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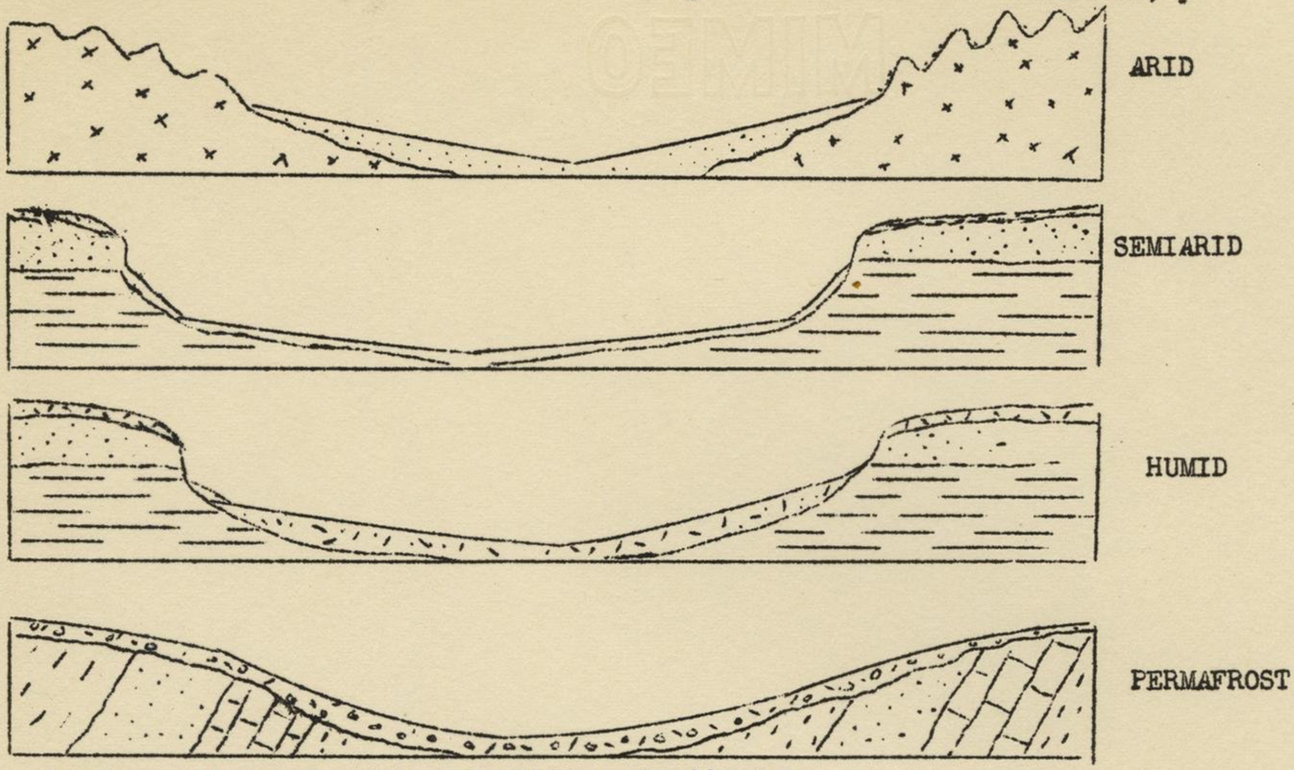
Pediplanation vs peneplanation.

Introduction. Although the subject of final stages in denudation by running water has been covered in previous supplements, data which has appeared in the past year offer further food for though on this extremely important problem. Before beginning a discussion, however, it is well to repeat that the definition of the word peneplain (peneplane of Johnson) is far from uniform among students of geomorphology. This makes it extremely difficult to argue about either processes or end results. Let us here return to the original ideas and neglect later attempts to change the definition to one which is so broad as to be almost meaningless.

"Normal climate" One of the often unwritten but necessary conditions for the origin of a peneplain (under the original meaning) is the so-called "normal climate", in other words a climate similar to that of northeastern North America and northwestern Europe where temperatures are moderate, rainfall well distributed seasonally, vegetation abundant, and chemical decomposition of the material of the earth's surface well developed. True, this climate is that in which a very large part of the civilized inhabitants of the world dwell, but from the areal standpoint it is certainly not that of the main portion of the present lands. We must look at a globe and not at a Mercator projection map to form an intelligent opinion on this point. Besides this fact, we must recognize the strong possibility that the present distribution of climates was not a permanent feature during the history of the earth. Evidence to prove this is not easy to obtain and rests largely upon inference. Soil profiles are not much help for many are not more than a few thousand years old. Marine deposits offer even less aid except insofar as they demonstrate wind and current directions. Hence we must turn to continental deposits and evaporites. With them the influence of now-eroded mountain chains must be evaluated. Besides this, many geologists offer the time-honored excuse of movement of either or both poles and continents. Whatever might be the correct conclusion on this debatable subject for the older geological periods, considerable evidence has been presented to demonstrate that the hypothesis of changes in latitude must be rejected for the Tertiary and Quaternary. Distribution of plants and of glaciation substantiate this. The occurence of glaciation alone proves that climatic changes of the first magnitude took place at that time. The later Tertiary is notable for the immense alluvial deposits of Western United States which must have been laid down under a decidely different climate than now prevails in the same place. It has often been suggested with considerable assurance than the present-day wind and climatic belts still show the effects of the Pleistocene glaciation because of surviving ice caps. Such being the case it is best to forget about such a thing as a "normal" climate and to realize that much more of the globe may have once been semi-arid. We should then reject the idea that either aridity or semi-aridity is a "climatic accident".

Climatic control of debris removal. Fig. 1 shows cross sections of slopes in arid, semi-arid, humid, and sub-arctic climates. All but the last have in common the presence of enough rain to remove more or less completely the debris formed by weathering. In the truly arid environment weathering is almost wholly mechanical. When it does rain the water is not enough in amount or duration of flow to remove the debris of weathering from the area but instead it accumulates in alluvial fans and filling of enclosed basins. Both chemical changes and restraint by vegetation are at a minimum. Resistant crusts of chemical origin are formed. In a semi-arid region some chemical weathering is pre-



Cross sections of valleys in different climates

FIG. 1

sent but vegetation is not important. Enough rainfall occurs to keep the debris shed from steep slopes moving toward the sea or other base level. Much debris is water-born, the only proviso being that the particle size distribution be within the competence of running water. In a humid land, however, chemical alteration of the bed rock is very important. Although the average particle size is thus reduced, the presence of vegetation slows down removal. Mass movement is, however, very important. Slow erosion is especially conspicuous where grass is present for all experiments demonstrate that it is by all means the most effective of all vegetation in restraining erosion. In a region of perpetually frozen ground the net result is to make all bed rocks and mantle rock alike into a solid, massive material. The seasonally thawed or "active" layer of the hills is moved in large part by mass movement to the streams.

Changes in climate. Due to the indubitable fact that climates change at any given locality it is expectable that we should find the characteristic climatic landscapes superimposed one upon another. Many believe that adjacent to the Pleistocene ice sheets vast areas were once frozen. Consideration of the heat requirements for melting of ice show that such could have been possible only during the advancing stages of the glaciers, if indeed it ever affected areas of marine climate. However, changes in amount of rainfall and vegetation can be and have been detected. Pluvial periods with more rain than at present have been postulated by many geologists in areas which are now semi-arid. Students of soils have also noted past climatic changes, particularly near to major lines of division due to climatic control. In this discussion, however, we will mainly concern ourselves with the later stages of erosion, the production of surfaces of low relief late in the progress of erosion.

Davis' idea of the peneplain. Fig. 2 shows two contrasted theories of the retreat of slopes. W. M. Davis held that the slopes on the sides of a stream

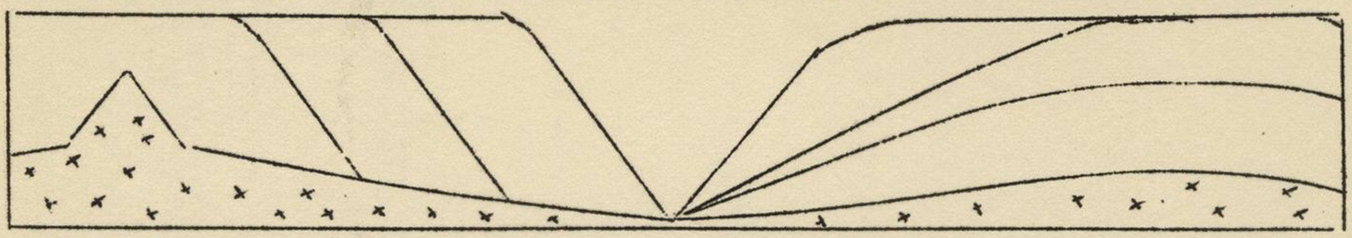


FIG. 2 Two ideas on slope retreat

constantly diminish in angle throughout the "cycle of erosion". Little attention was paid to details of just how material was removed from low slopes and less to the conclusion that a balance must ultimately be attained between the force available to remove material and the resistance of that material to erosion. Fig. 3 shows the original concept of the peneplain where it was concluded that

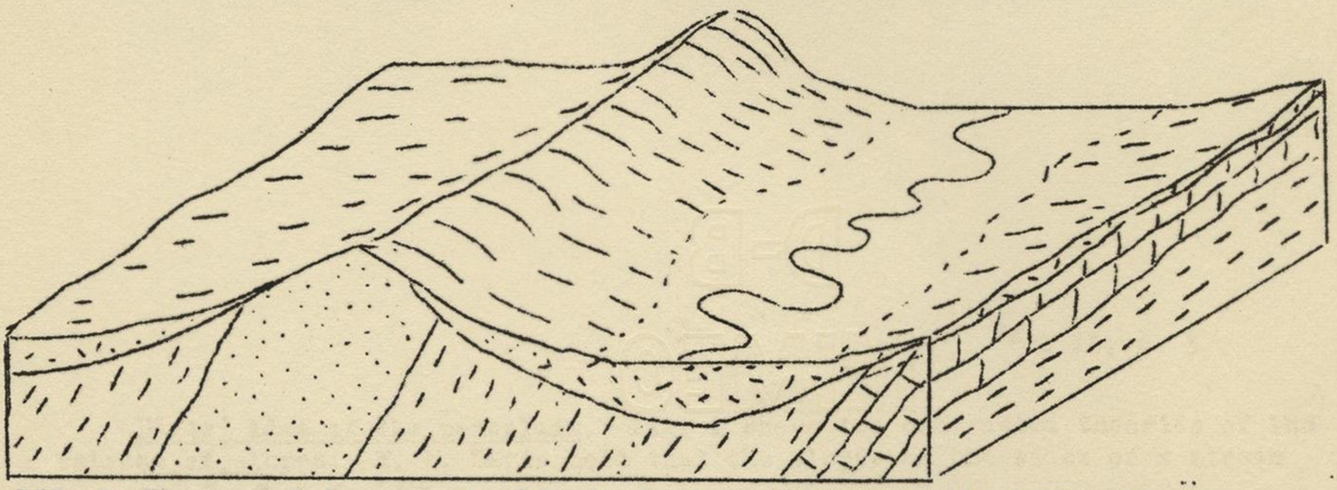


FIG. 3 The peneplain concept of W. M. Davis. Note survival of the ridge on hard sandstone, the thick layer of mantle rock and the wide floodplain. The last is what apparently led some of the later students to include depositional areas with peneplains. Note convex divides with any possible concave slopes buried under floodplain deposits.

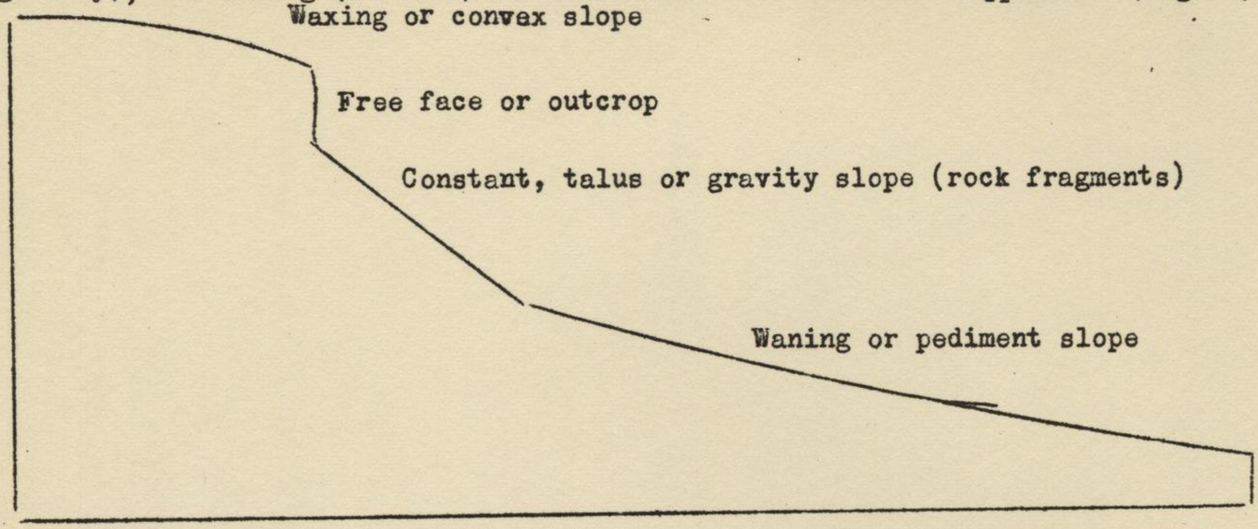
the streams would no longer be able to remove the debris of weathering as fast as it formed and would hence form extensive floodplains. A deep mantle of disintegrated rock was assumed to be present all over the area and residual elevations or monadnocks were left only where the bed rock was particularly obdurate to weathering and erosion. Elsewhere rounded convex divides should merge into the falts of the floodplains. The pre-Cambrian surface of Canada and north-central United States appears to fit fairly well with this concept, although we must recognize that it has been buried by marine sediments and later exhumed. There monadnocks are confined to extremely resistant materials, quartzite, hard iron formation, and fine-grained igneous rocks. Between these, slopes are in many places very low and divides are inconspicious. Bed rock is disintegrated to considerable depths not only in exposed areas but also where the cover of later rocks still persists.

Objections to the peneplain hypothesis. Other than buried and resurrected surfaces such as mentioned above, very subdued erosion topography is observable only on soft shales and on limestones where it is greatly aided by solution. The whole idea that a thick mantle of weathered material would form on surfaces of low relief ignores the head necessary to force water far below the surface. Absence of a deep residual mantle on the pre-Cambrian is generally ascribed to glaciation and it is true that in the lightly glaciated or unglaciated pre-Cambrian of central Wisconsin the mantle rock locally exceeds 140 feet in thickness in schist. The problem remains, however, to what extent was this due to chemical reaction by ground water while still buried. For that matter, how much erosion was caused by the waves and currents of the sea which transgressed this surface long ago! Other objections are of a more theoretical nature. Just how could debris be removed on very low slopes? Monadnocks should be rounded and grade into the adjacent landscape save perhaps where difference in bed rock geology is abrupt. A very serious objection lies in the apparent presence of old subdued surfaces near together and separated by a steep escarpments. Are these all explicable by differences in bed rock geology? Or is there something radically wrong in the hypothesis of origin of subdued erosion surfaces? Why did not the process that made the younger surface obliterate all those of older levels? Horton held that under his hydrophysical approach there must be "a definite end point for both stream and valley development." This point would be reached when the area between the streams is all within the belt of no erosion. Indeed Horton held that "most of the observed gradation of divides takes place before the streams which are separated by the given divide are developed--in other words, the terrain where the divide is located is graded in advance at a time when sheet erosion is taking place along or across the line which subsequently becomes the divide." He rejected entirely the idea that divides are graded down indefinitely. Horton also stated "The ultimate surface of erosion within a main basin boundary is neither 'almost a plane, as the prefix 'pene' implies, nor is it usually as close to being a plane as was the original surface area from which it has been derived. It seems better to call it a 'base surface' generally concave upward except along divides". Horton appears to have assumed soft material to considerable depths.

Parallel retreat of slopes. The theory that slopes do not lessen with time but retreat parallel to themselves after the initial formation was first presented by Penck and is shown on the left side of Fig. 2. This view requires the formation of a gently sloping surface between the foot of the steep slope and the channel of the adjacent stream. Material derived from the wearing back of the steeper slopes must be transported across this area by running water. This was the concept of the pediment, an idea also put forward by Gilbert from his observations in the semi-arid western part of this country. Davis did at one time write a paper on rock floors in which something of this theory was recognized although he rejected the idea of parallel retreat of slopes.

Strahler's equilibrium theory. Strahler used a statistical analysis of certain measurements in California and concluded that slopes lessen to a point where the adjacent streams can just remove the debris shed by weathering and fed into them by slopewash and mass movement. He found that these slopes have the same angle from top to bottom. It is apparent, however, that the area in the Coast Range probably represents a very early stage in the cycle of erosion, possibly prior to stabilization of slopes in relation to kinds of rock debris, each of which probably has a distinctive particle size distribution.

Wood's classification of slopes. Allan Wood's discrimination of types of hillside slopes into the waxing (convex), free face (outcrop), constant (talus or gravity), and waning (concave) was summarized in an earlier supplement (Fig. 4).



FIG° 4 Classification of hillside slopes after Wood.

Examples of each are found in almost all climates, although some may be absent at any given locality. We will first consider the methods by which each is formed and altered.

Convex or waxing slope. Formation of a rounded edge or convex surface on hill tops is not due to one process alone. It implies a removal of material toward lower ground at a rate which increases downshope. As pointed out by Davis long ago a sharp angle between original surface and hillside, such as is formed early in the cycle of erosion, is vulnerable since it is attacked by the agents of weathering from two sides. Once weathered, removal may occur either by slopewash or mass movement. Variation in intensity of rainfall causes the boundary of Horton's "belt of no erosion" to fluctuate in position. This should result in rounding off the corner. King has a similar idea for he states: "as the volume of water increases with distance from the crest of the slope and its speed downhill increases with the steepening declivity, there comes a stage where modification of the surface under the action of running water exceeds the modification due to soil creep. This is the end of the waxing slope." Soil creep is favored by this rounding off of the corner, by rock which weathers into a mantle which has low viscosity when wet, and by the presence of a restraining cover of sod or other vegetation which minimizes sheet wash. In the White River Badlands of South Dakota it has long been noted that convex divides occur only on the weaker layers.

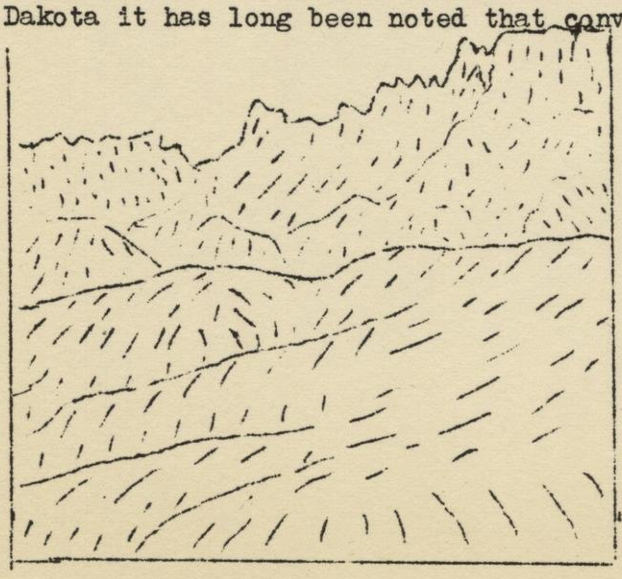


FIG. 5 Convex divides in White River Badlands of South Dakota from photograph by F. T. Thwaites. Note that these are confined to a certain soft stratum whereas the harder beds above make the craggy divides in the background. Note also the very steep sides below the convex crests which slope down to beds of ravines and in other places to true pediments. Small residual masses of the soft clay resemble haystacks.

Wherever firm material is present the divides are jagged and narrow. Convex divides are, then, best developed in humid lands with weak bed rock and abundant protecting vegetation. Rock exposures, other than large boulders moved from their original position, are rare in true convex slopes. However, convex slopes are not of universal occurrence.

Free face or outcrop. In the zone of the free face or rock outcrop it is evident that the debris of weathering derived from above must be moving with much greater speed than it does near the hill summit. Acutal outcrops can occur only where the bed rock is fairly resistant to weathering and are best developed in regions of horizontal strata, particularly where the resistance of different layers varies considerably. In the latter case there may be more than one such line of exposure. The actual type of rock forming outcrops varies with climate. In semi-arid regions we even find that gypsum, which is water soluble, is exposed because of its mechanical resistance. In very humid regions sandstone, quartzite, or fine-grained igneous rocks are common ledge-makers. Where slope development is reaching its endpoint, due either to a long time or to the weakness of the underlying material to both weathering and erosion the free face may be absent. Obviously this is most common where relief is low.

Talus, debris slope, or constant slope. Since the free face or outcrop is exposed to the elements it sheds fragments of rock. The size distribution of these depends upon bedding and jointing which is in turn an inherent feature of the type of rock. These fragments roll, slide, or fall into the slope below which is varyingly described as talus, scree, debris slope, or constant slope. The mechanics of this zone, which in many localities has a constant declivity, have been previously discussed. However, the fact that with most rocks and in most climates talus fragments disintegrate through weathering. The resulting finer material may be retained between the larger rocks for a time because of their protection and the restraint of vegetation. If there is enough moisture, and clay has been formed, mass movement of the talus is possible. Landslides may then reveal the sloping surface of only slightly weathered bed rock which is the underlying basement of these slopes. This may reduce the slope of the lower part of the talus. If removal of material both thus and by rill erosion is not fast enough the free face above will be buried and talus formation will cease. Rill erosion is more probable than unconfined slope wash because the steep slope promotes high turbulence with associated channel erosion. It is the view of King that in South Africa such erosion is enough to cause retreat of the face of a hill so that the burial of the outcrop is postponed and the entire slope retreats at a constant angle, that determined by the size of rock fragments. Some talus slopes are interrupted by ledges where resistant formations have not been buried and by projecting butresses of bed rock which is more resistant than adjacent material. Rock outcrops may, therefore, be found in some places within this zone. Material which is removed from the talus only when its particle size is within that which can be transported by water on the available gradient, but it is evident that running water will be unable to decrease the angle of the entire slope because of the protection afforded by the larger rock fragments. To wear back a talus slope to a significant distance must involve weathering and erosion of its bed rock floor.

Waning or pediment slope. In many localities valley filling has obscured and buried everything below the talus slope. This is the case throughout the Driftless Area of the Upper Mississippi Valley and the cause is valley filling consequent upon nearby glaciation. In the Coastal Plain a recent rise of sea level has had the same effect and in much of the western part of the United

States climatic change has interferred with the normal development of hill slopes. In many places slopes are undercut by streams of considerable size which also prevents the formation of a concave lower slope. It is in semi-arid regions of sparse vegetation that these slopes are best observed and many of them were at first confused with the somewhat similar form of coalescing alluvial fans. Where typically developed these slopes are underlain by rocks which readily disintegrate to particles within the range of water movement. They have a thin veneer, locally absent at the top, of water-transported detritus which rests upon relatively fresh bed rock, The surface is scarred with rill marks which grade into less abundant ravines (dongas of South Africa). It is the problem of just how these smooth surfaces developed which is not yet solved to the satisfaction of everyone. Suggestions include (a) lateral erosion by streams which are at local baselevel fixed by a balance between erosion and deposition, for many grade into depositional slopes downhill; (b) erosion by many rills similar to those described from the talus slopes; and (c) erosion by sheet or slope wash including the sheet floods of McGee. King has gone out onto such slopes during rains to observe what actually happens. Higgins has dug trenches across little pediments and filled them with a different sand to check on rills vs. sheet wash. In rains of moderate intensity King found only clear water in the sheet flood close to the upper limit of the slopes. This disclosed laminar flow by having a depressed surface above obstacles. Just how such flow, which was not eroding or transporting material, could shape the pediment was a problem. Material eroded in the talus above must in this case have been deposited temporarily at or near its lower border. However, later studies showed that farther downslope and in heavier rains turbulent sediment-transporting flow is present, although deep floods like those described by McGee were not observed. It is obvious that to have sheet flow there must first be a smooth surface on which the water can spread out. King explains this by the multitude of small rivulets which descend the talus. He rejects the idea of lateral stream rosion largely because the great escarpments of South Africa are parallel to the coast, do not extend far up rivers. He thinks of them as originally as great monoclines which erosion has worn back parallel to themselves through several geologic periods at a rate of one foot in 150 to 300 years. He also rejects the stream erosion hypothesis because of the comparatively straight and level bases of the escarpments. However, this view does not seem to meet all observed conditions. The lateral extension of pedimented surfaces joining into a pediplain with only small residual, steep-sided hills rising above it implies recession of valley sides. In other areas it is evident that pediments have formed along fault scarps. Moreover, some form of channel erosion would seem a prerequisite for preparing the ground for widespread sheet floods. Possibly Horton's theory of rill grading

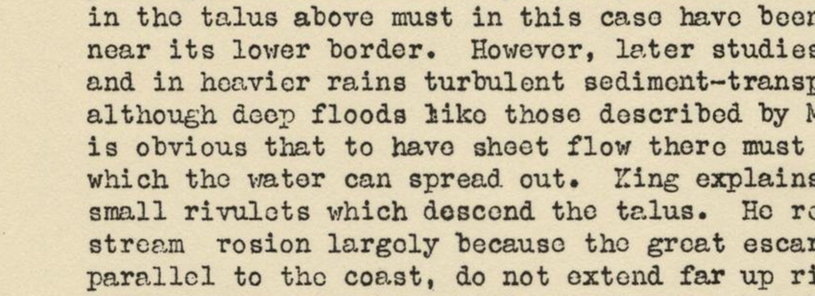


FIG. 6 After King Steep-sided residuals of granite rising from smooth pediment which has a thin grass cover. Slopes of hills are talus blocks. Similar residuals are common in The Great Plains. From photograph. East of Pietersburg, Transvaal

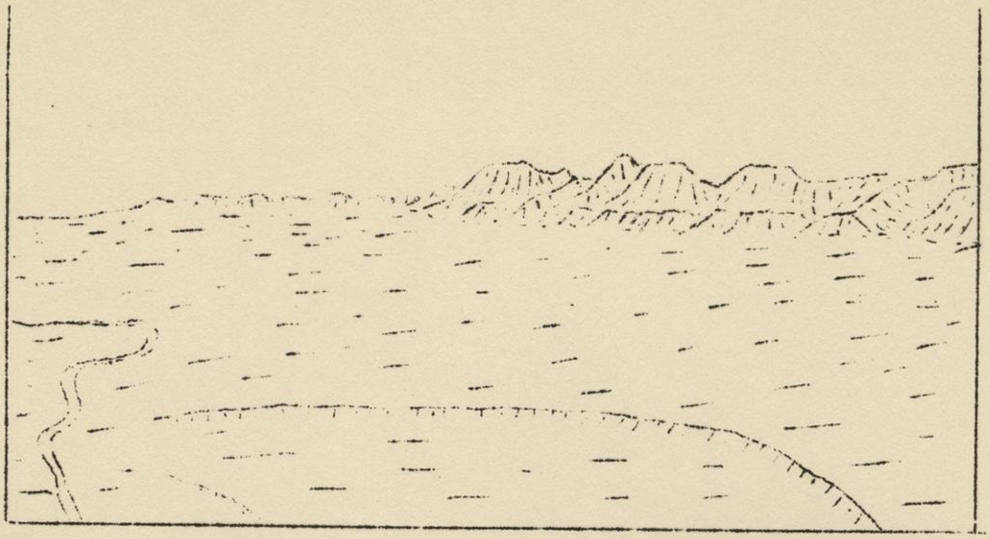


FIG. 7 After photograph by Fair published by King. The river has no real flood plain but pediments rise gently to the steep-sided residuals of andstone and dolerite (basalt). No convex hilltops can be distinguished but the concavity of the pediment is plainly shown. Vegetation appears to be scanty brush, possibly some thin grass. The Karroo, South Aftrica.

is the key. But when all is said and done the reality of these rock-cut slopes must be admitted. They do not fit in with the old concept of peneplains. They could explain preservation of remnants of more than one erosion cycle in adjacent hills for on top of the remnants erosion is very slow. They do not require for formation a very arid climate and might occur in somewhat modified form in humid regions unless deeply buried by crept mantle rock. They explain the apparent youthfulness of the mountains of the Basin and Range province despite the width of valleys, a fact which puzzled early students of that area.

Form of pediment cross section. Pediments have a characteristic concave cross section leading down from the more or less level, abrupt upper limit either to streams or to an alluvial fill in the center of the adjacent valley. Wide stream spacing may be a factor in pediment formation. The sharpness of the upper contact is best developed in hard rocks. In weak rocks this contact is a gradational curve. The various causes of the concavity due to running water have been explained in a previous supplement. The matter is not simple and is unlike conditions on alluvial fans for rain falls all across the pediment slope.giving increased depth down slope with consequent decrease in shearing force. Indeed, it has been declared that pediment slopes are formed in order to facilitate disposition of sudden heavy downpours which are common in semi-arid regions. As pediments join at divides the divide is commonly abrupt and angular rather than rounded, although both forms may occur apparently depending upon the resistance of the bed rock. The best-developed pediment profiles occur where the bed rock is granite rather than soft sediments such as shale or limestone. Residual elevations within a pediment or pediplain (area of coalescing pediments) characteristically have concave sides. Mount Monadnock, New Hampshire, rises in this fashion from adjacent uplands of the same kind of rock. However, this area was glaciated and a basal mantle of decomposed rock might have been eroded by the ice or the base might have been eroded by waves. A feature of pediment slopes is that gullies (dongas of South Africa) occur entirely on them rather than on higher slopes locally extending to the upper border. Some change to low alluvial fans below. It is thought that these ravines are due to local concentrations of the sheet flow which set up more turbulent flow which causes erosion. Some are certainly due to disturbance of the ground by farming. Rock outcrops occur in the walls of such gullies, at the head of the slope of pediments, and in small isolated "islands" of residuals. The only cause of convex profiles in pedimented areas is erosion at an accelerating rate due to later uplift, or to climatic change toward greater humidity. In this connection we may ask if erosion surfaces which bevel the bed rock and yet show deep weathering are (a) pediments developed in humid climates or (b) pediments which have been altered by a change of climate. Since the theory of pedimentation can explain the occurence of several different levels in the same region it opens up many new possibilities in interpretation, Could it be that the Piedmont Plateau of southeastern United States is a pediment whose surface was later eroded by a more humid climate possibly associated with uplift? Such a view would explain the anomaly of stream capture along the youthful divide of the Blue Ridge to the northwest, features which seem impossible under the peneplain hypothesis. The convex divides of the Piedmont together with deep disintegration of the bed rock would be more recent than the original bevel. Widespread gravels of late Tertiary age in the Coastal Plain seemingly support this view. The Harrisburg terrace, which is so conspicious throughout the entire Appalachian region, would then be correlated with the Piedmont and possibly also the Highland Rim surface west of the high plateaus. Many will object to this suggestion because it seems to imply a marked climatic change, but just how much of a change is debatable. Perhaps only enough to affect the vegetation cover to a moderate extent. Turning to the Rockies, it is obvious that the upland surfaces are true pediments correlated with alluvial filling of adjacent lowlands. Climatic change, possibly associated with, or due to, uplift, has removed much of the fill but a remnant persists in the Gang Plank west of Cheyenne, Wyoming. Surely, it is inappropriate to call the upland surface a peneplain if we stick to the original meaning of that word. Some in the Uinta Mountains have in part been described as pediments. Throughout the Great Plains many of the residual hills have steep concave sides which appear to demonstrate pedimentation.

<u>Summary</u>. The following table, adapted from King shows the differences between what may be inferred as characteristics of peneplains (under the original Davis view) and those of pediplains. We must note that peneplains are inferences, whereas pediplains may be actually observed in the field. Moreover, it seems doubtful that there can be any sharp line of division on the basis of either climate or kind of rock. King declares that the peneplain, as originally defined, is an "imaginary landform", so that it may be that debate is futile. The exact method of formation of the theoretical peneplain is only vaguely described in the literature and is not backed by actual observation. A factor in comparison, which King suggests, is that the mantle of grass which so effectively restrains erosion and makes for convex divides was not present prior to the middle Tertiary. Indeed, others have suggested that vegetation on the lands was absent in the earlier geologic periods, and that erosion was then everywhere like that of semi-arid

regions of today.

Peneplain (Davis, theoretical)	Pediplain (observational)
Broad flood plains.	Narrow flood plains.
Convex or subdued divides with much creep of a deep mantle.	Divides sharp with concave slopes on both sides, locally convex over a narrow width.
Residuals gentle and convex.	Residuals sharp with concave sides except where top is very weak rock.
Lower slopes only, concave.	Dominantly concave slopes, except on very weak rock.
Origin by slope flattening.	Origin by scarp retreat and pedimentation by running water.
Origin destroyed all older surfaces.	Several levels may be present in one locality.
Mantle rock due only to weathering and creep.	Mantle rock thin, and water-transported.
Bed rock deeply weathered(?)	Bed rock fresh.

REFERENCES

Bryan, Kirk, The retreat of slopes: Am. Assoc. Geogr. Annals 30: 254-268, 1940

Bryan, Kirk, Gulley gravure, a method of slope retreat: Jour. Geom. 3: 80-109, 1940

Davis, W. M., Rock floors in arid and humid climates: Jour. Geol. 38: 1-27, 1930

Davis, W. M., Sheet floods and stream floods: Geol. Soc. Am. Bull. 49: 1337-1416, 1938

Gilbert, G. K., The convexity of hilltops: Jour. Geol. 17: 344-350, 1909

Higgins, C. G., Miniature "pediments" near Calistoga, California: Jour. Geol. 61: 461-465, 1953

Horton, R. E., Erosional development of streams and their drainage basins: Geol. Soc. Am. Bull. 56: 275-370, 1945

King, L. C., Canons of landscape evolution: Geol. Soc. Am. Bull. 64: 721-752, 1953

Lawson, A. C., Epigene profiles of the desert: Univ. Calif. Pub. Dept. Geol. Bull. 9: 29-43, 1915

McGee, W. J., Sheetflood erosion: Geol. Soc. Am. Bull. 8: 87-112, 1897

Penck, Walther, Die morphologische analyse, 1924 (English translation now available)

Wood, Allan, The development of hillside slopes: Geol. Assoc. Proc. 53: 128-146, 1942

Definitions of words peneplain and peneplane.

Wooster, p. 193
The peneplain, originally defined by Davis as almost a plain, -- designates the ultimate stage reached in a normal cycle of erosion. It represents a large land area that has been reduced nearly to baselevel by streams. In reality peneplains may not be "almost plains" but actual plains in the true topographic sense of the word. Some may approach the quality of a geometric plane, therefore, may be properly designated peneplanes (almost planes). The final process by which a land mass composed of rocks of varying structure and composition is reduced to a peneplain is planation brought about by the lateral erosion of streams---. As a rule the surfaces of peneplains are not flat but gently rolling.

VonEngeln, p. 83
For an indefinitely long period is at the disposal of the normal degradational processes and agencies, namely weathering processes and streams flowing down to the sea, it is obvious that such activity will eventually bring about the reduction of the highest and broadest of uplifted regions to an ultimately lowest level.
As unchanged peneplains in situ are not available for observational study many of the characteristics of peneplains must be deductively inferred.

Lobeck, p. 634
It is admitted by most investigators that peneplanes may be formed subaerially by streams, or by marine planation, or by wind action under arid conditions. Some authorities restrict the term peneplane to surfaces developed only by stream action, but in this text it refers to an almost flat surface produced by destructive forces.

Cotton, p. 20
---the surface of very faint relief which the cycle theory requires shall eventually result from the prolonged action of normal erosion on a land surface without interruption by further uplift or other earth movements is a peneplain.

Salisbury, p. 153
It is doubtful whether any extensive land area was ever worn down to a perfect base-level; but great areas have been worn down almost to that level--- a region in this condition is called a peneplain (almost plain) (gives an illustration from Camp Douglas, Wis.)

Davis, Physical Geography, p. 152
It may be imagined that, at a very late stage of development, even the mesas and buttes of an old plateau may be worn away, the whole region being then reduced to a gently rolling lowland, a worn-down plain, or "plain of denudation" --a lowland of this kind may be called a "peneplain", because it is an "almost plain" surface.

Webster dictionary
Plain (noun) = level land or broad stretch of land having few irregularities of surface.
Plane (noun) = a surface, real or imaginary, in which if any two points

are taken, the straight line which joins them lies wholly in that surface; or a surface any section of which by a like surface is a straight line; a surface defined completely by any three points not colinear; or a surface more or less approximating a geometrical plane. (illustration, inclined plane).

Wooldridge and Morgan, p. 183
In the orthodox presentation of the cycle of erosion, the later stages are represented as largely concerned with the gradual lowering of the interfluves by atmospheric wasting. This process is regarded as continuing long after active valley deepening has ceased, so that it tends to the obliteration of the strong relief of maturity, producing in the limit, a rolling upland, on which rivers flowing with gentle gradients are separated by low swells of the surface. For such a surface W. M. Davis proposed the term "peneplain".

Johnson, D. W., Plains, planes, and peneplanes, Geogr. Rev. 1: 443-447, 1916
We must recognize (1) the perfectly plane surface of ultimate erosion and (2) the imperfect "almost plane" surface which characterizes the penultimate stages of the several erosion cycles.
(1) The level erosion surface produced in the ultimate stage of any cycle may be called a plane.
(2) The undulating erosion surface of moderate relief produced in the penultimate stage of any cycle may be called a peneplane. A low-relief region of horizontal rocks would be called a plain.

References not included in general list

(1) Cook, H. L., Outline of the energetics of stream transportation of debris: Am. Geophy. Union Trans. 16: 456-463, 1935.

(2) Laws, J. O., Measurements of the fall-velocity of water drops and raindrops: Am. Geophy. Union Trans. 22: 709-721, 1941.

(3) Horton, R. E., Sheet erosion-present and past: Am. Geophy. Union Trans. 22: 299-305, 1941.

(4) Knapp, R. T., A concept of the mechanics of the erosion-cycle: Am. Geophy Union Trans. 22: 255-256, 1941.

(5) Straub, L. G., Discussion: Am. Geophy. Union Trans. 22: 311-315, 1941.

(6) Shulits, Samuel, Rational equation of river-bed profile: Am. Geophy. Union Trans. 22: 622-631, 1941.

(7) Matthes, G. H., Basic aspects of river-meanders: Am. Geophy. Union Trans. 22: 632-636, 1941.

(8) Claxton, Philip, Meandering of alluvial rivers governed by a fixed law: Engr. News-Record 99: 268, 1927

(9) Fairchild, H. L., Earth rotation and river erosion: Science 76: 423-427, 1932

(10) Jagger, T. A. Jr., Experiments illustrating erosion and sedimentation: Harvard Univ. Mus. Comp. Zool. Bull. 49: 285-305, 1908

(11) Towl, R. N., Behavior of rivers in alluvial flood plains: Engr. News-Record 102: 433-435, 1929

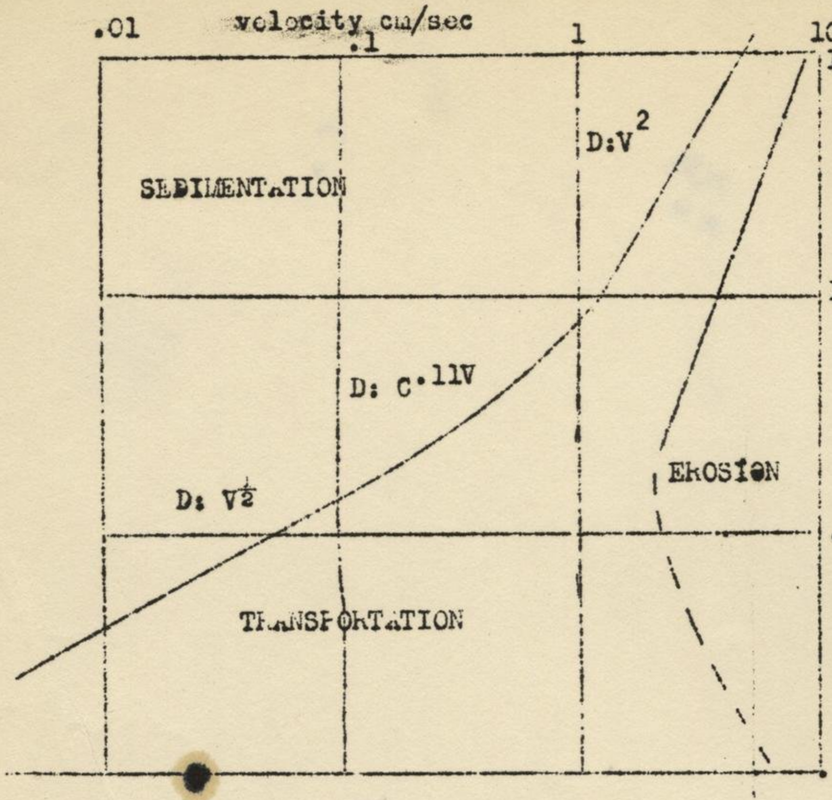


Fig. 51, p. 34
Relation of velocity of water to erosion, transportation and sedimentation of particles with different diameters, D. after Nevin, G. S. A. B . 57: 674
Note that for D 1 mm up the kinetic energy of the water is the major factor. For D less than about .2mm viscosity is dominant. There is a gradual change in the transition region. The curve for start of erosion is difficult to draw for so much depends upon the degree of packing of the small sizes of material.

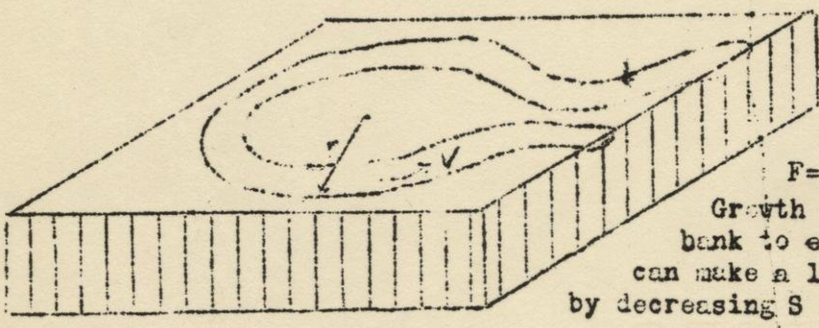
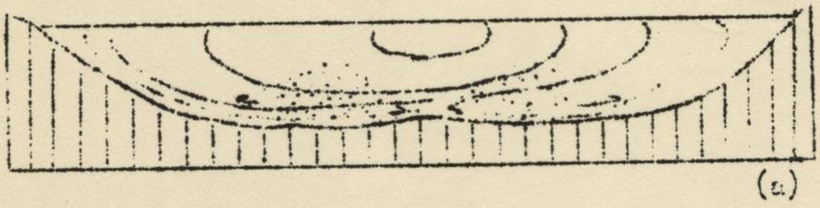


Fig. 55, p. 37
Rotational component of force in a curveed or meandering stream.
Radius of curve = r Slope = S
$F = mV^2/r$ as $V: S^{\frac{1}{2}}$ then $F: m.S/r$
Growth ceases when F = resistance of bank to erosion. Only a large stream can make a large meander. Increase of length by decreasing S also serves to set a limit.


(a)

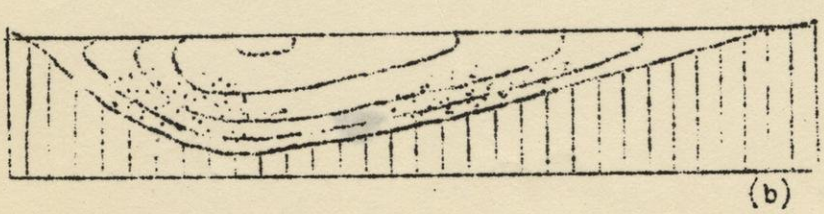

(b)

Fig. 56, p. 37
Distribution of velocity and inferred intensity of turbulence in (a) straight and (b) curved strea ms.
Intensity of turbulence is rate of transfer of energy. Hence sediment s hould move away from the dotted areas . This explains erosion of cut banks a nd trans fer to insides of bends and may also explain start of sand bars in middle of a stream, prehaps the beginning of braiding where accumulation of deposits is rapid.

Geomorphology

1-4

Climate.

Why important (adjustment to environment) Evidence of inconstancy. Glaciation- extinct lakes-evaporites x desert deposits-loess formation of mountain ranges- change of level, land, water

Transmission of moisture (other factors)

source - water, soil, plants

Condensation (not precipitation) due always to decrease of carrying ability
Causes- rise of moist air over mountains, etc or over other air masses
Local rise due to heating Equatorial condition
Idea of "polar front"

Winds- primary cause difference in temperature
Types- Belts of calms
Monsoon winds over large land masses
Trades flowing into equatorial belt - hurricanes or typhoons
Westerlies (cause??) Belt of variable winds, so-called cyclones
"eather comes from west
Horse latitudes or subtropical highs
Polar easterlies

Why belts now distributed as they are

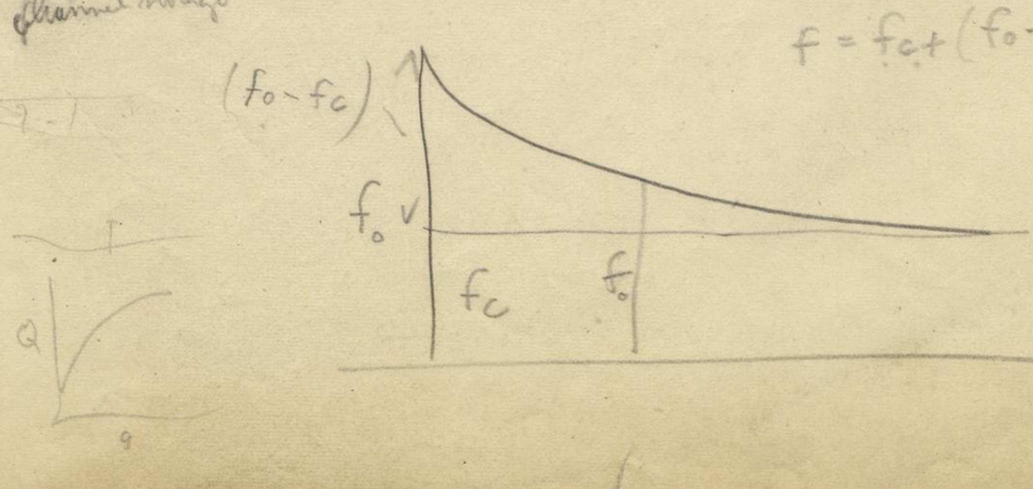
Maps of average climate of less value than maps of runoff, evaporation, freezing, exceptional rainfall, maximum winds, ~~frost~~

Disposition of precipitation
Surface runoff-relation of rate of rainfall or snow melting.
Percolation-why proportion changes with duration. Equation should have a minus exponent (meaning inverse relation) Air escape
Condition for no runoff How percolation is measured
Evaporation How found?
Includes water used by plants-diurnal variation Why some runoff where theoretical evaporation exceeds average rainfall
Chemical entrapment in weathering (probably small)

Stream flow-how measured-how platted. Meaning of peaks of curve, of line through low spots. Evaluation of mean runoff compared to that of mean precipitation
Relation of runoff to climate, to forest cover-to geology

channel storage

$$f = f_c + (f_0 - f_c)e^{-K_f t}$$



Materials.

Geomorphdogy interested in durability only.
Duralbility related to both chemical and mechanical alterations of weathering and to rapidity of removal by erosion. Hence: amount of energy required for destruction and/or removal
If total energy requirement cannot be determined then relative amounts are of importance
Source of informations measurments of durability of building stones

Bed rocks.
"Hard"vs "soft" rocks Interlocking cyystals vs cemmentation or compaction
← Mantle rocks
Hard rocks
Factors in mechanical durabilty
Crushing strength. a measure of force required for destruction
Resistance to temperature changes
involves expansion rates (coeff. of expansion)
grain size or texture plus porosity

Factors in chemical durability
Molecular changes atomic changes
Weathering
solubility governed not only by material but by
size of particles, porosity, permeability(difference)
permeability due to fractures also
Define permeability and give unit, darcy
involves cc. sec water, spec. tempr, pressure one atm.
Structure, such as foliation
Atomic changes known chiefly as time measures of age

Soft rocks
Mechanical durability
crushing strength related to cemenetation and/or compaction
temperature changes
importance of uniformity of material, grain size bedding or foliation
Chemical durabilty
Limestone vs dolomite, Evaporites
Porosity vs permeability Nature of solvents present
Kind and amount of cement

Resistance of mechanical removal
Importance of density. Archemedes law.

Mantle rocks or unconsolidated material
Direct removal, weathering not so importanct
Size of particles, effect of variation
Density or specific gravity of particles
Degree of compaction

1" = 5200
1/10 = 520

199
5280
1
53

192
10
5280

Weathering-here interested in effect on land forms
 Definition
  mechnical
  chemical-organic

 Mechanical.
  Effect on surface area of particles law of cube
  Processes
   Freezing. Total amount of pressure, volumetic vs linear
    expansion. Cube of a + da if a = 1 then only importance factor is
    1 + 3da errors in many statements

$a^3+3a^2\Delta a+3a\Delta a^2+\Delta a^3$

   frozen ground or permafrost. Requisite condition = excess of heat lost
    per year over heat gained. Heat gained from (a) interior of earth,
    (b) direct solar radiation, (c) conduction from winds
    heat lost by (a) direct radiation, (b) conduction to winds
    Rate of heat transfer in soil depends upon conductivity.
    Time of heat transfer. Max effect of seasons decreases with depth.
    Lag in time of max. soil temperature. Depth of unchanged level
    at mean annual air temperature about slightly modified by
    internal heat. Modifying factors: snow cover whith low conductivity,
    vegetation cover same effect, amount and movement of internal
    water.
    To get frozen ground mean air temp must be below freezing
     Is present permafrost now forming or is it inherited from
      former colder climate?
     Is cold associated with glaciation in time?
   Effects of frozen ground-formation of actual layers or masses of ice
    mounds due to escape of water. Local artesian conditions
    between two frozen layers. Extent of survival of ice effects?
    Lakes due to local thaw-permanent?? Pitted ground (Sager)
    Present blanket of moss etc.
   fracture of rocks by frost, repeated tension
   Breaking of rocks by other temp. changes.
    Must include as factors specific heat of rock, rate of absorption
    of direct radiation or heat from wind Conductivity which governs
    tempeature gradient and hence differential expansion-
    number of times of repition-associated chemical alterations-
    Griggs experiments with clock and hot plate
 Chemical including organic
  Agents- trend toward simpler chemical composition with both release of
   chemical energy and increase of volume and number of particles (1953)
  Exfoliation not simply mechanical but also due to chemical alteration
   and probably to relief of original stress Hydration of feldspar
   exfoliation domes why?
  (1952) Relative chemical susceptibility-quartz, muscovite, orthoclase, biotite,
   alk.plagioclase, hornblende, cal. plagioclase, olivine
  Soil formation. Importance to landforms. Define soil, mantle rock
   soil profile, why Is soil formation a phase of weathering?
   (1951) Describe soil profile
   Climatic control of soil profile Podzolization gleization, etc.
    pedocal pedalfer groups Prairie soils cause of lack of trees.
    caliche layer and other arid land crusts. Seasonal rainfall.
    Effect of soil horizons on erosion

$$(a+b)^2 = a^2+2ab+b^2$$

$$a+b$$

$$a^3+2a^2b+ab^2$$

$$a^2b+2ab^2+b^3$$

$$a^3+3a^2b+3ab^2+b^3$$

let $b = \Delta a$

$$a^3+3a^2\Delta a+3a\Delta a^2+\Delta a^3$$

12-16

Rate of soil formation. Leaching of calcium carbonate easily measured. Observation shows average of 275 lbs-A in humid temperate climate or about 31×10^{-4} gm/cm^2/yr Check on ground water at 250 p.p.m. carbonates = 25×10^{-4} with 10 cm. of percolation Vegetation has first call on percolatio and is not separable. Yet ground water addition much less than unaccounted for water Assume that bulk density of soil is same after as before leaching. Then original thickness of leached layer is

$$\% \text{ X BULK DENSITY} \qquad \frac{\text{thickness leached zone}}{100 - \%\text{carbonate}} \times 100$$

~~Thiks~~ thickness x % carbonate = total carbonate removed. Divide this by annual rate to get time of leaching.

Example: Leached zone 50 cm. thick Bulk density = 2.0 carbonates 25%

$\frac{50 \times 100}{100-25}$ = 67.7 cm = orginal thickness leached

67.7 x 2 x .25 = 33.2 gm. carbonate removed

$$\frac{33.2}{30 \times 10^{-4}} = 11{,}000 \text{ years}$$

If we used 12 cm. percolation and 250 p.p.m. carbonate result is same

Erodibility of soils Most work only on effect of different kinds of vegetation. Grass leads in general See supplement, 1950 Direct impact of raindrops important only on bare ground Ease of disperson important. Maximum where alkalie compounds occur generally in dry regions. Some soils swell when wet. Granulation of particles important but not shown in mechanical analyses. Silt-clay ratio, dispersion ratio, amount of organic matter, infiltration rate and other factors not fully understood must be considered. Most tables of erodibility worthless

Depth of mantle rock, water circulation necessary, Cause

Mass movement

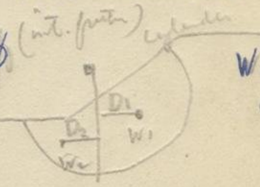
engineers analysis of banks cylinder, shear strength soil mechanics

angle of repose of loose materials Coulomb equation $S = C + p \tan\phi$

Creep- solifluction

need = unit wt., cohesion, angle of int. friction

p = pressure, C = cohesion



$W_1 D_1 = W_2 D_2$ + cohesion + shear

Talus formation

retention by friction. retardation of falling stones, relation of friction to size of stones effect of snow

talus (S. Africa) 3-4' angle 30-35° 2-3' 23-29° 1-2 19-23°

general expression angle of slope in deg = 19 + 5.5 D'

gravel to 40° sand to 38° clay about 16° max.

relation of talus to bed rock. Effect of subsequent weathering

recognition of talus slopes by straight line.

Physics of mass movement

Define solid, liquid, plastic Limitation of time factor

Pascals principle in liquids Fluidity or viscosity, Poise unit.

Landslides

causes of failure mainly difference in amount of water

Change from loose to tight packing. Shaking out water

Decrease in viscosity of wet clay

Fracture in slopes, slice faulting, curved surfaces cat steps

Slope failure Elastic curve Difficulty of analysis

dry wet sand – no cohesion
moist .. cohesion
down flow = solid rock
up flow = quicksand

.37
3 / 11.1
.9
2

9
55
5 / 50
45
50

12-16 cont.

Base failure-passage to fluid mechanics mudflows. rock glaciers,

Creep slopes. cause, component of weight along slope

53

Observation-mantle rock fairly uniform in thickness

mantle rock being formed continuously along slppe

How did slope get to such condition?

Math analysis. How is slope measured? degrees, percent, ft/mile,

ft. per foot = tangent of angle of slope

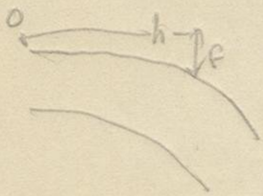
sine and tangent nearly same for small angles.

Limitation that slope has reached steady condition and is unaffected by other agents

orce = wt. unit volume x sin slope in deg= essentially WS

In order to take care of uniform production of amntle and keep thickness uniform then slope must increase away from divide in order to increase velocity of motion

hence V: S : h (horizontal distance)



Fall, f in any distance from divide, h must then be product of average slope x h Av. S:= h/2

hence f : h^2 / 2

Test by log-log platting for any equation $y = x^n$ can be also written log y = n.log x which will plat as a striaght line

caution: the proper origin of 0 point must be known in order to find value of n Just where is the divide? Field tests

$S = \frac{df}{dh}$

now since $S = Ch$

$\frac{df}{dh} = Ch$

$df = Ch \cdot dh$

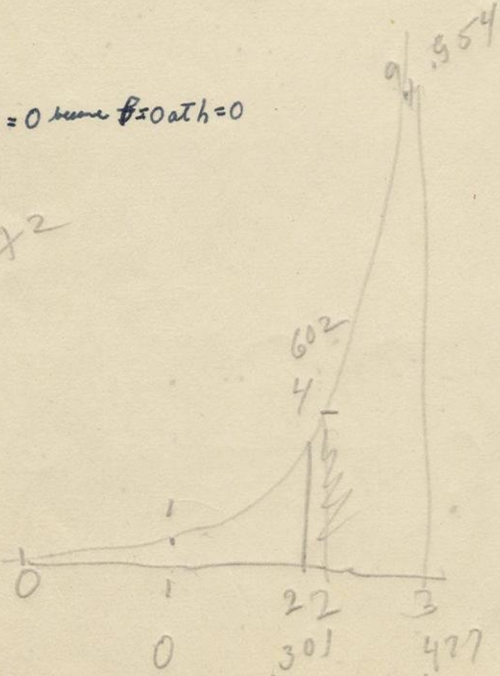
integrate both sides

$f = C\frac{h^2}{2} + c$ which = 0 because f = 0 at h = 0

Solifluction, definition Supposed periglacial climate.

false if we do not relate

$y = x^2$



log 1 = 0

2 = .301

3 = .477

4 = .602

9 = .954

16 = 1.204

25 = 1.398

17-20

Stone rings and stripes of cold climates landforms? periglacial problem.
How recognize past permafrost - How recognize landslide topog.

1954 Solution

Susceptibility Halite, gypsum, aragonite, calcite, dolomite, magnesite carbonate

Weathering of dolomite. Niagara of Wisconsin has 55% Ca to 44 Mg or very near to the 40/24 molecular ratio .55/.525 molecular ratio of carbonates

1953 Ground water average is 53.5 Ca to 27 Mg in ppm. Molecular ratio 1.33/1.12

But after assuming that all SO_4 is taken up by Ca the ratio is 1.05 /1,12 or about 94% of molecular equality. Hence dolomite is dissolved and there is no selective solution concentrating Mg

Chemistry of solution recognizes work of organic acids but ground water contains only bicarbonates as shown by lime softening process.

1952 Presence of suplhate reduces saturation point with carbonate.

Ground water analyses show total solids, total hardness, alkalinity both of last two expressed as $CaCO_3$

Rate of solution. Max alkalinity of ground water known.

Given annual percolation rate is found.

Example: assume 30 cm. annual percolation and total solids 350 p.p.m. there is dissolved in 1 year 30 X 350 X 10^{-6} = 1.05 x 10^{-2} gm from every cm^2 Taking a density of 2.6 each cm^3 weighs 2.6 gm.

Hence 2.6 x10^2 / 1.05 = 247 years to dissolve 1 cm^3 of limestone which is equal to a lowering of the surface of about .004 cm every year provided all solution is done there.

Susceptibility must include primary and secondary permeability including amount of impurities and impermeable beds.

Most limestone perm is due to joints and bedding planes.

Original openings filled with connate salt water.

Flushing out of this extends to depth fixed by availability of passages and hydrostatic balance with sea water.

Colums A and B must balance when A x1.0 = B 1.03 relative densities.

But A = B + h (heigth of fresh water above sea level or outlet sill

Then B + h = B 1.03 Let h = 120 feet and B = 4000 feet

this is max depth to which fresh water might penetrate.

1951 Oil tests in Florida appear to confirm this roughly. Effect of digging Florida sea level canal. Results of drilling.

$A = B + 120$
$B + 120 = B \cdot 1.025$
$120 = .025 B$
$B = \frac{120}{.025} = 4800$ ft

Relative pressure loss in openings. All formulas for turbulent flow which occurs in reasonably large openings,

V = velocity, Q = quanity, S = slope or loss of pressure head, R = radius of opening, D = width of long flat opening with length many times the width. A = area of section

$V = Q/A = Q/2 \pi R^2$ in circular opening or Q/D in flat opening

V^2 = DS or RS from which loss of head $S = V^2/D$ or V^2/R

By substiution for value of V in terms of quanity and dimensions loss of head, S is inverse to cube of width D in long flat openings and is inverse to R^5 in circular openings

Hence larger openings carry much more water than small ones and are much more dissolved. Deep circuitous passages are not much enlarged unles no other path is available.

$S = \frac{V^2}{D}$ or $\frac{V^2}{R}$

now $V^2 = \frac{Q^2}{A^2} = \frac{Q^2}{4\pi^2 R^4}$

hence $S = \frac{Q^2}{4\pi^2 R^5}$

flat opening

$V^2 = \frac{Q^2}{R^2}$

unit here $S = \frac{Q}{R^3}$

1954 Redeposition in many openings above water level.

Topographic effects here considered only. Favoring of underground drainage due to relative speed of enlargement vs time required for formation of valleys.

But deep penetration of water is possible mainly because of erosion of valleys

Formation of enclosed depressions or sink holes. Natural bridges

Theoretical endpoint a plain unless certain parts lack permeability. - Stream cut to baselevel.

Technical terms all from Czeckoslovakia

21-23 Major relief features

Difference of continents from ocean basins. Continental shelf, continental slope
contrast, average not well known, Sounding methods
Interpretaions of shelf: sedimentary or erosional, adjusted either to
present or to some lowered sea level. Dietz and Menard, A. A. P. G.B
35: ~~11~~ 1994-2016, 1951 advocate that it is erosional and adjusted to lowered sea level
sea level as shown by coarse sediments and rocky bottom near outer edge.
Lack of any definite wave base for currents which may occur much deeper.
Depth varies from 50 to 70 fathoms. Myth of 100 fathoms.
to 25° Slope average 8%, $4\frac{1}{2}$ deg. 422 ft/m. Great variation - variations
1954 Difference in bed rock of continents and ocean basins generally assumed
Evidence not conclusive although generally accepted.
Some specimens dredged but mostly based on gravity and velocity measurments
Method of getting gravity, g. Pendulum, ~~gravimeter~~ gravimeter
Reduction of observations to allow for density at depth
sial or silica-alumina rocks av. density 2.67 generally thought of
as continental. Sediments
sima or basaltic rocks more common under oceans. Exceptions proved.
Av. density about 3.0
andesite and basalt districts of Pacific
velocity determined by square root of ~~density~~ elasticity/ density. $V = \sqrt{\frac{E}{d}}$
Contradiction since two are interrelated
Theory of isostacy
1951 Evidence? Postglacial rise; "deviation of plumb line" actually failure
to check triangulation by latitudes. Erroneous positions determined
by astronomic observation.

Hubberts calculations of time of adjustment depened upon constancy of
viscosity of rock. Assume no strength against long continued force at
depth and that rock behaves as a true fluid not a crystalline substance
Define: strain, stress, strength, elastic limit, level of compensation
elasticity
Final criticism
How tell results of compaction from those of isostacy?
How tell effect of ice from other causes unknown? at other times?

Officer, C. B, Ewing, Maurice, and Wuenschel, P C
Seismic refraction measurements in the Atlantic Ocean IV -- GSA B 63: 777-808, 1952

Ontario
6.15 Km/sec
35 Km 6.45 "
8.20 below

Nares deep
1.52 - unconsol. = 1.70 consol. = 4.51
~~[illegible]~~ 10 km depth.
6.63 no sial under ocean
8.03

Land forms due to vulcanism. Distinguish from effects of intrusions
Variation in type of rock basalt, andesite, rhyolite
types of eruption Hawaian, Strombolian, Vulcanian, Pilean
1952 Viscosity of lavas amount of gases
Relation to temperature, decreases with rise
to composition decreases with SiO_2 content
But melting temperature is not related and increasew with reduction of SiO_2 100 C or more
Viscosity determined from speed and thickness of flows. Temperature hard to get Laminar flow where $V: D^2S/2u$ $u=D^2S/2V$
Distribution of volcanoes, Pacific ring of fire. Relation to disturbed belts, exception
Kinds of ejecta.
Pillow lava below water
Degree of crystallization in flows. Importance to erosion
Cooled top, amygadloid, pahoehoe or broken skin,
aa = clinker
Dip of flows related to viscosity basalt 1400 C viscosity 80-140 poise, but increases to thousands at 1200 C
andesite 150 to 160000 Effect of difference on initial dip, increase of slope outward from vent making convex summit.
Amount of foaming, clinker, pumice, scoria, tuffs water worked sediments or fragmental volcanics, all gradations mud flows

Land forms
1952 Basaltic- domes very low slope, lava fields, spatter cones, scoria or "ash" cones with talus sides up to 35 deg. Lava caves
acidic- domes , spines ejected in solidified state, fragmental cones with talus slopes, craters, calderas.
Origin of calderas-Crater Lake etc. next time

25-27

Vulcanic forms cont.

Slopes of volcanic cones. log-log plats. error why
convex form origin at crater edge yields slope of over 1 in 1= convex form
Several straight lines if origin is unchanged.
Free sliding slopes of fragmental material give 1 in 1 slope = talus
Below that an unchanged origin gives less slope. Change of origin to break point
gave nearly (1 to 1) slope for Mt. Hood, Vesuvius, Fujiyama not so clearly.
This means that a false origin too high in elevation was used.
Sucession of talus slopes with decreasing angle due to finer material in
part due to weathering and slope wash. Is it really a concave slope?
Ideasof Milne, Becker certainly not due to shear of lava either
molten or solid Where, if at all does wash enter the picture?
Falacy of matching curves.

Craters and calderas. Origin of calderas. Crater Lake.
Explosion craters-maars "Cryptovolcanic structures" land forms
volcanic or not → renewed faulting - salt domes (10-12 m³ area)

Total removed 17 m³ - eruption (C14 date) 6453 ± 250 5 m³ pumice (now) unaccounted for 10 m³ +

1 Hypos - sinking by withdrawal of magma or sinking due to lost gas
2 explain

27-30

Earth movement.
Discrimination of land forms due directly to such and those due to erosion . conditioned by former movement of materials How much erosion of tectonic uplifts? volcanic rocks? Is there any original constructional form left?

Folding, faulting, impact
Compton quadrangle, Calif. How told from a stripped fold
use PawPaw if possible
Jura Mts. Coast Range of Calif.

1952

Faulting. types
Evidence of fault vs evidence of a recent fault which displaced land surface
Straight border of Mts. best seen by horizontal view
Discordance with internal structure not always present
Relative steep sides of Mts. = talus vs the water-washed slopes below
formation of pediments Upturned hard formations
Springs
Trianglular facets not necessarily due to recent faults might be only displacement of hard against soft formations

Displaced surfaces of deposition. fans, recent lake deposits, lavas
erosion; ~~pediments~~ pediments or peneplains
Temporary nature of evidence
formation of enclosed depressions, also temporary,

1954 / 1953 Examples, fault scarps of Col. Plateau.
coast Rangles of Calif. Fault of Glacier Park

Conclusion. Little proof except in areas still active with earthquakes
erosion dominant factor in present surface details almost everywhere

Impact.
Discrimination of volcanic explosions.
Nature and discovery of meteorites geophysics
Energy of impact $E = \frac{1}{2}mV^2$ Meteorite vel. up to 40 m/sec. per
= 64.6 Km/sec or 6.46 x 10^6 cm/sec for unit mass this is
2.08 ergs x 10^{13} Reduce to joules = 2.08 x 10^6; reduce to calories x .239
= .49 x 10^6
Difficulty of comparison with ordinary explosives which commonly give only calories with no information on rate of explosion
Atomic bomb $E = mc^2$ or for unit mass $E = 9 \times 10^{20}$
reduce to joules = 9 x 10^{13}, to calories 2.14 x 10^{13}
only 1/1000 used (~~or~~ available) = 2.14 x 10^{10} calories/gm.

Comparison of effect of high and low-power explosives
Examples. Meteor crater, Arizona / Carolina Bays Chubb Crater
'53
Hypotheses
Steam explosion
Weathering of volcanic neck or pipe
Lakes shaped by rotary currents
Solution of salt domes
Spring action
Tests geophysics test drilling

#17 out in review questions
add - How distinguish permafrost from topog.
" " past permafrost

31-32 Running water. importance

1954

Physical definitions: velocity, accerlation, force, weight, mass, work, power, kinetic energy, friction coefficient (KE of rotation $\frac{1}{2}m\ r^2 \times v^2/r^2$ = same for part)
(Capacity vs competence) hydraulic radius (Reynolds number)
tractive force, settling velocity) Archemendes principle / viscosity

1953

Methods of flow- laminar or viscous
Turbulent
shooting

$F = uV$ $F = zwS$ $\frac{F}{V} = u$

Derivation of laminar flow velocity (unit density)
velocity at a point at depth z Force at this point = zS
hence $u\ dv/dz = F = zS$ $= uV$ $w\,z\,dz\,S = u\,dv$
To obtain velocity at surface with total value of z = D or depth
clear and $u\,dv = z\,dz\,S$ and integrate both sides when
$uV = D^2S/2$ (same as multiplying by average depth D/2)
clear and then $V = D^2S/2u$
This type of flow important only in materials of high viscosity or very low velocity (underground waters, sheet wash, glacier, ice, rock, earth etc)

$z = 0 - D$

Derivation of formula for turbulent flow.
Cause of turbulence
Cause of no acceleration of falling body for resistance = force
Take unit length cross section of perimeter P, area A, slope S
force downhill = wt of water in unit section x S
+ A W S where w = unit weight

for wide stream or unit width — DwS

force downhill = resistance
resistance = coefficient . perimeter . unit weight . V^2
$= f \cdot p \cdot w \cdot V^2$ — $f\,w\,V^2$
Hence
$A\,w\,S = f\,p\,w\,V^2$
divide through by p and $R\,W\,S = f\,w\,V^2$ because A/p = R hydraulic radius
divide by w and then by f
$R\,S = f\,V^2$ or $V^2 = R\,S/f$ Chezy formula $R = D$
Now the value of f depends in part on the value of R and in part on nature of bottom hence Mannings expression $V^2 = R^{4/3}\,S \times$ coeff
for B.E. units the coefficent is about 37 for most streams or 30 to 37 — $\frac{1.5}{n}$, n = roughness

unit width: $DwS = fwV^2$, $DS = f \cdot V^2$, $V^2 = \frac{DS}{f}$

Implications of this equation wide stream R = D depth

1952

Mixed flow important in thin sheets here $V^2 = C\,D^{1.8}\,S^{1.4}$ or $V ; C\,D^{.9}\,S^{.7}$
Constant slope Q: quantity = V·D hence by sustitution $Q : D^{5/3}$ or $D^{2/3} \cdot D^{3/3}$ (unit width)
for a constant quantity slope inverse to $D^{10/3}$

$Q = VD$ $D^{2/3}S^{1/2}D$ $D^{5/3}S^{1/2}$

Solve for V with R = 1, S = .01 const = 37 and V = 3.7 ft/sec.
R = 27, S = .0001 V = 3.32 ft./sec.

$\sqrt{1/100} = 1/10$ $\sqrt{\frac{1}{10000}} = \frac{1}{100}$ $\frac{37.9}{100}$ $S = \left(\frac{1}{D^{5/3}}\right)^2 = \frac{1}{D^{10/3}}$

use mean depth

Lec 54 32-34

Erosion or detachability of material.

Methods, direct lift of loose particles Work by impact which = area . ~~sin~~ V^2

wt. . sin A = const. V_b^2 area (pi R^2). cos. A

since tan A = S and for low angles is nearly = sin substitute S

wt = density under water . g. 4/3 pi R^3

above can be solved for D, diamter or R radius of particle which is then proportioned to V^2 if particle is over ~~2x2xmm~~ diameter = 1 mm

due to partial burial of particles this applies best to transportation

protection of larger particles

abrasion. If clear water flows over cohérent material no erosion until particles are added to abrade (tools). But if more than a certain amount is present in water at given velocity erosion ceases

water-in soil

1953

impact of large particles, loss of weight under water. viscosity of water. impact of raindrops. size, velocity of drops

cavitation or water hammer important only with very high velcoity

Resistance to erosion due to coherence. + permeability Very variable, Protection of vegetation

Competence of flow. Confusion with load or capacity

Confusion of weight (or mass) vs diameter (or radius) of largest particle

Sixth power law abused

1951

Methods of expressing energy of running water

Impact = area .V^2

Tractive force = component of weight of unit column parallel bed or total potential energy D. unit wt. slope

Hydraulic lift or venturi effect. Differential velocity. conservation of momentum

KE grade or V^2/ D or $V^2/2g$ derivation (unit width)

1952 Turbulence or upward component of motion. Difficulty of computation related to velocity gradient

$V_z = C \log z$ $\frac{dV}{dz} = \frac{1}{z}$

Laws of settling velocity. See above for sand and pebbles. Can substitute depth and slope for velocity Other things equal, diameter of largest pebbles proportioned to slope (?)

KE vel gradient

best gradient of vel

V: z (height above bottom)

$\frac{dv}{dz} = \frac{D}{z}$ limit in D

1953

Particles less than 0.2 mm diameter viscosity of water is determining factor. Derivation of formula not given. experimental in part diameter related to square root of velocity

Transitional law. variable exponent $e^{.11x}$

1951 X

Disposition of total energy: viscosity; k. e. of rotation in part recoverable; tra nsportation overcoming gravity of particles ; erosion or friction; surface waves; rippling of bottom

Interrelation is complex and variable with conditions; depth-slope formula meaningless

1954

Derive Chezy formula for velocity

Attempts to obtain thickness of layer of laminar flow at bottom depend in absorption of enitre K. E. in this layer

$V_m^2 = R. S = u V_b/d$ where d = thickness of this layer and u is coeff. of viscosity

whence $d = uV_b/RS$

Rubey's attmpt to find a "bottom velocity"

Quantity . fall = area (wetted) . friction. distance   same dimensions   A = area of x-sec.

$(V_mA)(V_mS) = (P V_b)(\text{coeff} . V_b^2)(V_b)$ P = perimeter under water

$V_m^2 AS = \text{coeff } P . V_b^4$ or $V_b^4 = V_m^2 RS/\text{ coeff}$ divide by P (could use instead of A)

Substitute $V_m^2 = RS$ altered to Mannings formula $V_m^2 = R^{4/3} S$ in above and

$V_b^4 = R^{7/3} S^2$ whereas $V_m^4 = R^{8/3} S^2$ (coefficient neglected)

No important difference in relations only in magnitude

Methods of carr ying load vs methods of picking up

suspension, saltation, bed load variation with velocity

No single formula for relation to velocity or any other variable.

formulas work only within range for which they were derived

any formula relating to velocity must have an exponent twice that of a formula based on depth and slope. because $V^2 = DS$

Factors of detachment: boundary shear, eddy shear, fluid impact, particle impact, loss of weight

Resisting or opposing forces are: gravity, support of adjacent particles, mechanical binding, surface coating, resistance to flow through material

exam

What is needed is expression for power, not for work or force.

Now power = Fv If force of moving water is related to V_m^2 then power is related to V_m^3

$V_m^2 \cdot V_b = \text{work}$ (?)
$V_b = V_m^2 RS$
$V_m^4 RS = \text{work}$
work = FS

Ruby's derivation of power

Load . settling velocity = wt. in unit time . S

$L.V_s = (f.\text{den}, g)(Q.V_m) \cdot S$

$= (f.\text{den}, g)(V_m A.V_m) \cdot S$

dividing by P $LV_s/P = f.d,g,(V_m^2 R S)$ f= a coefficient, d = density, 1 for water

Since $V_b = V_m^2 R S$ then

load for unit width $L/P . V_s = g V_b^4$

Since V_s is proportional to V_b then $L/P : V_b^3$ where's the catch here — is there — this is vertical component

Schoklitsch bed load formula

Load/unit width : $S^{3/2} (Q-Q_0)$ where Q_0 = quanity at which bed motion starts

Since $V_m : S^{\frac{1}{2}}$ this becomes V_m^3 and since quantity : $V_m \cdot D$ it is then equivalent to $V_m^4 D$ (allowing for an inital depth at which movement begins)   unit width

37-40

Critical value of velocity, slope, discharge before load begins to move. ordinarily subtracted. could be percentage or other relation?

1952

Overloading

Experiments with flumes defects

Horizontal form of stream course.

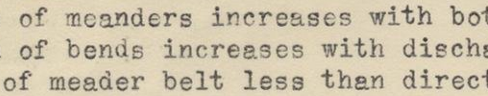
Cross section -relation to nature of banks and bed.

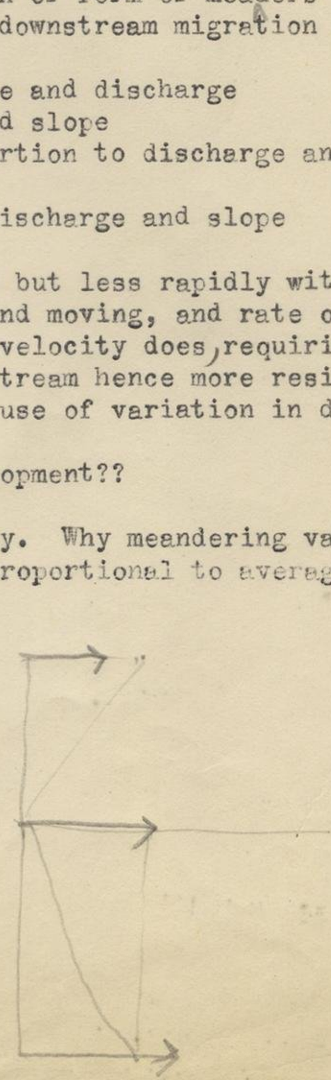
Relation of forward and lateral velocities

Meandering. Forces diverting stream. Obstruction – rotation of earth
Rotation. relative velocity-plane of reference
F (dynes) = 2 ang. vel. (radians/sec) x rel. vel (Cm/sec). sin latitude
Rotational force = V^2/r (dynes if other units are c.g.s.)
substitue value of S

rhythm 1954

Vicksburg experiments. No effect of rotation noted.
Angle of attack Bank erosion Downstream sand transport not related
Rate of bank erosion inverse to slope, discharge Rapid streams do not meander
Deflection self perpetuating Crossings and deeps
Braiding, cause. slope is great
Relation of slope to bank material Relation of form of meanders to uniformity of material. Cutoffs all due to non-equal downstream migration or sweep
195 Normal limit involves formation of chutes
Radius of meanders increases with both slope and discharge
Length of bends increases with discharge and slope
Width of meader belt less than direct proportion to discharge and slope
Length of bend inverse to angle of attack
Width of meander belt less than direct to discharge and slope
Angle of attack related to velocity
Sinuosity increases directly with discharge but less rapidly with slope
Discharge (inc. channel form), amount of sand moving, and rate of bank erosion all interrelated. If slope increases velocity does, requiring smaller channel. Material of banks becomes finer downstream hence more resistance to bank erosion. Balance never attained becuse of variation in discharge of natural streams.
Are meanders related to stage of stream development??
Are sandbars related to turbulence?
Width of meanders belt as determined empirically. Why meandering valleys show wider belt Low water channel supposed to be proportional to average discharge. Error





to 40 cont.

$\frac{2\pi \text{ rad}}{86,164 \text{ sec}} = .00007292 \frac{\text{rad}}{\text{sec}}$

7.29×10^{-5}

Basic derivation of effect of earths rotation

Radial velocity varies with latitude. Any change of la titude meas ns change of velocity Compare with long range projectile noting that all latitude parl away from equator are not great circles. Equ. vel 465 m/sec.

Superimpose two velocities and consider that vectors cover equal areas in equal times. Work out components in two directions omitting all factors not dependent on rotation. Combine to final expression

1954 Misfit streams Explanations Lehmann's principle. Comment on importance

How meanders are destroyed. why move downstream

$2 \times \frac{2\pi}{60 \times 60 \times 24} \cdot 200 \cdot \sin 70 =$ .94

$\frac{4 \cdot 3.14}{36 \times 10^2 \times 2.4 \times 10} = \frac{4 \cdot 3.14}{3.6 \cdot 2.4 \cdot 10^4} = \frac{12.5}{8.64 \times 10^4} = 1.44 \times 10^{-4} \times 2 \times 10^2 \times .94 = 2.88 \times .94 \times 10^{-2}$

$= 2.7 \cdot 10^{-2}$ dyne

for 50 cm/sec $= 0.7 \cdot 10^{-2}$ dyne

$r = 1 \text{ km} = 10^5 \text{ cm}$ $\frac{V^2}{r} = \frac{4 \times 10^4}{10^5} = \frac{4}{10} = .4$ dyne | for 50 cm/sec $\frac{2.5 \times 10^3}{10^5} = 2.5 \times 10^{-2}$

$V = 200$ cm/sec 2×10^2 10^3

Inequality will decrease with velocity sineeratio is V^2/V or simply V

increase " decrease of latitude as sine approaches 0

Formation of entrenched meanders. two types, entrenched, ingrown

25×10^2 2.5×10^3

1951 Longitudinal profile of rives a curve becoming less steep downstrema. all need not apply

Attempts to relate to increase in volume, to decrease in size of largest particles. to constancy of eroding or transporting force, to change in manner of flow of water. Difficulty of finding origin to plat.

Normal drainage basin pear-shaped. Increase of discharge downstream not direct to distance Since maximum pebbles are only small part of load how come they control slope? How about average size and if so how computed? How about debris derived nearby?? Any computation of force or bed load capacity involves changes in discharge. Concavity shown also in alluvial fans, desert portions of streams, and in outwash plains of deposition where volume is essentially constant.

What is relation of velocity/ diameter ratio?

Particles over 1 mm D, slope-diameter ratio is unity.

" below .2 , D: S^2 between transition

how combine these??

Can it be due to a combination of factors all trending in same direction?

Absurdity of relation to competence hence to any possible law of deduction on wear of large particles.

Probably related in some way to mean size and particularly to grade of size which predominates. Phi mean = log base 2 of weighted mean. Observation shows fair relation to slope. Phi mean also cloessely related to log of geometric mean. With large particles D;V^2 hence sinee V^2: S then D:S but this does not work for bulk of material transported. This lies in the transition zone of size/diam/ to velocity ration. This changes from D:V^2 for over 1 mm to D^2;V for less than .2 mm Must also consider effect of bottom load on both density and viscosity of tranporting water in the bottom layer.

types of means. arithmetical = sum n items/n geometrical = nth root of product of n terms.

exam to here

 Exam to here

Slope wash or overland flow
hydraulics mainly mixed flow not turbulent as assumed by some.
$V: D^{.9} S^{.7}$

Students, Little, Horton
Little used expression V^2/D as denoting force of erosion
Horton used depth-slope formula
In order to compute slopes of uniforn erosive force different assumptions as to relation between depth and distance from divide were used.
Little used a rainfall equation relating to intensity of rain for duration
— Used a flat percentage of soak-in
Horton ~~Little~~ paid more attention to experimental results Since discharge on unit depth is related both to depth and to velocity and velocity is related to depth then discharge is proprtional to a power of depth which varies from 1 to 2, theoretically should be 5/3th power for turbulent flow only- 3rd power for laminar (D.D²)

1954/ unit width unit range

1951 Attempts to obtain a profile of uniform erosive force yield various results. probably few slopes do show this relation. All unite that increase in depth downslope must result in slope concave upward. reduced shear?

Resistance to erosion is vital. Horton combines all losses in energy into a figure for resistance expressed in lbs/in² which he computes as varying from .05 to .5 depending in nature of soil and vegetation.
Most important contribution is that erosion begins where energy = resistance. Since energy depends upon quanity of water there must be a "belt of no erosion" along all divides within which average rainfalls do not accumulate enough water to begin erosion. Variables in factors governing width of this belt are rainfall rate, duration, ratio of infiltration, slope, resistance of soil

correct how measured

1952

Misprint top of page 43

Beginning of rill erosion on slopes

breakdown or "failure"

Horton's mathematical relations depend upon gross or potential energy of flow figured instead of depth.slope, unit weight as unit weight of water 1 inch deep x sine of slope because he used length of slope instead of horizontal distance.
Quantity of water is product of length of slope by rainfall intensity
Depth = quantity divided by velocity
Hence using turbulent flow depth =(rainfall rate. length of slope/ slope)$^{3/5}$
By substitution we find force is equal to ~~wink~~ unit weight(rainfall intensity)$^{3/5}$ x sin slope/ tan slope$^{3/10}$

$Q = DV \quad D = \frac{Q}{V} \quad Q = CD^{5/3} S^{1/2}$

$V = CD^{2/3} S^{1/2}$

$D = \frac{CD^{5/3}}{D^{2/3} \cdot S^{1/2}} = \frac{CD}{S^{1/2}} = C\frac{Q^{3/5}}{S^{3/10}}$

$Q = D^{5/3}$

$D = Q^{3/5}$

Exam to here?

$F = D \cdot S \sin\alpha$

$Q = CD^{5/3}$

$F = DS = \frac{CQ^{5/3}}{S^{1/2}}$

Raescher

Map of Brown W

43-45

Formation of valleys rills at first, concentration, cross grading
Change of slopes by this. Assumption of soft material - overall slope
Subdivision and resubdivision until all inter channel areas are within belt of no erosion

1951 Relation of streams to ground water
1954 Entrance angle of tributaries.
Hortons system of stream orders - unbranched tribs = 1 Strahler not always yet
1952 1951 Drainage density Stream frequency branch not trib = 2
Drainage texture. Causes of variation
Bifurcation ratio r_b

$= \frac{\text{length of all stream}}{\text{area}}$ - function infiltration + resistivity

l_0 = length of overland flow $= \frac{1}{2D_d}$

Frequency $= \frac{\text{No. of streams}}{A}$

No. of given order $N_0 = r_b^{(s-0)}$ s = order of main stream

" " all streams $N = \frac{r_b^s - 1}{r_b - 1}$

Number of diff order = inverse geom. series - first term 1, ratio is bifurcation
lengths direct " " " " av length of 1st order
slopes inverse geom. series

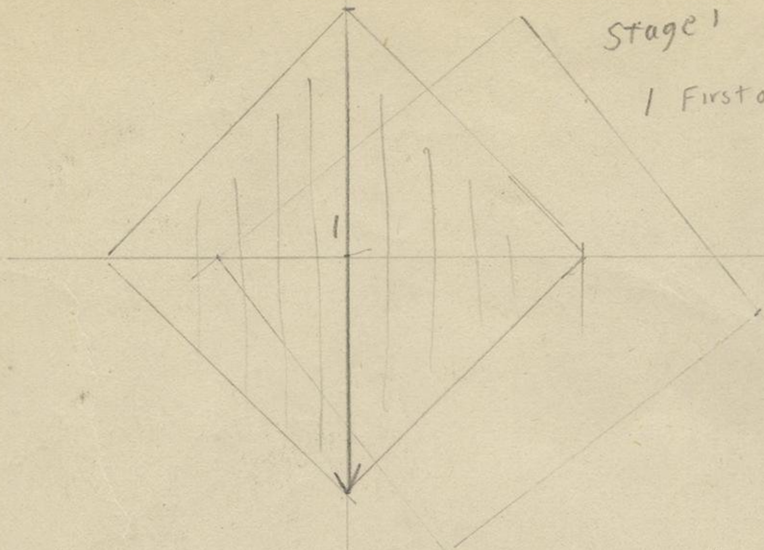
geometric series 1, 2, 4, 8
1 3 5 7

a	r = ratio	r = 2 a = 1	
ar		1	2
ar^2		2	4
ar^3		4 = 2^2	8
		8 = 2^3	16

arithmetic - constant diff

1, 3, 5, 7 (diff = 2)

$N_0 = r_b^{(s-o)}$

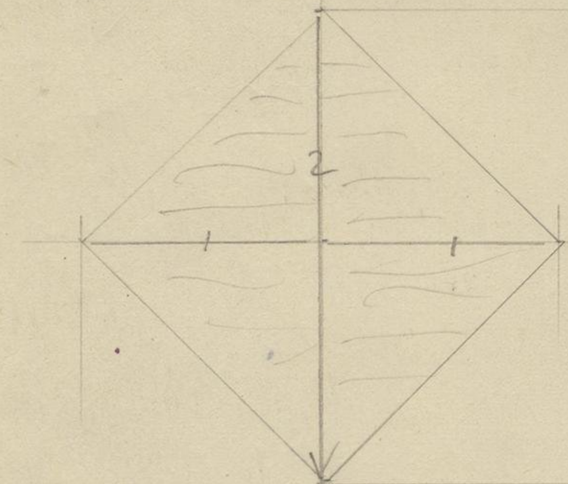


Stage 1

1 Firstorder

$\overset{1}{a x} \quad a x^2 \quad a x^3 \quad a x^4$

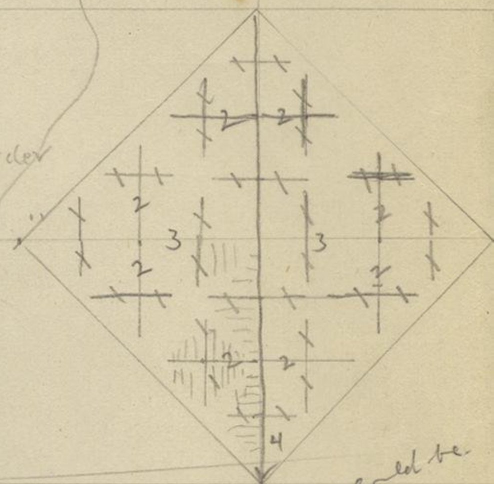
1 2 8 32



Stage 2

2 Firstorder

1 Second "



Stage 4

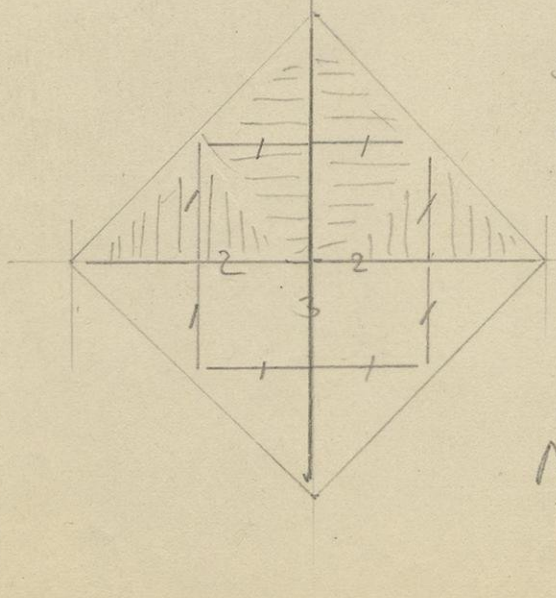
Should be

2^5 32 First = 2^5 $2^3 = 8$ $r = 2$

2^3 8 second = 2^3 $2^2 = 4$

2^1 2 Third " 2^1 $2^1 = 2$

1 Fourth " 1



Stage 3

4 8 First order

2 second "

1 Third "

$rb = 2^2$

$N_0 = 2^{(4-\text{order})}$ or

1	1	1
2 = rb	2	3
4		9
8	3	27
16	4	

$N_o = r_b^{(s-o)}$

rb = number next to highest order = 2 here

45-52

1953

Drainage patterns. Were or were not streams preceeded by slope grading ?
Definitions- dendritic, trellis, distributary, consequent, subsequent
water gap. Fall recession, plungepool, pothole, spring recession
Change from deposition to erosion.
alteration of valley sides to slope result of incomptence of material
variation in width of belt of no erosion contributes to convexity
Baselevel and Playfair's Law.
Lateral erosion-cause - cut banks importance to sediment and meandering
later Pediment formation. Problem lateral erosion vs slope wash.
1954 Change from turbulent flow in gullies and on steep slopes to mixed
flow on flat. Flat implies material which can be removed by water.
1957 Low slope needed to cause sheet wash. Nature of rock in talus
slopes above. granite, sandstone, shale ([illegible])
Define pediment, pediplane, pediplanation, sheet flood, overland wash
relation to alluviation relation to climate, to vegetation
1953

1952 Cylce of erosion. Define youth, maturity, old age, peneplain
evidence of past peneplains-upland levels, buried surfaces
monadnocks, inselberge peneplain of solution - panplain or plain
later of lateral stream erosion
Interruptions of the cycle
1954 Terraces, definition. Define grade, floodplain, nickpoint

aggradation of streams Profile of deposition-relation of curve of
transportaion. Plats of outwash streams, alluvial fans, etc.
Exponent 7/10 Slope then inverse to 3/10 power.
Average or mean size of sedimentmust be considered not maximum size
ar. mean .440 Plummleys observation that ~~log of~~ geom. mean directly proportional
geo " 352 to slope. Hence fall would be related to g.m. ~~product of g.m. by log~~
phi " .340 ~~of same minus g.m.~~ This involves a change of g.m. with distance
of transport. Sternbergs "law" which was given originally
as a percentage change of size or variable exponent in which
1953 distance of transport is modified for kind of rock

Change of slope with distance on melting back of ice. Increase in
discharge also modifies result
Fill of valleys in Driftless Area. Climate vs uplift?
Terrace topography scars, cusps, paired and unpaired, ice contact,
rock-defended
Correlation problem

Omit Incised meanders (see before under misfit streams), Ingrown vs entrenched
slipoff slope Inference from presence of entrenched meanders.
Destruction of meanders. Type of rock for preservation

$$V^2 = \frac{\text{wt of particle in water} + 9n^2 + 3n}{\text{radius } 2}$$

$$\frac{\frac{4}{3} g d_2 (d_1 - d_2) r^3 + 9n^2 + 3n}{d_2 r^2}$$

(density of medium $= 1 = d_2$
n = coeff of viscosity)

52-54

Streams on floodplains, natural levee network pattern braided pattern
meandering pattern Yazoo tributaries, distributaries Old Yazoos

Deltas internal structure,

Alluvial fans, profiles resemblance to outwash plains

Natural bridges

Drainage modifications-capture Case of different material in adjacent streams
Problem of how final capture is effected Greybull type of capture
Superposition
Antecedence
Evidence of capture. snails Crosby J. G. 45:465 Jour. Geomorph 2:251, 4:307 5:59
Case of Tennesee R. St. Louis River etc

54-56 61

End point of cycle of erosion
Peneplain, definition original idea of humid climate
Method of removal of interstream ridges
Crickmay's idea based on failure to find any peneplains
why should floodplains increase in size with progress in the cylce?
climate needed? Cut banks residuals King concludes a savanna type
Etchplain of Wayland= removal of weathered zone by lateral stream erosion
present only in humid tropics
Pediment-pediplane Name given by Howard includes both cut and built parts
Process of removal of weathered material where resistance to erosion is small. Controversy: lateral erosion of water courses vs slope wash.
Relation to kind of rock to slope
depth of weathering
kind of weathering
covering deposits
degree of slope concavity of slope
regional extent
survival of remnants of older cylces

Recognition of eroded erosional bevels
Even skyline even ridgetops
Residual areas stream spacing (Shaler)
Degree of adjustment of drainage to structure
Bevel of geology
Lithology of monadnocks
Explanations of even crests or summits
Spontaneous development- timber line- limit of glaciation.
isostacy? upward limit of intrusions, of metamorphism
Separation of levels Parallel lowering?
Horizontal growth of peneplain of pediment
Buried surfaces-alteration during burial
Water and wind gaps 4 explanations

Standing water 61-63

Friction of wind against water. relation to roughness to turbidity of air.

setting up of rotational motion, why not same everywhere? $h = 2R$ $R = \frac{h}{2}$

Radius = R Wave length = L velocity = V T = time of period

L = 2 pi R R = L/2pi V= L/T T = 2pi(-R/g)$^{\frac{1}{2}}$ $T^2 = 4\pi^2\left(\frac{L}{2\pi g}\right) = \frac{2\pi L}{g}$ $\frac{2a}{T^2} = \frac{ag}{L}$

By substitution V= 2piR/2pi(R/g)$^{\frac{1}{2}}$ or (gR)$^{\frac{1}{2}}$ Complexity of real waves $V^2 = \frac{gL}{2\pi}$

Energy = sum of KE both vertical and horizontal V in either direction is component

of velocity around circle(sin or cos depending on direction) + pot. energy

Since KE = $\frac{1}{2}mV^2$ and energy is obtained by integrtion of both hor. and vert.

velocities we obtain E = unit weihgt of water . wave length . wave heigth^2 / 8 E = wLh^2/16 each

Total KE + PT

1952 P roblem of fetch. Empirical formula takes no account of duration of wind
h= 1.3 fetch$^{\frac{1}{2}}$ (stat. miles) Limit of extent of winds.

1953 Depth of wave work or wave base. Is there a real limit considering currents?

Waves in shallow water. Deflection by refraction. Friction on bottom
Breaking of waves – undertow Rip currents to 2 m.p.h.
Other waves
Constancy of wave action compared to other forces
Efficiency of waves in moving debris. Loss of weight-horizontal movement
methods of erosion, cavitation, pressure, moving debris

Currents. Alongshore component. Compare deep water wave with breakers.
Tides, true wind currents, density currents floating of fresh water on salt.
temperature, rip currents

1953 details (gross vs delicate form)

1951 Wave erosion. Limit of work vertically. Caves, stacks, cliffs, hanging valleys
boulder lines. terraces, profile of equilibrium

$V^2 = gR$ $R = \frac{L}{2\pi}$

$V^2 = \frac{gL}{2\pi}$

$V^2 = \frac{gL}{2\pi}$

yehle 89

$\frac{w}{2g}\int \frac{gL}{2\pi}$

63-66

Subaqueousridges   origin, distribution

1954

alongshore transportation. breakers vs alongshore current
depositional changes of shore outline. spits, hooks, tombolos
offshore barriers   cuspate points

1952 1951

Classification of shore lines. submerged emerged   late movements of sea
1951 Shepards classification   primary or due to formation of the land
secondary or due to work of the sea and its organisms
1953 Cycle of development of shorelines   recession of barriers?
endpoint of the cycle
Pleistocene terraces of the Atlantic coast. discrimination from stream forms
cause of present level. glacial control theory

66-68   see AAPG 34: 203

Coral reef problem
- Controls
  - nature of water-temperature Depth
  - other organisms
  - Low level of Pleistocene seas- presence of ice, cooling
  - Causes of shoals volcanic, tectonic
  - Emerged reefs
  - Submerged reefs
  - Growth of reef mainly on outside
  - No evidence that lagoons due to solution
- Distribution known volcanic cores true atolls
- Theories
  - Subsiding basement
  - Rising basement - stationary basement
  - Glacial control
    - Tests by boring, by emerged reefs   by depth of lagoons
      - Bikini boring Science 107: 51-55, 1948 Emerald...

Recent; calcareous ss and reef limestone	75	75
Pleis. poorly cemented white ls, moulds only		
Tertiary	350	425
Limestone, soft, white and tan sand	300	725
Soft, sandy, shallow water fossils	375	1100
Limestone	35	1135
Sand, medium to fine, tan, few fossils	1121	2256

Miocene below 1790 at 6000-13000 hard material with velocity of 17000 ft./sec. Marked velocity break at 800 with gradual increase below to 11,000 ft./sec.

Funafuti hole to 1114 all talus toward bottom recent fossils
N. Borodina hole to 1416 struck a Plio-Pleistocene dolomite at 340 to
soft muds sands, some limestone below passing into Miocene and Oligocene
Great Barrier reef all recent to 732   Volcanics at Bermuda
1953 Borneo reef drilled to 1407 with no age determinations
How could this amount of subsidence be explained? deep flow? cooling? compaction? or ??

1951 X
Other organisms
salt marsh, mangorve, fresh marsh, moat problem, beach levels.

68-70

Submarine canyons

Discovery   surveying methods   echo sounding location methods

Description. Underwater contouring   cross section   slope   tributaries, relation to continental slope, to existing rivers – to drainage areas to deep sea   rough areas between valleys

Hypotheses

(1) Tectonic   relation to enclosed basins?   to structure? to depth of water?

(2) Subaerial valleys

presence of gravel to depth

why the change of level?   tectonic   glacial, local uplift of shelf sliding of valleys into depths, relation to salinity

(3) Submarine origin

1951 density currents-glaciation – sediments outside

mudflows or landslides

springs – Johnson – objection

earthquakes waves

tides

composite – Corsica

New England

amount solids to increase density 2 1/2 %

100 parts wet 1025 = 1000 + x(2.65 – 1.0) = 1000 + 1.65x

$x = \frac{25}{1.65} =$ 15.15 parts/1000 solids or 15,150 ppm wet =

$\frac{265}{165} = 1.6$

15,150 x 1.6 = 24200 ppm dry weight

70-72 work of the wind

contest of wind vs vegetation
difference of wind from water. Loss of weight of particles in each
av. density of air = 1.22×10^{-3} actual viscosity vs kinematic viscosity.
same for water = 10^{-2} air viscosity = 1.7×10^{-4} kin. viscosity is v divided by density for air = $.17 \times 10^{-3} / 1.22 \times 10^{-3}$ = 0.14 which is much above that of water Note error in omission of kinematic vis. on p. 71
Terminal velocity of fall of particles in air. Normal upward component of horizontal velocity is about one fifth
Distinction of sand moved only near surface and in violent winds and dust which may be kept in suspension for long periods and reach high levels. Division at about 0.2 mm diameter = 1/5 vel of 5 m/sec or 11 m/hr
Movement of sand by saltation, impact dislodges grains or moves them on surface= creep Small particles in suspension

1954 Manner of flow of air always turbulent
Horizontal component of velcity retarded by drag on ground. Hor. vel. increases at log of heigth from ground Then plats a straight line on semi-log paper. Straight line extends to 0 at level k which is about 1/30 of surface roughness
1951 Ordinaily force is related to ($\frac{1}{2}$ density . V^2) with air the drag is related to density mult. by "drag vel"^{2} Drag velocity is defined as tangent of slope of the velocity line on semi log paper. Slope measured from vertical.
$V_\#$ = vel diff in cm/sec divided by 5.75 x log heigth difference.
V at any height z = 5.75 $V_\#$ log z/k
$V_\# = (\text{drag}/\text{density})^{\frac{1}{2}}$

Effect of sand movement on velocity gradient. Net effect is to raise the 0 velocity point to level k' This point is not at 0 vel. but is focus of all different velocity lines It is a velocity which is that of beginning of sand movement by impact, the dynamic threshold. Distinguish from fluid threshold where there is only slight movement of sand by air. Water has only the ~~impact~~ fluid threshold
1953 Note Reynolds number should consider ~~dynamic viscosity~~ kinematic viscosity.

Derivation of rate of transport
final vel of grain = u distance of jump = l g = accel gravity, w= vert comp. velocity
drag = quantity (Qs) x u/l or Density x $V_\#^2$

now u/l = g/w hence Qs = d/g .w. $V_\#'^2$ Now if w: $V_\#'$ then Qs = const. $V_\#'^3$

We can reach the same conclusion from relation of power to force P =FV
F: $V_\#'^2$ then P: $V_\#'^3$
To this must be added material moved by creep 15%
Now by the demonstration of Fig. 135 we can substitute $V_z - V_t$ for $V_\#'$ and arrive at rate for net wind velocity at fixed level z Note misprints
Constant d/g = $1.22 \times 10^{-3} / .98 \times 10^3 = 1.25 \times 10^{-6}$

Comparison with water Much less loss of momentum in air. Friction much greater in water No impact displacement of particles in water. Importance of bottom roughness bottom becomes smooth again at 7 $V_\#$ is greater than av. settling velocity

$$V'\# = \frac{(V_z - V_t)}{5.75(\log z - \log k')} = \frac{.174 (V_z - V_t)}{\log(z/k')}$$

since $\frac{.174}{\log(z/k')}$ is a constant $V'\#$ can be sub for $(V_z - V_t)$ at definite level

Suspension begins when $V_{\#}$ is greater than settling velocity /7 which is not same as in water where grains move like part of water when in suspension

Falling velocity proportioneal to grain diameter over a wide range hence a fair approximation is quanity = $V_{\#}^3 / D$

Threshold velocity to grain size Grains must be raised at angle of repose of loose sand

Equate forcce = resistance hence

$V_{t\#}$ = constant x (~~effective weight~~ D/ air density)$^{\frac{1}{2}}$ that is with other things equal $V_{t\#}$ is proportianal to square root of grain diameter D This holds only for grains over 0.25 mm diameter. Constant is 0.1 for such and larger whereas it is 0.2 in water. When Reynolds number $V_{\#}$ D/ kin. viscosity exceeds 3.5 a greater drag is required For D less than 0.2 mm constant increases. Note similar change with water

Cohesion interferes with force needed to start small particles.

Impact threshold = when impact becomes important. Fluid threshold is first start of ~~motion~~. Water has only a fluid threshold

Land forms produced by wind

Erosion

Hollows, pillars, measas, Notable hollows, Big Hollow, Wyo. Qtara Depression

Basin-Range problem

1952

Deposition

Sources of sand in humid regions

Erg of deserts

Humid land dunes- a contest of wind vs vegetation

Beach dunes, foredune form

1953 Wind eroded hollows or blowouts. wind direction

Complex dunes of belt of westerlies

How to tell wind direction by slip face

Arid land dunes

Shadow dunes

Barchane dunes distinguish from blowout dune

Seif or longitudinal dunes. distribution slip face both sides theories

Whalebacks

Sand sheets

Loess

origin, nature land forms like snowdrifts

Work of ice

76-78

Method of approach Glacial geology vs glaciology

Definition of glacier
Origin of ice. analogy to rock alteration
Physics of motion. Coefficient of viscosity. Solid, plastic, fluid
Threshold stress or force. Difficulty of experiment
differences in value of coefficient Critical depth?
Temperature in ice. Polar vs temperate glaciers
1952 Gravity vs extrustion flow. Difficulty of demonstration of latter
continental glacier flow Reversal of relation of depth to velocity
1953

Ice erosion
1954 Grinding vs plucking
Friction = wt. x coefficent of friction "Weight" not simply thickness but resultant of motion and weight
Power = force x velocity Now for viscous flow v : D^2 hence power should be related to cube of depth in fact since viscosity is also affected by depth power increases more rapidly than cube giving a great advantage to thick glaciers
Plucking related to pressure melting and refreezing. Experiments
1 deg C for 2100 meters
power advantage of plucking vs grinding
1953 Plucking replaced by sapping in bergscrund. Effect of normal freezing of meltwater from above.
Evidence of ice erosion by valley glaciers
Cirque, corrie, cwm
Rock basin
195 U cross section or catenary
Fiord with threshold hanging valleys
Roche moutonee Von Engeln
1954 Cycle of mountain glaciation. Examples in field

Depositional forms valley glaciers
Work of glacial meltwater. To work of running water
valleys a cross divides scablands potholes, etc.
Depositional forms
Erosional forms of continental glaciers
1951 Finger Lakes Great Lakes

Depositional forms of continental glaciers
Endmoraines ground moraine drumlins
Work of continental meltwaters To work of running water
Outwash eskers

Work of expanding ice on lake shores In north latitudes
polygons, beaded streams, earth flows mounds cave-in lakes
vegetational evidence of depth to permafrost Melting of permafrost
special section

Maps:
Section - geology
air photos
block diagrams 2 & 1 point perspective

Balchim, W. G. V, and Pye, N. Piedmont profiles in the six arid cycle:
Geol. Assoc. London, Prod. 66: 167-181, 1956

These authors made a trip to southwest U. S. to test the theories. They divide into forms due to erosion and forms due to deposition. Mountain slopes range from 25 deg to vertical. Retreat parallel due to unimpeded removal of products of weathering. Actual slope depends upon jointing which fixes size of blocks. Talus slopes vary from 25 to 45 degrees. Presence or absence depends upon relative rates of weathering and removal. Bahada form arises in piedmont zone along with erosion of canyons above. Fans may reach 20 deg slope but 7 down to 1 deg more common. Fans may be confused with true pedimnet. Material is diStinctive Pedimnet has been confused. They limit it to exposed rock surfaceLeast slopes opposite largest canyons, steeper slopes next mountains between canyons. Rocks must weather into small fragments to make pediments. Veneer of debris very thin where present. Does this surface extend below alluvial deposits below? Tried boring. No luckGrade is uniform Some evidence suggests steepening away from mountains, convex form see Lawson. Surface is rough and not smooth. Stream flood action not determined Alluvial zone outside of pedimnets. Less than 5 degrees Limits pedimnet to depth of cover thin enough for weathering. Combined pedimnet and alluvial zone or peripedimnt make up pediplane. Sudden increase in thickness of cover into a fault trough. Brlow this may have either playa lake deposits or stream terraces. Transverse profiles-mountains are uniform or level Bshada is undulating. Pediment theories vary. Rock fans of Howard and Johnson. Concave according to Davis. They found level profile. Same in peripediment and playas. Piedmont angle is distinctive between gravity controlled slopes of mountains to fine sediment on pedimnet slope Removal must be by sheet or rill transport as fast as weathered material is formed. Not work of lateral erosion. Can be locally present only. Howard. Find that similar rocks with similar climate give same forms but slightly different rocks with same climate or same rocks with different climate make different forms.Limited erosion of rock surface in pediment zone. Excessive weathering may bury piedmont angle. porducing bahadas

References in part

Berkey, C. P., and Morris, F. K., Geology of Mongolia, 1927
Bradley, W. H., Geology of the north flank of the Uninta Mountains: U. S. Geol. Survey Prof. Paper 185: 145-172, 1936
Childs, O. E., Geomorphology of the Little Colorado River,Arizona: G. S. A. B. 59: 353-388, 1948
Gilluly, James, Physiography of the Ajo region, Arizona: G. S. A. B. 48: 323-347, 1937
Glock, W. S., Pe.monitory planations in western Colorado: Pan.-Am. Geol. 57, 29-37, 1932
Lee, W. T., The origin of the debris-covered mesas of Boulder, Colorado: Jour. Geol. 8: 504-511, 1900
Mackin, J. H., Erosional history of the Big Horn Basin: G. S. A., B., 48: 813-893, 1937
Ogilvie, I. H., the high altitude conoplain: Am. Geol. 36: 27-34, 1905
Ray, L. L, and Smith, J. F., Geology of the Moreno valley, New Mexico: G. S. A. b. 52: 177-210, 1941
Sharp, R. P., Geomorphology of the Ruby -East Humboldt range, Nevada: G. S. A., b., 51: 337-371, 1940
Tator, B. A., Piedmont interstream surfaces of the Colorado Springs region: G. S. A B. 63: 255-274, 1952
Tator, B. A., Pediment characteistics and terminaology: A. A Geogr. Annals 42: 295-317, 1952; 43: 47-53, 1953
Tolman, C. F., Erosion and deposition in the southern Arizona bolson region: Jour. Geol. 17: 136-163, 1909
Hack, J T Studies of longitudinal stream profiles in Virginia and Maryland, USGS Prof Paper 294.B 1957

GEOLOGY 109
GEOMORPHOLOGY

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(4)Define: trade wind belt, blot of westerlies, equatorial rain belt, cyclone, polar front, air mass, monsoon, anticyclone, two types of runoff.
(5) Define: weathering, soil, mantle rock, soil profile, caliche, podsol, prairie soil, pedalfer, pedocal, chernozem, laterization, conductivity, solifluction, creep, landslide, residium, liquid, viscosity, porosity, permeability, exfoliation
(6) Discuss results of temperature changes including frost.
(7) Compare control of soil formation by climate and by parent material.
(8) Discuss relative susceptibility of minerals to both mechanical and chemical weathering.
(9) Discuss relative resistance of rocks to both mechanical and chemical weathering.
(10) Compare land forms due to creep to those caused by landslides.
(11) Derive mathematical form of creep slopes.
(12) Discuss exfoliation and resulting land forms.
(13) Discuss solution, including kinds of rocks affected, rate, limit to rate, primary and secondary porosity, circulation of ground water, redeposition.
(14) Discuss topographic effects of solution and cavern formation.
(15) Define: continental shelf, continental slope, gravity, anomaly, isostacy, stress, force, strain, law of square and cube, strength, strain (volumetric and linear), compaction
(16) What two lines of evidence definitely show that material below the continents is lighter than that below ocean basins? Discuss fully.
(17) Show how time required for isostatic readjustment is computed and discuss how this affects the problem.
(18) Discuss types of volcanic activity in relation to nature of ejected materials.
(19) Discuss relation of composition and temperature of lava to viscoity including bearing on resulting land forms.
(20) Discuss relation of composition of volcanic materials to land forms.
(21) What factors control slope of ash cones? of lava domes?
(22) Discuss craters, calderas, volcanic subsidence, volcanic necks, dike ridges, cryptovulcanism.
(23) How is topography due directly to recent earth movement distinguished from forms controlled by erosion of ancient uplifts? Examples?
(24) Discuss craters due to impact, including the Carolina Bay problem.
(25) Define: force, work, power, competence, transportation rate, capacity, hydraulic radius, slope, laminar flow, turbulent flow, shooting flow, slopewash, sheet flood, Mannings formula, formula for laminar flow, formula for mixed flow, mixed flow, cavitation, erodabilty, settling velocity, impact law, suspension, bed load, slatation, Stokes Law, hydraulic lift, Archemedes principle, overland flow
(26) Discuss relation of force need for erosion to that required for transportaion of different sized particles.
(27) Discuss derivation and application of "sixth power law".
(28) Discuss derivation of formulas showing relation of load to velocity of streams including experiments.
(29) Define: effective weight, effective density, bed velocity, critical velocity, meander, meander belt, cutbank, rotational force, bifurcation ratio, cut-off, oxbow, stream density, drainage texture, consequent,

subsequent, superimposed, antecedent, nickpoint, natural levee, ingrown, slip-pff, sweep, floodplain, network, braided, monadnock, pediment, peneplain, tractive force, free-fall velocity, Playfairs Law, cross-grading, kinetic energy

(30) Explain several ways in which the force exerted by a stream on its bed can be computed.

(31) Compare kinetic energy of stream with the with the retarding force exerted by its bed telling how energy is absorbed.

(32) Discuss factors which control the horizontal shape of stream courses including meanders, braided streams, etc.

(33) Discuss factors which control width and cross section of stream channels and the line of maximum transportation.

(34) What factors control the radius of meanders and width of meander belt?

(35) Discusss entrenched meanders (meandering valleys) including cause, size, cut-offs, misfit streams.

(36) Explain attempts to find a mathematical expression for stream profiles.

(37) Discuss cause of effect of rotation of earth on stream courses (do not derive the formula but tell its relation to latitude).

(38) Compare merits of two methods of expressing erosive force of overland flow or slope wash and equation of slopes of constant force.

(39) Discuss the cause, width, and variation of width of the "belt of no erosion" including its effect in considering erosional history.

(4) Define stream order and account for the fact that there is a mathematical law which governs the bifurcation ratio.

(41) Discuss cause of variation in entrance angle of tributary streams.

(42) Explain relation of drainage patterns to geology.

(43) What relation do different kinds of original surface have to history of erosion and resulting land forms?

(44) Discuss processes which widen stream valleys and reduce the level of divides including production of level areas on divides.

(45) Discuss the problem of the endpoint of stream erosion under different climatic controls.

(46) Compare features of peneplains and pediments.

(47) Describe topographic form of stream terraces and explain several conditions which give rise to terraces.

(48) Describe and discuss origin of depositional landforms due to stream work.

(49) How is stream capture brought about and what evidence is needed to prove that it has taken place?

(50) Account for natural bridges in limestone and in other rocks.

(51) Compare merits of different evidences which have been used to discriminate the survival of remnants of erosion surfaces of different ages, including alternative explanations and field examples.

(52) Give several explanations of water and wind gaps, including the theory that the latter record erosion levels or "local peneplains".

(53) Discuss the proper use of peneplain, peneplane, terrace, local peneplain, erosion level, rock terrace, treppen, pediment.

(54) Define: wave of oscillation, wave of translation, wave velocity, fetch, wave heigth, wave period, energy, wave refraction, undertow, alongshore current, breaker, wave base, tide, subaqueous ridge, low and ball, eustatic, hook, barrier, boulder line, spit, bar, tombolo, atoll, barrier reef, fringing reef, glacial control, cuspate foreland, echo sounding.

(55) Discuss mathematical relation of waves to fetch, period, length, heigth, velocity of progress, including both deep and shallow water conditions.

(56) What controls depth to which waves disturbe the bottom? currents?

(57) How do waves erode the shore, transport material offshore and alongshore?

(58) Discuss causes of currents in lakes and sea including their relation to transportation of sediment.

(59) Describe and account for the results of wave erosion and wave deposition.

(60) Discuss the endpoint of wave erosion giving examples and telling how discriminated.

(61) Compare the merits of two or more different systems of classification of shorelines

(62) Discuss the idea of a cycle of shoreline development and its application.

(63) Discuss evidences of changes in amount of water in the oceans and changes in capacity of the ocean basins.

(64) Explain the controversy over formation of coral reefs comparing merits of the several hypotheses.

(65) List the factors which control rate of growth of corals and places where they begin to form reefs.

(66) What other organisms besides corals cause shoreline changes in fresh water, in salt water.

(67) Discuss the problem of discovery and mapping of submarine topography.

(68) Describ e the physical features of submarine valleys or canyons.

(69) Compare the merits of several theories of origin of submarine valleys including the general classification of such hypotheses.

(70) Define: dust, sand, terminal velocity, sand-storm, drag velocity, velocity gradient, dynamic threshold, impact threshold, blow-out, desert pevement, dune, slip-face, foreset, whaleback, barchan, seif dune, longitudinal dune, hammada, sand sheet, erg, loess, catstep, creep, saltation in air.

(71) Discuss difference of behavior of dust and sand in air.

(72) What relation has the velocity gradient of wind to the ground surface?

(73) What effect do gentle winds have on sand distribution? strong winds?

(74) What is effect of sand movement on surface wind?

(75) Derive the law which governs quanity of sand transported in given time by wind of given velocity.

(76) Compare sediment transportaion by air with that by water.

(77) Discuss suspension of debris in air.

(78) Discuss relation of threshold velocity to size of material.

(79) Describe and account for the land forms due to wind erosion.

(80) Discuss the land forms due to wind transportation and deposition in humid climate.

(81) Describe and account for the land forms due to wind transportaion and deposition in an arid climate.

(82) Comare the merits of two explanations of seif or longitudinal dunes.

(83) What evidence proves that loess is transported by wind?

(84) Describe and account for land forms due to loess deposition and to erosion of loess.

(85) Discuss the source and age relations of loess.

(86) Define: glacier, valley glacier, piedmont glacier, continental glacier, gravity flow, extrusion flow, plucking, sapping, till, drift, cirque, hanging valley, rock bais, ice fall, fiord, roche moutonee, terminal moraine, endmoraine, lateral moraine, medial moraine, valley train, scabland, drumlin, esker, crevasse filling, outwash, ground moraine, kettle hole, drift plain, till plain, pitted outwash, pressure melting, ice-push ridge.

(87) Describe formation of glacial ice and methods of flow including statement of formulas for gravity and extrusion flow.

(88) Discuss methods of erosion by valley glaciers including formation of cirques, hanging valleys, roche moutonees, formula for power of glacier.

(89) Distinguish between and account for drowned valleys and fiords.

(90) Describe and account for the depositional land forms of valley glaciers.

(91) Describe and account for the depositional land forms of continental glaciers and associated meltwater.

(92) Discuss and describe land forms due to erosion by continental glaciers.

(93) Compare merits of several different ways of showing land forms on maps, and drawings, or other illustrations.

(94) Discuss methods of drawing profiles (cross sections) and their use in studies of gemorphology.

(95) Explain merits of aerial photographs for studies of geomorphology, their disandvantages and the methods of use.

(96) Explain methods of making block diagrams including their advantages and disadvantages.

(97) How can faults be distinguished in aerial photographs? on maps showing topography?

10 (98) Why are some lines of faulting marked by valleys and others by ridges?

(99) Explain how topography may be used to work out structure of folded rocks.

(100) How do gently inclined sedimentary formations affect topography?

(101) Compare topographic effects of sedimentary strata and lava flows.

(102) Define: dip slope, pitch, anticlinal ridge, synclinal ridge, monoclinal ridge, hogback. flatiron.

(103) Compare merits of more than one theory of origin of even-crested ridges caused by resistant formations.

(104) How do you discriminated between antecedent and superimposed drainage?

(105) Why has the subject of peneplaination been so greatly stressed in many reports?

(106) Discuss basic postulates on which the theory of the cycle of erosion is based including possible variations of these assumptions.

11 (107) To what extent is the idea of the cycle of erosion based on fact and to what extent upon reasoning only?

(108) Compare the development of the cycle of erosion in humid and in arid climates.

(109) Does the cycle concept apply to other processes than running water? Explain fully.

(110) Compare advantages and disadvantages of the quanitative approach to geomorphology.

(111) Explain fully the process of mathematical analysis of slopes.

(112) Compare relative degree of success in application of mathematics to different processes, including what can be done to improve results.

12 (113) Discuss ways in which geomorphology is an aid to geology.

(114) Where can the line be drawn between geology and geomorphology.

(115) Discuss advantages and disadvantages of technical terms.

write on any ~~10~~ 5 (please be brief and to the point) or fewer if examiner requests run 5 more of 4 review

THWAITES

GEOLOGY 109
GEOMORPHOLOGY

Calendar 1954-55

Pages in mimeographed outline. Note supplements issue late. Exams will include these.

Month	Day	Pages / Topic
Sept.	20	Introduction
	22	1-4 Climatic controls
	24	4-7 Materials
	27	7-12 Weathering
	29	12-16
Oct.	1	17-20
	4	21-23 Relief features
	6	23-25 Volcanism
	8	25-27
	11	27-30 Earth Movement
	13	31-32 Running Water
	15	32-34
	18	34-37
	20	37-40
	22	40-41
	25	41-43
	27	Review
	29	Six weeks exam
Nov.	1	43-46
	3	46-49
	5	49-50
	8	50-52
	10	52-54
	12	54-56
	15	56-58
	17	58-61
	19	Review
	22	Midsemester Exam (2 months)
	24	61-63 Standing water
	29	63-66
Dec.	1	66-68
	3	68-70
	6	Review
	8	70-72 Wind
	10	72-75
	13	Review
	15	Exam (2 months)
	17	76-78 Ice
Jan.	3	78-79
	5	79-81
	7	81-82 Techniques
	10	82-84
	12	Air photograph interpretation
	14	Same
	17	Review
	19	Review
	22	<u>Final exam 1:20 P.M.</u>

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(60) Discuss the endpoint of wave erosion giving examples and telling how discriminated.

(61) Compare the merits of two or more different systems of classification of shorelines

(62) Discuss the idea of a cycle of shoreline development and its application.

(63) Discuss evidences of changes in amount of water in the oceans and changes in capacity of the ocean basins.

(64) Explain the controversy over formation of coral reefs comparing merits of the several hypotheses.

(65) List the factors which control rate of growth of corals and places where they begin to form reefs.

(66) What other organisms besides corals cause shoreline changes in fresh water, in salt water.

(67) Discuss the problem of discovery and mapping of submarine topography.

(68) Describ e the physical features of submarine valleys or canyons.

(69) Compare the merits of several theories of origin of submarine valleys including the general classification of such hypotheses.

(70) Define: dust, sand, terminal velocity, sand-storm, drag velocity, velocity gradient, dynamic threshold, impact threshold, blow-out, desert pevement, dune, slip-face, foreset, whaleback, barchan, seif dune, longitudinal dune, hammada, sand sheet, erg, loess, catstep, creep, saltation in air.

(71) Discuss difference of behavior of dust and sand in air.

(72) What relation has the velocity gradient of wind to the ground surface?

(73) What effect do gentle winds have on sand distribution? strong winds?

(74) What is effect of sand movement on surface wind?

(75) Derive the law which governs quanity of sand transported in given time by wind of given velocity.

(76) Compare sediment transportaion by air with that by water.

(77) Discuss suspension of debris in air.

(78) Discuss relation of threshold velocity to size of material.

(79) Describe and account for the land forms due to wind erosion.

(80) Discuss the land forms due to wind transportation and deposition in humid climate.

(81) Describe and account for the land forms due to wind transportaion and deposition in an arid climate.

(82) Comare the merits of two explanations of seif or longitudinal dunes.

(83) What evidence proves that loess is transported by wind?

(84) Describe and account for land forms due to loess deposition and to erosion of loess.

(85) Discuss the source and age relations of loess.

(86) Define: glacier, valley glacier, piedmont glacier, continental glacier, gravity flow, extrusion flow, plucking, sapping, till, drift, cirque, hanging valley, rock bais, ice fall, fiord, roche moutonee, terminal moraine, endmoraine, lateral moraine, medial moraine, valley train, scabland, drumlin, esker, crevasse filling, outwash, ground moraine, kettle hole, drift plain, till plain, pitted outwash, pressure melting, ice-push ridge.

(87) Describe formation of glacial ice and methods of flow including statement of formulas for gravity and extrusion flow.

(88) Discuss methods of erosion by valley glaciers including formation of cirques, hanging valleys, roche moutonees, formula for power of glacier.

(89) Distinguish between and account for drowned valleys and fiords.

(90) Describe and account for the depositional land forms of valley glaciers.

(91) Describe and account for the depositional land forms of continental glaciers and associated meltwater.

(92) Discuss and describe land forms due to erosion by continental glaciers.

(93) Compare merits of several different ways of showing land forms on maps, and drawings, or other illustrations.

(94) Discuss methods of drawing profiles (cross sections) and their use in studies of gemorphology.

(95) Explain merits of aerial photographs, their disandvantages and the methods of use.

(96) Explain methods of making block diagrams including their advantages and disadvantages.

(97) How can faults be distinguished in aerial photographs? on maps showing topography?

(98) Why are some lines of faulting marked by valleys and others by ridges?

(99) Explain how topography may be used to work out structure of folded rocks.

(100) How do gently inclined sedimentary formations affect topography?

(101) Compare topographic effects of sedimentary strata and lava flows.

(102) Define: dip slope, pitch, anticlinal ridge, synclinal ridge, monoclinal ridge, hogback. flatiron.

(103) Compare merits of more than one theory of origin of even-crested ridges caused by resistant formations.

(104) How do you discriminated between antecedent and superimposed drainage?

(105) Why has the subject of peneplaination been so greatly stressed in many reports?

(106) Discuss basic postulates on which the theory of the cycle of erosion is based including possible variations of these assumptions.

(107) To what extent is the idea of the cycle of erosion based on fact and to what extent upon reasoning only?

(108) Compare the development of the cycle of erosion in humid and in arid climates.

(109) Does the cycle concept apply to other processes than running water? Explain fully.

(110) Compare advantages and disadvantages of the quanitative approach to geomorphology.

(111) Explain fully the process of mathematical analysis of slopes.

(112) Compare relative degree of success in application of mathematics to different processes, including what can be done to improve results.

(113) Discuss ways in which geomorphology is an aid to geology.

(114) Where can the line be drawn between geology and geomorphology.

(115) Discuss advantages and disadvantages of technical terms.

Meandering of rivers, based on experiments by J. F. Friedkin at U. S. Waterways Experiment Station, Vicksburg:

The artificial stream used varied from 1 to 5 feet in width, 50 to 150 feet in length, 0.05 to 0.3 feet in depth, and had a discharge up to 0.15 ft^3/sec (second feet). The conclusions were (with a few additions by the writer):

Meandering is due to deflection of the current against a bank locally increasing turbulence and causing caving. Deflection is due to obstacles. No effect of the rotation of the earth was observed. The only requirement for meandering is bank erosion. Amount of material thus made available to the stream is governed by nature of the bank and the angle of attack of the current.

The stream channel is altered in an endeavor to carry off this locally-derived load and thus bring the channel into equilibrium with amount of sediment. Rate of bank erosion is not related directly to rate of downstream sand movement.

Sand is carried across the channel to next bar on the other side downstream, thus trading sediment from one bank to the other. At the bar velocity of current is at a minimum.

Rate of bank erosion is decreased by increase in slope or discharge, by increase in length of the stream, by straightening which reduces the angle of attack, and by shoaling. Thus rapid streams do not meander.

With relatively low velocity of the stream a bend begins to form, which by deflecting the current from side to side causes other bends below which are eroded into the bank. This is like a ball rolling down a trough when deflected to one side. Material thus derived forms bars which cross to the convex points of the other bank where sand is deposited. Thus a stream becomes a series of deeps and bars or crossings. Crossings are eroded at low water.

If the river banks are very easily eroded the channel becomes very wide and shallow thus making a braided stream. Braided streams maintain a relatively steep slope. Long straight reaches of rivers exhibit this character.

Rate of meandering depends upon the materials of the banks as does depth of the channel. Resistant material is associated with deep water and little, if any, meandering (or bank erosion). Slope is least in resistant materials. Scour of the deeper parts of the bed results from either decrease in amount of sediment or increase in velocity. Deposition is due to the converse.

The curves of the meanders are smooth in uniform material; non-uniformity of material causes irregularities.

Meanders migrate steadily downstream in uniform material and never form <u>cutoffs</u> through the narrow necks. Such are the result on non-uniform material slowing up part of one bend.

The radius of curvature of the meanders increases with both slope and discharge; thus only large rivers make large meanders.

Length of bends is directly proportional to discharge and slope, but width of the meandering zone increases with both at less than direct proportion. Length of bends is inverse to angle of attack, but width increases at less than direct ratio; thus the radius of the bends is decreased. The angle of attack varies with velocity of flow.

Sinuosity (length of the stream compared with airline distance down valley) is directly increased by discharge but increases at less than direct ratio to slope.

Width of bends is limited by formation of <u>chutes</u> or short circuits across points (not to be confused with cutoffs).

The three variables, discharge combined with channel form, amount of moving sand, and rate of bank erosion are interrelated. Increase in slope is counteracted by increase in velocity so that a smaller channel with less hydraulic radius is required for the same discharge. Complete balance of these factors is never attained in nature. In the valley of the Mississippi below Cairo, the bank material becomes progressively finer and more resistant downstream. Thus slope decreases downstream along with rate of bank erosion. Meandering stops near New Orleans and depth of the channel increases downstream.

Rate of meandering is slowed in soft material by the wider and shallower stream channels. A natural river has a variable discharge and hence is continually changing the form of its bed.

Introduction: Permafrost or perennially frozen ground is important to land forms in its effect on (a) weathering (b) erosion, (c) ground water circulation, and (d) formation of relief both by the freezing and the melting of ice. Although known for many years attention has been devoted to this problem recently because of its effects on the works of man. Criteria for its recognition from surface indications are, therefore, important. Attention has also been given to the former distribution of permafrost, which has left a record in land forms.

Origin-Sources of heat: The surface of the earth obtains heat by (a) direct solar radiation, (b) conduction from the air, (c) conduction from the interior heat of the globe, and (d) from latent heat set free by condensation of atmospheric moisture. Study of (c) has been based upon known rates of downward increase of temperature in drill holes and mines combined with laboratory determinations of the conductivity of the materials of the crust. It is generally believed that the rate of heat transmission from the interior of the earth is very slow, probably less than 0.2 calories/cm^2/day. Average conductivity for rocks is generally given as about 340 cal/cm^2/day/deg. C., for ice as 457, snow as about 43 and water as 118. In other words, the conductivity of solid ice is much above that of water or rock. Conductivity of mantle rock or permeable materials is greatly affected by the presence of either ice or water, particularly if the latter is moving. The low rate of heat escape from the earth is due to the prevailingly low temperature gradient. Although the conductivity of air is very low, about 1 percent of ice, its specific heat (.237) is relatively high, almost half that of ice (.502). This property makes it possible for warm winds and rain to contribute much heat to the earth by conduction. Direct solar radiation decreases with latitude because of the low angle of the sun's rays to the horizon but although the very long days somewhat compensate for the short northern summer. Direct radiation may contribute several hundred calories to a square centimeter per day. Formation of fog may contribute much heat.

Loss of heat: Heat is lost from the ground by (a) conduction into the air and (b) radiation. Loss of heat is impeded by both snow cover and a mat of vegetation. Both have very low conductivity and serve to keep out heat from the sun. But both are good radiators and promote loss of heat to the air when the ground is the warmer of the two. In the Arctic strong winds keep snow from accumulating to great depths by concentrating it into local drifts, whose summer melting is the source of streams of water. In most northern lands snowfall is not heavy. In order to have freezing of the ground it is necessary first to have moisture present, for dry materials cannot be frozen. Second, the temperature of the ground must be reduced to below the freezing point of water for some considerable time. High winds low air temperature, and good conditions for radiation from the earth all favor deep freezing. Whether or not bare ground freezes more quickly than areas with a matt of frozen mosses is debatable. The depth to which frost extends probably increases at less than direct ratio to the duration of low temperatures. If the summer thaw reaches only to a slight depth, the next winter, which is much longer than the summer, will add frost so that the congealed layer exteds deeper and deeper with time. Ice is a better conductor than dry rock or earth. Permafrost has been reported up to nearly 2000 feet deep. Ice occurs in irregular masses, sheets, wedges, and granules. Wedges narrow downward and may extend 30 feet below the surface. For ground temperature observations see figures 1 and 2, p. 7

Summer thaw: Depth to which thawing occurs in the short Arctic summers depends upon the (a) absorption of radiant heat from the sun, and (b) conductivity of the ground. The matt of tundra vegetation is a good insulator. The impermeability of the permafrost retains much water in the thawed layer. The prevailingly slight rainfall the the Arctic slows down melting. Summer ground conditions are then like those of more southerly latitudes during a dry spring when melting of the frost is very slow due to lack of warm rain.

Technical terms suggested by Bryan (see next section on permafrost)

Pergelisol = permafrost or permanently frozen ground

Mollisol = surface zone thawed in summer, the "active layer"

Intergelisol = transition zone at bottom of mollisol, thawed at times

Tabetisol = unfrozen ground above, within, or below the pergelisol or frozen ground

Congelifraction = frost-splitting of rocks

Congeliturbation = frost action including frost-heaving and mass movement of the active layer or mollisol

Congeliturbate = disturbed material of active layer or mollisol

Cryopedology = science or study of intensive frost action, frozen ground, etc.

Cryoplanation = process of leveling of topography under frozen ground conditions, similar to peneplantion is warmer climate

Pergelisol table = top of pergelisol

Subgelisol = unfrozen ground below the frozen zone

Supragelisol = zone above the pergelisol

Pergelation = process of forming permanently frozen ground at any time.

Refreezing: When colder temperatures return in the fall a new frost layer forms on top of the melted zone. This thickens until it merges with the permafrost below. Locally ground water is trapped between two layers of frost. Fig. 3, p. 7

Distribution of permafrost: Permafrost is widespread in northern North America and in Siberia, as well as on some high mountains. Approaching more mild climates from either the Arctic or from the mountains, the permafrost becomes more and more patchy and shallower. Even in far northerly latitudes there is no permafrost under thick glaciers or adjacent to large rivers and the sea.

Topographic effects: The topgraphic effects of permafrost may be divided into (a) those due directly to the ice and (b) those caused by the thawed or "active" layer of summer. Frost heaving is believed to form hills ("pingos") up to 600 feet across and 230 feet high. These occur chiefly in fine-grained lake sediments. They contain radiating ice veins. Peat mounds with a core of ice do not exceed 25 feet high. One of the most prominent features which is readily seen in air photos, is the polygonal pattern due to melting of the tops of ice wedges. These display trenches up to 2 feet deep. The diameter of the polygons is for the most part only a few feet although a maximum of 600 feet is recorded. The shape varies widely and is rectangular on a slope. The best examples occur in fine-grained sediments and poorly drained areas. On rocky ground they grade into stone nets on flat areas and stone stripes on hillsides. The pattern of polygons is etched into the lower side of ice on ponds until that exceeds half a foot in thickness. In the centers the polygonal areas may be either depressed and covered with a mixture of ice and peat or elevated forming low mounds. This second condition is thought to be an older stage of development. When small streams form on an area of cracks they are angular in course interrupted by small pools due to ice melting in the centers of the polygons ("beaded streams"). The form of the cracks is thought to be similar to the contraction which formed columnar basalt or mudcracks. However, it is much larger units. The thawed or active layer is equivalent mechanically to thin mantle rock overlying impermeable massive bed rock. The confining of ground water to such a thin zone makes for extensive mass movement with folding, contortion, and considerable chemical weathering due to the abundant organic acids and high mineralization. Some regard the abundant silt of Alaska as a product of this weathering. Results of soil flow are also visible in leaning trees ("drunken forest"), and lobate waves on hillsides. The minimum slope showing them is above 5 degrees. Final result should be rounded convex hills covered by a mantle of frost-weathered rocks. Final production of a "peneplain" is problematical. Where thawing is deeper or complete "thermokarst" topography with sinkholes, dry valleys, cracks, and depressed areas is very prominent. "Cave-in lakes" are abundant in some areas underlain by silt and their outline in altered by wave work. South-facing slopes and the margins of sandy terraces show little frozen ground. Since most water comes from the south-facing slopes valleys are asymmetric. The sides of terraces next to the hills are eroded producing a slant down toward the margin of each terrace. Vegetation gives a clue to the depth to frost. Black spruce and tamarack may indicate as little as 2 feet, paper birch from 3 to 8 feet, poplar and balsam over 6 feet, willow and aspen 10 feet or more, white spruce 1 foot for each 10 feet of height. Much of the permafrost melts once the vegetation is removed suggesting it is a survival of past climate. See figure 3, p. 7

Past permafrost: Where the permafrost has melted completely along the south margins of the present areas and on the lower slopes of mountains some evidence of its former presence is left. Although the trenches may be filled with silt, sand, or gravel a cross section will display them. Some geologists have suggested that certain soil mounds, such as the Mima mounds of the outwash plains of the Puget Sound region, are relics of permafrost. In the Matanuska Valley of Alaska irregular hummocks are left when the frost melts as a result of cultivation of the ground.

Caution in interpretation of melted permafrost: Despite the fact that climate has indubitably changed in much of the world, certain cautions are necessary in the search for former permafrost phenomena. Many have assumed that of necessity the "periglacial" climate was much colder near to the margins of the continental glaciers than it now is. Granting that air drainage from the high continental ice caps might bring about many periods of cold winds, it is fair to recall that due to the large amount of heat needed to melt ice glaciers could (and still do) terminate in climates where growth is impossible. Moreover, descending winds are warmed by compression. To melt a glacier must require a warmer climate than required for permafrost. Such a conclusion may, however, apply only to the conditions which led to the final melting of a glacier, not to the climate during its growth. However, climate favorable to heavy snowfall is unfavorable to production of permafrost. Let us also recall that much mass movement perhaps forming cracks as well as folds of glacial drift undoubtedly took place because of the high water content when first deposited. Besides, mass movement of mantle rock undoubtedly takes place without the aid of underlying impermeable permafrost. Relics of ice wedges may also be confused with weathering along the courses of former tree roots, or cracks due to mass movement of mantle rock. Certainly neither all masses of crept material nor talus deposits demand the former presence of permafrost. The "stone rivers" around Baraboo, Wisconsin, are the result of present-day erosion by water from melting snow removing the finer material from the residual mantle above the impermeable quartzite. A few, which are higher in the center than at the margins, might, however, be true "rock glaciers". But when we find that the snow now lasts longer among the rocks than elsewhere does this idea demand a much different climate? Possibly the mantle of rocks and clay might have crept more rapidly when the climate was wetter than now, but the impervious quartzite bed rock could have taken the place of frozen ground. The hypothesis of permafrost origin of the mounds in Washington does not fit well with either the marine climate of today or their localization on well-drained sand and gravel outwash. Somewhat similar mounds in Oklahoma and other southern states have been explained by the hypothesis of former drying rather than of permafrost. Supposed "convulutions" in the surface of outwash plains in Illinois might be due to ground water work during soil formation. Some found in sand and gravel in northeastern Wisconsin are almost certainly due to shove by a glacier which left so little till that the soil-making processes have rendered it now unrecognizable. The "mottled ground" of the same region occurs in red glacial till which appears to overlie older end-moraines. The mottling is due to small knolls and ridges which show out in the air photography because the high spots photograph a lighter tone than do the damper hollows. It is probably a phenomenon of compaction of an irregular thickness of red glacial till with a high content of silt and clay. We must keep in mind the fact that the condition, which in permafrost regions lasts all summer, occurs almost every spring in lower latitudes and that in certain snowless winters frost penetrates to considerable depths.

See p. 2 for key to technical terms suggested by Bryan.

Nikiforoff, Constantin, The perpetually frozen subsoil of Siberia: Soil Science 26: 61-78, 1928

Bryan, Kirk, Glacial climate in non-glaciated regions: Am. Jour. Sci. 216: 162-164, 1928

Taber, Stephen, Mechanics of frost heaving: Jour. Geol. 38: 303-317, 1930

Porsild, A. E., Earth mounds in unglaciated arctic northwestern America: Geogr. Rev. 28: 46-58, 1938

Cressey, G. B., Frozen ground in Siberia: Jour. Geol. 47: 472-488, 1939

Sharp, R. P., Ground-ice mounds in tundra: Geogr. Rev. 32: 417-423, 1942

Rockie, W. A., Pitting in Alaskan farm lands: A new erosion problem: Geogr. Rev. 32: 128-134, 1942

Sharp, R. P., Periglacial involutions in northeastern Illinois: Jour. Geol. 50: 113-133, 1942

Taber, Stephen, Perennially frozen ground in Alaska: its origin and history: Geol. Soc. Am. Bull. 54: 1433-1548, 1943

Bryan, Kirk, Cryopedology, the study of frozen ground and intensive frost-action with suggestions on nomenclature: Am. Jour. Sci. 244: 622-642, 1946

Conrad, V., Polygon nets and their physical development: Am. Jour. Sci. 244: 277-296, 1946

Cabot, E. C., The northern Alaskan coastal plain interpreted from aerial photographs: Geogr. Rev. 37: 639-648, 1947

Muller, E. R., Permafrost or perenially frozen ground and related engineering problems, 1947

Wallace, R. E., Cave-in lakes in the Nabesna, Chisana, and Tanana river valleys, eastern Alaska: Jour. Geol. 56: 171-181, 1948

Black, R. F., and Barksdale, W. L., Oriented lakes of northern Alaska: Jour. Geol. 57: 105-118, 1949

Bryan, Kirk, The geological implications of cryopedology; Jour. Geol. 57: 101-104, 1949

Hopkins, D. M., Thaw lakes and thaw sinks in the Imuruk Lake area, Seward Peninsula; Jour. Geol. 57: 119-131, 1949

Krinitsky, E. L., Origin of pimple mounds: Am. Jour. Sci., 247: 706-714, 1949

Smith, H. T. U., Periglacial features in the Driftless Area of southern Wisconsin: Jour. Geol. 57: 196-215, 1949

Peltier, L. C., The geographic cycle in periglacial regions as it is related to climatic geomorphology: Ann. Assoc. Am. Geogr. 40: 214-236, 1950

Black, R. F., Permafrost: Smithsonian Inst. Rept. 1950: 273-301, 1951
also in Trask, P. D., Applied sedimentation, 247-275, 1950

Horberg, Leland, Intersecting minor ridges and periglacial features in the Lake Agassiz basin, North Dakota: Jour. Geol. 59: 1-18, 1951

Sager, R. C., Aerial analysis of permanently frozen ground: Photogrammetric Engineering 17: 551-571, 1951

Yardley, D. H., Frost-thrusting in the northwest territories: Jour. Geol. 59: 65-69, 1951

Newcomb, R. C., Origin of the Mima mounds, Thurston County region, Washington: Jour. Geol. 60: 461-472, 1952

Jennes, J. L., Erosive forces in the physiography of western Arctic Canada: Geogr. Rev. 42: 238-252, 1952

Knechtel, M. M., Pimpled plains of eastern Oklahoma: Geol. Soc. Am. Bull. 63: 689-700, 1952

Nikiforoff, C. C., Origin of microrelief in the Lake Agassiz basin: Jour. Geol. 60: 99-103, 1952

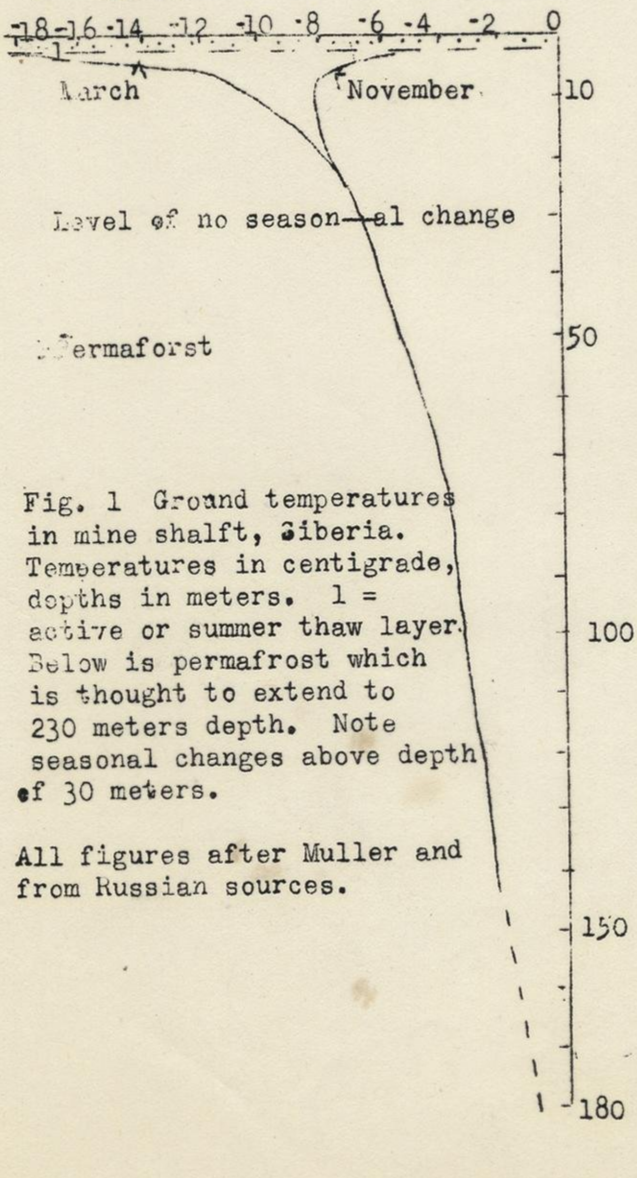
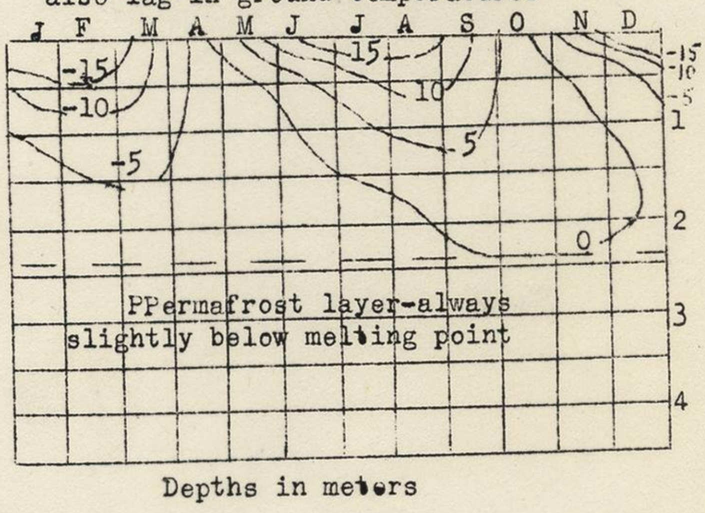


Fig. 1 Ground temperatures in mine shalft, Siberia. Temperatures in centigrade, depths in meters. 1 = active or summer thaw layer. Below is permafrost which is thought to extend to 230 meters depth. Note seasonal changes above depth of 30 meters.

All figures after Muller and from Russian sources.

Fig. 2 (below)
Seasonal temperatures of ground, Siberia. Months shown by initials. Temperatures in Centigrade. Note that melting temperature reaches top of permafrost for two months, also lag in ground temperatures



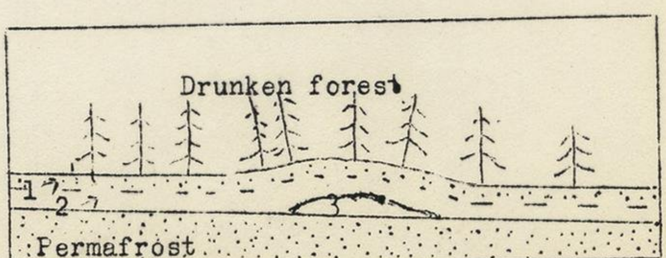


Fig. 3 Origin of pingo. 1= refrozen layer 2= water-bearing (artesian) layer 3= intrusion of water which later freezes and breaks through to surface in crack.

Carolina Bay Problem, 1952

The Carolina Bays ~~may~~ have been ~~due~~ either ~~to~~ purely terrestrial forces such as waves, currents of air or water, ~~or~~ to solution by ground water, or ~~to~~ meteoric impact. Modern coverage with air photography demonstrates many things which were previously unknown or ~~simply~~ surmised.

Facts. (1) Typical "bays" occur only in the Coastal Plain and are absent in the adjacent sea bottom and Piedmont. (2) Bays occur from Florida to New Jersey but are most abundant in the Carolinas. (3) The total number of well-formed elliptical bays is estimated at about a half million. (4) The ~~typical form~~ rounded outline is ~~more or~~ less ~~altered~~ irregular in regions ~~of~~ underlain by limestone (5) Most bays have a unstratified sand rim which is best developed around the south east end. (6) Orientation of long axes of bays varies only slightly and changes are gradual between different regions. (7) Many bays overlap one another or have more than one rim. (8) Most bays are filled with peat which is thickest (15 to 30 feet) toward the SE end; the peat is underlain by lake silt. (9) Only a few springs occur in bays. (10) Bays are equally well developed in all regions suggesting the same age. (11) No similar basins occur anywhere in the world.

~~Johnson's theory~~. The theory of Douglas Johnson ~~lays~~ primary emphasis on solution. But there is no relation between bays distribution and ~~underlying~~ ground water ~~solution~~ circulation ~~and~~ presence of ~~either~~ permeable or soluble rocks. The lack of any relation to a joint pattern is evident. There is no relation of bays to rock structure and no noticable difference of bay ~~age~~ in differt localities. The theory appears to exaggerate both the actual amount fo rising ground water and its ability to dissolve material. The superimposed theory of wind and wave action in sinkholes to explain the sand rims fails to take into account the rim distribution which does not agree with the known direction of winds. The impostance of ~~windx~~ water surrents in relatively small and shallow lakes also seems decidedly exaggerated. Compared ~~with~~ the slight amount of such work in most lakes of glacial origin. Overlap of one bay on another is also hard to explain by Johnson's theory.

The ~~idea~~ that the springs were submarine and were frequented by great shoals of fish which swam around in circles (~~Grant~~) seems entirely too far-fethed. One ~~is~~ bay is 7 miles long. Besides it would not account for the sand rims.

Prouty's revised meteoritic hypothesis is based mainly upon the shock wave or cone which occurs with bodies moving through the air at supersonic speed. Impact of a vast shower of meteorites ~~that is~~ (a comet) would thus account for the formation of so many elongated craters in the sand of the Coastal Plain and not in adjacent firmer material. Many meteorites have been discovered in the Piedmont to the northwest. This idea also explains the striking perfection of outline, the marked parallel orientation, the overlaps, and the sand rims. Two checks have been presented. First the shapes of the bays agree with small craters formed in fine sand overlying clay by high-velocity rifle bullets fired at an angle of 30 to 35 degrees to the surface. Second, magnetometer work has disclosed many local "highs" nearly south and distant from the rim by about the length of the short axis of the bay adjacent. ~~Such~~ Magnetic work is confused by linear magnetic highs due to basement rocks, by the great number of bays in some districts, and the difficulty ~~of~~ making readings in swamps where the ground is unstable. The highs do not check the idea of redeposition of iron oxide ~~associated with~~ solution of the bay, either in strength or position. Limonite is not strongly magnetic. ~~Further checks.~~ Presence of meteoric material causing magnetic highs can only be established by test drilling. A survey by air-borne magnetometer might also be of value.

References (see book by Douglas Johnson)

McCampbell, JC, A geomagnetic survey of some Bladen County, North Carolina, "Carolina Bays" Jour. Geol. 53: 66-67. 1945

Grant, Chapman, A biological explaination of the Carolina Bays: Scientific Monthly 61: 443-450, 1945

Melton, F. A., The Carolina Bays: Jour. Geol. 58: 128-134, 1950

Schreiver, William, On the origin of the Carolina Bays: Am. Geophy. Union Trans, 32: 87-95, 1951

Prouty, W. F., Carolina Bays and their origin: Geol. Soc. Am. Bull. 63: 167-224, 1952

~~Carolina Bay problem~~

~~Based on~~ Prouty, W. F., Carolina Bays and their origin: Geol. Soc. Am. Bull. 63: 167-224, 1952

Defines "Bay" as an elliptical depressed area with a sand rim.

~~Distribution Most abundant in Carolinas, less so north to New Jersey, and south to Florida~~

Theories: Toumey: springs Glenn: blocking of bays by sand bars or depressions enclosed by gigantic sand ripples. Melton: meteoric scars or possibly submarine scour. Cooke: ~~due to~~ southeast winds altering lagoons by elliptical currents; later concluded ~~held that~~ gyroscopic action due to rotation of earth set up such currents. Johnson: solution with wind-built margins Lobeck: solution aided by currents and wind. Johnson in book: artesian spring solution plus lake currents plus wind work Raisz: wind work especially from glacier ~~Glxxxx~~ Grant: shoals of fish around submarine fresh water springs.

Facts: Bays occur only in Coastal Plain Distribution and size both very irregular. No relation to geologic formations. Bays become less numerous to both SW and NE (New Jersey to Florida) Total number estimated at about half a million. Direction of long axes varies slightly and gradually between extremities of area. Most sand rims ~~mainly~~ highest at SE end of ~~ea~~ each bay. Rimmed depressions many times larger than the projectile have been made by firing a high-velocity bullet into light powder resing on clay and are ascribed to the shock wave in air. No similar bays are known anywhere else in the world. Overlapping bays differ slightly in age. Many bays have more than one rim. Bay form is modified in areas of soluble rock Shell beds of normal shallow deposits absent where canal cuts bays. Almost every bays has a well-defined magnetic high a little E of S of SE end. Magnetic highs of liner shape ~~type~~ are different in origin and affect readings. Sand of rims is unstratified. No meteoric material has been found in the region of bays. Most bays are younger than nearby beach ridges. Only a few bays have fresh-water springs mainly near SE end. Peat in Bays is 15 to 30 feet thick (deepest in SE parts). Silt is found below peat.

The peat rests upon silt and contins evidence of burning in the upper part. It is the filling of a lake and not of a subsiding sinkhole. Drying of the swamps is explicable by lowering of water table through stream erosion. All bays appear to be of the same age, late Pleistocene.

objections to solution theory: solution is much more widespread than bays. Bays are not wall best developed in limestone areas. There is no relation of bays to level of ground whereas solution should be most in elevation regions. There is no relation of shape of bays to any joint pattern as there is in the solution lakes of Florida. The sand rims of bays are not present around sinkholes. Overlap of bays is hit or miss following no definite pattern. The advocates of solution regard the magnetic k highs as due to deposition of dissolved iron oxide. Bays have no relation to slope of land and opportunity for escape of ground waters. There is no relation of long axes of bays to the regional dip of strata/or to probable direction of ground water motion. Quanity of ground water seems to have been exaggerated and there are no adequate erosion channels for its outflow. The position of the sand rims is not in harmony with the known southwest winds. There is no suggestion of a northwest migration of springs up dip. Overlapping bays do not agree with spring origin. Distribution of bys is not related to known ground water conditions.

Objections to fish theory: No similar phenomena are known elsewhere.
fresh
Cold water would rise to the surface of salt. Orientation of bays is entirely too regular. The idea that fish face the prevailing wind is unporved. SSand rims should not occur as they do. Age of bays should be different at different levels. Bays up to 7 miles long are too large.

Prouty revised the orignal meteoric theory to now include the air shock wave explaining effect of combined shock wave and earth rotation on tandem meteorites. The shock wave is really a compression cone.

Revised meteoric hypothesis explains: limited distribution of bays, similarity of age of all bays, formation of one bay inside another. Best rim at southeast end.

Associated magnetic highs at SE ends; Most abundant meteorites in clay soil of Piedmont to the N.W.; Position of deepest parts of bays toward SE ends; Lack of any relation to character of bed rock; Similarity of oreientation; Overlapping bays; great size of bays; Deep water deposits in bottoms of bays.

Magnetometer surveys. Magnetic work is complicated by presence of some linear highs probably related to the basement rock; It is Difficult to find areas of scattered a bys in dry land; Cannot make readings in swamps on account of unstable peat; Most highs are nearly south SE ends about length of short axis of the bay; Splitting of meteorites and weathering must be considered; Shapes of bays check well with experiments with bullets fired into loose material at angles of 30 to 35 deg.; Bays confined to Coastal Plain because conditions for crater formation and preservation are best there; Agreement with magnetometer surveys is good.

Impact - Structure

3 Schriever, Wm. On the origin of the Carolina Bays

A G U T1, 32, 87-95, 1951

supports his meteoric hypothesis

1 Grant, Chapman, a biological explanation of the Carolina Bays

Sci. Mo. 61: 443-450, 1945

Jakosky J.J, Wilson, CH and Daly, J W Geophysical examination of Meteor Crater, Arizona - Geophy. Prospecting. Am Inst Min. Engr, Trans, - 63-98, 1932. Shows good sections - some doubt of results

Watson, Fletcher, Jr. Meteor craters. Pop. Astronomy 44: 1-16, 1936

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GEOLOGY 109
GEOMORPHOLOGY

Submarine canyon problem, cont. 1952 Supplement III, 1953, p.1

Introduction. Since the supplement on the problem of submarine canyons appeared some important papers have been published and it is desirable to add some material which was omitted previously. Progress has been mainly along two lines: (a) suggestions that canyons are of more than one origin, and (b) tracing of canyons into the deeper parts of the ocean.

Hypotheses. Kuenen has suggested that submarine canyons may be divided into two great classes: (a) true drowned valleys, the Corsican type, and (b) troughs due to density currents, the New England type. In addition, it is recognized that drowned valleys may have been clogged with marine sediment and then reexcavated and/or extended by density currents. This history can be regarded as in a way a transition between the two major divisions. The author presents charts which show the difference between the submarine extensions of land valleys on coasts where there has been relatively recent orogeny. Although theoretically the drowned valleys should terminate in submerged deltas that fact is hard to prove and it is possible that slides and density currents may have obliterated or altered them beyond recognition, as suggested by Shepard. Shepard also suggested that the continental shelf between valleys may have been built up with sediments during the time that the valleys were kept open by slides and density currents. We must not loose sight of the strong probability that there are tectonic depressions on the continental shelf in regions of mountain building. And last we must always give due weight to the "personal equation" in the drawing of submarine contours, as well as to the limitations of acoustic sounding.

New England type of canyons. Kuenen lists major characteristis of canyons of the New England type which cannot possibly be regarded as the submerged extensions of land valleys. In brief these are: (a) V-cross section with sides sloping at about 22%; (b) course is straight down the continental slope, (c) Locally the course is different inside the break in slope, (d) widely rounded curves, (e) continuous seaward slope of bottom, (f) steepest grades are near head and decrease outward, (g) with rare exceptions there is no break in slope at the continental terrace, (h) no abrupt falls are known, (i) tributaries are accordant, (j) all canyons extend clear down the continental slope and some have been traced far to sea, (k) the canyons are not connected with submerged river channels on the continental shelf. In considering origin of these canyons Kuenen rejects Shepards idea of builind up of the continental shelf bewtween canyons because there is no change in side slope to indicate a difference in sediment. He thinks a very great amount of deepening by submarine currents would be needed to eliminate such a feature. Orign by density currents is therfore concluded.

Proof of density currents. As previously noted in the former supplement one of the weakest points of the density current hypothesis originallly proposed by Daly is that it is extremely difficult to find such penomna actually at work. Daly concluded that their activity is a thing of the past and that low glacial sea levels furnished much more sediment to flow down the continental slope than is now the case. It is well to note that this is entirely in line with recent theories of the origin of the continetal shelf which shows indubitable evidence of a lower sea level. It is suggested that the observed density currents in freshwater lakes and reseroirs are not a fair comparison because of the gentle grades and the presence of concurrent sedimentation from water which in the case of glacial meltwaters, floated on top of the lake by reason of temperature difference. The channels on deltas are more of the levee type and are not true canyons. Sliding may also have taken place, as on the delta of the Mississippi.

The Grand Banks earthquake. It is to phenomena which followed upon the earthquake on the Grand Banks of Newfoundland in 1929 that advocates of density currently mainly turn for evidence. The quake occured on 18 Nov. 1932 at 2032 hours G.C.T. Instantly six cables near to it broke but for 13 hours 17 minutes thereafter there was an orderly sequence of breaks of other cables at progressively great distances from the epicenter. Computation then enables The velocity of the force which brought about these delayed breaks can easily be computed and compared with the known slope of the ocean bottom. The affected area broadened with distance and the velocity decreased from 63 miles per hour to about 14 miles per hour at a distance of about 300 miles from the first break. Every cable broke in two places and the space between these breaks increased with the elapse of time. The cable within the between the two breaks was in all cases either buried or carried away so far that it could not be recovered. Although most geologists at first considered the cause of breaking to be faulting opinion has now changed to the transformation of a landslide to a turbidity current. In this connection we may note that the breaking strength of a new submarine cable is 12 ordinary tons and its wight under water is about 1.3 tons per mile. The necessity of assuming more powerful force than lack of support due to erosion is evident. In making repairs to the cables "sharp sand and small pebbles " were dredged up in about 16800 feet of water. Kuenen showed that with existing formulas the size of and velocity of the inferred density current are credible.

Midocean canyons. A recent publication by Ewing and his associates gives much more data on canyons in deep water than was available only a few years ago. They state "In recent years exploration has revealed that the canyons do not end at the base of the continental slope but continue across the continental rise to the abyssal plains of the ocean floor. Studies of the sediments from the floors, walls and seaward extremities of these canyons---- have proved that powerful turbidity currents have repeatedly carried large volumes of sediment through the canyons and deposited them in well-sorted beds on the abyssal plains" One of the canyons has been definitely traced for nearly 1400 land miles and it may extend for more than 2800 miles. ~~Sharp~~ steep sides and flat floors are indicated by the cross sections with a depth below the adjacent ocean bottom of ~~600~~ 60 to ~~60~~ 600 feet. The longitudinal slope is ~~about~~ from 2.5 to 5 feet per mile. Maximum recorded depth to the bottom of the channel is about 16500 feet. The mid-Atlantic channel crosses the Southeast Newfoundland Ridge in a narrow gap It is not certain that ~~the~~ its end has yet been reached. "In general the cores indicate that the turbidity currents depositing ~~sa~~ sand and silt in the canyon feathered out on the banks. The burial of these sands and silts by over a meter of clay and silty clay would indicate that the last major turbidity current probably occured in Wisconsin time." "Faulting offers no explaination of the sediment relations or the streamlike longitudinal profile so easily explained by turbidity currents." The evidence of these channels ~~with~~ and their asociated sediments seems to present a very ~~much~~ much more formidable case for the reality of turbidity currents than was even dreamed of when the theory was first advanced. Preservation of topographic forms with little alteration in the normally quiet realm of the ocean depths can readily be understood.

References

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Buffington, E. C., Submarine"natural levees": Jour. Geol. 60: 473-479, 1952

Ewing, Maurice and others: Exploration of the northwest Atlantic mid-ocean canyon: Geol. Soc. Am. Bull. 64: 865-868, 1953

Heezen, B. C., and Ewing, Maurice, Turbidity currents and submarine slumps, and the 1929 Grand Banks earthquake: Am. Jour. Sci., 250: 849-873, 1952

Kuenen, P. H., Density currents in connection with the problem of submarine canyons: Geol. Mag. 75: 241-249, 1938

Kuenen, P. H., Estimated size of the Grand Banks turbidity current: Am. Jour. Sci. 250: 874-884, 1952

Kuenen, P. H., Origin and classification of submarine canyons: Geol. Soc. Am. Bull. 64: 1295-1314, 1953

Shepard, F. P., Landslide modifications of submarine valleys: Am. Geophy, Union Trans. 13: 226-230, 1932

Shepard, F. P., Mass movements in submarine canyon heads: Am. Geoph. Union Trans. 32: 405-418, 1951

Stetson, H. C., and Smith, J. F., Behavior of suspension currents and slides on the continental slope: Am. Jour. Sci. 235: 1-13, 1937

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Submarine canyon problem, 1952

Introduction

Since the original text was written there have been several important developments in the submarine canyon problem. First: funds have been available for much more sounding ~~in~~ deep water both for navigation and for ~~purely~~ scientific interest. Sedond; methods of taking cores of unconsoldiated sea-bottom materials have been much improved. Third: movement of water due to the increase of density ~~caused~~ by ~~a content of~~ sediment content have been observed and studied. Fourah: several deep drill holes have been put down on coral islands. ~~Fifth: submarine seismic-refraction surveys have been made over considerable area. The following aims at a general summary of results.~~

Soundings: Recent sounding expeditions, using the acoustic method, have extended some of the submarine canyons scores of miles from where first observed into very deep water. For instance, the Hudson canyon has been traced about 200 miles out to sea and according to newspaper reports a recent voyage demonstrated a system of submerged valleys in the North Atlantic comparable in size to the Mississippi system. These ~~deeper~~ valleys in the ocean bottom are by no means as spectacular as those in the continental slope and are possibly more like channels of rivers on a floodplain in being bordered by ridges ~~natural levees~~ which are larger and more massive than any natural levees on land. Nevertheless, they are distinct channels unquestionably due to some kind of flowing water. Besides the channels many flat-topped submarine mountains (Guyots) have been discovered. There is little regularity in the depth of water above these.

Sediments. The deposits off the Hudson canyon have been most fully described although ~~some~~ scattered cores have been taken over a wide area. On both sides of the Hudson channel there is an extensive sand deposit with some annotated layers of gray calcareous clay. In the channel itself there is gravel ~~occurs~~ with pebbles up to 15 mm diameter. The sand is very well sorted but its otherwise much the same as the sand on the continental shelf. Interbedded with the sand are layers of normal red non-calcareous deep-sea clays. The pebbles can be matched with rocks which outcrop in the steep sides of the canyon.

Opinion seems to now be trending to surf zone erosion of the continental shelf and final deposition of clastic sediments at foot of the continental slope

Density currents. Studies of sedimentation in reservoirs have demonstrated that ~~without doubt~~ the mud-laden water which enters at the head sinks to the bottom and flows along it to the dam. The rate of flow has been measured and seems to fit with a modified form of the formula for turbulent flow in open channels. The Chezy formula ~~need only be~~ has been modified by introducing the excess of density of the water above unity and by changing the constant. Measured velocities in the ~~very~~ low-gradient bed of Lake Mead, in the Colorado River valley, strongly suggest the possibility that similar currents in the steeply-sloping submarine canyons could readily erode the bottom thus adding to their velocity. Trenchs with marginal ridges due to sinking muddy water have long been known in Lake Geneva, Switzerland. ~~These are bordered by ridges like natural levees on land.~~

Evidence of subsidence of ~~sea~~ ocean bottom. In recent years very deep drill holes were put down on several atolls of the southwest Pacific. On Bikini shallow water deposits occur to a depth of over 2500 feet. On Eniwetok volcanic rock is encountered below ~~4500~~ 4100 feet. These tests demonstrate that the ~~sea~~ ocean bottom has actually been subsiding but the age of the lower marine deposits ~~is middle~~ runs back to early Tertiary~~, and not recent~~. Whatever the cause, the change of sea level has been very slow. (see section on coral reefs) The flat-topped peaks found in deep water (3000 to 6000 feet), whose form suggests wave-eroded volcanoes, are in line with this conclusion.

Johnson's theory. Johnsons's suggex conclusion that submarine canyons are due to the recession of fresh water springs emerging from permeable formations of the Coastal Plain is now thoroughly discredited, because, first, its disregard of physical principles and second, the presence of canyons in impermeable rocks. Fresh water would rise directly to the surface and would not make a canyon.

Density current theory. The failure to demonstrate marked density or other currents in existing canyons of the continental slope is explained away by two suggestions. Daly originally proposed that during the moderately lower sea level of glacial times much more sediment was carried over the edge of the continental shelf than is now the case. This suggestion is supported by distribution of coarse sediments out to the margin of the shelf in many localities. On the California coast it has been suggested that alongshore transportation of wave-derived material is blocked at certain headlands. If, in such locations, the slope of the bottom is steep enough, a canyon is eroded by a descending density current. A further suggestion is that earthquakes loosened much sediment causing density currents down previously formed depressions. Under the density current theory no great change of sea level is required for the formation of submarine canyons. The sands and gravels now at great depths were thus transported from nearer the surface and interbedded with normal deep water deposits. Currents which spread out from the major channels deposited adjacent ridges.

Emergence theory. Although the density current idea has gained much support in recent years advocates of great emergence of the lands have not been idle. Landes proposed a theory that, with a periodically shrinking earth, the ocean bottoms of heavy sima should subside first. As a major cause of such sinking he suggested the solidification of basalt magma to solid rock with a very large volume decrease. He thought that the lands of lighter sial would not sink at once but that when they did horizontal compression would result. Such marked contraction is certainly not proved by present knowledge of the physical state of the earth's interior, but, if such a process is possible, no distinct limit could be set on the depth to which the ocean level receeded without loss of water.

Compromise view . Shepard offered a compromise view which is intended to avoid some of the above difficulties. He thought that the shoreward portions of the canyons, down to prehaps only 1000 feet depth, were eroded by streams during continental uplifts, not necessarily all at the same time. This is the only portion which has been examined by diving, photography and detailed sounding. The lower extensions of canyons, which are extremely steep in slope and irregular in grade with few, if any, tributaries, are charageable to density currents. This applies with especial force to the very lowest parts which are not canyons but troughs. There is no definite lower limit to canyons with a series of deltas as there should be were land elevation alone the cause. Some submarine valleys could then lead into enclosed depressions in the ocean bottom. Some canyons might be very old in time of first erosion, then filled with sediments, and later reopened by slides of the soft material. It may be added that some might have originally have been tectonic in origin with only superficial alteration by erosion. Some of the Pacific coast canyons seem to be in part cut into very young sediments. Sedimentation and mass movement of deposits has been observed in the heads of some of these.

Submarine canyons, selected references

Kuenen, P. H., Density currents in connection with the problem of submarine canyons: Geol. Mag. 75: 241-249, 1938

Bell, H. S., Density currents as agents for transporting sediments: Jour. Geol. 50: 512-547, 1942

Daly, R. A., The floor of the ocean, 1942

Sharp, R. P., Mudflow levees: Jour. Geomorph. 5: 222-227, 1942

Hess, H. H., Drowned ancient islands of the Pacific basin: Am. Jour. Sci. 244: 772-791, 1946

Shepard, F. P., Submarine geology, 1948

Emery, K. O., A suggested origin of continental slopes and of submarine canyons: Geol. Mag. ~~62~~ 87: 1 02-104, 1950

Ericson, D. B., Ewing, Maurice, and Heezen, B C., Deep-sea sands and submarine canyons: Geol. Soc. Am. Bull. 62: 961-966, 1951

Dietz, R. S., and Menard, H. W., Origin of aburpt change in slope in continental shelf margin: Am. Assoc. Pet. Geol. B ull. 35: 1994-2016, 1951

Woodford, A. D., Stream gradients and Monterey sea valley: Geol. Soc. Am. Bull. 62: 799-852, 1951

— Society of Econ. Geol, Palenon. Turbidity currents, Spec. Pub. 2, 1951

Tolstoy, I., Submarine topography in the North Atlantic: Geol. Soc. Am. Bull. 62: 441-450, 1951

Buffington, E. C., Submarine "natural levees": Jour. Geol. 60: 473-479, 1952

Ericson, D. B., Ewing, Maurice, and Heezen, B. C., Turbidity currents and sediments in North Atlantic: Am. Assoc. Pet. Geol. 36: 489-511, 1952

Crowell, J. C., Submarine canyons bordering central and southern California: Jour. Geol. 60: 58-63, 1952

Dietz, R.S. Geomorphic evolution of continental terrace (continental shelf and slope): Am. Assoc Pet Geol Bull. 36: 1802-1819, 195–

Landes, K. K., Our shrinking globe: Geol. Soc. Am. Bull. 63: 225-240, 1952

Emery, K. O., and Natland, M. L., Our shrinking globe - a discussion: Geol. Soc. Am. Bull. 63: 1069-1072, 1952

Landes, K. K., Our shrinking globe- a reply: Geol. Soc. Am. Bull 63: 1073-1074, 1952

Shepard, F. P., Composite origin of submarine canyons: Jour. Geol. 60: 84-96, 1952

Dietz, R. S., Geomorphic evolution of continental terrace (contineta1 shelf and slope): Am. Assoc. Pet. Geol. Bull. 36: 1802-1819, 1952

width 10 to 150 m. Outer margin close to 65 fath.

Theories:	Wave-built embankment	DowWarped	continental surface
	Daly, Stetson, Rich	Veatch, Smith	
Faulting	Wave-cutt ing	Sedimenttion causing isostatic subsidence	
Shepard	Shepard	Kuenen	

First involves wave work and currents bottomed at wave base. Last discussed in previous paper. No sharp downward limit except at the breaker zone. Angle of repose of sediments is very low. Most basins and banks show rock. Continental slope varies from 2 deg to 22 deg. Hence slope must be structural. Sea floor movements must prevent steep sedimentary slopes. Evidence of very deep currents. Although turbidity currents have not been proved they are coming to be accepted as only reasonable explaination of sand, gravel, shallow water fossils in deep water. May be slowed by too much mud which increases viscosity.

Cycle of development. Initial stage tectonic, contact of sial and sima.

Youth involves surf action to 5 fath Detritus carried won slope by mass movement plus turbidity currents. Forms concave apron at bottom. Some of turbidity flows may make canyons. Headward sapping of canyons.

Maturity Wider shelf, deeper canyons. Isostatic settling of sediments at foot of slope. Also rise of continent because of erosion. Continued faulting on slope.

Old age. Apron built up to top of slope. Time too long to permit this end point very often. Interrruption by diastorphism

Presents examples of youth in Pacific Atlantic terrace = maturity

Prograding of shoreline when supply of sediment is too much for transport to deep water. This may account for bank of sediments on this coast.

Old age shown in part of Antarctic coast. Gulf terrace shows rejuvination of old age slope by faulting since when gravity movements have altered slope. Have mantled upper part

Shelf break rarely shows sliding of material. Explains as due to Pleistocne lowering of sea level Finds older breaks at different levels. Atlantic coast at

50 and 100 fathoms. Lower one due to former low level plus downwarp.

Antarctica at 230 to 280 fath. Depression by weight of ice?

65 fath level probably Wisconsin age.

Conclusions

Clastics on shelf = hinter surf sediments

Exposed shelves have little sediment with no size relation to distance from shore.

Edge of sediments neither a fault nor foreset beds down continental slope

Subsidence not due to shelf, if present due to deposits at foot of slope.

Wave base is unimportant vut surf zone dominates sedimentation

Deep sea at bottom of slope an important realm for clastics.

Turbidity currents are important

In absence of compression of crust shelf sediments are monoclinal and not synclinal

Dietz, R. S., and Menard, H. W., Origin of abrupt change in slope at continental shelf margin: Am. Assoc. Pet. Geol. Bull, 35: 1994-2016, 1951

Average width of shelf 40 m. Slope typically about 10 ft/m. Typical cont. slope much steeper, say 5 deg., much more irregular. Aburpt change. Avoids any discussion of origin of rock of the shelf. No single name used for the break in skopel Proposes term "shelf-break" New soundings show it is abrupt.

Theories: (1) Sedimentary in equilibrium with present sea level

(2) Sedimnentary related to a lower sea level.

(3) Abrasional in eqilibrium with present sea level.

(4) Abrasional related to a lower sea level.

Idea of wave base or abrupt bottom to wave action. Sedimentary origin laid to Barrell. Abrasional origin charged to Shepard. Hoever, tridal currents might have carried the coarse sediment to margin of shelf.

Concept of wave base found of limited value. Finds currents moving sediment at great depths. No level of negligable motion exists. Turbidity currents produced artifici ally in one of the canyons. Breakers normally form where depth is 1.1 to 1.5 time heigth of wave. This fixes maximum depth of abrasion. Almost all of wave energy expended in surf zone. Shepard showed that there is no gradation of sediments seaward. Many bed rock areas neqr break. No break in ~~Nk~~ Nile delta Depth of break same on ex osed and less shores of islands. Absence of terraces due to sedimentation. No difference between sheltered and exposed coasts

Conclusion. Shelf break related to eustatic change of sea level. Depth is 45 to 80 fathoms. Rise of sea level rapid compared to diastropic movement.

Rise averages 0.33 ft. century but ~~iasally~~ claimed to have has reached 2.0 ft/cent.

Sea lowered 5 to 15 ft since climatic optimum

Emery, K. O., A suggested origin of continental slopes and of submarine,canyons: Geol. Mag. 87: 102-104, 1950

Subaerial erosion best hypothesis but difficuulty in lowering sea level enough. Low declivity of continental slope gnerally 4 to 5 deg. Four possible origins of slope: wave-built platform, step faults, normal fault dipping a low angle to sea, downwarped peneplain. First eliminated by rock and gravel out to margin of shelf. Considers faulting, vanished sources of sediments. Geophysical work has shown downwarped peneplain along Atlantic coast. Bends up near continental slope. Could have carried down canyons.

15 Shepard, F. P., Composite origin of submarine canyons: Jour. Geol. 60: 84-96, 1952

Hypotheses: glacial control of sea level has increased objections.now.

Deeep borings into atolls, shallow water fossils on tops of sea mounts, ~~lackxof~~ no proof change of Mediterranea n to enclosed lake Extension of canyons there below level of sill. No proof of much increased salinity of oceans.

Alternatives: either canyons made below water or they were eroded at varous times and then reopened while below sea level. Idea of turbidity currents of Daly, amplified by Kuenen and Crowell. Last suggests currents alongshore carry debris to a place where velocity is less. If that is favorable for erosion current turns downslope and erodes a canyon. Shepard now revives a formerly abandoned idea of remote age of canyons. Events: slopes of continents elevated at times allowing river erosion. Canyons kept open by landslides combined with turbidity currents where conditions were favorable. Others were filled Some of the filling may still be found on walls of canyons. The deltas formed at mouths of the canyons when sea level was low have disappeared by slump plus turbidity currents. Such submarine erosion make apparent continuations of the real canyons. Unfilled canyons were extended headward during low water stages due to glacial control. Here valleys occur in recent deposits.

Reviews evidence of submergence. Maximum depth of deep steep-walled canyons is about 6000 feet. Cobbles on sea-mounts, shallow water or land deposits to considerable depths below present sea level(6500 ft at C. Hatteras) etc. flat topped-"guyots" of Pacific Shallow valleys known in deltas of glacial lakes. These like lower "canyons"

Agrees with Crowell that velocity of longshore currents is least at canyon heads but thinks it result rather than cause of canyon. Effect of headlands on currents does not agree with canyon location off California. Uplift of only 1000 feet would account for most of the canyons.

(8) ~~6~~ Tolstoy, I Submarine Topography in the North Atlantic: GSAB 62:
441-450, 1951

(5) Hess, H H, Drowned ancient islands of the Pacific basin AJS. 244: 772-791, 1946

~~Landes, KK our shrinking globe GSAB 63: 225-240, 1952~~

(9) ~~8~~ Soc Econ geol, Paleo. Turbidity currents, spec Pub 2, 1951 not in library

(13) ~~9~~ Emery KO and Natland ML. our shrinking globe - a discussion GSAB 63: 1069-1072 - 1952

(14) ~~15~~ Landes, KK our shrinking globe - a reply GSAB 63: 1073-1074, 1952

(12) # Landes, K. K., Our shrinking globe: Geol. Soc. Am. Bull. 63: 225-240, 1952

Earths surface two levels now in isostatic eqilibrium. Ocens floored with basalt, continents lighter. If interior of earth shrinks heavier ocean basins will sink first. This downard movement compresses crustal segments causing mountain formation.

Possible causes of shrinking include downard solidification of liquid coreContraction due to slidification of basalt is 11.5 % Hence thickness of crust of 1820 miles reduced radius of earth 140 m. and circumference 880 m.

Uses this idea to explain submarine canyons and coastal subsidence to great depths. Canyons cut before continents sank to catch up with ocean bottoms. Also uses the idea to explain glacial climates. During Pleistocene three subsidences of at least 5000 ft and one of prehaps 25000 ft.

Causes of contraction: downward solidification, cooling, pressure conversions to greater density or by any other process. Boundary at 1820 miles is chemical but could be physical as well. Escaping heat via volcanoes is originally from atomic decay.

Evidence of changes of level: submarine canyons may reach 15000 ft. Flat tops of submarine mountains up to 9 m. Across in depth of 3000 to 6000 ft. Foundations of many atolls. Ripple marks, gravel in great depths

Full bibliography

Crowell, J. C., Submarine canyons borderign central and southern California: Jour. Geol. 60:58-63, 1952

Review work of previous writers. Davis called them "mock valleys"

Many maps and profiles of valleys or canyons. No striking relation of present streams. Some go to depth of 11,000 ft. Others extend into enclosed basins. End at foot of abrupt slopes. Depth related to submarine topography only. Longitudinal profiles very irregular and extremely steep. Not like profiles of land rivers.

No correlation of nicks in profiles. Transverse sections normal for youthful valleys. Courses winding. Tributaries mainly near head and not as numerous as with land streams. Canyon system as whole is decidedly youthful compared to erosion of shore areas. Rocks similar to those of above-water areas nearby. Some eroded into Pleistocene and Recent deposits. No convincing evidence of a Pleistocene sea level more than 300 ft. below present. Glaciation of nearly mountains does not check with idea of great sea level lowering plus upwarp of continent margins. No record of high salinity

Summary: Canyons have irregular long rpfiles. Have very steep grades Tributaries grouped around heads. Occupy only a very small part of contineal slope.

Many head close to prest ent shoreline despite known recent warping of California coast. Sharp nick in profiles near river mouthsalways at or near present sea level. Graded to many differet levels down to minus 10000 ft. Related to breaks in original slope not to changed sea level. Many have no relation to shore rivers. Heads of many in very young deposits. No proof of warping of contintal borders.

Suggests relation of alongshore transportation of sediment to form of shoreline and underwater slope. Canyons due to present-day processes because of form of shore line necessary. 3 conditions: source of sediment, steep underwater slope, reduction in rate of shore transport. Canyons probably due to erosion by this movement of sediment

Kuenen, P.H. Density currents in connection with the problem of submarine canyons Geol. Mag. 75: 241-249, 1938

Putnam J A Munk W H and Traylor M A The prediction of longshore currents: Am. Geop. U. Trans. 30: 337-345, 1949

(12) # Ericson, D. B., Ewing, Maurice, and Heezen B. C., Turbidity currents and sediments in North Atlantic   Am Assoc Pet. Geol. Bull. 36: 489-511, 1952

Traced Hudson Canyon 200 m out from shelf to depth of 2400 fath. Lost on broad plain which slopes to deeper water. 6000 m^2 of sand called "delta." Layers interbedded with red abyssal clays. Pleistocene fossils in sand. Vertically Grades ito the red clay through calcareous gray clay. Sands better sorted but otherwise exactly similar to those of the shelf. Not due to wind because of pebbles to 15 mm. Too well sorted and widely distributed for glacial origin. (floating ice) Not due to surface streams for such would have to leave the North Atlantic only a series of puddles.(This does not deny glacial lowerings of a few hundred feet). Turdibity currents favored by lowered sea level. Gravel only in stream bed. Deposition related to depth. Interbedding with deep water sediments No evidence of weathering solution of Tertiary sediments found in region near Bermuda in depth of 410 fathoms.

10 Buffington, E. C., Submarine "natural levees": Jour. Geol. 60: 473-479, 1952

Describes a number of such off California coast in up to 3600 ft of water. Compares with ridges left by mudflows but thinks these are result of turbidity currents

2 Bell, H. S. Density currents as agents for transporting sediments: Jour. Geol. 50: 512-547, 1942

3 Daly, R. A. The floor of the ocean, 1942

4 Sharp, R. P., Mudflow levees: Jour. Geomorph. 5: 222-227, 1942

7b Ericson, D. B., Ewing, Maurice, and Heezen, B. C., Deep-sea sands and submarine canyons: Geol. Soc. Am. Bull. 62: 961-966, 1951

Records results of depth survey and bottom coring along the Hudson submarine canyon Covers area of 15,500 km^2 with depths from 2390 fathoms to 2700 fathoms. Canyon traced 280 km. from edge of continental shelf into a submarine "delta on which 30% of sediment is sand with much graded bedding. Some ~~is a~~ gray calcareous clay unlike normal deep-sea deposits. Abrupt change from incoherent sand to normal deep-sea deposit. Sand grains are mostly anglular and composed of quartz. ~~Besides~~ Feldspar, ferro-magnesian minerals, micas, glauconite, etc., particles of red and gray shale, limestone, fine-grained sandstone, and mica schist were found. Resemblance to the shelf deposits near the head of Hudson Canyon is close except for better sorting in the deeper area. Foramnifera are like those of the continental shelf.

Age shown by fossils is post-Wisconsin. Cores outside canyon show recent clay on cold-water clay. Cores from canyon walls have green pyritic clay with midddle Tertiary fossils Cores from canyon floor have sand or gravel with pebbles of older rocks ~~back to~~ Eocene and younger.

Conclusions: Deep sea sands are not wind-transported. Lowered sea level is not proved because of the ~~by~~ presence of normal deep-water sediments outside the delta. Mineral and fossil content of the sands relates them to the shelf sediments. Transportation was through the canyon by turbidity currents. Total sand volume is about 100 km^3. Considerable or all of the erosion of the canyon must have taken place. Other similar submarine "deltas" must occur but are not yet explored. Slumping of material supplied the debris to the turbidity currents which are filling depths of the oceans to a smooth bottom.

(1)

Kuenen, P. H., Density currents in connection with the problem of submarine canyons: Geol. Mag. 75: 241-249, 1938

Reviews Daly's ideas noting great depth to which canyons extend. Daly applied the Chezy formula for velocity modifying it by adding the density of water above 1 (effective density) V^2 = const. hyd. radius. slope. effective density

By using some known velocities for instance in Lake Mead V = 27 cm/sec. he obtains values for the constant which range from 230 to 660 for c.g.s system.

Then applies this to grade of a canyon concluding that erosion by such currents is distinctly possible.

SCIENCE IN REVIEW

System of Canyons Found in Atlantic Ocean Is Vast as Mississippi River and Tributaries

By WALDEMAR KAEMPFFERT

After spending eighty-seven days at sea on the ocean-going tug Kevin Moran, eight scientists associated with Columbia University landed at Hoboken, N. J., last week with important news. The head of the expedition of eight, the distinguished submarine geologist, Dr. W. Maurice Ewing, announced that in the course of the Kevin Morgan's oceanic peregrinations a new ocean canyon had been discovered approximately 1,000 miles east of Boston and midway between Bermuda and the Azores—a canyon which, with its undersea channels, constitutes a system as vast as the Mississippi River and its tributaries.

This undersea canyon is from one to two miles wide and 250 to 300 feet deep. Ewing and his associates followed it for 800 miles and found that it winds sharply to the west for 150 miles toward Virginia and that it lies at a depth of about three miles. Dr. Ewing believes that the canyon is part of a system of great gorges of which two were discovered four years ago in Davis Strait between Greenland and Newfoundland. On previous voyages of exploration Dr. Ewing had noted what seemed to be ditches in mid-ocean. Now he knows that the ditches are really sections of the newly discovered great canyon. His ship had crossed the canyon here and there, which explains why "ditches" were inferred. By proceeding along the line of the canyon its true character was established. It is probable that this new canyon in the Atlantic has a branch which lies in Denmark Strait between Iceland and Greenland. Scattered soundings lead Dr. Ewing to this conclusion.

Submarine canyons began to receive attention back in 1863 when the celebrated American geologist, James Dwight Dana, called attention to one which is a continuation of the Hudson River. Equally well-known are the steep-walled submarine canyons of the Congo and Indus. Three years ago Dr. Ewing traced the Hudson Canyon to a point 225 miles out into the Atlantic.

Grandest of Scenery

The exploration of submarine canyons leaves no doubt that the grandest of all scenery lies under water. We marvel at the Alps and the Rocky Mountains, but there are far more imposing ranges in the oceans. In June and October, 1951, H. M. S. Challenger dropped a weighted wire six miles into the Marianas Trench, about 200 miles south of Guam in the Pacific Ocean. The corrected depth proved to be 5,872 fathoms (35,232 feet, or 6.2 miles). Put into this deep Mt. Everest would be covered by over a mile of water.

Geologists talk of the "continental shelf," a continuation into the Atlantic of the beaches that extend from Nantucket to Cape Hatteras. About seventy-five mile southeast of Atlantic City the shelf plunges sharply to form the "continental slope." Look seaward from the edge of the shelf, assuming that all the water were removed, and you would be thrilled by the sight of deep gorges and rolling hills 10,000 feet below them. Between Cape Hatteras and Georges Bank (200 miles off Cape Cod) there are a dozen canyons grander than those of the Far West. They wind like river valleys; they have branches like those of large rivers; and the floors lie at great depths. There is reason to believe that the level of the sea must once have been lower than it is today.

Whence came the water that later raised the level of the sea? From melting ice caps and glaciers at the Poles. We are living at the end of the last ice age, and the caps at the Poles are all that remains of it. Once upon a time the Arctic cap extended as far as Virginia, and in some places the ice and snow were a mile and more deep. Since much water was converted into the polar ice caps it follows that the Atlantic coast lay farther eastward than it does today. This means that the Hudson Valley extended out into the Atlantic and that for 200 miles or so there must have been dry land where there is now seawater. Soundings prove that this is so.

Geological Changes

Dr. R. A. Daly has suggested that thousands of years ago the sea retreated to approximately 10,000 feet below its present level at two different periods and that during these periods streams cut valleys through the soft sediments of the coastal plains. Dr. Ewing doubts that the level of the sea was lowered more than 300 feet. Still, even this reduction of sea level is of geological consequence. A waterfall of 300 feet—and there were such falls—is something that would account for some erosion of the Hudson Valley after glaciers in the north melted. What erosion means is demonstrated by what has happened at Niagara Falls in the memory of living men. Besides there was glacial ice.

Shipmasters used to assume that if they were 100 miles or so off shore they ran little risk of grounding. Sometimes they were disastrously in error. In 1916 the steamer Bear, misled by soundings obtained in a submarine depression, ran aground two miles north of Cape Mendocino, Calif. The wreck cost the lives of six and of a vessel valued at $1,000,000.

In 1929 there was an earthquake in the Grand Banks off Newfoundland, an earthquake so strong that twelve submarine cables running south on the continental slope from the center of disturbance were broken in twenty-eight places. The breaks did not occur all at once but one after another. Why the cables broke has been a subject of controversy for years. The breaks have made it possible for Dr. Ewing to formulate a new hypothesis of canyon formation.

Formation of Currents

It is Dr. Ewing's conclusion that a severe earthquake on the continental slope starts landslides and slumps. The material of the slides and slumps is mixed with water. In this way thick turbidity currents are formed. These converge into a mighty, swift river that crosses the sea floor. As it swept on, the turbidity current (a veritable river in the ocean) broke one cable after another in 1929—an indication of great erosive power. But not a cable that lay on the continental shelf was disturbed. The slumps on the continental shelf were transformed into turbidity rivers or currents, which deposited sediment far out in the ocean over gentle bottom slopes.

This turbidity current hypothesis of Dr. Ewing's is supported by samples of sediment that he has brought up. The samples show grading of the sediment—what would be expected. The speed of these currents is probably as high as fifty knots at the outset, but at a distance of 400 miles from the slide about twelve knots. But even in a twelve-knot current there is enough energy to destroy miles and miles of cables. So it is not earthquakes that play the most important part in submarine activity, but landslides that become turbidity currents. The earthquakes are merely the triggers that start slides.

Artifical Lung

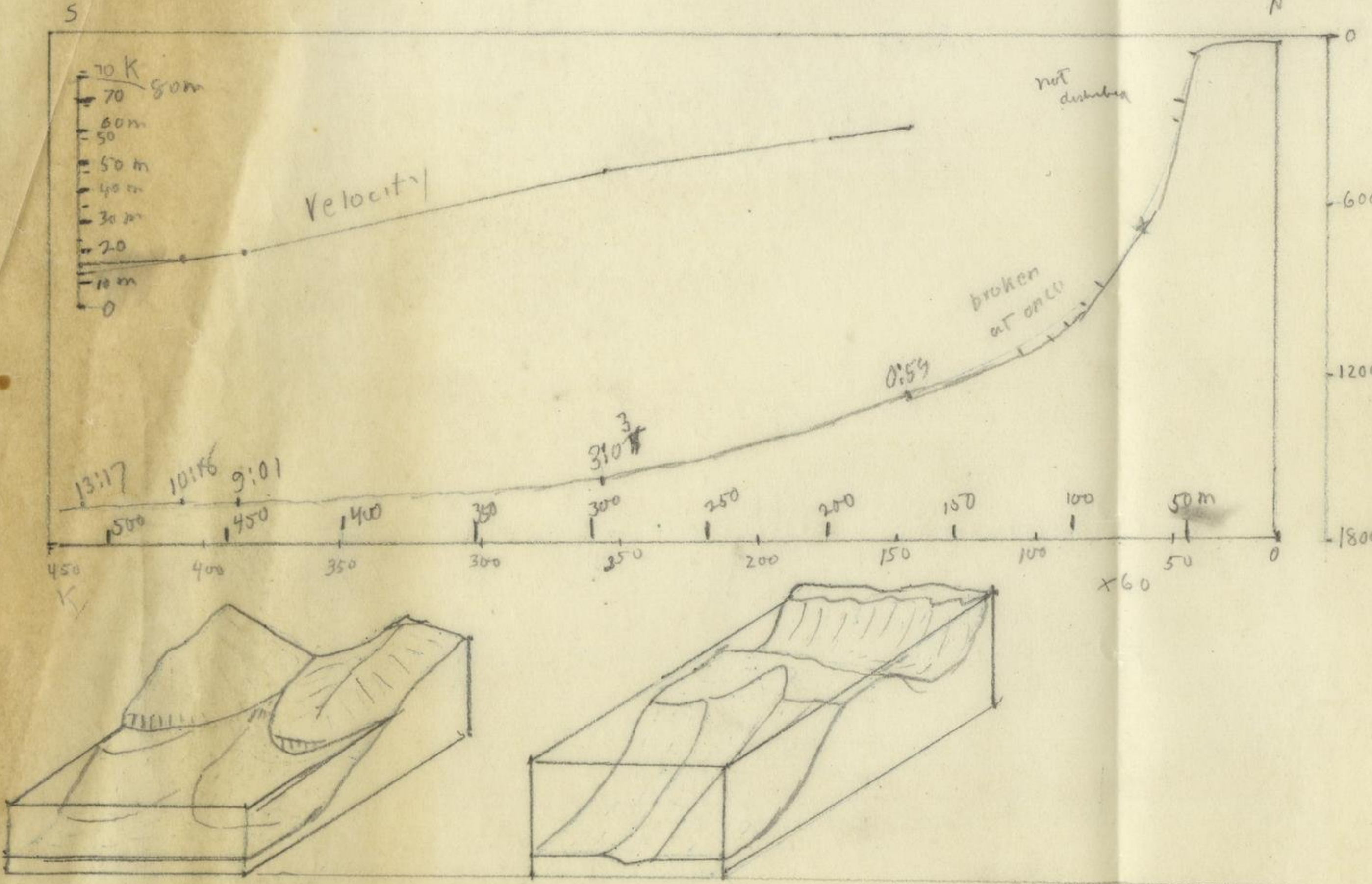
Anesthetized Patient Assisted By an Automatic Machine

An artificial lung which can breathe for an anesthetized patient on the operating table and which automatically takes over when breathing becomes irregular and inefficient comes from Peter Bent Brigham Hospital, Boston. The lung has been used in more than 800 cases. Dr. William S. Derick, Chief Anesthesiologist at Peter Bent Brigham and Associate in Anesthesia at Harvard Medical School, Dr. James V. Maloney, formerly of the Harvard School of Public Health, and Dr. James L. Whittenberger, Professor of Physiology at Harvard School of Public Health, are the inventors.

Peter Bent Brigham's staff would not use so simple a term as "artificial lung," and so they talk of a "respiratory assistor." The invention is an important aid in chest surgery because it reduces motion within the chest and greatly aids the surgeon's work, especially in heart and blood vessel surgery.

The machine comprises a plastic dome, a special respiratory valve, a tank of compressed gas and a breathing meter. It is attached to the standard anesthesia machine. The action is controlled by the patient's own breathing because the machine assists each breath to the degree shown necessary by the meter. If natural breathing ceases, the anesthetist pushes a button, whereupon the machine starts to breathe for the patient on the table.

The first human patient was a young man who had to undergo an operation on his lung. The machine not only greatly assisted his breathing, but did away with the "choppy sea" motion against which the surgeon has to work in the chest area where the heart and other organs are pulsating.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Supplement, 1952, part 3, p. 1

Some principles of soils mechanics important to geology and geomorphology.

Introduction. Soil mechanics is a branch of engineering which has to do with those physical properties of unconsolidated materials which are important in engineering operations. The term "soil" is here employed in the sense of all mantle rock regardless of depth or origin. "Mechanics" refers to the resistance of these materials to either fracture or compaction (settling or consolidation.) Fracture or other movement of the material is termed "failure". It is evident that the properties are related to several geomorphic processes, for instance the slumping of wet glacial drift, and land forms due to mass movement of unconsolidated material. Moreover, the engineering determinations are a valuable tool in the description, correlation, and history of the surficial materials of the earth. Since geologists are frequently consulted in relation to engineering problems in subsidence, excavating, and mining it is very important to understand these relatively new tests and physical measurments.

Geological descriptions. In the past geologists have to a large extent ignored physical properties of unconsolidated materials. Their descritions have been almost entirely origin, particle-size distribution, mass chemical analysis, and to some extent mineralogy, It is evident that origin is too general to furnish much help in most problems. The second is known as mechanical analysis and consists in screen separation of the particles down to a diameter of about 0.07 mm. The smaller diameters after dissociation by use of a strong alkalie are placed in suspension in water. Use is made of the known rates of settling and the density of the mixture to find relative proportions of different grades. Results of such analyses are presented in various kinds of diagrams. Prior to the development of X-ray examination and the electron microscope, mass chemical analysis was the only possible tool for examination of the sub-microscopic particles. Attempts to apportion the elements reported by the chemist into minerals part 3, p

were most uncertain. Now the mineralogy, shapes, and arrangement of the small particles is much better known. Their diameters are often expressed in microns or thousandths of a millimeter. The shapes of those smaller than about 2 microns cannot be seen with the ordinary microscope. Most of the small particles are flaky and are lumped together as clay minerals. Particles smaller than 0.1 micron are termed colloids and posses peculiar properties which, together with those of other small particles, influence the physical nature of the entire mass to an extent out of proportion to ther quantity. One of these properties of colloids is a negative electric charge which attracts the hydrogen of water molecules. The resulting layers of adsorbed water contain the ions of electrolytes. These products of dissociation of molecules react with one another causing the phenomenon of base exchange. Much of the void space between small particles is filled with adsorbed substances. Both cohesion and plasticity ARE PROPERTIES DUE TO COLLOIDS and the physical arrangement of the small minerals varies widely with the state of consolidation due to pressure.

not caps l.c.

Soils mechanics determinations. It is evident that the ordinary geological description of ~~one of the accumulations~~ a ~~deposit~~ mantle rock which contains a large proportion of fine particles leaves much to be desired in knowledge of its physical nature. For this reason engineers have used a wide variety of other determinations. Those most commonly measured comprise: (a) bulk density or unit weight (in gm/cm^3 or lbs/ft^3); (b) voids in percent ~~either of weight or~~ of volume of solids; (c) water content in percent of dry weight, (d) Atterburg limits which consist of plastic limit or percent of water of dry weight at which crumbling ceases, liquid limit or percent of water of dry weight at which flow begins under specified conditions, and plasticity index or difference of these two; permeability or rate of water movement through the material under specified conditions as a coefficient; shear strength under standard conditions (gm/cm²); unconfined compressive strength similar to the measurment on firmer material (gm/cm²); cohesion (gm/cm²) determined from part 3, p.

compression with sides under pressure (gm/cm²); compression rate as tested with force applied to only one end of a cylinder; and precompression limits an estimate of apparent compression of the material earlier in its history, or prior to being brought to the surface. (In reports of these tests it is important to note that kg/cm² is almost exactly equal to short tons/in².) (kg/cm² or tons/in²)

Plasticity. We do not need here to detail the arbitrary ~~criteria~~ standards which have been set up to make plasticity measurements but their relation ~~sixgx~~ to the origin of the clays is important to geology. When liquid limit is platted against plasticity index on ordinary coordinates all results for the same kind of clay from the standpoint of origin fall either on or close to a straight line. The slope of lines for different clays ~~is closely the same as shown in~~ does not vary much (Fig. 1). Clays which contain sodium require much more water to become plastic than those with minerals containing calcium or hydorgen. It is also to be noted that in liquid limits we have an approximation to the point at which clays ~~cease to behave like solids and~~ become similar to liquids. Considerable difficulty is found in duplicating these tests and different laboratories do not always agree.

Fig 1 leave 3"

Strength tests. Long ago the strength of unconsolidated material was expressed ~~in~~ by Coulombs equation, ~~strength~~ shearing force = cohesion plus force ~~normal to a plane of shear~~ times the tangent of ~~the~~ the "angle of ~~that plane~~ internal friction".
$S = c + p \tan \phi$. In the case of a sand which is dry and shows no cohesion the angle phi is ~~evidently~~ the angle of repose at which the material will ~~will~~ rest. This angle is about 34 degrees in dry sand with ~~rounded~~ angular grains and slightly less when the sand is below water. As in a talus the sand is held together by internal friction. When a finer material than sand is below water the value of p is reduced by the amount of pressure of the water. Unconfined compressive strength is readily measured on a cylinder of cohesive material. It ranges in clays from .25 to about 4.0 kg/cm². The values of cohesion and of phi are not so easily determined. When a sample is confined in a flexible water-proof container and is subject to

part 3, p–

Some tests have been made by finding the force needed to break a cylinder of undisturbed material by sliding one half of a containing box over the other. Another method is to enclose the specimen in a water-tight flexible cover. It is then immersed in a liquid which can be put under pressure before force is applied to one end. ~~Contained~~ Pore water may or may not be allowed to escape from the container. Pressure is applied until the specimen fails. This type of test is known as ~~a~~ a triaxial. The confining force or pressure ~~is and the~~ is platted on the horizontal line of Fig. 2. The value of the force, ~~at time of~~ at failure then lies to the right. The distance between is halved and a circle drawn passing through both points. This is known as the Mohr circle of stress. If the proceedure is repeated with another specimen of same material and larger stresses a second circle can be drawn. Then a line is drawn tangent to both circles. Its slope from the horizontal then determines the value of phi and the distance of its intersection with a vertical line through the origin at left measures the value of cohesion. However, a commonly used value of shearing strength for soft wet clay is half the unconfined compressive strength. Specimens must be from cores, not cuttings.

Fig 2 3½"

Compression. The phenomena of compression are measured by placing a short section of undisturbed core in a circular ring. Opportunity for escape of water is provided at the bottom and pressure is applied at the top. At first the rate of dimension change is rapid, then it slows up and, if the test is carried on far enough, would eventually cease. (Fig. 3). However, it is customary to plat ~~change~~ percentage of voids against logarithm of pressure as in Fig. 4. This enlargement of the horizontal scale for small forces changes the curve so that the first part has a gentle slope which on increasing pressure changes to a straight line. Under this condition, rate of change of voids is inverse to pressure. This line may be extended upward in the diagram until it intersects the horizontal line representing the estimated original void ratio.

Fig 3 leave 4" across page (Fig 4 no extra space)

Recompression. If after reaching the straight line portion of the graph pressure is gradually reduced ~~it~~ the sample expands, although the original pore space ratio is not attained. Recompression then gives a curve which has been displaced to the left. It has been claimed that the characteristics of this curve enable the discovery of the point at which pressure was reduced in the first experiment. The proceedure is to first draw a tangent to the ~~ari~~ ~~second~~ curve at the point of minimum radius as estimated by eye. A horizontal line is then drawn through the point of tangency. (Fig. 3 ~~4~~) The angle between these two lines is bisected and the line from point of tangency extended until it intersects the extension of the straight portion of the ~~second~~ curve. ~~The value of pressure thus obtained is supposed to equal that at the termination of the first test.~~

Precompression stress. ~~Fig. 5 shows how~~ some investigators have used the above method to ~~discover~~ the amount of pressure that a clay once sustained prior to either erosion of overlying material or melting of ice. A load of water has no effect on precompression of a clay which it enters. If the method ~~is~~ always reliable it would affor a valuable tool to the geologist. Unfortunately, a very similar effect results from drying of a clay. It has been stated that this method often gives too small a thickness of eroded material. In samples taken from test holes or pits it may be checked with the load which rested on the specimen before it was brought to the surface. A marked consistent departure of the values of precompression stress from actual load is nevertheless a proof of either erosion or former drying. Note that in the figure the straight portion of the final compression curve is extended upward until it meets a horizontal line drawn at the level of an assumed original void ratio. Another line parallel to the final curve is also drawn which is supposed to be the maximum possible position of a curve if the specimen had been compressed when in its original condition prior to the deposition of any overburden. This also is extended until it intersectes the line of original void ratio. The difference of pressure read on this line between this and the actual recompression (or compression) curve is then recorded as "range of precompression stress" A mark is often placed to indicate the "probable value", The value of this range is in a sense a measure of the amount of compaction which the material has undergone. It xseems as if it is based on too many estimates to ever be an exact determination.

Failure of slopes. One of the ever-present problems of engineers is how high and how steep is it safe to leave the side of an excavation in unconsolidated material. Geologists are interested in this problem in considering the natural reduction of slope of valley sides and the attainment of equilibrium in slopes. We must recognize at the outset that the physical conditions withing a bank of "soil" may vary greatly by reason not only of its physical chemical and mechanical make-up ~~as the material was originally formed~~ but also because of subseqnet changes for instance by weathering or percolation of water. Engineers use a number of different assumptions as to the strength of materials and the amount of pressure which tends to collapse a slope. One ~~basic~~ ~~assumption~~ is that the shearing strength of coherent material in a bank is half the unconfined compressive strength. Fig. 6 shows the computation by which the strength of a bank is determined. Here ~~a~~ radius of a circles and its center are both assumed. Then several ~~the~~ circles are drawn with various changes in these ~~quanities.~~ The moments of force due to weight of material which causes failure and that which resists it are readily computed from mass density (unit weight). The shear strength along the assumed circle of sliding is then computed for the different types of material cut by that circle. The total resisting force is then compared with that which might cause failure. The ration of the two is the "factor of safety" and the structure is designed to keep this as great as is economical. It is evident that such analysis is not of much value to the geologist. It ignores all natural planes of weakness such as shrinkage cracks in clay. Fig. 7 presents a somewhat different analysis of the forces in a vertical slice of unconsolidated material of uniform physical state. Total weight increases directly with the height but only that component which is directed to the foot of the slope is important. As long as this does not exceed the shearing strength on a curved surface the bank is safe.

Since the angle of the force is inverse to height of the bank a curve proportioned to the logarithm of distance back from the face should result. The unknown feature of this analysis is the factor which control the distance back from the top of the bank at which breaking starts. Possibly this is related to drying or to shrinkage cracks in clay. It is here assumed that shearing has no relation to the angle phi and can take place in any direction. An involved derivation used in most text books of soil mechanics arrives at the conclusion that the safe height of a bank is four times the shear strength divided by the unit weight. Taking an unconfined compressive strength at 1000 gm/cm^2 and a unit weight of 2 gm/cm^3 this figures out at 4 x 500 /2 or 1000 cm (10 meters) as the safe height of a bank. Under the view taken above the pressure on a square cm at depth 1000 cm would be 2kg/cm^2 horizontal and the component on a surface inclined about 45 degrees would be half this per square centimeter which is twice the assumed shear strength. As a matter of actual field conditions the problem in many cases defies analysis for the presence of water in the pores of a clay may greatly reduce its strength and the amount of such reduction may vary widely. Besides this the above analysis neglects the fact that the shear strength is not attained throughout most of the probable surface of failure.

Conclusion. The subject of soil mechanics offers an important field for the advancement of knoledge of the nature of unconsolidated materials but considerable study from the geological standpoint is still required. The existing state of knowledge for pre-compressed clays leaves much to be desired. Fig. 8 is some data on an actual test hole where foundation settling had been excessive. Geological interpretations have been added.

References

Athy, L. F., Density, porosity and compaction of sedimentary rocks: Am. Assoc. Pet. Geol. Bull. 14: 1-24, 1930

Casagrande, A., Determination of the pre-consolidation load and its practical significance: Int. Conference Soil Mechanics ~~Proc.~~, II, ~~vol.~~ 3: 60-63, 1936

Kaye, C. A., Principles of soil mechanics as viewed by a geologist: Trask, P. D., Applied sedimentation: 93-112, 1950

Rominger, J. F., and Rutledge, P. C., Use of soil mechanics in correlation and interpretation of Lake Agassiz sediments: Jour. Geol. 60: 160-180, 1952

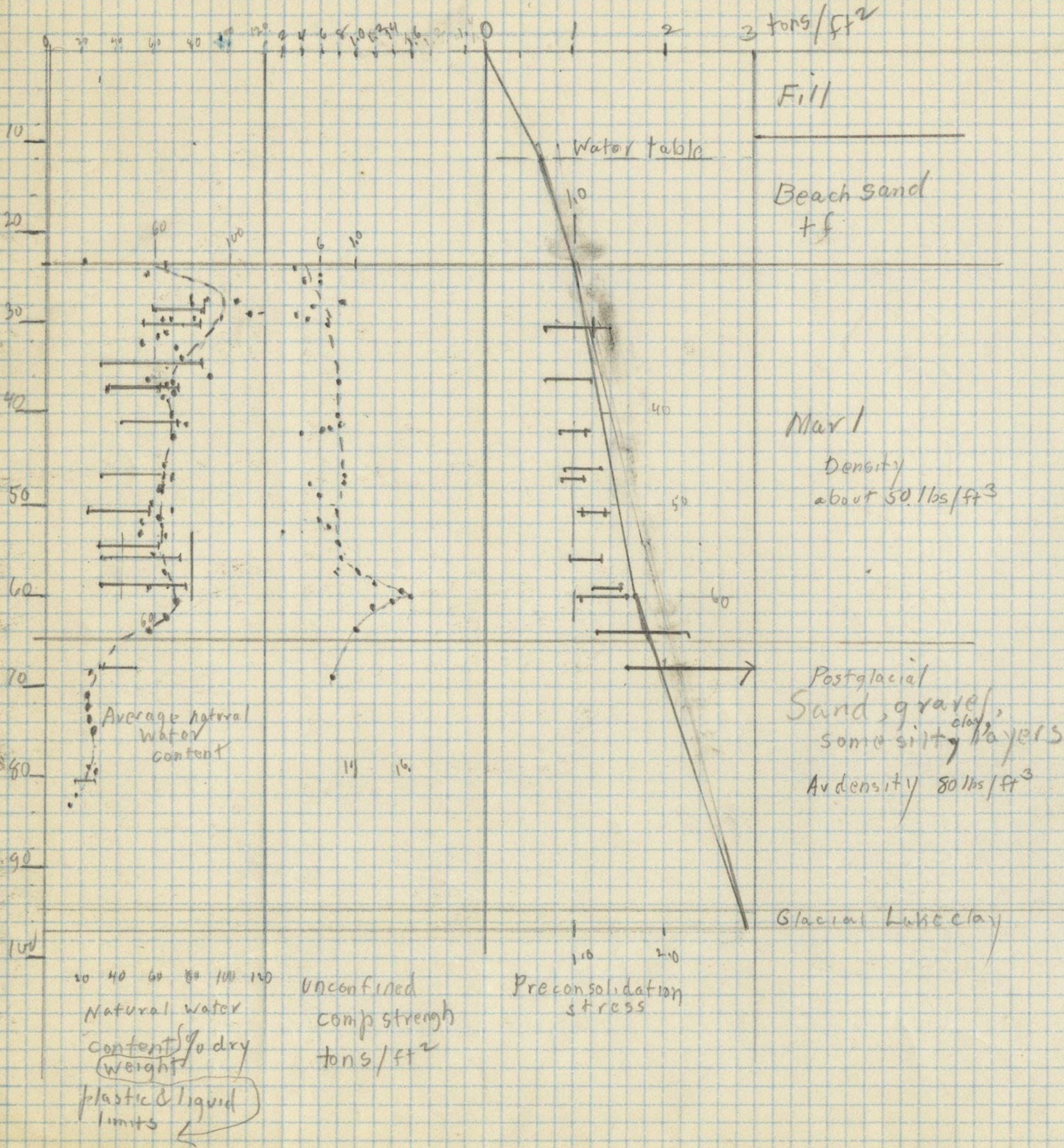
Jones, O. T., The compaction of muddy sediments: Geol. Soc. London Quart. Jour. 100-137-160, 1944

Skempton, A. W., Notes on the compressibility of clays: Geol. Soc. London Quart, Jour. 100: 119-136, 1944

Terzaghi, K., and Peck, R. B., Soil mechanics in engineering practice, 1948

Van Burkelow, Anastasia, Angle of repose and angle of sliding friction: Geol. Soc. Am. Bull. 56: 669-708, 1945

Varnes, D. J., Relation of landslides to sedimentary features: Trask, P. D., Applied sedimentation: 229-246, 1950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Water table
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about 50 lbs/ft³
Postglacial
Sand, gravel,
some silty clay layers
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Glacial Lake clay
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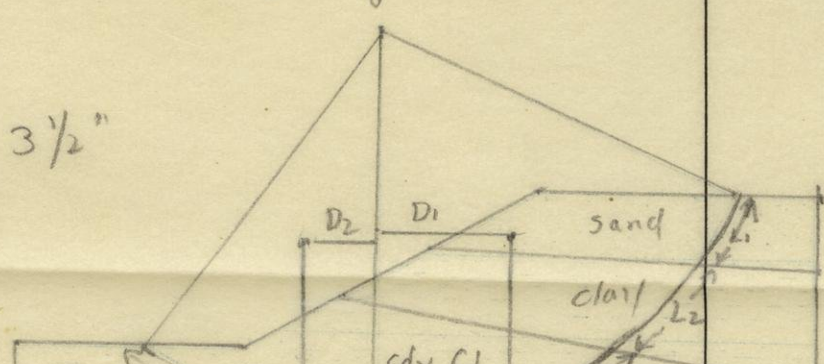
tons/ft²
Preconsolidation
stress

Fig 8

Kaye

Fig 6

3 1/2"



W = weight
S = shearing strength

Dist. moment $W_1 D_1$
Resist moment = $S_1 L_1 + S_2 L_2 + S_3 L_3 + W_2 D_2$

Kaye - Fig 2

Factor safety = $\frac{\text{res. moments}}{\text{dist. moment}}$

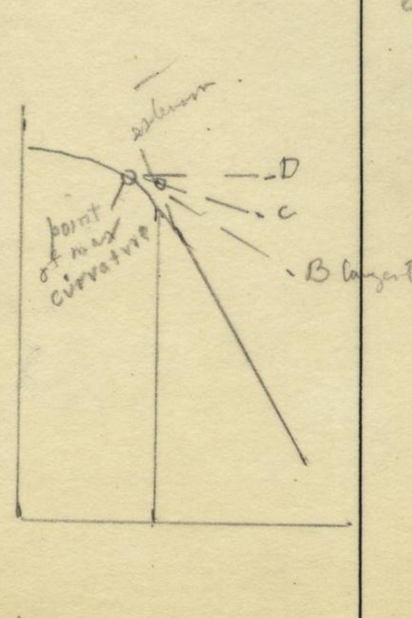


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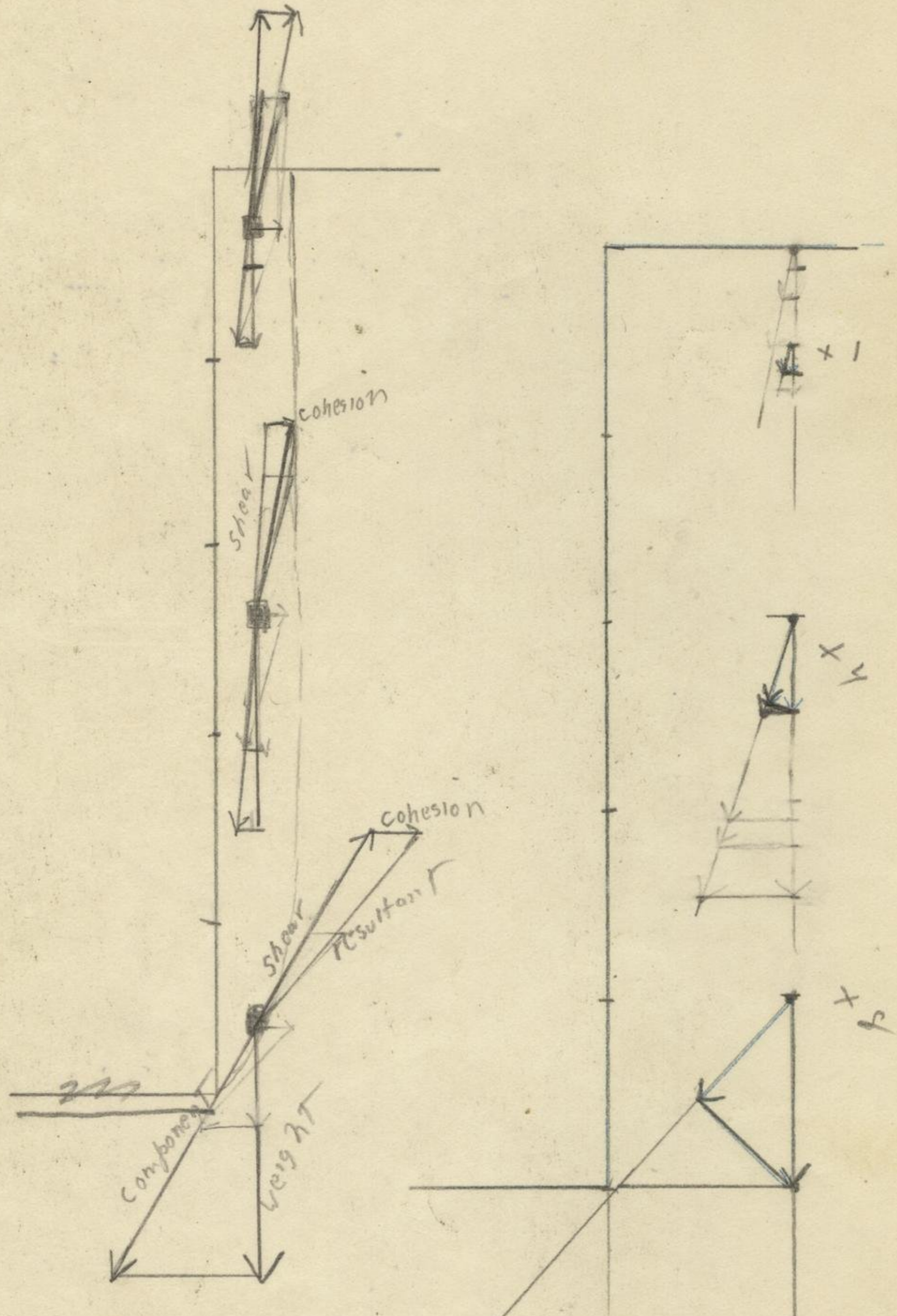
Fig 3

6"

Fig 7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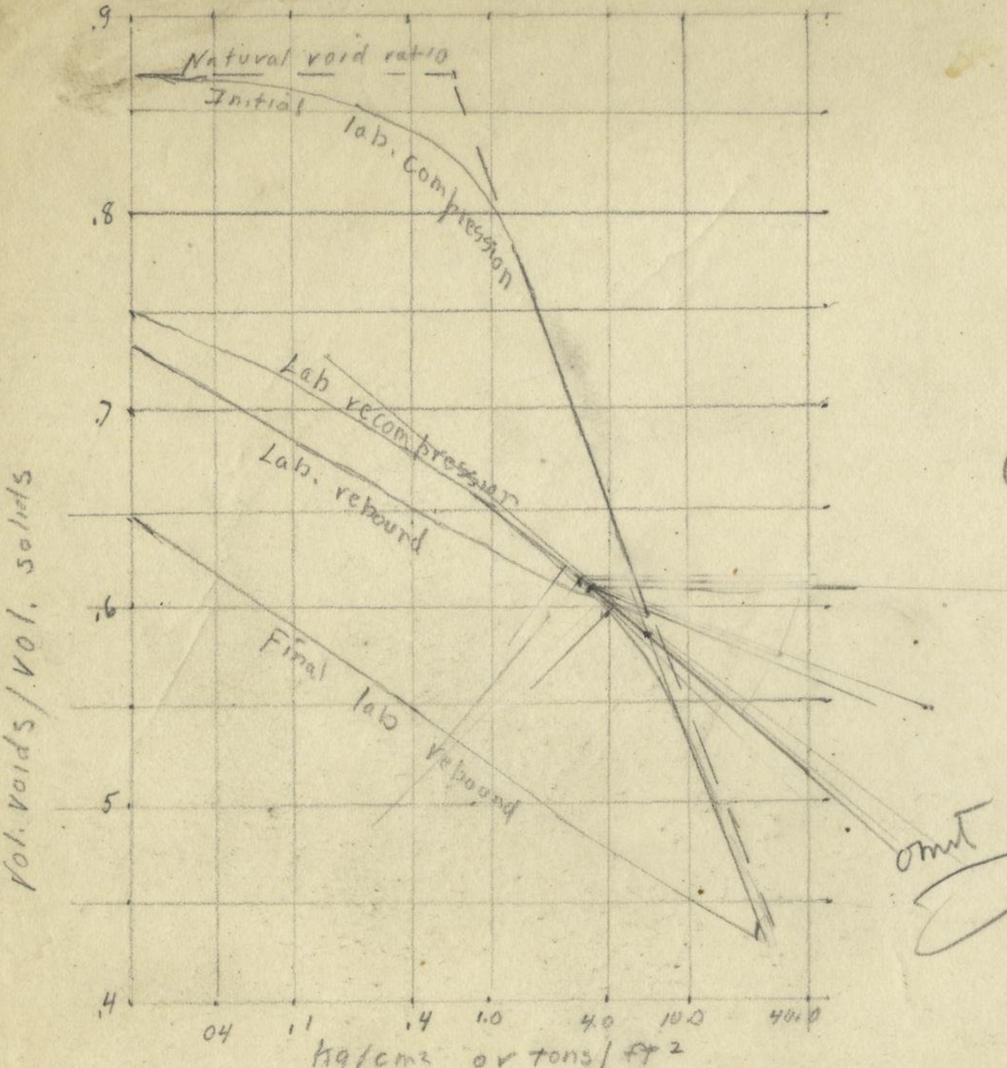

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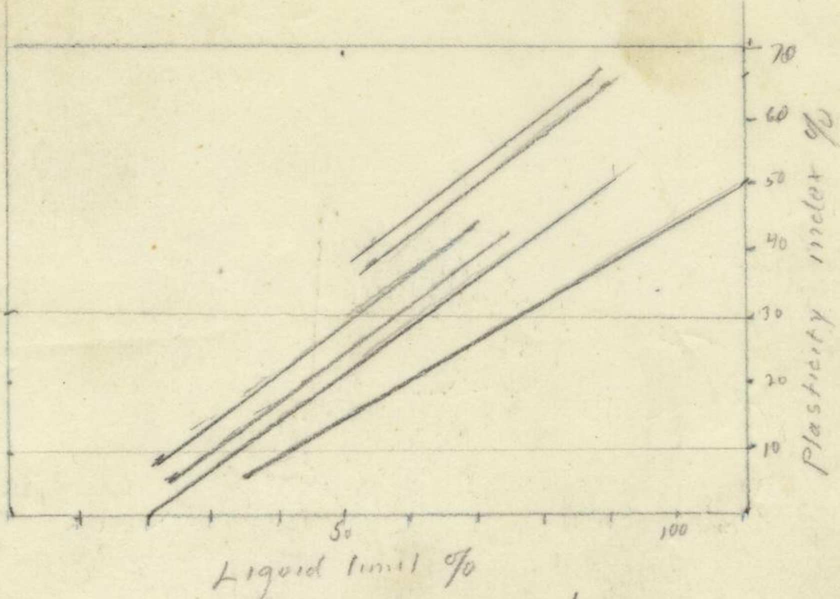


Fig 1 after Casagrande

1A Athy, L. F. Density, porosity and compaction of sedimentary rocks AAPG B 14: 1-24, 1930

2 Kaye, C. A., Principles of soil mechanics as viewed by a geologist: Trask, P. D., Applied sedimentation: 93-112, 1950

Soil mechanics uses term soil for all mantle or unconsolidated material. Importance to geologists in estimate of former depth of burial of clays, conditions leading to landslides, shear and failure in unconsolidated material. Generally it is an introdution of mechanical concepts into geologic thinking.

Subjects of soil mechanics = quanitative apprisal of stress-strain relationships.

Soils consist of solid, water, and gas. 3 catagories: result is rupture or failure, moderate stress resulting only in deformation, and permeability.

Last is important in flow of water through dams or subsoil, pressure of pore water and consolidation by extrusion of pore water. Stability problems involve critical height of slopes, earth pressure, bearing capactity. Deformation includes study of settling.

In clays the border between solid grains and fluid-filled voids is not definite.

Layers of adsorbed water producing strength not present in granular material.

In coarse-grained non-cohesive soils shear strength is due to friction between grains.

Exhausing of air from rubber bag filled with dry sand gives increased strength.. Gives result equal to conditions prevailing at depth of about 20 ft.

Take a tank filled with loose sand and then filled with water. A hole cannot be dug in the sand. If water flows through the sand and out of a hole at bottom a hole can be excavated. If the flow is upward the sand becomes quick and flows. Down flow increased pressure between grains.. Up flow cancelled gravity and reduced friction.

Cohesion also affects strength. Wet or moist sand can be moulded because of capillary tension.

Shear strength of soil is due to combination of two factors Coulomb's equation

s = c + n tan phi where C = cohesion, n = pressure normal to shear plane and tan phi = angle of internal friction. Not always valid. Varying relation of c and n

Sampling involves both disturbed and undisturbed material. Commonest tests are mechanical anyalsis, liquid and plastic limits (Atterburg limits)

Specific gravity of particles, natural water content, degree of saturation, unconfined compressive strength comprise index property tests. Simulative tests included compaction, consolidation, direct shear, triaxial shear, and permeability.

Atterburg ~~limist~~.limits Clay passes from solid through plastic state to a liquid. Standard method of testing. Difference of two values is plasticity index. Greater the index the greater the plasticity, compressibility, dry strength When platted on ordinary coordinates clays of same general type form straight line. Clays of different origin form parallel lines Coordinates are plasticity index and liquid limit.

Stability of slopes. Importance to landslide problem.

Determinations: wight of unit volume, cohesion, angle of ~~it~~ internal friction, level of water table. Cross section platted normal to slope. Center of a circle chosen at random. Use circle because it is fair approximation of what in fact is irregular due to bedding, fissures, fractures, concentration of pore water.

Divide forces into a disturbing moment, ~~wi~~ weight of unit length multipled by lever arm out to its center of gravity. Resisting moment = weight of other or downhill part of the circle times its lever arm plus resistance to shear according to Couloms equation of each type of material along circumferance below ground Pressure of ground on each surface must be found (normal pressure only). Ratio of disturbing moment to resisting moment = factor of safety. Then other circles are drawn and results compared. That circle with smallest ratio is the critical circle and displays the surface most likely to fail. Uncertainties include the error in determing cohesion and internal friction. Sometimes assume that shear resistance along the surface of failure is half that of unconfined result. Seepage forces also give uncertainty. not to mention cracks, layers, permeable beds, etc.

Consolidation. Compression of saturated clays un er load Assume that mineral particles are incompressible and reduction on volume must be due to decrease in voids. Extrustion of pore water. Time lag is measure of permeability.

Soil sample is compressed by stages and water allowed to escape. Results platt ed as voids vs log of pressure. See fig. 3. After a certain pressure the semi-log line becomes straight. Some think shape of this void-log p curve reflects previous history of the clay. Point b is found by line aC from point on curve with least radius of curvature Line aB is tangent at this point. aD is a horizontal line. aC is bisector of angle between lines aD and aB and on extension of straight line part of the curve. Some support the idea that this point measures the previous history of the clay, i.e. load due to ice or removed material. (pre-consolidation pressure).

Relation to geology. More study now of geology for this is needed to account for variability of materials. Many landslides are due directly to high pore-water pressures Study of minor structures of deposit is vital. Also of history of pre-consolidation load, changes in water table, Compaction vs. crustal movement?

Studies of grain sizes and shapes needed. Chemical composition vs permeability. Loss of cohesive bond in clays is important. Possible stabilization of soils by elctrical methods.

References Casagrande, A., The detrmination of the preconsolidation load and its practical significance: First Int. Conf. on soil mechanics, Proc. 3:60, 1936

Texts by Krynine, 1947 Taylor, 1948, Terzaghi, 1943

Rominger, J. F., and Rutledge, P. C., Use of soil mechanics data in correlation and interpretation of Lake Agassiz sediments: Jour. Geol. 60: 160-180, 1952

Points to neglect of soil mechanics data. Few papers relating it to geology.

Primary properties of material depend on source and environment of deposition.

Intermediate and secondary depend upon post-depositional history.

Primary: specific gravity of grains, grain size distribution, grain shape, Atterberg plasticity limits(liquid limit, plastic limit, plasticity index, shrinkability limit), permeability, compaction characteristics.

Intermediate: natural water content and void ratio, unconfined compressive strength, shearing strength relations, consolidation characteristics

Secondary: pre-consolidation stress, relative water content also called "water plasticity ratio" or "liquidity index".

Authors used liquid limit, plastic limit, plasticity index, natural water content, preconsolidation stress and relative water content.

Liquid limit = water content in % dry weight at which remoulded material is just able to resist shearing stress. Aribitrary point at which when shaken a groove of fixed dimensions flows shut. Depends upon minerals plus grain size and sorting. Not related to stratification, porosity etc.

Plastic limit = water content at which a predetermined remoulded thread of material will crumble. Mass property of mineralogy plus grain size.

Plasticity index = difference of these two percentages of water.

Natural water content in % dry weight = ratio of loss at 105 C to dry sample. Depends upon grain to grain relationships as affected by deposition plus subsequent loading. Not related to a water table.

Preconsolidation stress is basis of studies of settling of buildings.

Platted as relation of log of compressive stress to void ratio. Void ratio is ratio of volume of voids to volume of (sediment) solids.

Initial change is small and forms a curve which then straightens out.

Shape of curve is similar to that obtained by release of a load followed by recompression

Rominger 2   Rebound is shown after release of stress.

This led to idea tat shape of first curve is resu t of previous loading

Must use undisturbed samples not dried out . There is a displacement of straight curve after recompression. Original or preconsolidation stress not less than value obtained by intersection of straight line with natural void ratio nor greater than force at point of maximum possible rebound. Useful in finding thickness of ice or overburden removed by erosion. or results of former drying of a surface.

Relative water content is 100 times ratio of natural water content less liquid limit water content divided by plasticity index (diff. of natural content and liquid limit content)

Tables of data show graphically: Plastic limit; natural water content; liquid limit.

Plasticity index and relative water content in % of dry weight

Range of preconsolidation stress in tons/ft^2

3 X Jones, O. T., The compaction of muddy sediments: Geol. Soc. London Quart. Jour. 100: 137-160, 1944

5 X Skempton, A. W., Notes on the compressibility of clays: Geol. Soc. London Quart. Jour. 100: 119-136, 1944

Terzaghi, R. A., Compaction of lime mud as a cause of secondary structure: Jour. Sed. Petrol. 10: 78-90, 1940

SOIL MECHANICS
REFERENCES

1. "Soil Mechanics, Foundations, Earth Structures" by Gregory P. Tschebotarioff, McGraw-Hill, 1951. Consolidation.

2. "Soil Testing for Engineers" by T. W. Lambe, John Wiley & Sons, 1951.

3. "Introductory Soil Mechanics and Foundations" by G. B. Sowers and G. F. Sowers, Macmillan, 1951.

4. "Soil Engineering" by M. G. Spangler, International Textbook Company, 1951. Slopes 3.

5. "Pile Foundations" by R. D. Chellis, McGraw-Hill, 1951.

6. "Procedures for Testing Soils," American Society for Testing Materials, July 1950.

7. "The Mechanics of Engineering Soils" by P. L. Capper and W. F. Cassie, McGraw-Hill, 1949.

8. "Laboratory Manual in Soil Mechanics" by R. F. Dawson, Pitman, 1949.

9. "Fundamentals of Soil Mechanics" by D. W. Taylor, John Wiley & Sons, 1948. Slopes. 1, Consolid.

6 8 X 10. "Soil Mechanics in Engineering Practice" by K. Terzaghi and R. B. Peck, John Wiley & Sons, 1948. Slopes. 2, Consol.

11. "Substructure Analysis and Design" by Paul Andersen, Irwin-Farnham, 1948.

12. "Soil Mechanics--Its Principles and Structural Applications" by D. P. Krynine, McGraw-Hill, 1947.

13. "An Introduction to Soil Mechanics" by W. L. Lowe-Brown, Pitman, 1947.

14. "Theoretical Soil Mechanics" by K. Terzaghi, John Wiley & Sons, 1943.

15. "Soil Mechanics and Foundations" by F. L. Plummer and S. M. Dore, Pitman, 1940.

16. "Contributions to Soil Mechanics" by various authors, published by the Boston Society of Civil Engineers, 1940.

17. "Engineering Properties of Soil" by C. A. Hogentogler, McGraw-Hill, 1937.

7 Van Burgsalow, Anastasia, Angle of repose and angle of sliding friction GSA. B 56 : 669 - 708, 1945

8 Varnes, D. J., Relation of landslides to sedimentary features: Trask, P. D., Applied sedimentation: 229-246, 1950

Major factors: composition, structure, state of stress.

Texture- permeability very important Shape of particles

Mineral content-base exchange removing calcium through glauconite causes alkaline water which deflocculates clays. Gypsum can dissolve More knowledge needed on clay mineral group. Physical properties. Depend largely on smallest particles which carry a negative electric charge which attacts positive hyrodgen parts of water molecules. Thickness of water films causes plasticity. More water makes mass a liquid. Clays containing Na adsorb more water in thick oriented films Require more water than Ca or H minerals. 5 to 6 times as much to become ~~plastic~~ liquid

Water content- Water around grains of small sizes influence forces holding grains together. Disturbance of even vibration decreases shear strength. Vibration can cause freeing of water with resulting semi-liquid condition. Disturbance of material also may cause semi-liquid condition.

Influence of bedding, joints etc.

Permeability. Permeable layers allow water to enter and lubicate surfaces.

Stress distribution. Two sets of forces, those tending to produce slide and those which oppose it The angle phi in Coulombs equation is about the angle of repose of sand. Cohesion of sand varies with water content.

Pore water pressure should be subtracted from the constant which affects tan phi.

Extensive bibliography

TEST HOLE NO. 2, JONES ISLAND, MILWAUKEE, WIS.

Near center sec. 33, T. 7 N., R. 22 E. Elevation 9, city datum
Klug and Smith Co., Engineers
Milaeger Well Drilling Co., Contractors, 1951
Samples examined by F. T. Thwaites, Nos. 155769-155789

DRIFT		0-9½	9½		Fill
		9½-23½	14		Sand, fine to pebbly, gray, shells modern lake deposit
		23½-34	10½		Marl, black = filling of lagoon
		34-43½	9½		No samples, marl
		43½-65½	22		Marl, light gray
		65½-79	13½		Sand, fine, gray, silty= river or beach sand
		79-94½	15½		Gravel, fine, sandy; sand, medium to fine, lt. gray; silt, gray 79-81; wood (postglacial)
	97	94½-97	2½		Clay, light gray, dolomitic(glacial lake dep)

Depths rounded off to half feet

GEOLOGY 109
GEOMORPHOLOGY

Supplement, 1952, part 2

Some principles of soils mechanics ~~in relation~~ important to geology and geomorpholog y

<u>Introduction</u>. Soil mechanics is a branch of engineering which has to do with those physical properties of unconsolidated materials which are important in engineering operations. The term "soil" is here employed in the sense of all mantle rock regardless of depth or origin. "Mechanics" refers to the resistance of these materials to either fracture or compaction (settling or consolidation.) Fracture or other movement of the material is termed "failure". It is evident that the properties are related to several geomorphic processes, for instance the slumping of wet glacial drift, and land forms due to mass movement of unconsolidated material. Moreover, the engineering determinations are a valuable tool in the description, correlation, and history of the surficial materials of the earth. Since geologists are frequently consulted in relation to engineering problems in subsidence, excavating, and mining it is very important to understand these relatively new tests and physical measurments.

<u>Geological descriptions</u>. In the past geologists have to a large extent ignored physical properties of unconsolidated materials. Their descritions have been almost entirely origin, particle size distribution, mass chemical analysis, and to some extent mineralogy, It is evident that origin is too general to furnish much help in most problems. The second is known as <u>mechanical analysis</u> and consists in screen separation of the particles down to a diameter of about 0.07 mm. The smaller diameters after dissociation by use of a strong alkalie are placed in suspension in water. . Use is made of the known rates of settling and the density of the mixture to find relative proportions of different grades. Results of such analyses are presented in various kinds of diagrams. Prior to the development of X-ray examination and the electron microscope, mass chemical analysis was the only possible tool ~~of~~ for examination of the sub-microscopic particles. Attempts to apportion ~~of~~ the elements reported by the chemist into minerals

were most uncertain. Now the mineralogy, shapes, and arrangement of the small particles is much better known. Their diameters are often expressed in microns or thousandths of a millimeter. The shapes of those smaller than about 2 microns cannot be seen with the ordinary microscope. Most of the small particles are flaky and are lumped together as clay minerals. Particles smaller than 0.1 micron are termed colloids and posses peculiar properties which, together with those of other small particles, influence the physical nature of the entire mass to an extent out of proportion to ther quantity. One of these properties of colloids is a negative electric charge which attracts the hydrogen of water molecules. The resulting layers of adsorbed water contain the ions of electrolytes. These products of dissociation of molecules react with one another causing the phenomenon of base exchange. Much of the void space between small particles is filled with adsorbed substances. Both cohesion and plasticity ARE PROPERTIES DUE TO COLLOIDS and the physical arrangement of the small minerals varies widely with the state of consolidation due to pressure.

Soils mechanics determinations. It is evident that the ordinary geological description of a ~~deposit~~ mantle rock ~~one of the accumulations~~ which contains a large proportion of fine particles leaves much to be desired in knowledge of its physical nature. For this reason engineers have used a wide variety of other determinations. Those most commonly measured comprise: (a) bulk density or unit weight(in gm/cm^3 or lbs/ft^3); (b) voids in percent ~~either of weight or~~ of volume of solids; (c) water content in percent of dry weight, (d) Atterburg limits which consist of plastic limit or percent of water of dry weight at which crumbling ceases, liquid limit or percent of water of dry weight at which flow begins under specified conditions, and plasticity index or difference of these two; permeability or rate of water movement through the material under specified conditions as a coefficient; shear strength under standard conditions (gm/cm²); unconfined compressive strength similar to the measurment on firmer material; cohesion determined from part 2, p-

compression with sides under pressure; <u>compression rate</u> as tested with force applied to ~~only~~ one end of a cylinder; and <u>precompression limits</u> an estimate of apparent compression (kg/cm² or tons/in²) of the material earlier in its history, or prior to being brought to the surface. In reports of these tests it is important to note that kg/cm² is almost exactly equal to short tons/in²

<u>Plasticity</u>. We do not need here to detail the arbitrary criteria which have been set up to make plasticity measurements but their relation ~~sings~~ to the origin of the clays is important to geology. When liquid limit is platted against plasticity index on ordinary ~~coordinates~~ ordinates all results ~~fro~~ for the same kind of clay from the standpoint of origin fall either on or close to a straight line. The slope of lines for different

3' clays ~~is closely the same as shown in~~ does not vary much. (Fig. 1). Clays which contain sodium require much more water to become plastic than those with minerals containing calcium or hydorgen. It is also to be noted that in liquid limits we have an approximation to the point at which clays ~~cease to behave like solids and~~ become similar to liquids. Considerable difficulty is found in duplicating these tests and different laboratories do not always agree

<u>Strength tests</u>. Long ago the strength of unconsolidated material was expressed by <u>Coulombs equation</u>: shearing ~~strength~~ force = cohesion plus force ~~normal to a plane of shear~~ times the tangent of the angle of ~~that plane~~ internal friction. ($s = c + p \tan \phi$.) In the case of a sand which is dry and shows no cohesion the angle phi is ~~evidently~~ the <u>angle of repose</u> at which the material will will rest. This angle is about 34 degrees in dry sand with ~~rounded~~ angular grains and slightly less when the sand is below water. As in a talus, the sand is held together by internal friction. When a finer material is below water the value of p is reduced by the amount of pressure of the water. Unconfined compressive strength is readily measured on a cylinder of cohesive material. It ranges in clays from .25 to about 4.0 kg/cm². The values of cohesion and of phi are not so easily determined. ~~When~~ a ~~sample is confined in a flexible water-proof container and is subject to~~

Some tests have been made by finding the force needed to break a cylinder of undisturbed material by sliding one half of a containing box over the other. Another method is to enclose the specimen in a water-tight flexible cover. It is then immersed in a liquid which can be put under pressure before force is applied to one end. Contained water may or may not be allowed to escape from the container. Pressure is applied until the specimen fails. This type of test is known as ~~a~~ triaxial. The confining force or pressure ~~is andxthe~~ is platted on the horizontal line of Fig. 2. The value of the force at ~~time of~~ failure then lies to the right. The distance between is halved and a circle drawn passing through both points. This is known as the Mohr circle of stress. If the proceedure is repeated with another specimen of same material and larger stresses a second circle can be drawn. Then a line is drawn tangent to both circles. Its slope from the horizontal then determines the value of phi and the distance of its intersection with a vertical line through the origin at left measures the value of cohesion. However, a commonly used value of shearing strength for soft wet clay is half the unconfined compressive strength.

Compression. The phenomena of compression are measured by placing a short section of undisturbed core in a circular ring. Opportunity for escape of water is provided at the bottom and pressure is applied at the top. At first the rate of dimension change is rapid, then it slows up and if the test is carried on far enough would eventually cease. (Fig. 3). However, it is customary to plat ~~change~~ percentage of voids against logarithm of pressure as in Fig. 4. This enlargement of the horizontal scale for small forces changes the curve so that the first part has a gentle slope which on increasing pressure changes to a straight line. Under this condition, rate of change of voids is inverse to pressure. This line may be extended upward in the diagram until it intersects the horizontal line representing the estimated original void ratio.

Recompression. If after reaching the straight line portion of the graph pressure is gradually reduced ~~it~~ the sample expands, although the original pore spece ratio is not attained. Recompression then gives a curve which has been displaced to the left. It has been claimed that the characteristics of this curve enable the discovery of the point at which pressure was reduced in the first experiment. The proceedure is to first draw a tangent to the ~~ari~~ ~~second~~ curve at the point of minimum radius as estimated by eye. A horizontal line is then drawn through the point of tangency. (Fig. ~~3~~ 4) The angle between these two lines is bisected and the line from point of tangency extended until it intersects the ext ension of the straight portion of the ~~second~~ curve. ~~The value of pressure thus obtained is supposed to equal that at the termination of the first test.~~

Precompression stress. ~~Fig. 5 shows how~~ some investigators have used the above method to ~~discover~~ estimate the amount of pressure that a clay once sustained prior to either erosion of overlying material or melting of glacial ice. A load of water has no effect on precompression of a clay which it enters. If the method ~~is~~ were always reliable it would affor a valuable tool to the geologist. Unfortunately, a very similar effect results from drying of a clay. It has been stated that the method often gives too small a thickness of eroded material. In samples taken from test holes or pits it may be checked with the load which rested on the specimen before it was brought to the surface. A marked consistent departure of the values of precompression stress from actual load is nevertheless a proof of either erosion or former drying. Note that in the figure the straight portion of the final compression curve is extended upward until it meets a horizontal line drawn at the level of an assumed "original void ratio." Another line parallel to the final curve is also drawn which is supposed to be the maximum possible position of a curve if the specimen had been compressed when in its original condition prior to the deposition of any overburden. This also is extended until it intersectes the line of original void ratio. The difference of pressure read on this line between this and the actual recompression (or compression) curve is then recorded as the "range of precompression stress" A mark is often placed to indicate the "probable value".

The value of this range is in a sense a measure of the amount of compaction which the material has undergone. It xseems as if it is based on too many estimates to ever be an exact determination.

Failure of slopes. One of the ever-present problems of engineers is how high and how steep is it safe to leave the side of an excavation in unconsolidated material. Geologists are interested in this problem in considering the natural reduction of slope of valley sides and the attainment of equilibrium in slopes. We must recognize at the outset that the physical conditions withing a bank of "soil" may vary greatly by reason not only of its physical chemical and mechanical make-up as the material was originally formed but also because of subseqnt changes for instance by weathering or percolation of water. Engineers use a number of different assumptions as to the strength of materials and the amount of pressure which tends to collapse a slope. One basic assumption is that the shearing strengthof coherent material in a bank is half the unconfined compressive strength. Fig. 6 shows the computation by which the strength of a bank is determined. Here a radius of a circles and its center are both assumed. Then several circles are drawn with various changes in these quanities. The moments of force due to weight of material which causes failure and that which resists it are readily computed from mass density (unit weight). The shear strength along the assumed circle of siding is then computed for the different types of material cut by that circle. The total resisting force is then compared with that which might cause failur The ration of the two is the "factor of safety" and the structure is designed to keep this as great as is economical. It is evident that such analysis is not of much value to the geologist. It ignores all natural planes of weakness such as shrinkage cracks in clay. Fig. 7 presents a somewhat different analysis of the forces in a vertical slice of unconsolidated material of uniform physical state. Total weight increases directly with the height but only that component which is directed to the foot of the slope is important. As long as this does not exceed the shearing strength on a curved surface the bank is safe.

part 2, p -

Since the angle of the force is inverse to height of the bank a curve proportioned to the logarithm of distance back from the face should result. The unknown feature of this analysis is the factor which control the distance back from the top of the bank at which breaking starts. Possibly this is related to drying and to shrinkage cracks in clay. It is here assumed that shearing has no relation to the angle phi ~~axxxxy~~ and can take place in any direction. An involved derivation used in most text books of soil mechanics arrives at the conclusion that the safe height of a bank is four times the ~~productxofxthe~~ shear strength divided by the unit weight. Taking an unconfined compressive strength at 1000 gm/cm^2 and a unit weight of 2 gm/cm^3 this figures out at 4 x 500 /2 or 1000 cm (10 meters) as the safe height of a bank. Under the view taken above, the pressure on a square cm at depth of 1000 cm would be $2kg/cm^2$ horizontal and the component on a surface inclined about 45 degrees would be half this per square centimeter which is twice the assumed shear strength. As a matter of actual field conditions the problem in many cases defies analysis for the presence of water in the pores of a clay may greatly reduce its strength and the amount of such ~~reduction~~ water may vary widely. Besides this, the above analysis neglects the fact that the shear strength is not supposed attained throoughout ~~most~~ half of the probable surface of failure.

Conclusion. The subject of soil mechanics offers an important field for the advancement of knowledge of the nature of unconsolidated materials but considerable study especially from the geological standpoint is still required. The existing state of knowledge ~~for~~ of "pre-compressed" clays leaves much to be desired. Fig. 8 is some data on an actual test hole where foundation settling had been excessive with geological interpretations ~~, have been added.~~

OK

Surface activity – adsorbed layer

clay minerals & colloids

most ~~[illegible]~~ particles below .2 micron are clay minerals

when so small that surface activity affects properties of aggregate they are colloids – This is from 2 to 1/10 micron

all colloids below 1/10 micron

consolidation = reduction of free water

plasticity = a colloidal property

change in void % / change in pressure = coeff. of comp.

Time consolidation – decrease with time

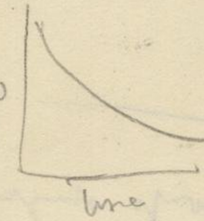
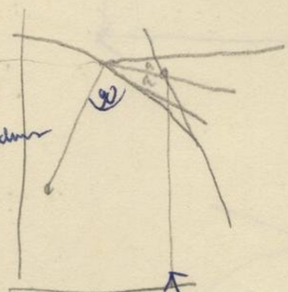
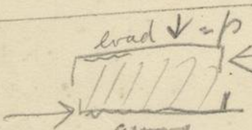


Fig 26 p 71



expansion due to release of load

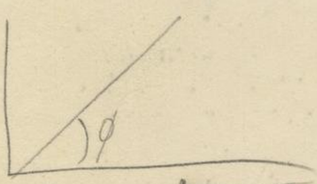
Shear resistance



force measured by [illegible]

quick or slow tests

also use a ring

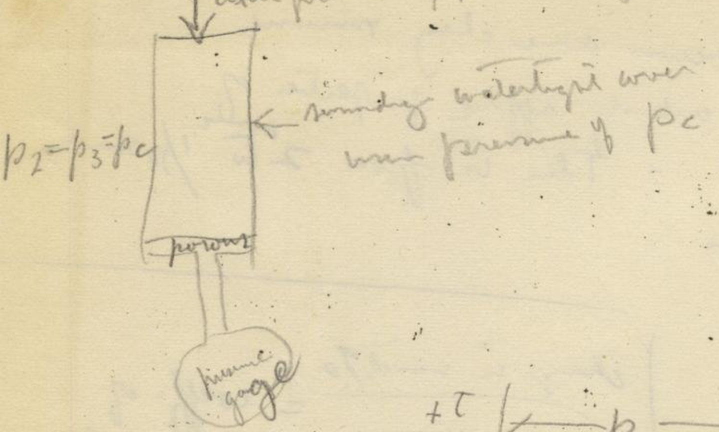


$S = p \tan \phi$ $\tan \phi$ = coeff of int friction

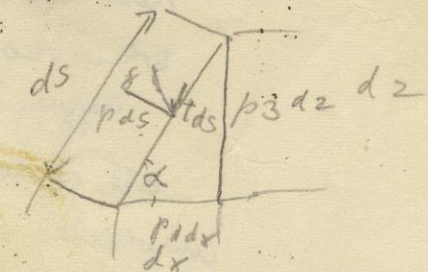
ϕ = angle of internal friction = nearly angle of repose of loose material

cohesion meaning resistance $S = C + p \tan \phi$ ϕ is 1 to 2 deg less in submerged than in dry sand but very loose sand may pass quickly to liquid flow

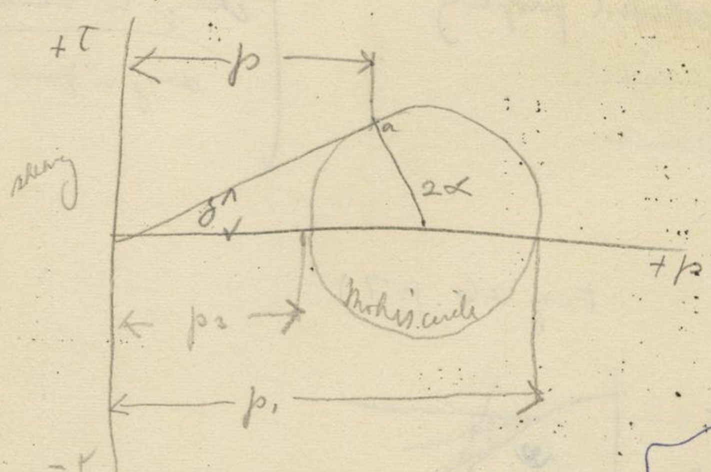
Triaxial test $p_1 = p_0 + q$



failure on inclined planes



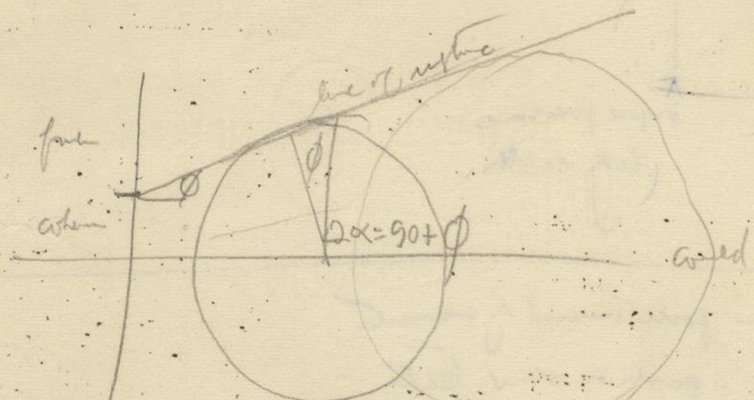
δ = angle of shear force to plane



no cohesion

angle of repose of
sand – round 28.5°
angular 34°

unconfined comp. strength =
force / unit area for
failure of a cylinder
shear strength along plane of
sliding = about 1/2 U.C. strength
S



could draw more circles

Stability of slopes – p.181 generally accepted theoretical analysis

failure along toe circle all slopes over 53°

some analyses need a "firm base"

shear strength about half unconfined compressive strength

Expansion of clay by relief of stress upon cracks – little in water

critical height of vert. slope = 3.85 { cohesion / unit wt. }

see p 30 clay range of unconfined compressive strength kg/cm² from .25 to over 4.0

cohesion about half this

critical height = Hc
angle β

$Hc = Ns \frac{c}{y}$ where

Ns is a number depending on slope and depth of a firm base
c = unconfined comp. strength

p 95

Fig 37

$c = \frac{H_c Y}{4}$ wt of sec.

$v =$

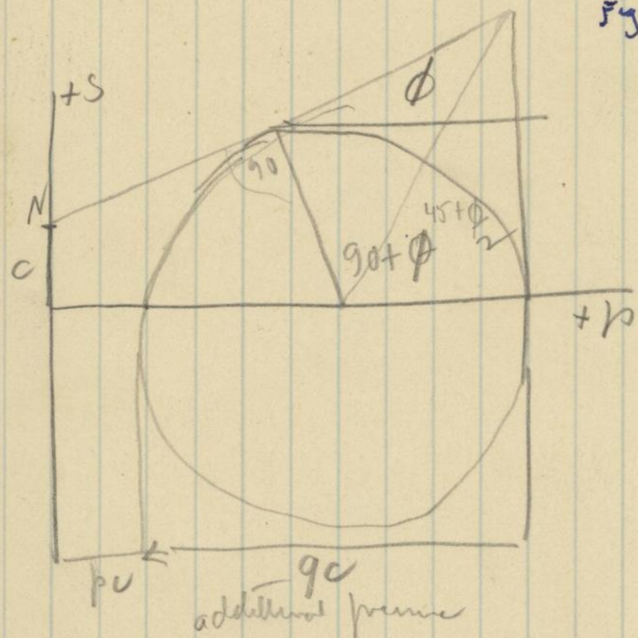
$H_c = 4 \frac{c}{\gamma} = 4 \frac{\frac{1}{2}\text{ un. comp. strength}}{\text{unit wt}}$

$\frac{40000}{2}$ = 2 miles

Fig 1 - clays

2 from Casagrande

3 " "



Kaye, C A

Principles of soil mechanics as viewed by a geologist

in Trask, P.A. applied sedimentation, 93 – 112, 1950

Soil = all unconsolidated material = solid, water, gas

rupture or failure
deformation
permeability

"solids" of clays include borderline colloids

strength of soil related to stress in liquids

experiment. 1 Casks of sand filled with water. standing cant dig a hole

2 flow upward through sand = quicksand.

3 water flowing through sand not standing = rigid

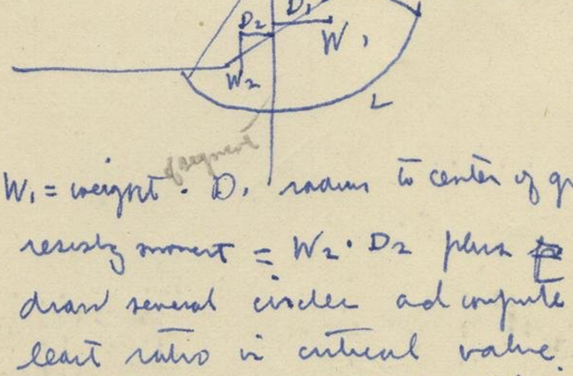
cohesion – Coulomb's equation not accurate in relating everything to cohesion and internal friction

Tests: mechanical analysis – grain size

Spec. gravity of particles
water content
. degree of saturation.
. liquid and plastic limits – Atterberg limits of plastic range from solid to liquid
unconfined compressive strength

difference = plasticity index
plasticity index plotted against.
liquid limit = straight line
for deposits of same type or origin
index related to compressibility and dry strength

stability of slope. needs data on
unit weight, cohesion, angle of internal friction
draw x-sec – then form a circle with center above face.



W_1 = weight of segment. D_1 radius to center of gravity – disturbing moment = $W_1 D_1$

resisting moment = $W_2 \cdot D_2$ plus cohesion and friction on surface of contact

draw several circles and compute ratio of 2 forces – that having least ratio is critical value. (resisting moment / disturbing moment)
showing surface most likely to fail

where seepage is present values cannot be found accurately

Consolidation – plotted on semi log paper – ratio of void ratio e to pressure p on log scale e here = total vol voids / total vol. solids.

Terzaghi, Karl Soft ground tunneling in Trans applied sedimentation 1950

ground: firm, raveling, running, flowing, squeezing, swelling

ravel = falling chunks

running bar slope of 34°

flowing = viscous liquid

squeezing = subsidence

swelling = increase in volume

Turnbull W.J., Krinitzsky, EL and Johnson, S.G.

Sedimentary geology of the alluvial valley of the Lower Mississippi and its influence on foundation problems Trans, Applied Sed. 210 - 226 : 1950

follows Fisk interpretations - little new

Varnes, D.J. Relation of landslides to sedimentary features - Trans - 229 - 246, 1950

Follows Sharpe and Coulomb.

$S = c + p \tan\phi$ c (cohesion) = 0 in clay & soft sed

p = normal pressure of overlying material

ϕ = ∠ internal friction = ∠ repose in ~~sed~~ sand

Sand has cohesion when moist, not saturated

load applied rapidly may transfer force to water lowering internal friction

pressure on pore water

Black RF Permafrost - Trans 247 - 275, 1950

influence on ground & surface waters, solifluction

involutions, frost boils, hummocks, altiplanation terraces etc

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Smith HTU Physical effects of Pleistocene climatic changes in nonglaciated areas - - - GSAB 60: 1485-1516, 1949

Mason MA Geology in shore-control problems Trans, 1950

maximum energy : $T^2 H^2$ (square of period × height)

Weathering

Moneymaker : BC

Some broad aspects of limestone solution in the Tennessee valley AGUT 29;

93 -96, 1948 good general discussion

Hubbert
AAPG 29:1630

Rate of flow in viscous substance

w = velocity on z axis - σ_z = stress on z axis

μ = viscosity

$$\frac{dw}{dz} = \frac{\sigma_z}{3\mu}$$

$$w = \int \frac{dw}{dz} = \frac{\sigma_z}{3\mu} z$$

z = distance along specimen

In time dt a particle at z = $w\,dt = \frac{\sigma_z}{3\mu} z\,dt$

sub $w = \frac{dz}{dt}$ and

and strain =

$$\frac{dz}{z} = \frac{\sigma_z}{3\mu} dt$$

divide through by z

$\log_e$ / $\log_{10}$ ($\log_e$) Then $\ln \frac{z}{z_0} = \frac{\sigma_z t}{3\mu}$

Integrate and $\frac{z}{z_0} = e^{\frac{\sigma_z t}{3\mu}}$ ratio of final length to original at time t or $t = \frac{3\mu}{\sigma_z} \ln \frac{z}{z_0}$

(same as $\log_e z - \log_e z$; $\log_e$ = number)

Take a cliff 370 meters high = 10^8 dynes cm^2

$37000 \times 2.65 \times 980 = 10^8$ dynes/cm^2 = σ_z

assume $\mu = 10^{22}$

substitute values $t = \frac{3 \times 10^{22}}{-10^8} \ln (1 - 10^{-6})$ = 3×10^8 or 10 years

one part in 1 million

$22 - 8 - 6 = 8$

or 1 part in 10 $t = \frac{3 \times 10^{22}}{-10^8} \ln (1 - 0.1)$ [10^{-1}] $= 3 \times 10^{13}$ seconds = 1 million years

$22 - 8 - 1 = 13$

Griggs, David, Creep of rocks: J. G. 47, 225–251, 1939

Pseudoviscous flow = deformation at constant rate
elastic flow, decreases logarithmically with time

Total perm. def. S time = t

(2) then $S = A + B \log t + Ct$
(elastic) (pseudoviscous)

differentiating to get velocity

$$\frac{dS}{dt} = v = \frac{B}{t} + C$$

in long time $\frac{B}{t}$ becomes small and flow is constant

solid viscosity is not constant with varying magnitudes of shear stress

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Griggs, D. T
Deformation of rocks under high confining pressures – experiments
(1) at room temperature | J. G. 44, 541–577, 1936

Relation of "strength" to time
Plastic deformation before rupture decreases with duration of test
reverse of popular opinion

Griggs D T, Experimental flow of rocks under conditions
(3) favoring recrystallization
GSAB 51; 1001–1022, 1940

logarithm of vel. of deformation: stress or as stress increases
rate of flow is exponential

Hardness of Tenn. limestone waters

St Louis - Warsaw		Fe	Ca	Mg	SO_4	Alk.	Hardness
av. of 27		0.73	59	10.0	20.0	189	[illegible]
Silurian	4	.17	37	8.1	15.0	125	162
Lexington & Cattery	5	.67	99	26.0	114.0	354	437
Rigby	5	.67	78	10.8	56.0	240	470
Hermitage	4	.64	63	15.0	76.0	216	314
Stones River	13	.59	84	18.0	58.0	286	381
	58				6) 339. (56.5		6) 1973 (329

Removed per year per m^2 (15% of 40 = 6")

$5.28^2 \times 10^6 \times .75 =$

$27.88 \times 10^6 \times .75 = 20.9 \times 10^6$ ft^3 water $= 62.4 \times 20.9 \times 10^6$ lbs

$= 1300 \times 10^6$ lbs water each mill lbs contain 329 parts solids

$= 1300 \times 329 = 428,000$ lbs solids. $= 4.28 \times 10^5$ lbs.

$= 214$ tons per m^2 at density 2.6 1 ft^3 = 162 lbs.

$\frac{428,000}{162} = 2650$ ft^3 of original rocks per m^2 per year. $= 2.65 \times 10^3$

divided by $27.9 \times 10^6 = \frac{2.65 \times 10^3}{27.9 \times 10^6} = \frac{2.65}{27.9 \times 10^3} = .095 \times 10^{-3}$ or 9.5×10^{-5} ft

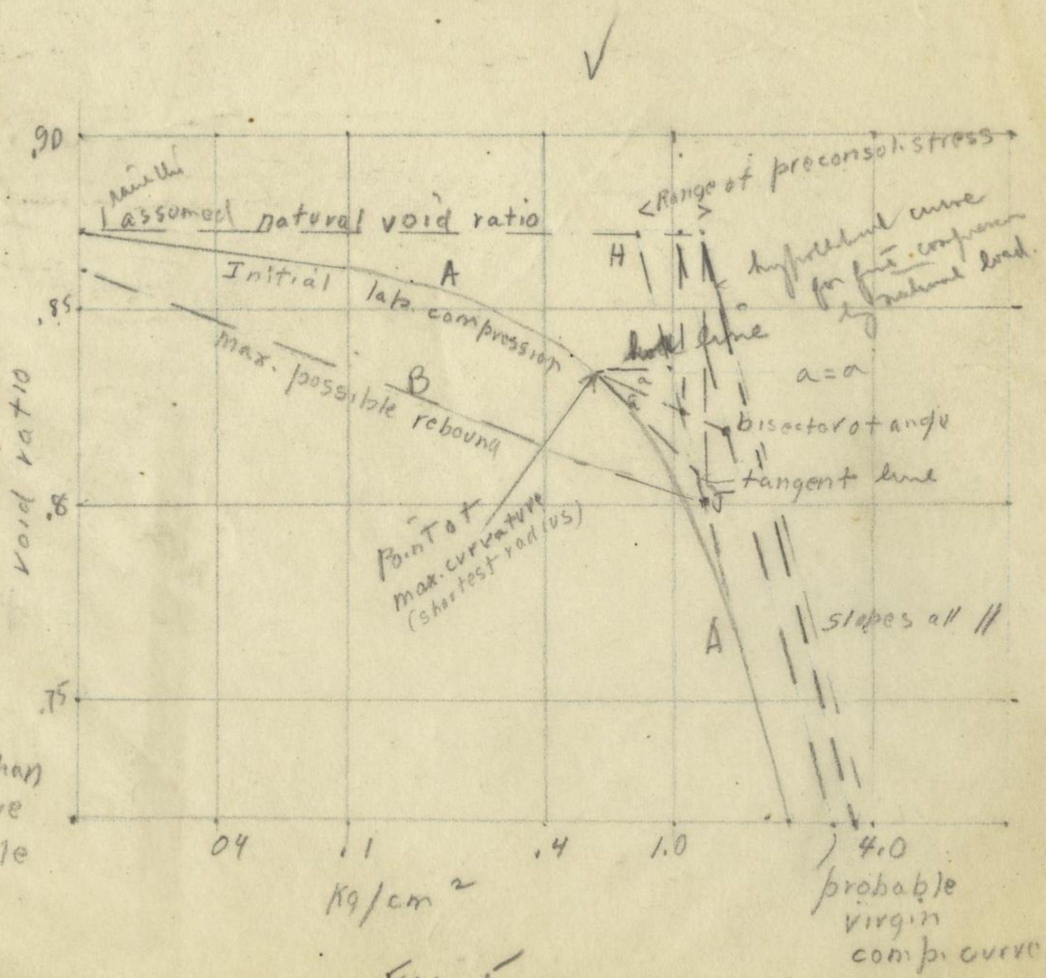
$= .000095$ ft less than 1/1000 ft

To form 1 ft of residium, density 1.3 from rock 10% insoluble would require about 5000 years.

.1 -1
.01 -2
.001 -3
.0001 -4
.00001 -5

528
528
4224
1056
2640
278784

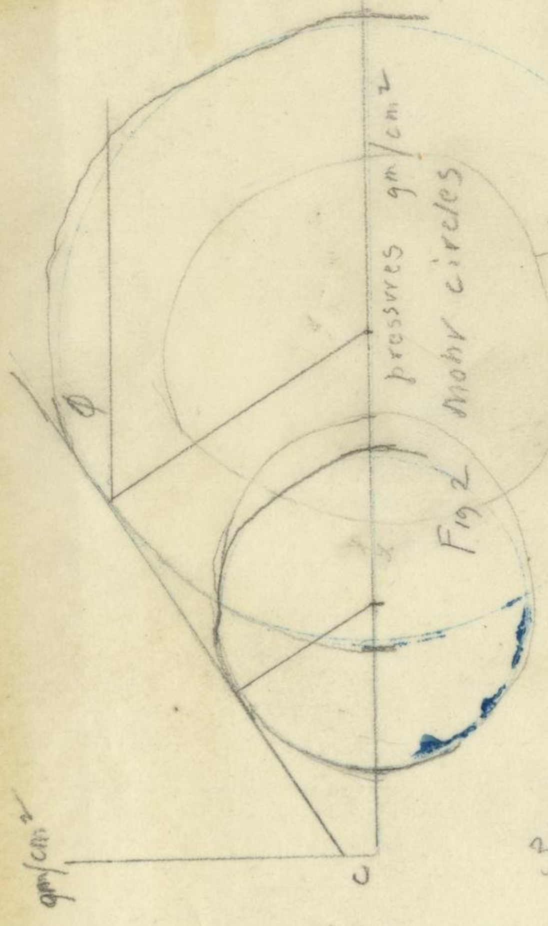
5 n



Preconsol. stress cannot be less than at H nor greater than at J. Probable value by bisector of angle

Fig 5

Romnger & Rutledge



3½"

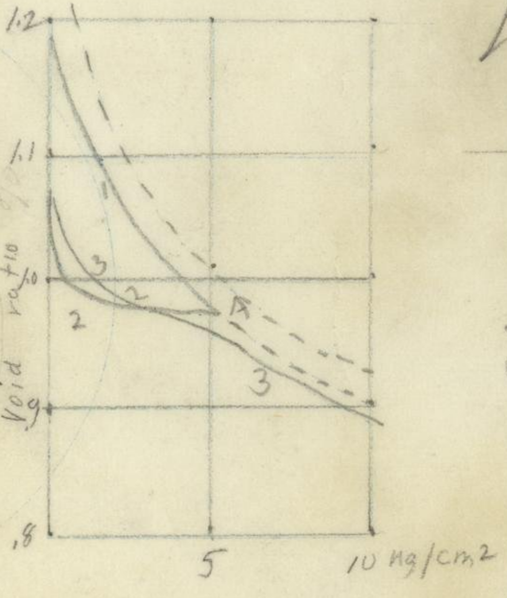


Fig 3

3½"

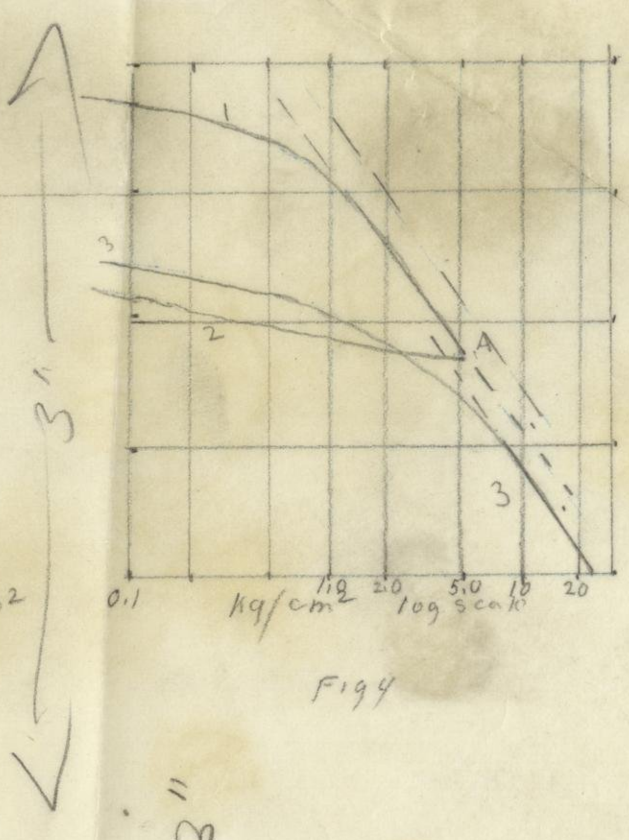


Fig 4

3"

put on same line