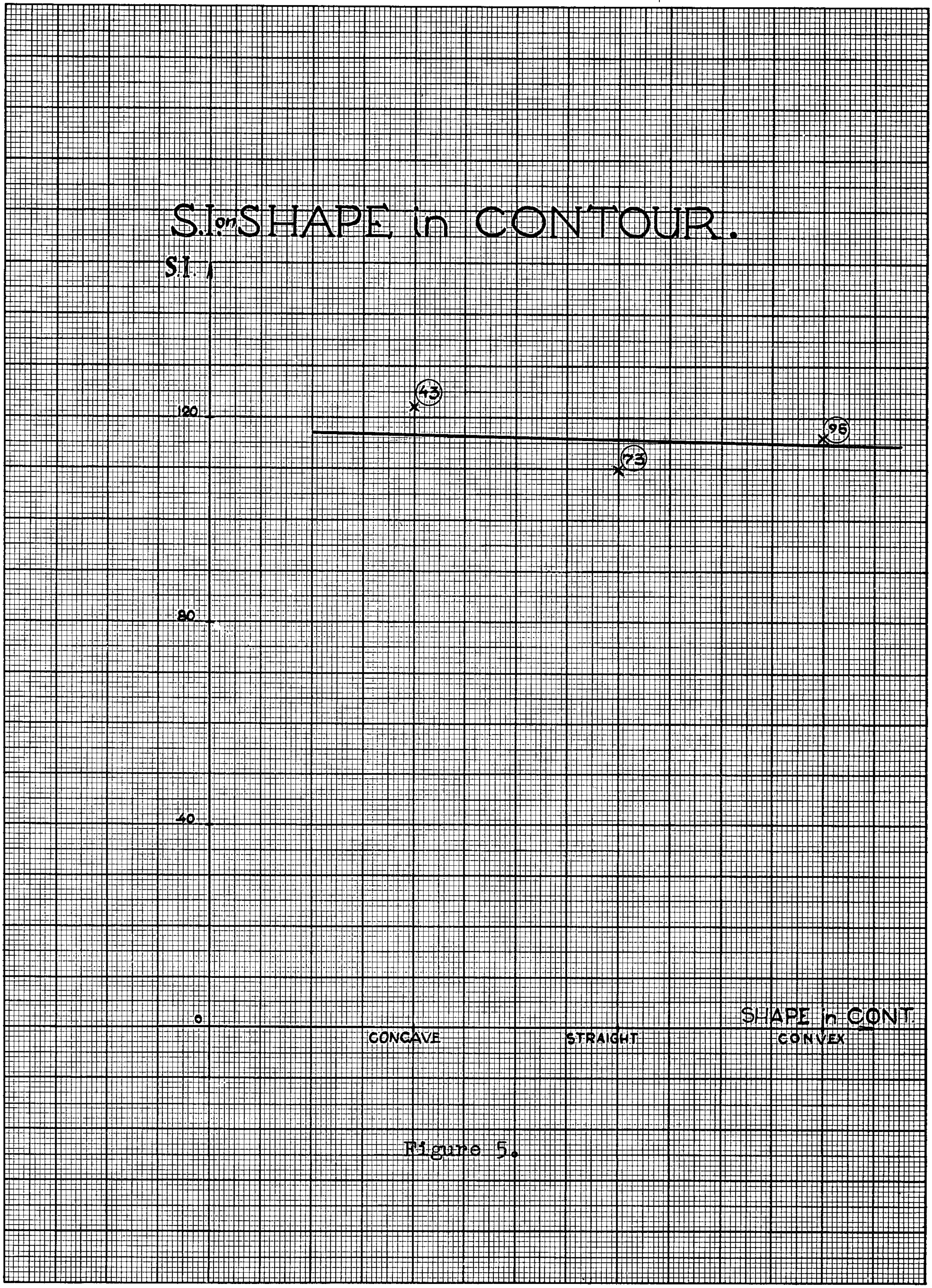

S.I. on SHAPE in CONTOUR.
S.I.
120
80
40
0
43
73
95
CONCAVE
STRAIGHT
CONVEX
SHAPE in CONT.

Figure 5.

S.I. on POSITION on SLOPE.

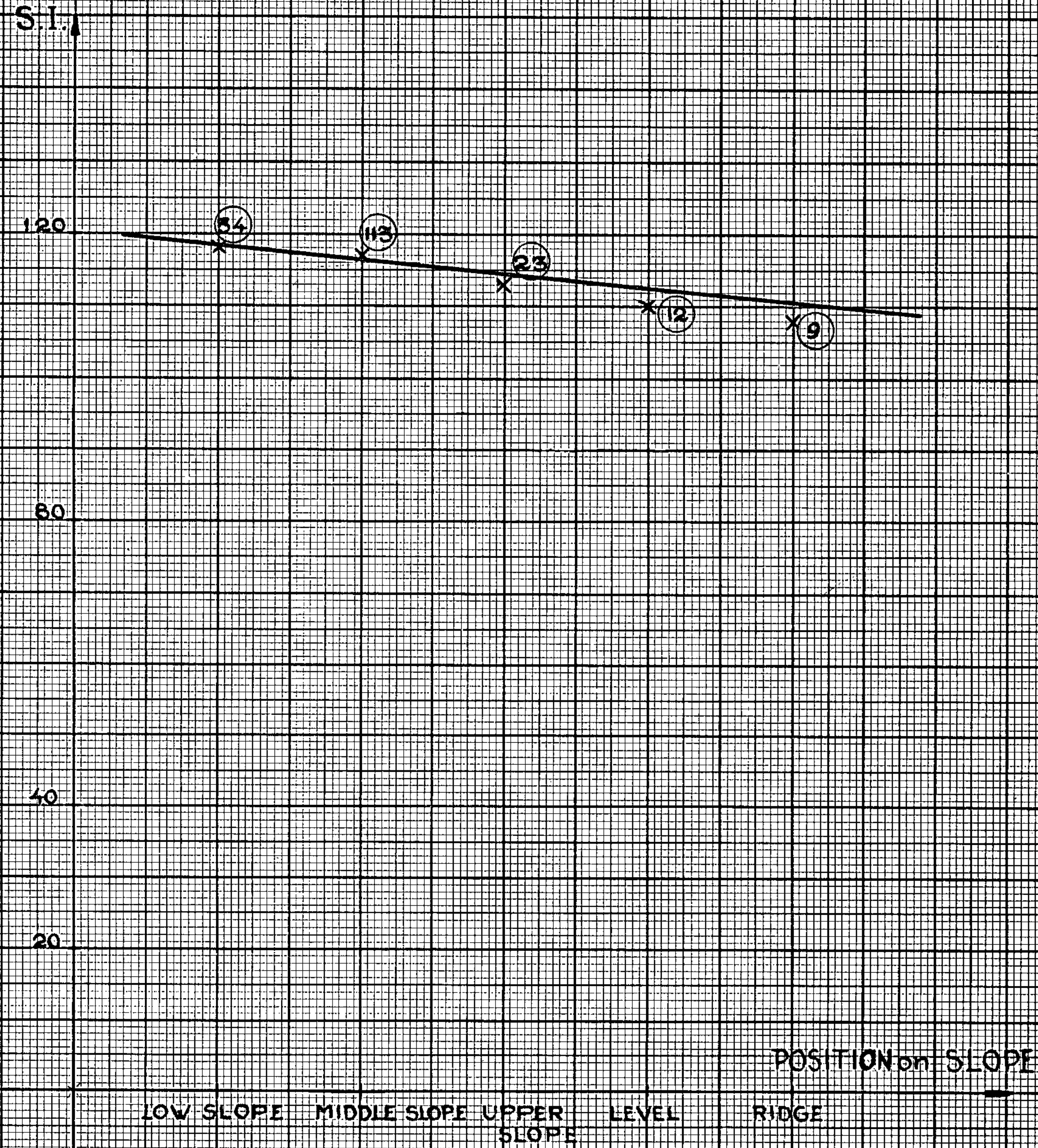
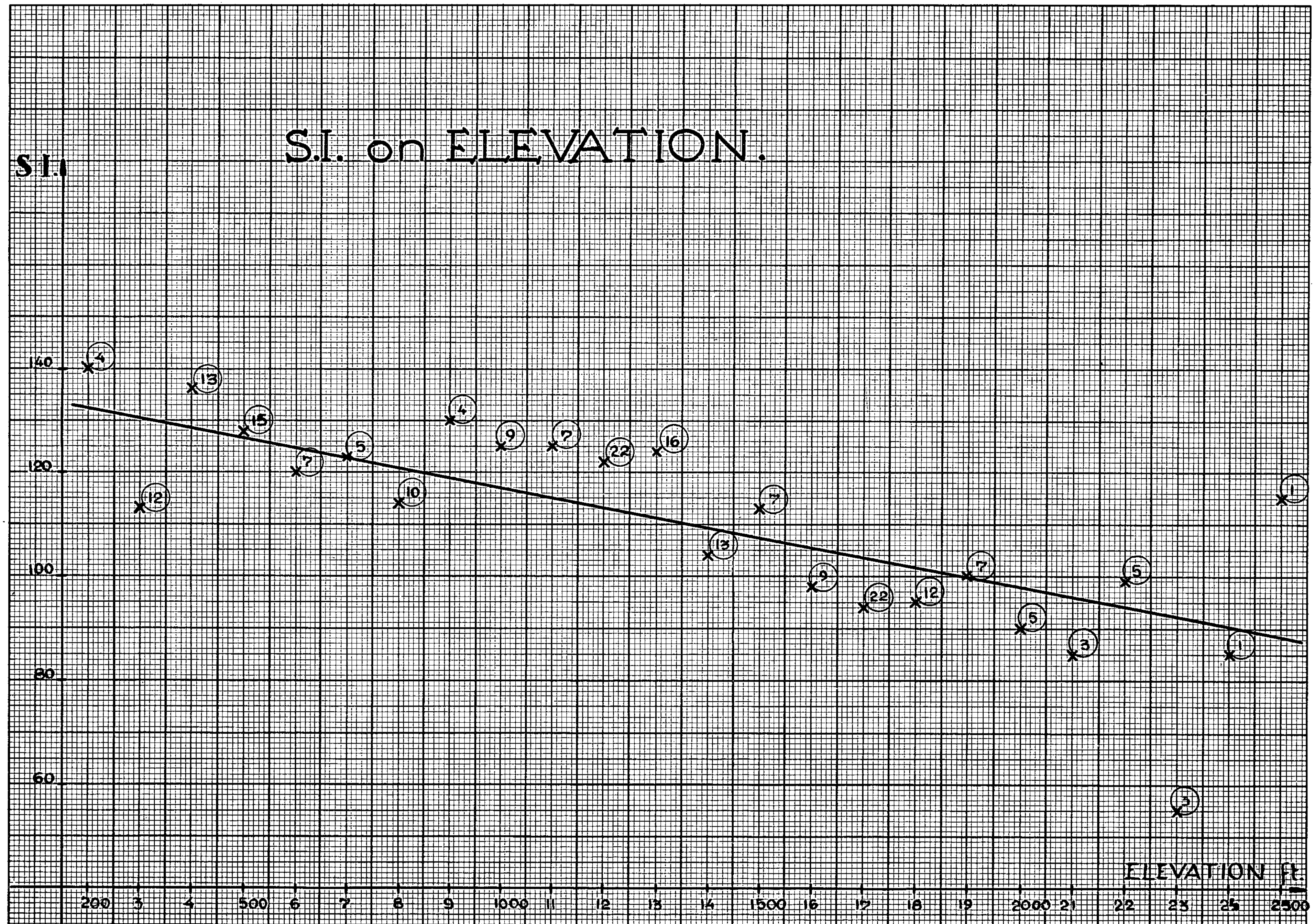


Figure 6



S.I. on ELEVATION.
S.I.
140
120
100
80
60
ELEVATION ft.
200 3 4 500 6 7 8 9 1000 11 12 13 14 1500 16 17 18 19 2000 21 22 23 24 2500

Figure 7.

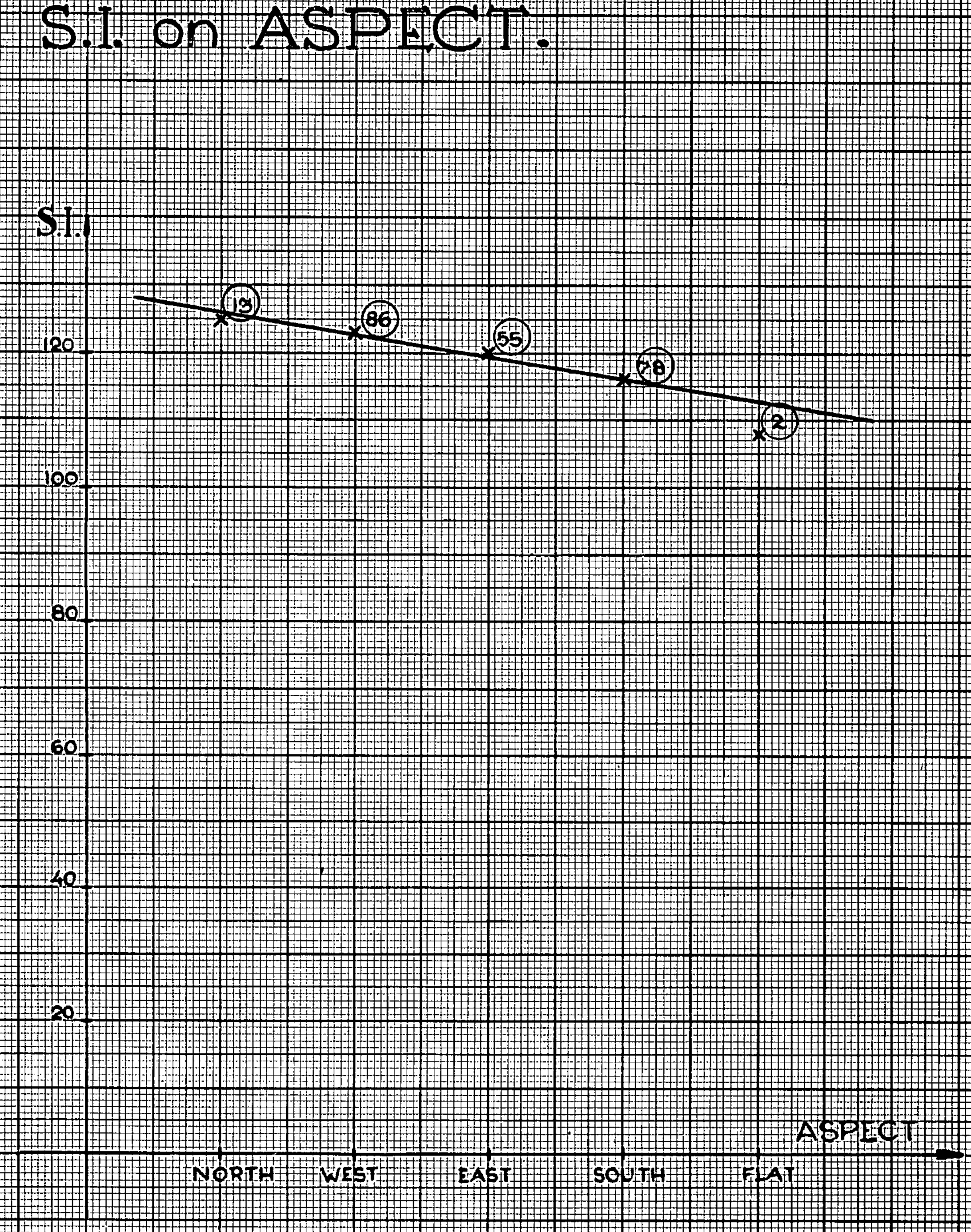

S.I. on ASPECT.
S.I.
120
100
80
60
40
20
13
86
55
78
2
ASPECT
NORTH
WEST
EAST
SOUTH
FLAT

Figure 9.

S.I. on LOCAL POSITION on SLOPE.

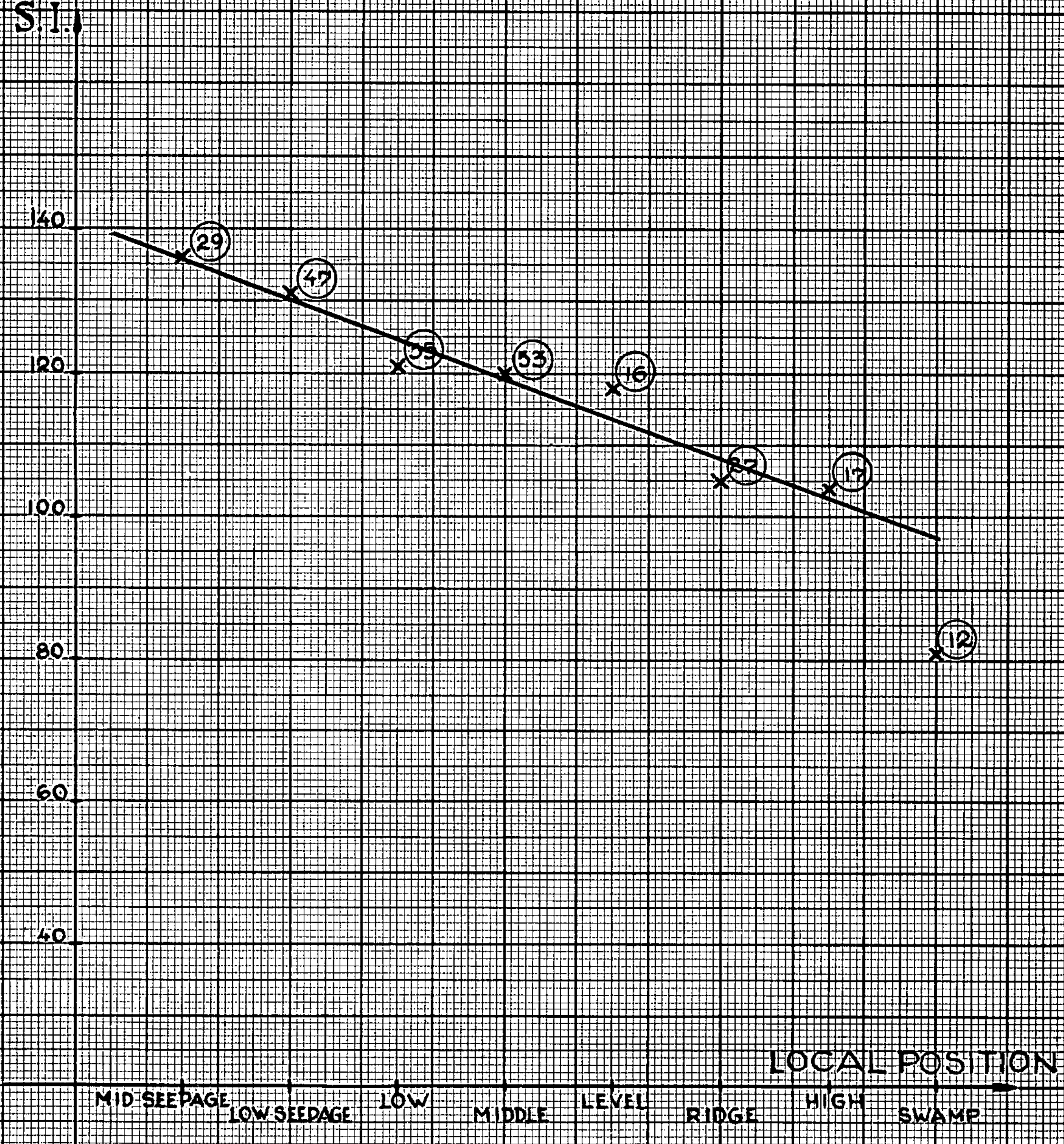


Figure 10.

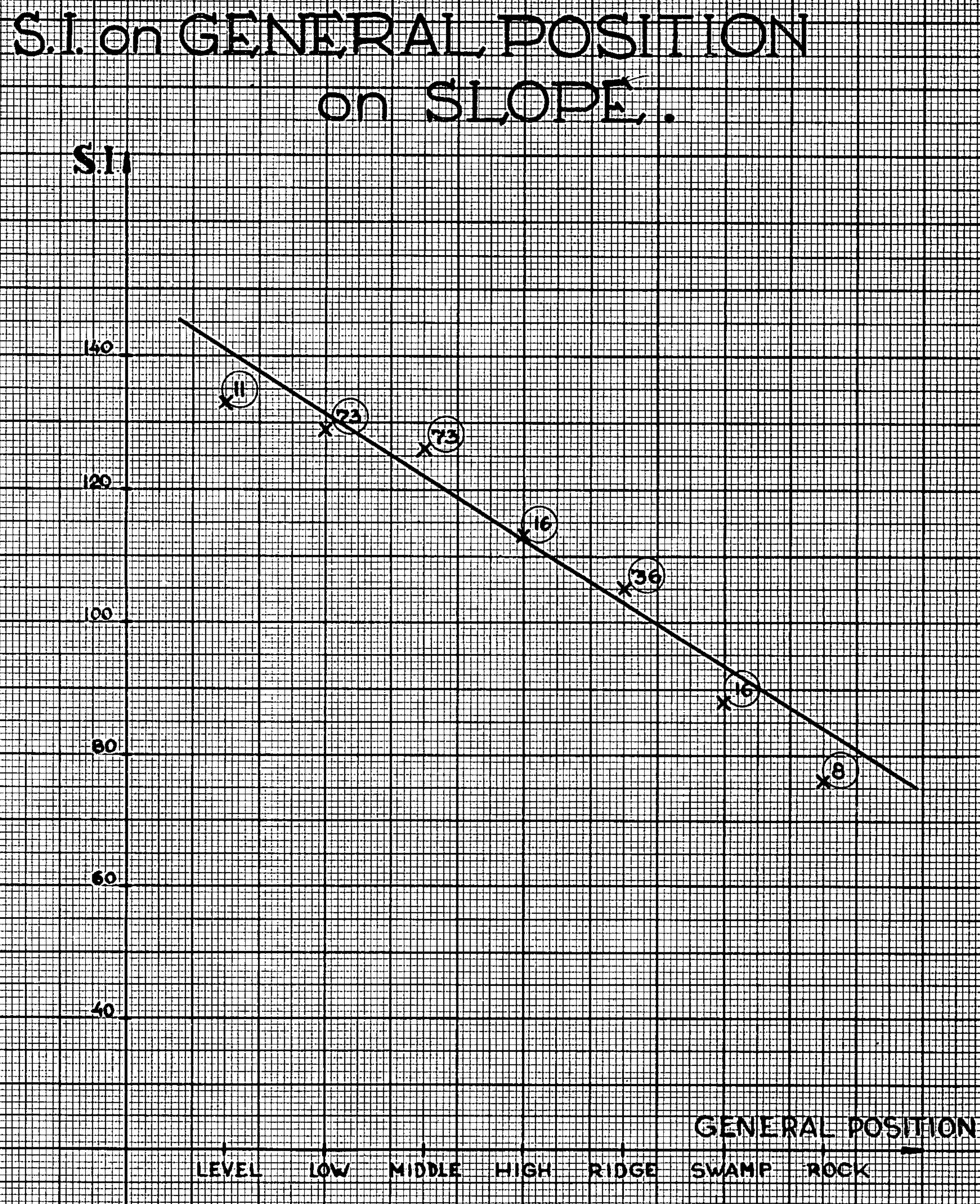

S.I. on GENERAL POSITION on SLOPE.
S.I.
140
120
100
80
60
40
11
73
73
16
36
16
8
GENERAL POSITION
LEVEL
LOW
MIDDLE
HIGH
RIDGE
SWAMP
ROCK

Figure 11.

S.I. on % of SLOPE.

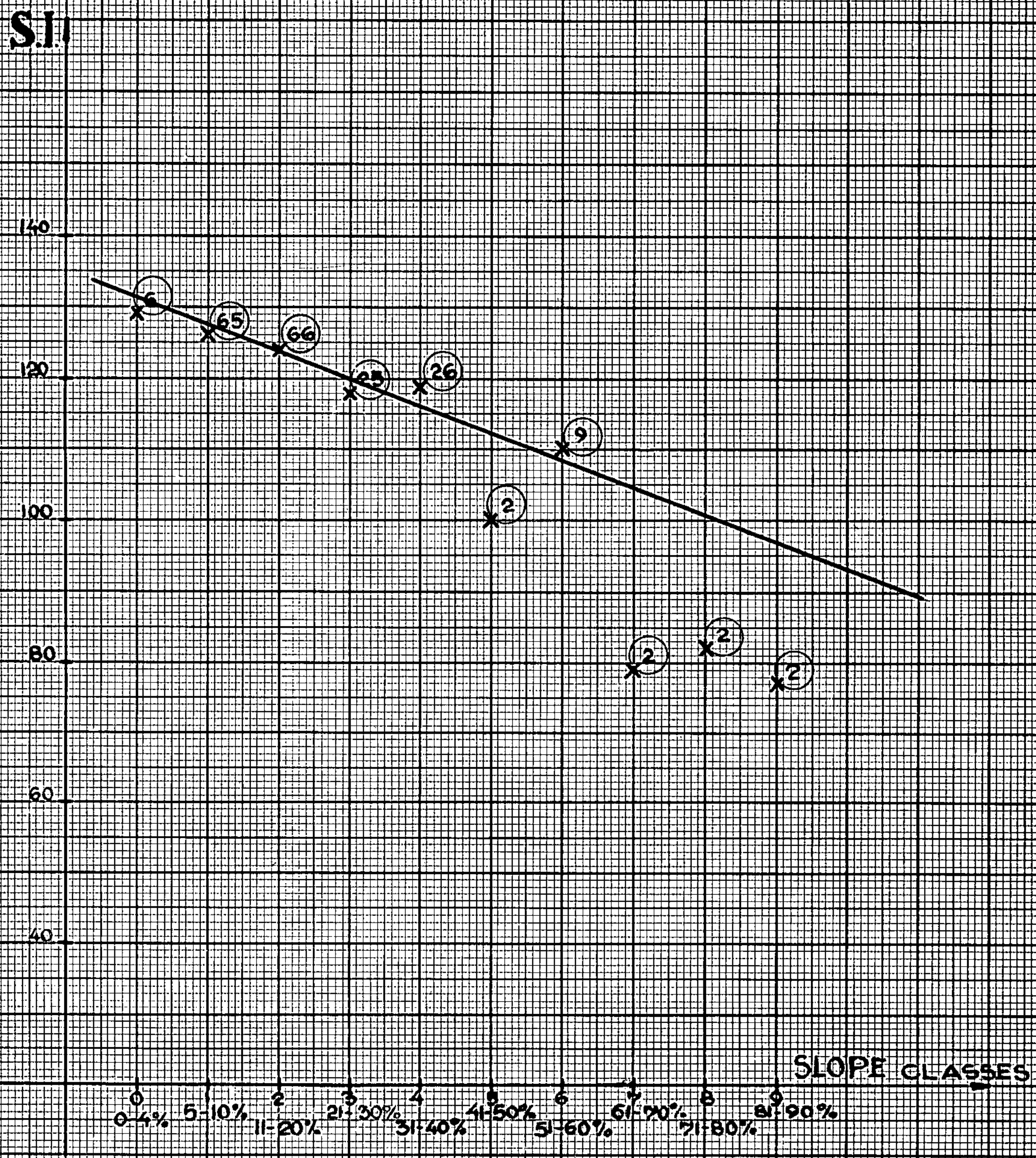


Figure 12.

S.I. on SHAPE in PROFILE.

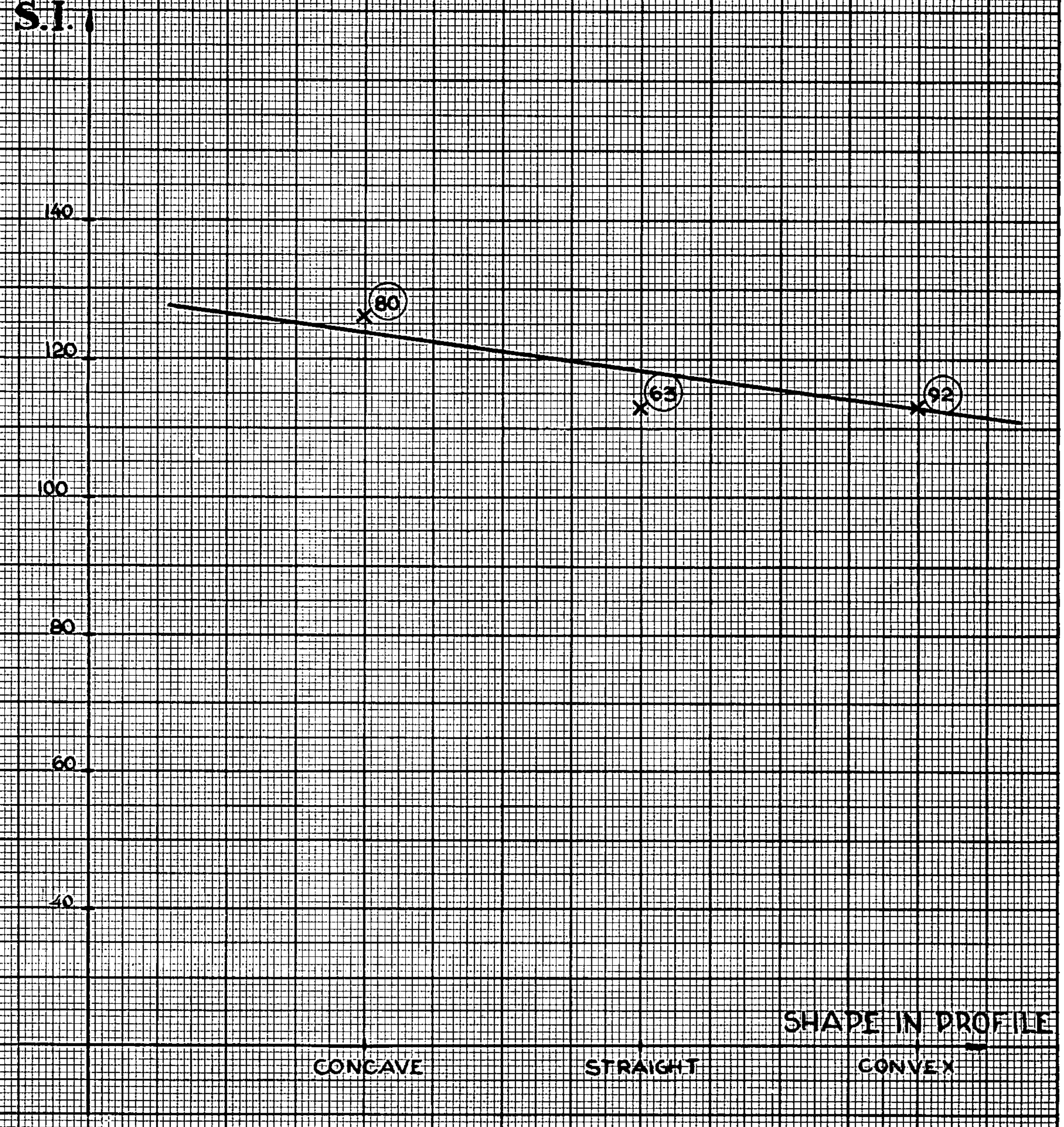


Figure 13.

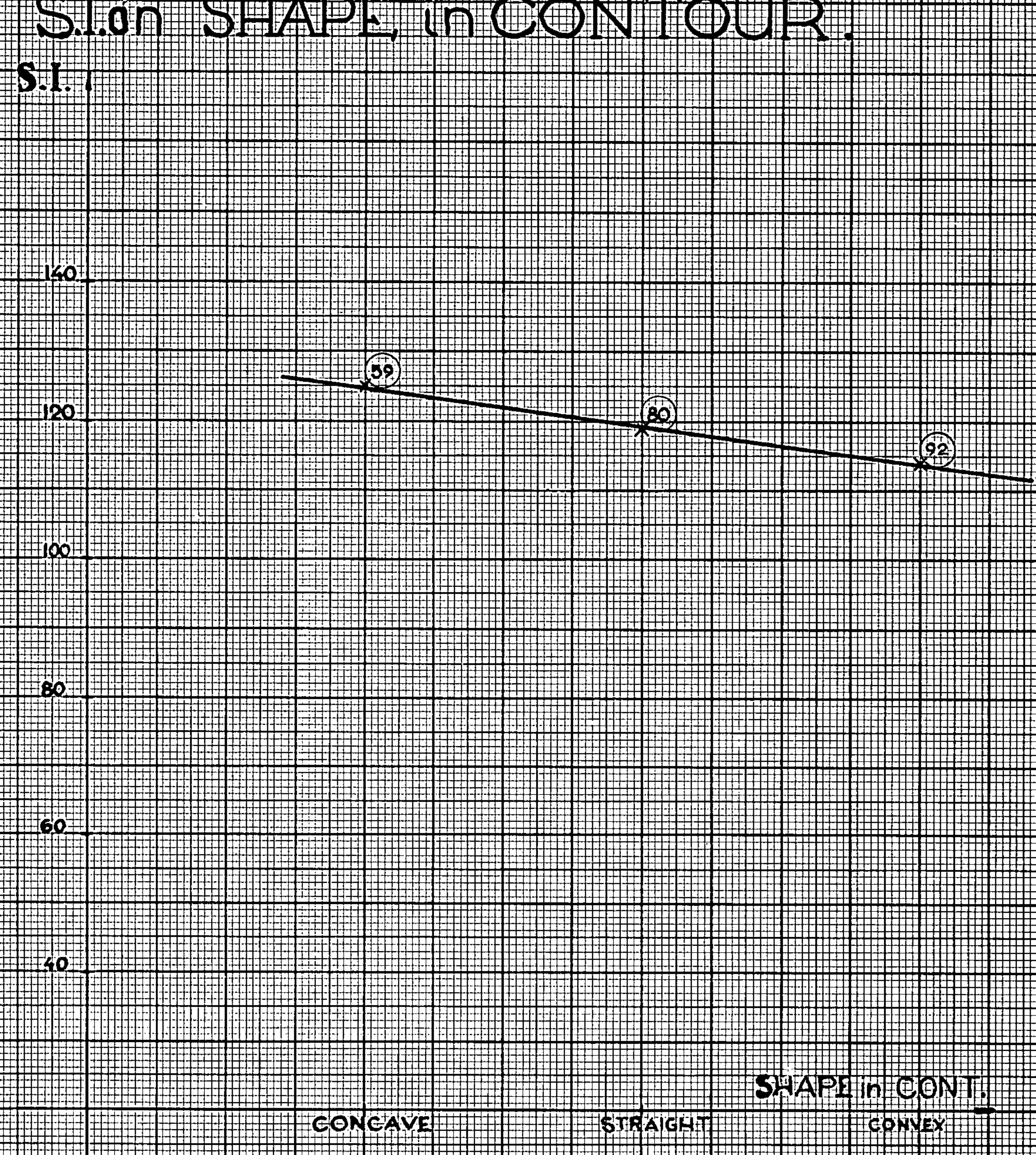

S.I. on SHAPE in CONTOUR.
S.I.
140
120
100
80
60
40
59
80
92
SHAPE in CONT.
CONCAVE
STRAIGHT
CONVEX

Figure 14.

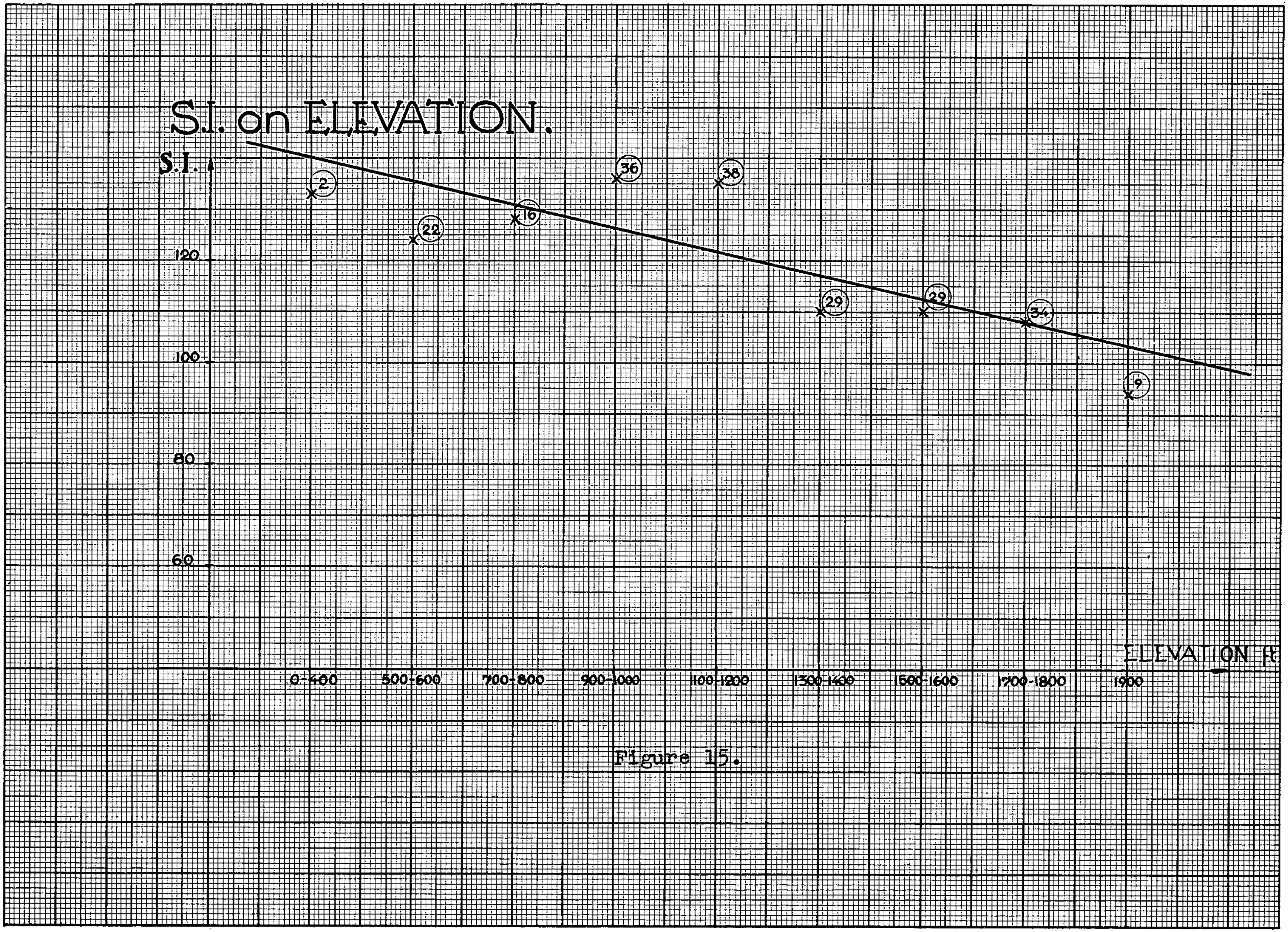

S.I. on ELEVATION.
S.I.
120
100
80
60
2
22
16
36
38
29
29
34
9
0-400
500-600
700-800
900-1000
1100-1200
1300-1400
1500-1600
1700-1800
1900
ELEVATION

Figure 15.

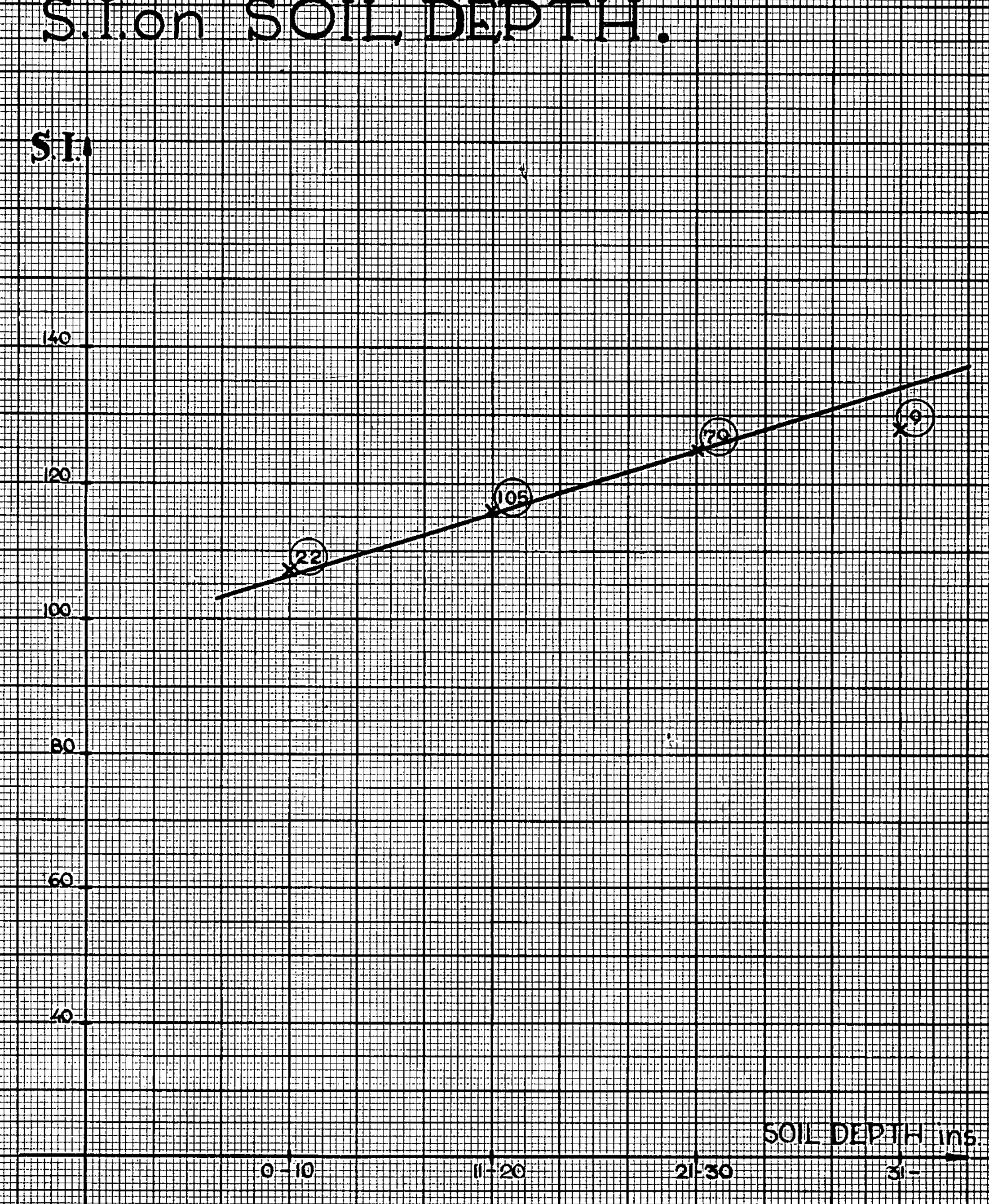

S.I. on SOIL DEPTH.
S.I.
140
120
100
80
60
40
22
105
79
19
SOIL DEPTH ins.
0-10
11-20
21-30
31-

Figure 16.

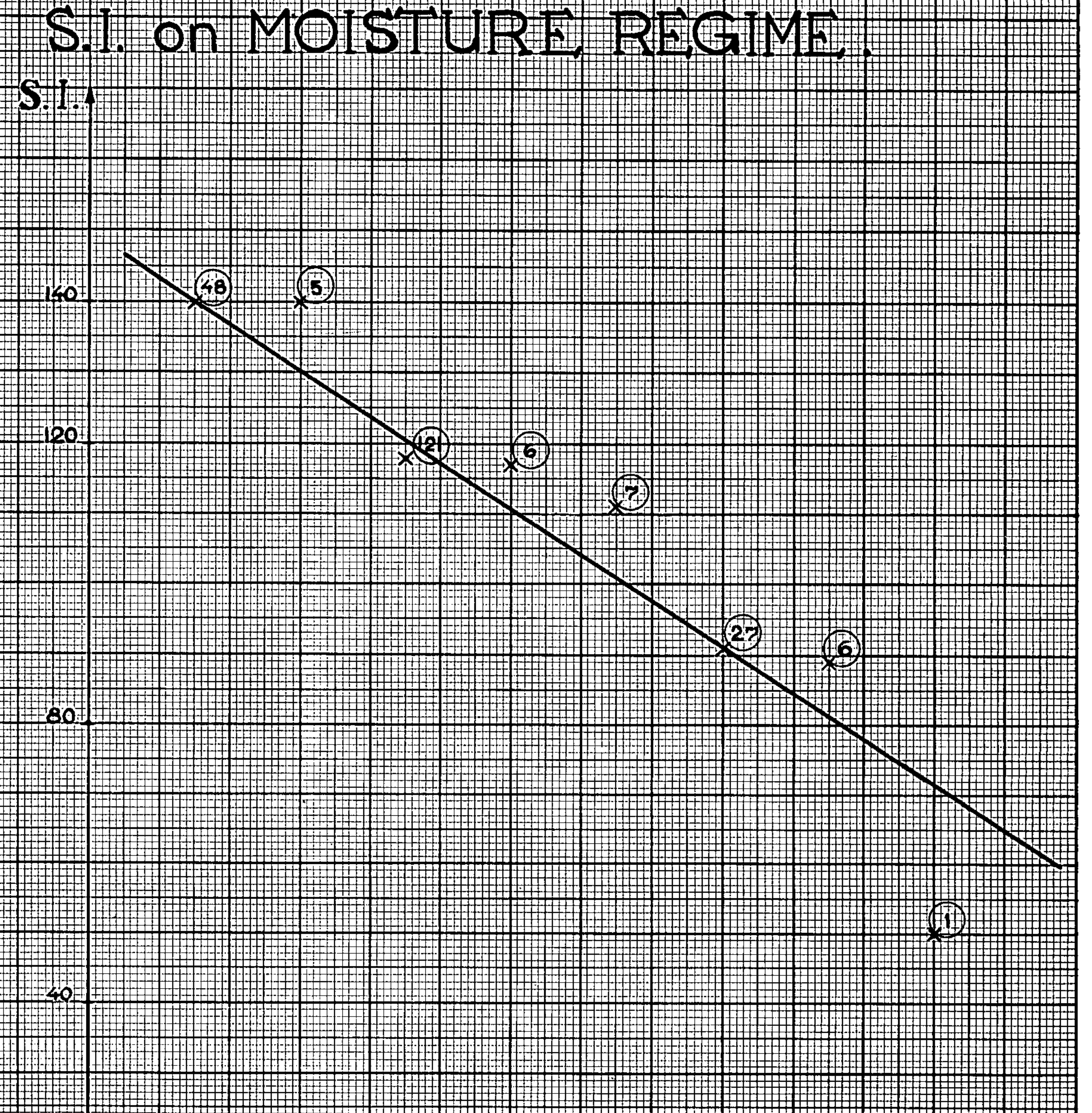

S.I. on MOISTURE REGIME.
S.I.
140
120
80
40
48
5
12
6
7
27
6
1
MOISTURE REGIME CLASSES
NORMAL (OPT)
SOMEW. MOIST
SOMEW. DRY
MOIST
SOMEW. WET
DRY
WET
EXTREMELY WET

Figure 17.

S.I. on PORE PATTERN.

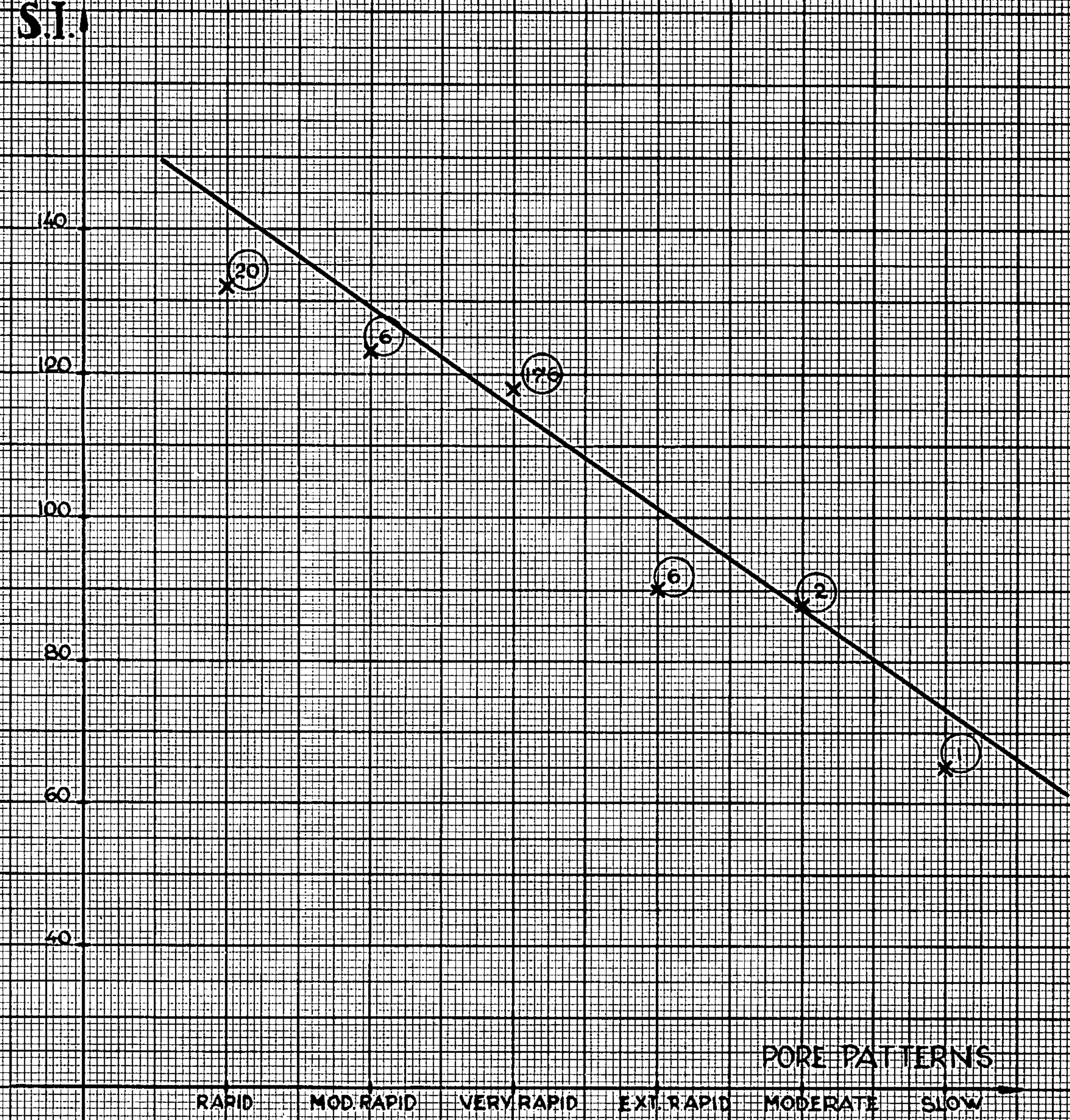


Figure 18.

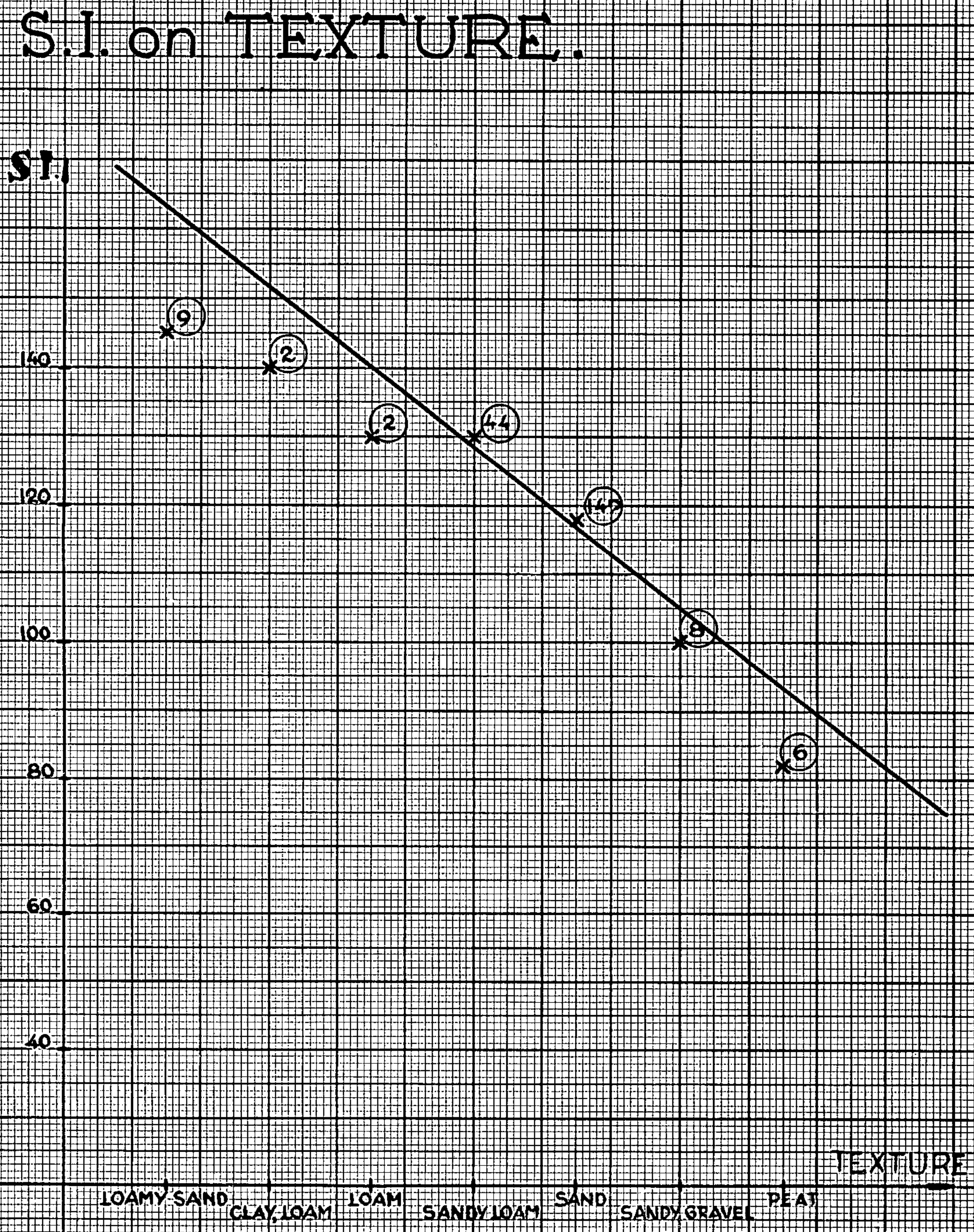

S.I. on TEXTURE.
S.I.
140
120
100
80
60
40
9
2
2
44
147
8
6
TEXTURE
LOAMY SAND
CLAY LOAM
LOAM
SANDY LOAM
SAND
SANDY GRAVEL
PEAT

Figure 19.

S.I. on "H" LAYER.

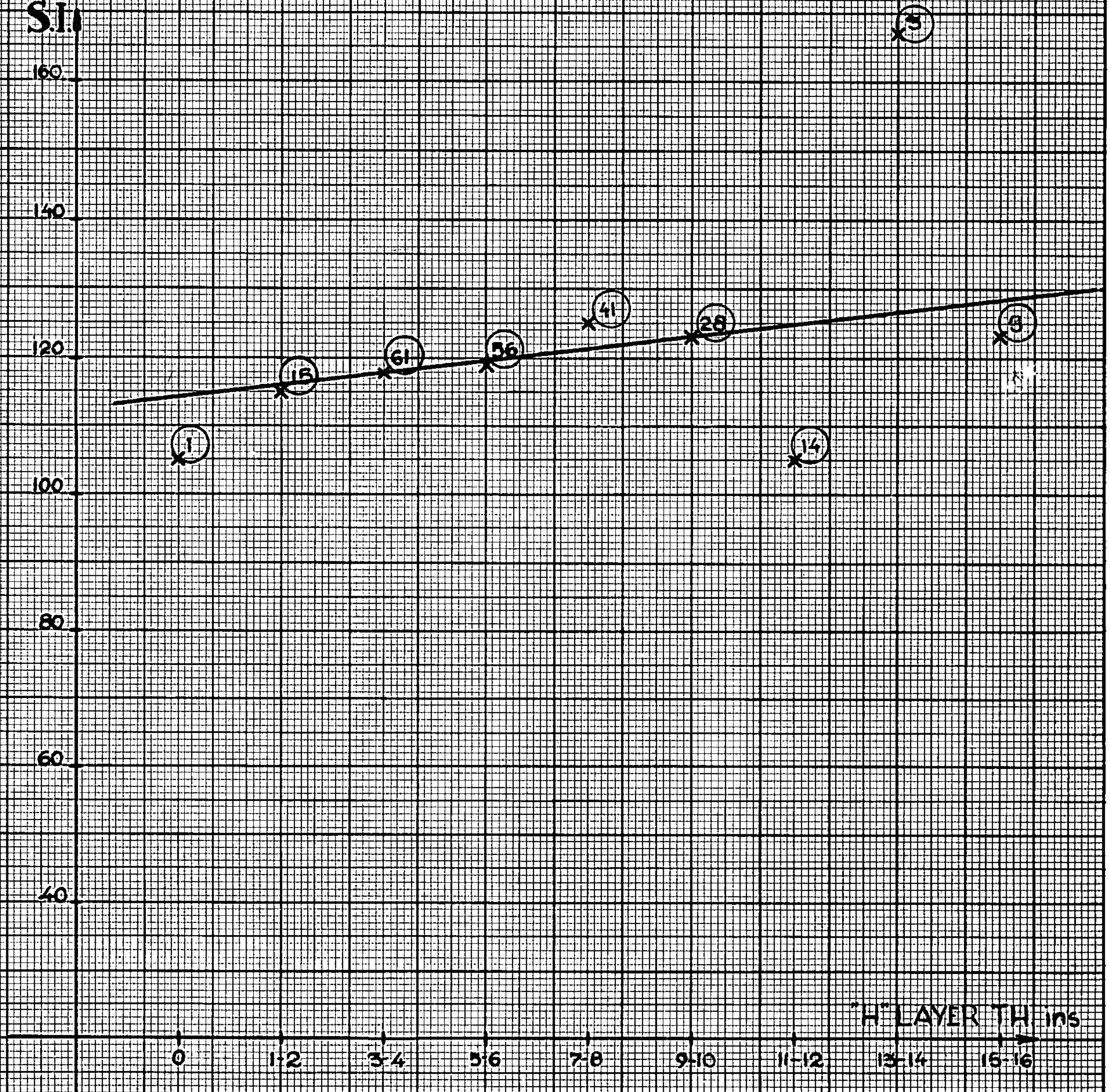


Figure 20.

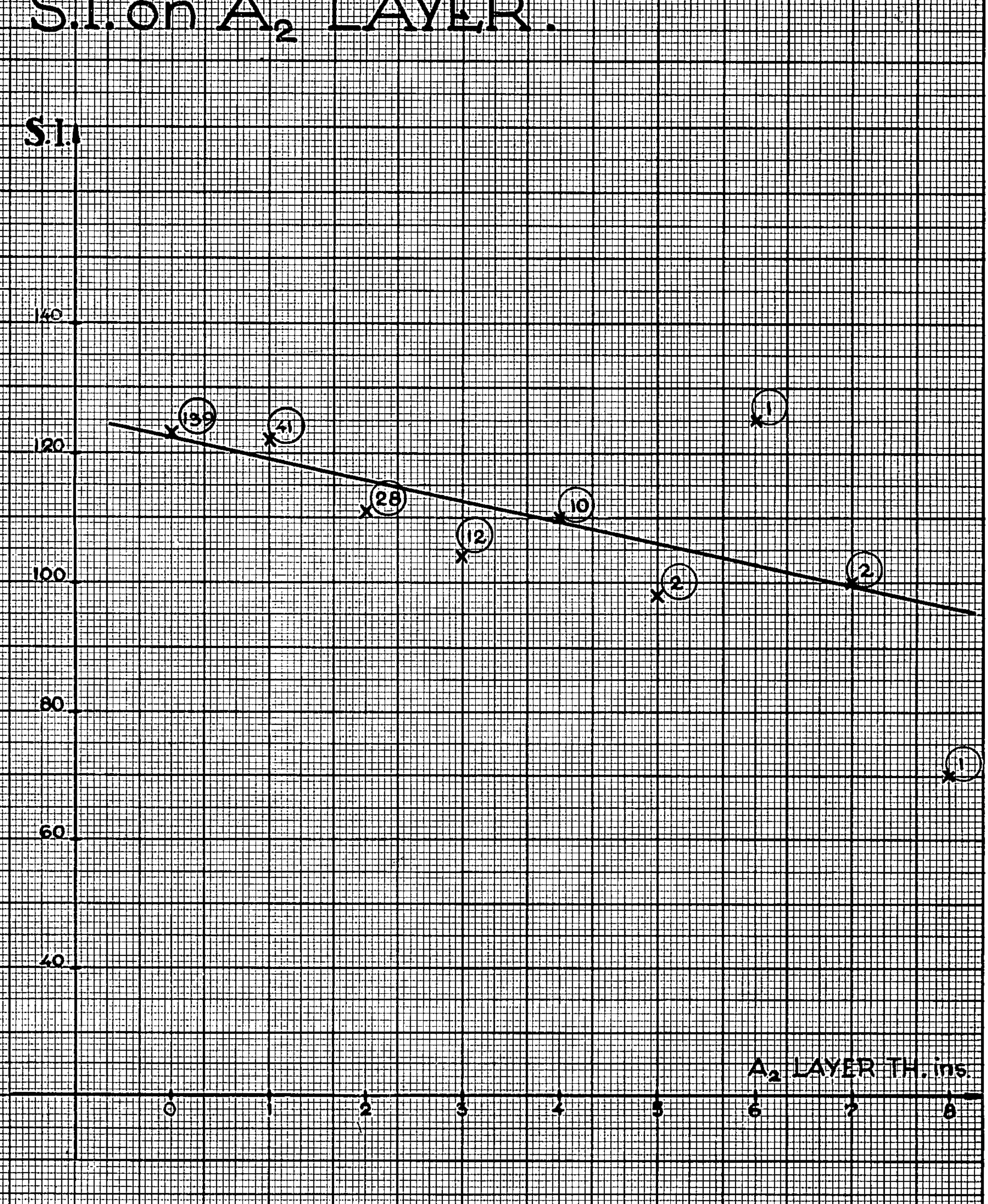

S.I. on A2 LAYER.
S.I.
140
120
100
80
60
40
139
41
28
12
10
2
2
1
1
A2 LAYER TH. ins.
0
1
2
3
4
5
6
7
8

Figure 21.


SITE MAP FOR DOUGLAS FIR
UNIVERSITY RESEARCH FOREST
HANEY B.C.
1 Inch = 1,000 feet
N
PLACID LAKE
MARION LAKE
Legend
Site index
— 60
61 — 80
81 — 100
101 — 120
121 — 140
141 — 160
161 — 180
181 —
181

SITE MAP
UNIVERSITY RESEARCH FOREST
HANEY B.C.

1 Inch = 1,000 feet

Legend

Site index

— 60	
61 — 80	
81 — 100	
101 — 120	
121 — 140	
141 — 160	
161 — 180	
181 —	181

TOPOGRAPHIC TYPE MAP

UNIVERSITY RESEARCH FOREST

HANEY B.C.

1 Inch = 1,000 feet

Legend:

- Type number — 17
- Type boundary
- Sampling points
- Permanent sample plots
- Lakes
- Roads
- Western limit of railroad logging
- Border of new logging
- Creeks