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Pacific Landforms and Vegetation: OPNAV-16-VP 107, May 1945 -- [Part 1, Landforms]

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Pacific Landforms and Vegetation  
OPNAV-16-VP 107, May 1945

by  
Air Intelligence Group  
Division of Naval Intelligence  
Office of the Chief of Naval Operations  
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Abstract

On the cover this report is listed as Photographic Intelligence Center Report 7, May 1945.

Note: The title page was torn out.

The purpose of this report is to acquaint photo interpreters with the military geology and vegetation of eastern Asia and the western Pacific areas where World War II was fought. It contains detailed descriptions along with numerous illustrations and photographs of various types.

The forward was signed by Marine Lieutenant Colonel Charles H. Cox as the Officer-in-Charge, Photographic Intelligence Center.

The report contains a list of 39 publications available and in preparation at the US Naval Photographic Intelligence Center.

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LANDFORMS AND VEGETATION

AIR INTELLIGENCE GROUP, DIVISION OF NAVAL INTELLIGENCE
OFFICE OF THE CHIEF OF NAVAL OPERATIONS, NAVY DEPARTMENT

MAY 1945
FOREWORD

It is the purpose of this book to acquaint the Photographic Interpreter with the predominant landforms and vegetation types of the Pacific Ocean Area. Numerous examples of these various types are shown in vertical, oblique, and ground views, with short descriptions to facilitate understanding in each instance. Whenever possible, emphasis has been given the military significance of the landform and vegetation types so that properly worded terrain reports may be prepared by reference to this publication.

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PART 1

LANDFORMS
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Restricted
INTRODUCTION

Landforms are frequently classified as Constructional or Destructional. Constructional forms include the large elements of the landscape which owe their origin essentially to forces within the earth (Endogenetic). Plains, plateaus and mountains fall in this category. Destructional forms are smaller elements that result from erosional forces acting on the major elements (Exogenetic). Any features produced by rivers, glaciers, waves, wind or weathering fall in this group.

A proper understanding of the physiography of an area requires that the interpreter recognize first, the Structure, whether it is plain, plateau or mountain; second, what Process has acted upon it, as streams or wind; and third, what Stage of development has been reached, youth, maturity, or old age.

Although an orthodox treatment of landforms usually follows the above order, thereby considering first plains, plateaus and mountains, the first section here is concerned with the physiographic cycle. This variation is used because subaerial erosional forces act on constructional forms from the instant that they are exposed above sea level. Therefore, needless repetition is obviated by preliminary analysis of the processes and stages that concern all landforms. Further, the major emphasis is given to the development of the physiographic cycle in a humid climate because it is more applicable to the problems of the Pacific. Stream patterns and the influence of climate on slope shapes and differential rock resistances are also briefly discussed.

In succeeding sections landforms that are associated with various structural elements and erosional forces are described briefly. Although genetic discussions and the use of technical nomenclature have been minimized, the terminology should prove adequate for the interpreter to write concise understandable reports without excessive empirical description. Because visual observation enables more rapid assimilation of the characteristics of landforms, text detail has been sacrificed for the large number of illustrative photographs.
PHYSIOGRAPHIC CYCLE AND STREAM DEVELOPMENT
PHYSIOGRAPHIC CYCLE AND STREAM DEVELOPMENT

PHYSIOGRAPHIC CYCLE AND STREAM DEVELOPMENT

The Cycle of Erosion is the time required for streams to reduce a newly formed land mass to base level (lowest erosional level—usually sea level). The Physiographic Cycle deals with the topography developed during the various stages of a cycle of erosion.

The topography will at first be youthful; gradually, it will attain maturity; finally, as the relief is diminished and base level is approached, the land surfaces will have become old.

The same terms, young, mature, and old, apply to streams. Although it is difficult to classify streams categorically by age, those that are actively down-cutting may be considered young, those that have attained grade, mature, and those that meander and deposit excessively, old.

In the humid cycle, Youthful Topography is characterized by wide, flat divides and streams with steep-walled, V-shaped valleys. There are usually few streams. These youthful streams, however, have high gradients and are actively cutting their valleys deeper. Waterfalls and rapids are numerous. Drainage is poor and immature, with lakes and swamps on the divide areas. Travel is often difficult along youthful streams and the steep valley walls and swamp areas are normally impediments to transverse routes.

Maturity is the stage of maximum ruggedness: divides are narrow, valley walls are less steep, the soil cover is thicker, many well developed tributaries drain the area, major mature streams are at grade (neither erosion nor deposition is dominant); valley flats, terraces, incipient meandering, and narrow flood plains are all characteristics. Travel, at best, is difficult through such regions. Usually the major valleys offer more favorable routes. if, however, the divides are relatively wide and continuous, these may be utilized.

In Old regions the divides are low, slopes are gentle and the whole landscape is subdued and near base level. The master streams are entirely graded and meander and deposit over their broad flood plains. These Meanders result from the lateral exertion of a stream's energy. Figure 1.12 has the many associated landforms annotated. It should be recalled that the current is swiftest and the streams deepest on the outer sides of the curves, the Undercut slopes. During flood appreciable deposition occurs along the stream banks which forms Natural Levees. These frequently offer the only ground suitable for transport.

It should be noted that a blending of stages is the rule rather than the exception. In a region of general youthful characteristics, some master streams and valleys may be mature, and conversely, in a mature region there will be some recently formed youthful streams and valleys.

Frequently the age of streams has little bearing on the stage of the physiographic cycle because the normal cycle may be interrupted at any time and another cycle begun. Rejuvenation results from an increase of stream gradient or volume or a decrease in load. Each one increases the stream's erosive ability and youthful valleys are formed. When an old region, a Peneplain, is uplifted, the streams develop new tributary systems and begin dissection of the old land. The summit areas will likely remain concordant until the region has again passed through maturity. If a mature region is uplifted, youthful valleys will be cut in the valley floors leaving Terraces. Entrenched Meanders are excellent criteria of such rejuvenation. If there is a decrease in gradient or volume or an increase in load, the stream's erosive and transporting ability is reduced and deposition occurs. All down cutting stops, valley floors are alluviated, and Braided streams may form.
Although the arid and humid physiographic cycles are similar in many respects, the difference in amount of rainfall, vegetation, and weathering requires a short description of features associated only with the arid cycle.

Arid region drainage is often centralized in Interior Basins (Holsens). In youth, short consequent intermittent streams cut V-shaped valleys in the mountain slopes. Alluvial Fans form at the mouths of the valleys and shallow Playa Lakes may form in the basins. Dunes may develop from the action of wind on the silts and sands deposited by the streams. The relief of the region is reduced rather than increased as in the humid cycle.

In maturity, the mountain fronts are reduced and cut back, divides are narrowed and the basins become wider and higher because of valley fill. The receding fronts may be separated from the alluvium by narrow, beveled rock plains (Pediments). Alluvial fans may have coalesced to form broad alluvial plains or Piedmont Plains.

In old age, the highlands are largely worn away; wind-scoured hollows and dunes are more numerous. Wind erosion may continue until the water table is reached, which is base level for the arid cycle.

Like the normal humid cycle, the arid cycle may be interrupted at any time.

Climate controls the weathering and erosion of rock masses to a large extent. Chemical Decomposition is most effective in warm humid climates and Mechanical Disintegration in cold and arid climates. Shales and sandstones are of the same order of resistance in all climates; sandstones usually form ridges and shales valleys. Limestones, which include coral, are very soluble rocks under humid conditions. In cold or arid regions, however, limestones may be ridge formers. Sedimentary rocks are generally less resistant than igneous rocks (solidified molten rock); acidic igneous more so than basic. Metamorphic rocks (modified by heat and pressure) vary considerably, depending on composition and structure; quartzites are very resistant. Flash flood precipitation and the lack of vegetal cover cause slopes in arid regions to be sharp and angular throughout the cycle rather than becoming round and smooth as in the humid.

A special erosion cycle may occur in humid areas underlain by thick horizontal limestones. Initial surface drainage is diverted underground as the soluble limestone becomes honeycombed with Sinks (circular surface depressions) and Caverns. In maturity, cavern roof collapse and sink coalescence form solution valleys and the resultant highly irregular surface is termed karst topography. By old age only irregular spaced ridges and Monadnocks (erosional remnants) remain and streams flow on underlying insoluble rocks.

Stream patterns are invaluable in the determination of the structure and, allied with vegetal types, the composition of rocks. During maturity, the stage of maximum relief, stream patterns are most strikingly presented. Here, as in the blending of physiographic types, many combinations and modifications occur.

A Dendritic pattern occurs in regions of homogeneous or flat-lying sedimentary rocks. The streams show little structural control and, as the name indicates, the systems assume a branch-like pattern. The streams are Consequent because their courses are determined by original surface irregularities.
PHYSIOGRAPHIC CYCLE AND STREAM DEVELOPMENT

FIG. 1.02  TRELLIS STREAM PATTERN

A Trellis pattern results from structural control and is found in regions underlain by tilted or folded sedimentary strata. The parallel streams follow the less resistant formations and are termed Subsequent. Rectangular

FIG. 1.03  RECTANGULAR STREAM PATTERN

patterns closely resemble trellis and are found in regions with well developed joint or fault systems. Cuestas and Hogbacks are conspicuous landforms associated with trellis drainage and subsequent streams. Cuesta is

FIG. 1.04  WATER AND WIND GAPS

applied to a long, narrow ridge formed where dips are low; the gentle slope is the dip slope, the steep slope the escarpment slope.

FIG. 1.05  RADIAL STREAM PATTERN

Radial patterns are found on young dome mountains and volcanoes. The streams flow outward in all directions from the high central area. An Annular pattern results when subsequent streams develop a circular course around a domed landform.

FIG. 1.06  ANNULAR STREAM PATTERN

The resistance, structure and permeability of a rock usually determine the texture of a stream pattern. If the rock is weak, as clay or shale, or thinly bedded, the drainage system is well developed with many tributaries and the texture is Fine. Badland topography, which occurs under arid or semi-arid conditions, is an extreme example. If the rock is resistant and massive, as granite and sandstone, or permeable enough that underground drainage becomes important, there will be few tributaries and the stream pattern exhibits Coarse Texture.
FIG. 1.07
A young consequent stream actively eroding a recently uplifted alluvial plain. Note the narrow "Y"-shaped valley, the paucity of tributaries, and the level divide area. During dry periods, travel, which does not cross drainage lines, is relatively simple on the undissected uplands.

FIG. 1.08  NEW BRITAIN
An oblique stereopair that shows young streams incising themselves in a relatively undissected lava plateau. The fine textured pattern developed on the divide areas is largely a result of the initial irregularities of the lava surface. All the low places have not yet been connected; integration is incomplete. Rain forest has combined with terrain to make movement unusually difficult.

FIG. 1.09  NEW GUINEA
An oblique stereopair of a mature mountainous region drained by young streams. The entrenched meanders are indicative of at least local rejuvenation. The stream pattern is dendritic.
FIG. 1.10

An example of maturity developed in easily eroded volcanics under subartic conditions. Note the narrow divides and wide valleys. The wide flood plains result from excessive alluviation.

FIG. 1.11  EMPRESS AUGUSTA BAY, BOUGAINVILLE

A low coastal plain with a meandering stream and numerous meander scars. Near the top of the stereopair are two meanders near the cut-off stage. The river mouth spit indicates long shore currents from right to left.
FIG. 1.12  BURMA
Stream meanders and associated features: meander scars, spurs, necks, oxbow lakes, undercut and slip-off slopes.

FIG. 1.13  BURMA
Natural levee along a large river near flood stage. When a river overflows its banks, velocity and transporting ability decrease abruptly. Coarsest material is deposited first. The levees are frequently the most stable ground.
PHYSIOGRAPHIC CYCLE AND STREAM DEVELOPMENT
ARID, BADLAND TOPOGRAPHY—SLUMP—ALLUVIAL FAN—LANDSLIDE

FIG. 1.21
Badland topography developed in non-resistant sediments under arid conditions. Note the level upland surface, the monadnocks and the fine textured dendritic drainage pattern.

FIG. 1.22
Slumping in homogeneous fine grained sediments that have become saturated.

FIG. 1.23
A small alluvial fan composed of eroded volcanics. Note the braided stream and alluviated valley.

FIG. 1.24
Landslides in unconsolidated material along an oversteepened valley.
FIG. 1.18 NEW GUINEA
Mature upland topography which has been little modified by two rejuvenations. Terrace levels are well developed. The ungraded stream indicates that it is now youthful.

FIG. 1.19 NEW GUINEA
An oblique that shows a mature mountainous area and two stream terraces.

FIG. 1.20
A braided stream. The stream's channel is choked when the gradient or volume is decreased or the load increased. Gradient usually decreases when streams flow from mountainous areas and volume when through arid regions. Note the alluviation.
PHYSIOGRAPHIC CYCLE AND STREAM DEVELOPMENT
ARID, BADLAND TOPOGRAPHY—SLUMP—ALLUVIAL FAN—LANDSLIDE

FIG. 1.21
Badland topography developed in non-resistant sediments under arid conditions. Note the level upland surface, the monadnocks and the fine textured dendritic drainage pattern.

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Slumping in homogeneous fine grained sediments that have become saturated.

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A small alluvial fan composed of eroded volcanics. Note the braided stream and alluviated valley.

FIG. 1.24
Landslides in unconsolidated material along an oversteepened valley.
FIG. 1.25
Talus cones at the base of a cliff composed of poorly sorted sands, gravels, and boulders. The finest material is found at the apex of the cone. The reverse is true of alluvial fans or cones.

FIG. 1.26 FRENCH INDO-CHINA
Karst topography. Note the very rugged terrain and wide alluviated valley.

FIG. 1.27
Dendritic drainage in a maturely dissected region. Note incipient flood plains.

FIG. 1.28 CHINA
Trellis drainage, subsequent streams, water gaps and beach ridges.
FIG. 1.29  CHINA
Trellis drainage in a series of steeply dipping sediments. The major stream transects structural ridges through water gaps. Subsequent streams follow the less resistant formations.

FIG. 1.30
Radial drainage on a small volcano with a breached crater.

FIG. 1.31
Oblique view showing the rather rugged surface created by radial gully ing in volcanic ash on the lower slopes of the cinder cone shown in the accompanying view.

FIG. 1.32
A volcano with wave-cut perimeter, two recent flows, tombolo and spit.
FIG. 1.33  CANTON, CHINA

An illustration of various constructional and destructional features. Note the complex mountains and the partially buried hogback ridges which are erosional remnants of fold mountains, the excessive alluviation exhibited by the wide expanse of flood and piedmont plains, the water and wind gaps, and the tributary and distributary systems.
SHORELINES, BENCHES, AND TERRACES.
SHORELINES, BENCHES, AND TERRACES

SHORELINES

Shorelines are usually classified as submergent, emergent, neutral or compound. Each has characteristic landforms that are developed by wave and current action under various conditions. These features are valuable in the analysis of landing sites.

A shoreline that has resulted from recent submergence is irregular to an extent determined by the nature of the surface depressed; stream valleys become bays; ridges and hills, peninsulas and islands. As wave erosion modifies the shoreline, cliffs are cut in the headlands and the detritus is deposited as beaches, spits and bars. Figures 2.04 to 2.11 illustrate the various types. By maturity the headlands have been cut back to the bay heads and the shoreline is quite regular.

The character of an emergent shoreline is dependent upon the nature of the raised surface. Along well developed coastal plains emergent shorelines are regular, and initial wave erosion carves a low cliff or rip. Subsequently, wave erosion and deposition result in the formation of an Offshore Bar or Barrier Beach which is separated from the shore by a brackish or salt water lagoon. Entrances or passages are usually maintained by tidal scour. As wave erosion forces the barrier beach shoreward, the lagoon is filled with sediment; by maturity, beach migration has destroyed the lagoon and the shoreline is not unlike a mature submergent shoreline.

Marine Benches and Terraces are found only on emergent shorelines and are best developed where offshore slopes are moderately high. Technically, the bench represents the portion that results from degradation and the terrace the part that has been formed by deposition of the detritus. In the tropics, many terraces are the elevated reef flats of fringing coral reefs. In any case, each terrace or bench represents a position of sea level in the past.

FIG. 2.01 ELEMENTS OF THE COASTAL ZONE

FIG. 2.02 SUBMERGENT SHORE CHARACTERISTICS

FIG. 2.03 EMERGENT SHORE CHARACTERISTICS
If multiple terraces are present, each is usually separated from the other by a cliff or sharp topographic rise. Some of the platform islands of the Pacific, as Tinian Island, consist of level central terrace areas surrounded by terrace rings. The character of bench and terrace surfaces is dependent upon the pre-uplift surface and erosional modification. Coral surfaces are usually rough, not only because of the originally uneven reef surfaces, but also because of solution effects since uplift. The oldest terrace is the highest and usually the roughest. Bench and terrace soils depend on the composition of the underlying rock and on the time interval since uplift. Old terraces may have deep residual soil. Movement between terrace levels is ordinarily easiest along stream valleys.

There are two minor types of shorelines: Neutral and Compound. The more important neutral shorelines include fiord, fault, reef, delta, and volcanic. The fiord is rugged and characterized by long, narrow, steep-walled inlets, the second is manifested as a fault scarp or cliff, the other three result from deposition on a static shore. Compound shorelines exhibit features that result from superimposition of the various types.

Aerial photographs, both high and low altitude, furnish the best means for beach analysis with the exception of actual ground reconnaissance. Although special techniques are available that enable reasonably reliable depth determinations, an experienced interpreter can frequently make fair estimates from a cursory examination and comparison with other photographs. Shapes and positions of spits and bars indicate the direction of currents and the attitude of wave fronts. The width of the beach may indicate the shape, composition, compaction, and underwater slope. A narrow beach is usually associated with steep landward slopes, coarse loose sands or gravels, and relatively high off-shore slopes. A wide beach ordinarily has gentle landward and underwater gradients and is likely to be composed of fine compacted sands. Some indications of the composition and grain size of the beach may be obtained from deposition and source studies. Sand dunes are common on emergent shorelines; the direction of prevailing winds is indicated by the shapes of the dunes.

For a comprehensive analysis of beach conditions, the interpreter is referred to Photographic Intelligence Center Report No. 4, Beach Interpretation.
Irregular headlands and branching embayments of drowned valleys along a youthful submergent shoreline. The absence of beaches indicates a lack of wave and current action. The approaches are steep and underwater gradients are high.
FIG. 2.06 DROWNED RIVER VALLEY
A drowned river valley with meander spurs still conspicuous. Sand dune development occurs on an old flood plain.

FIG. 2.07 TOMBOLO
A tombolo that has joined an island to the mainland.

FIG. 2.08 SPIT
A simple curved spit. The spit points in the direction of the current.
SHORELINES, BENCHES, AND TERRACES
BAY MOUTH BAR — SUBMERGENT KARST TOPOGRAPHY

FIG. 2.09 FORMOSA
A baymouth bar. Rivers emptying into the enclosed bay are gradually filling it with deltaic deposits.

FIG. 2.10 SUBMERGENT KARST, FRENCH INDO CHINA
A submergent karst shoreline. The crater-like bays are sink holes that have been breached by wave and solution action. The small "pocket" beaches are in most cases satisfactory for landing craft. Egress, however, is obviously restricted.
A coastal plain on an emergent coast. There is a beach ridge that rises slightly above the contiguous inner plain as well as several fossil beach ridges inland. The smooth regular shoreline is typical of emergent coasts.

Sand dunes on an emergent coast. Dunes stabilized by vegetation offer best travel route. Current here moves from top to bottom. Note that deepest water is found off heads of spits where current is strongest.
SHORELINES, BENCHES, AND TERRACES
EMERGENT

FIG. 2.13
Barrier beach and partially filled salt or brackish water lagoon. The beach is composed of fine-grained, firmly packed material and the underwater gradients are low. Travel is obviously confined to the bar.

FIG. 2.14 JAPAN
An emergent shoreline that exhibits slight recent uplift. Note the regular shoreline, the wave-cut nip, the incision of the youthful stream which resulted from rejuvenation and the dammed valleys.
FIG. 2.15 UNDISSECTED TERRACE  A recently uplifted, undissected marine bench.

FIG. 2.16 DISSECTED TERRACE

Maturely dissected marine benches and terraces. Although the higher (older) levels have been modified much more than the lower levels, they can be identified by the concordance of interstream divides. Travel is obviously difficult.
SHORELINES, BENCHES, AND TERRACES
EMERGENT

FIG. 2.17 DANA ISLAND
An uplifted coral reef flat that has been denied to aircraft by ground obstructions. Note the cross faults inland.

FIG. 2.18 CORAL TERRACES
Concentric coral terraces on an elevated headland.

FIG. 2.19 AGUIJAN ISLAND
An elevated coral platform island surrounded by multiple coral terraces. On undissected terraces movement between levels is difficult and usually entails considerable cut and fill. Coral terraces remain unmodified longer because the permeability of the rock permits underground drainage.
FIG. 2.20 ARCUATE DELTA, HAINAN ISLAND
A typical arcuate delta. Note the braided stream, the distributary system, the mud flats, mouth deflection as a result of longshore currents from top to bottom, and the periphery beach built by wave action.

FIG. 2.21 BIRD'S FOOT DELTA
Bird's Foot Delta. Distributaries maintain relatively regular channels as compared to those in Figure 2.20, a result of the deposition of finer, less permeable sediments.

SHORELINES, BENCHES, AND TERRACES
DELTA—RIVER MOUTH DEFLECTION

FIG. 2.22 RIVER MOUTH DEFLECTION
A river mouth deflected by longshore currents. Wave and current action are responsible for the regular beach and lack of delta.

FIG. 2.23 ESTUARINE DELTA
Small estuarine delta that was built by drainage from an alluviated glacial trough. The incision of the stream indicates recent slight uplift. Deltas found in such sites are composed of relatively coarse material and are comparatively stable. They frequently furnish the only landings as well as egress inland.
SHORELINES, BENCHES, AND TERRACES
NEUTRAL

FIG. 2.24 STRUCTURALLY CONTROLLED SHORELINE
A series of faulted sedimentaries that illustrates the scarp slope and dip slope (slope formed by surface of one formation) as well as the linear character of the shoreline.

FIG. 2.25 FIORD SHORELINE
A typical fiord shoreline. These long narrow deep inlets bordered by oversteepened valley walls are formed by glaciers that have eroded below sea level.

FIG. 2.26 BEACH RIDGES
Beach ridges (berms) on a neutral shoreline. Each ridge is formed by wave action, largely storm waves. An excessive amount of sediment available has facilitated the process here.
PLAINS AND PLATEAUS
PLAINS AND PLATEAUS

PLAINS AND PLATEAUS

Plains and Plateaus are usually underlain by horizontal or very gently dipping strata. The formations upon which the surfaces develop may range from unconsolidated sediments, clay, silt, or sand, to consolidated sediments, shale, sandstone, or limestone, or to extrusive igneous rocks as lavas and volcanic ash. The essential difference between a plain and plateau is the available relief. Plains are relatively near base level which means that valleys will be shallow, conditions which are usually associated with sites near sea level; while plateaus are elevated regions, frequently cut by deep valleys, high above base level, criteria that are ordinarily confined to areas some thousands of feet above sea level.

The origin, composition, and characteristics of the more common types of plains follow:

Coastal Plains result from regional emergence of the sea floor. The surface is usually composed of clays, shales, silts, sands, or gravels. Drainage is frequently poorly developed and during wet periods travel may be difficult or impossible.

Example: Coastal Plain in the Southern Seaboard and Gulf States.

Flood, Lake, and Delta Plains result from deposition of sediments under conditions associated with the various features. Since muds, silts, and sands are typical deposits, travel in wet weather may be impossible.

Example: Ohio River, Red River Valley (North Dakota and Minnesota), and the Mississippi River Delta.

Piedmont Plains, as the name indicates, are found at the foot of mountains. The plain is formed by deposition of overloaded streams which results from the abrupt change in gradient as they flow from the mountains. Dips may be quite high; silts, sands, and gravels are the usual deposits. Drainage, and, concomitantly, travel, is usually good, although steep sided arroyos, which frequently dissect higher portions of the plain, may provide difficulties.

Example: Great Plains.

Glacial Plains consist of moraine and outwash material deposited on a relatively level surface. The sediments may be well sorted.

FIG. 3.01 COASTAL PLAIN

FIG. 3.02 FLOOD PLAIN

FIG. 3.03 LAKE PLAIN

FIG. 3.04 DELTA PLAIN

FIG. 3.05 PIEDMONT PLAIN
If deposited directly from water, as an outwash plain, or heterogeneous if laid down by the ice. Silts, sands, gravels, and boulders are the usual materials and, although lakes, ponds, and swamps may be common, high areas are usually well drained and travel routes should be easily determined from photographs.

Example: Northern Minnesota.

Loessial Plains are composed of wind or water transported and deposited material of desert or glacial origin. The homogeneous dust-fine deposit usually stands in peculiar vertical walls. Drainage and erosion are rapid.

Example: North China.

Tundra Plains are largely a result of ground ice which consolidates mantle rock to complete imperviousness. In summer, melting of the surface may make travel difficult or impossible.

Example: Northern Canada and Northern Siberia.

Lava Plains are formed by quiet fluid extrusions which completely cover the pre-eruption terrain. Dips are gentle and beds of volcanic ash, which result from explosive action, are frequently found between successive flows. Example: Iceland.

As previously stated, plateaus differ essentially from plains in the amount of available relief. All of the above types of plains may be classified as plateaus under certain base level relationships. Since, however, erosion is more effective when the available relief is large, plateaus are usually capped by relatively resistant consolidated sediments or lava flows. Flat-topped Buttes and Mesas are conspicuous remnants.

With dissection, plains and plateaus assume quite a different aspect. Both become much more rugged; plains, hilly; plateaus, even mountainous. As maturity is attained, dissected plateaus give rise to Residual Mountains, as the Catskill Mountains of New York State, if the available relief is sufficient and the drainage coarse textured.
PLAINS AND PLATEAUS
COASTAL-DELTA-FLOOD

FIG. 3.12 COASTAL PLAIN
Recently uplifted coastal plain. Note the undissected character of the
surface and the regularity of the shoreline.

FIG. 3.13 DELTA PLAIN AND FLOOD PLAIN
A well developed flood plain, a small delta plain, a water gap, and
subsequent streams.
FIG. 3.14 PIEDMONT PLAIN, MINDANAO

A piedmont plain in a humid climate. Except for the small valleys, travel is obviously simple.

FIG. 3.15 JAPAN

Maturely dissected ridges separated by broad alluvial plains devoted to rice culture.
PLAINS AND PLATEAUS
ARID, PIEDMONT

FIG. 3.16 PIEDMONT PLAIN, ARID REGION
Piedmont plain at the foot of block mountains in an arid region. Ripples on the sand dunes indicate that wind direction is from left to right.
FIG. 3.17 TUNDRA PLAIN
A region of volcanic rocks that has been smoothed by glacial action. Ponds occupy ice-scoured depressions. The undulating plain is now covered by tundra.
FIG. 3.18 YOUNG PLATEAU
A young plateau. Dissection of the level upland by headward erosion of youthful streams is diagrammatically shown. The smooth valley walls indicate homogeneous rock.

FIG. 3.19 MATURE PLATEAU
A dissected lava plateau covered by tropical rain forest. The major streams occupy deep narrow canyons. The minutely dissected upland area stems from initial surface irregularities. There is also evidence of rejuvenation.
FIG. 3.20 PLATEAU REMNANTS

Erosional remnants of a plateau.

FIG. 3.21 OLD PLATEAU

A butte. An erosional remnant of a plateau. The resistant cap rock indicates the former level.
Mountains are usually defined as land masses of small summit area which rise conspicuously above the surrounding country. Although most mountains owe their origin to several factors, the dominant land forms often develop as a result of erosional forces that are guided by one type of structure. A simplified genetic classification and the physiographic development of each follow:

**Dome Mountain**

Dome Mountains are formed by uplift of a domal character which results from warping caused by compressional stresses or from the intrusion of igneous material. In the youthful stage, dome mountains are drained by streams whose headwaters rise near the center of the uplift. As erosion proceeds and the stream courses are modified by structural control, the radial drainage pattern is changed to annular with water or wind gaps located where the consequent streams cut through the resistant formations. This marks the mature stage, the stage of maximum relief, when a series of conspicuous hogback ridges usually encircle the uplift. Although the central igneous core may have been exposed at any time in the physiographic cycle, during old age erosion will have uncovered the greatest portion and will have reduced the relief features to a monotonous plain interrupted only by an occasional hill (Monadnock or Erosional Remnant).

Dome Mountain Example: Black Hills of South Dakota.

**Fold Mountain**

Fold Mountains are formed by stresses that compress sedimentary strata into a series of parallel Anticlines (upwarps) and Synclines (downwarps). In youth, streams are largely consequent and follow the structural valleys; with continued erosion, however, anticlines are breached and the stream courses are

**Fault Mountain**

Fault or Fault Mountains are formed by large vertical movements of segments of the earth's crust along faults that may be many
Complex Mountains result when intense disturbances, folding, faulting, and igneous intrusions and extrusions, effect a region. Earth forces of such magnitude frequently alter the rock to such an extent that recrystallization takes place and metamorphic rocks are formed. Under such varying conditions a categorical discussion of drainage or physiographic development is impractical. If the underlying rock is of a relatively uniform igneous type, drainage will assume a dendritic pattern. If it is well-banded metamorphic rock, a trellis-like pattern may form; sediments exert only local control. In these mountains, as in others, maturity is the stage of maximum relief and ruggedness.

Complex Mountain Example: Great Smoky Mountains

Volcanic Mountains are discussed in a special section, while Residual Mountains are briefly mentioned under plateaus.

Travel in any mountainous region is difficult. In practically all instances the interpreter will find that major stream valleys afford the best routes as well as lead to the lowest passes. If, however, undissected uplands that are amenable to transport exist, a study of the photographs should easily determine the route.
FIG. 4.08 FORMOSA, DOME MOUNTAIN

A very small dome mountain that effectively illustrates the characteristics of the larger types. Note the radial drainage pattern in the igneous mass, the hogback formed by sedimentary rocks and the annular drainage at the periphery.

FIG. 4.09 FOLD MOUNTAINS

An excellent example of fold mountains. Resistant members form ridges while non-resistant formations furnish sites for the subsequent streams. Water and wind gaps integrate the trellis drainage.

FIG. 4.10 OLD FOLD MOUNTAINS

Old fold mountains.
FIG. 4.11 HONG KONG, COMPLEX MOUNTAINS

A complex mountain mass cut by parallel faults. The rock is massive and homogeneous; probably igneous.

FIG. 4.12 BLOCK OR FAULT MOUNTAINS

Block or fault mountains in the distance. Each range is bounded by a fault along which large vertical movement has occurred. Note the piedmont plain formed by coalescent alluvial fans and the interior drainage to the basin.

FIG. 4.13 FORMOSA, COMPLEX MOUNTAINS

A complex mountain mass. Although it is impossible to determine the type of rock, from the regularity of the dendritic drainage pattern, valley slopes, and tone it may be assumed that the rock is largely homogeneous.
VOLCANOS
VOLCANOS

The forces of volcanism are endogenetic and develop constructional land forms that may result from quiet emission, explosive action, or both. The type of eruption is determined by the viscosity of the lava, which depends on the composition of the magma (molten rock). Basic magma is very fluid, while acidic magma is viscous and eruptions are usually marked by explosive violence with much ejecta (volcanic ash, bombs, etc.).

Fissure eruptions result from an upwelling of basic magma through a fracture. These give rise to extensive Lava Plains or Plateaus; the Columbia River Plateau covers 200,000 square miles with lava up to 4000 feet thick. These plateaus pass through normal physiographic cycles with lava capped buttes and mesas outstanding features.

The shapes of volcanic cones are largely dependent upon the composition of the parent magma. Shield Cones may present large topographic features but dips of the flows are low. The Hawaiian volcanoes are in this group. Dome Cones differ from shield cones in that they are much steeper, have narrower bases, and are built by lavas of intermediate viscosity. Mt. Lassen falls in this category. Composite Cones result from explosive eruptions and lava flows. Slopes are steep and dips are high. This type constitutes the majority of the great volcanoes; Fujiyama is an excellent example. Cinder Cones result from explosive action alone. They are developed as the fragments fall back around the orifice and are usually of relatively small size. Small cones that form on the flanks of larger cones are termed Parasitic Cones; they are usually Cinder or Composite Cones.

A large, low rimmed crater or Caldera may result from either explosive activity or subsidence. If at sea level, calderas may make ideal harbors (Rabaul, New Britain). New cones commonly build up within a caldera and produce a series of Nested Craters.

Erosion is abnormally active on volcanic land forms because of the steep slopes. Fresh ash, in addition to becoming greasy when wet, is soon dissected by steep walled gullies that make travel unusually difficult. Recent flows are difficult to traverse because of the rough surface; furthermore, valleys are usually steep walled and form effective barriers. Lava Caves are formed when the surface of a flow solidifies and the still molten underlying rock moves on, or by differential weathering along a cliff face. These caves frequently afford excellent storage and strong defensive positions. Lava weathers to form red residual soils that may prove very sticky when wet.

Volcanoes are found along well defined belts or arcs which mark zones of weakness in the earth's crust. The "Ring of Fire" around the Pacific extends along the American Cordillera from Cape Horn to the Aleutians, the Kuriles, Japan, the Philippines, New Guinea, the Solomons, New Hebrides, New Caledonia and New Zealand. A similar chain extends through the Netherlands Indies. All the islands in the Pacific Oceanic province are of volcanic origin.
FIG. 5.03 DUBLON ISLAND, TRUK
A volcanic island that has been exposed to erosion for a considerable period. The rock that crystallizes in the conduit of a volcano is usually more resistant than that of the flanks. The sharp peak here indicates such a relationship.

FIG. 5.04 SEGULA ISLAND
A young composite volcano. The separation of successive lava flows by ejecta or weathered material creates the banded effect.

FIG. 5.05 IWO JIMA
An oblique stereo view of Suribachi Yama, a cone partially destroyed by wave action. Wave-cut nips along the beach indicate recent uplift.

FIG. 5.06 PAGAN ISLAND
A cone with two prominent parasitic cones.
VOLCANOS
CALDERAS—CINDER CONE

FIG. 5.07 ONEKOTAN ISLAND, KURILES
An ideally symmetrical composite cone in a water-filled caldera (crater lake).

FIG. 5.08 RABAUL HARBOR, NEW BRITAIN
This stereo pair shows part of an excellent caldera harbor which is steep-to and has maximum depths of 150 fathoms. Vulcan Island, now joined to the caldera rim, consists largely of ejecta and is of very recent origin.

FIG. 5.09 VULCAN ISLAND
A large scale stereogram that shows the modification of the surfaces since 1937. Note the sharp gullies (barrancas) cut in the ash.
FIG. 5.10 KURILES

A lava tongue. Note the disposition of older flows, and the flow lines and lateral walls on the most recent flow.

FIG. 5.11 LAVA

An example of an unusually rough lava surface. The lava tongue has moved down a nested crater trough.

FIG. 5.12 LAVA FLOW

A low altitude oblique that shows the abrupt terminus of a lava flow and the character of the surface.
FIG. 5.13 ALEUTIANS

A mud flow that has resulted from water saturation of volcanic ash.

FIG. 5.14 LAVA FLOW, SAKURA JIMA

A stereopair that illustrates the rough surface of a recent lava flow in the subtropics.
FIG. 5.15 IWO JIMA

A volcanic island that has been truncated by wave action. Note the wave cut benches. The rough surface reflects the joint pattern.

FIG. 5.16 GAROVE ISLAND

A stereoview that indicates the type of surface that develops on relatively young volcanic flows in the tropics.

FIG. 5.17 FUJIYAMA

An oblique of Fujiyama that shows the pattern of cultivation far up the slopes. The drainage pattern and recent flows stand out.
Coral Reefs
CORAL REEFS

Coral Reef is a variety of limestone that is formed by small, primitive marine animals (Polyps) that secrete limy external skeletons. Factors that control and limit the growth of coral are salinity, turbidity, depth and temperature. Coral will not grow in muddy or brackish water, at depths over 200 feet, or in water colder than 68° F. Thus, coral formations are not ordinarily found in latitudes higher than 30° or opposite river mouths, factors that may aid in differentiating reefs and mud flats.

Coral Reefs are composed of living coral, skeletal accumulations and various plant remains. Living coral usually thrives at the outer edges of the reef where food is abundant.

Coral reefs are grouped in three general classes: Fringing Reefs, Barrier Reefs, and Atolls. Fringing reefs lie close against the shore and form platforms that are exposed at low tide. Unprotected fringing reefs are exposed to wave action which results in relatively regular seaward margins. Protected fringing reefs have irregular margins with many coral stringers and tidal pools. Barrier reefs lie some distance from shore and are separated from it by lagoons. Passages through the reef are usually maintained by the tide. Atolls are reefs, frequently circular, that enclose lagoons. Atolls, also, usually have passages.

Two recognized theories have been promulgated for atoll formation. The Subsidence theory holds that fringing reefs which formed on an island grew rapidly enough to keep pace with its subsidence. An atoll resulted when the land mass was completely submerged. The Glacial Control theory contends that the islands were truncated during the glacial period when the ocean level was lowered some 300 feet and cooler water inhibited protecting coral growth. When the water warmed, coral resumed growth on the wave-cut benches and built fringing reefs. These became atolls when the water locked in the glaciers returned.

The lagoons of coral atolls may be filled and with slight uplift coral islands are formed. If this filling has a high percentage of fish remains, phosphate deposits may result. Mauuru, Ocean, Marcus, and Anguar are of this type. Since coral is porous, soluble rock, an uplifted fringing reef will indicate an area easily defended because of caves and rugged terrain.

The evaluation of reef conditions from aerial photographs is difficult. High altitude coverage frequently fails to indicate the presence of nigger-heads and tidal pools as well as the composition of the lagoonal beaches. Undefended reef flats, however, dip gently to the seaward margin. Since the margin is usually at the level of low tide, tide tables will give an indication of depths to be expected.
FIG. 6.03 GUADALCANAL

Unprotected fringing reef. Note the reef chutes at the outer margin and the uplifted terraces.

FIG. 6.04 REEF ROCK

A 350' coral cliff that resulted from reef uplift. Arrows indicate sea level at different times.

FIG. 6.05 KILINAILAU ISLAND

A small atoll with a few small reef islands. Note the passages to leeward and coral heads in the lagoon.
FIG. 6.06 BABELTHUAP ISLAND, PALAU
Protected fringing reef. The black patchy areas near the margin are live coral; the light part is dead. The barrier reef can be seen in the left background.
FIG. 6.07 JALUIT ATOLL

A large sinuous atoll with relatively large reef islands. The shallow passages in the foreground are largely exposed at low tide. Most of this reef is dead.
A vertical stereo at 1:13,750 of the cantilever pier and phosphate refinery. Note the beach detail.

An oblique of the same area. It is obvious that a proper evaluation of the beach cannot be made from the stereopair.
FIG. 6.10 ANGAUR, PALAU

Stereopairs that show a phosphate island.
Compare the beach detail with that of the
low altitude oblique.

FIG. 6.11 ANGAUR, PALAU

The low altitude oblique clearly shows the
rough irregular surface of the uplifted
dead reef and the smooth character of the
beach.
This annotated stereogram (1:10000), when compared with the 12 ground photographs, illustrates the difficulties of accurate beach analysis from high altitude photographs. It is obvious that tone is not a diagnostic criteria of the character of beach material.
FIG. 6.13 Surf on the seaward margin. Water in the foreground is about 6 inches deep and the waves are 4-5 feet high.

FIG. 6.14 Beach and reef flat at low tide.

FIG. 6.15 An estimate of the beach gradient and the elevation of the island can be obtained. About two-thirds of sand zone is covered at high tide.

FIG. 6.16 The landing beach. Although the gradient was satisfactory, the beach could be used only at high tide.

Four photographs that illustrate gradations from sand to irregular shingle beach. No variation is discernable in the vertical photograph.

FIG. 6.21

FIG. 6.22

FIG. 6.23

FIG. 6.24

Four photographs that show the rough character of the dead reef surface. Although this is suggested in the verticals, an accurate evaluation is impossible.
GLACIERS

Glaciers are large masses of ice and snow that move slowly over the land from areas of accumulation. The two major types are Mountain Glaciers and Continental Glaciers. The essential difference is that mountain glaciers are smaller and, since their flows are confined to pre-existing drainage lines, their erosional activity tends to accentuate the ruggedness. Continental glaciers are large enough that their movement is usually unrestricted by pre-glacial topography and they tend to reduce the overall relief.

The landforms and deposits which result from glaciation are varied and numerous. Deposits that have been laid down by water are fairly well sorted while those deposited directly from the ice are heterogeneous. Although most glacial deposits are well drained, it may be generally stated that both types of glaciation increase the difficulty of travel because of the increase of relief or the interruption of drainage.

A brief description of landforms that result from glaciation follows:

Moraines are considerable accumulations of Till (unsorted rock and rock debris) that have been deposited by the glacier. Terminal, Lateral and Medial Moraines are ridges of till deposited at an ice margin. Ground Moraine is till that has been deposited beneath the ice.

Glaciated Valleys are oversteepened "U" shaped valleys which usually have rough floors that result from morainal deposits. Lakes are common.

Hanging Valleys are tributary valleys that enter the main valley at a level above its floor.

Outwash Plains, Valley Trains, Eskers and Kames are all glaciofluvially sorted deposits that have been built by ice-born streams.

Features associated only with mountain glaciation follow:

Cirques are amphitheater-like depressions at the head of valleys which served as the accumulation area.

Aretes are sharp sawtooth mountain divides formed by the headward sapping of cirques on both sides. Cols are saddles formed by the junction of two cirques as a result of headward erosion from both sides of the divide. Cols frequently are utilized as passes.

Fiords are glacial valleys that extend into the ocean. Because of their depth they form excellent channels or anchorages.
Figures 7.03 and 7.04 show typical rugged topography developed by mountain glaciation. The stereogram shows an ice-scoured, U-shaped valley occupied by finger lakes, several cirques and an arete. The oblique permits an evaluation of the terrain. Note the furrows.
FIG. 7.05 TALUS GLACIER

A *Talus* glacier, composed of unsorted gravels and boulders, that has been left by the ice tongue.

FIG. 7.06 ALASKA—GRILLON GLACIER

A, B, and C indicate the positions of formation, respectively, of lateral, terminal, and medial moraines. Notice the flow structure and the rough surface of the ice.

FIG. 7.07 MORAINES

Lateral moraine topography.
Close up of cirque and tarn (cirque lake).
FIG. 7.09 MOUNTAIN GLACIAL FORMS

An illustration of land forms that result from mountain glaciation. Horns, cirques, cols, serrated divides (aretes) and talus slopes are shown.
FIG. 7.10 GLACIAL MODIFICATION

An example of glacial modification of a relatively level pre-glacial surface. Note the rounded hills, ponds, and interrupted drainage.

FIG. 7.11 GROUND MORaine TOPOGRAPHY

Characteristic ground moraine topography. Note the "erratics" (boulders carried by ice), "hill and kettle" topography and morainic ridge.

FIG. 7.12 MOUNTAIN GLACIAL FEATURES

An oblique stereogram that shows some of the characteristics of mountain glaciation: cols, serrate divides and "U"-shaped valleys. A fault lies in the foreground.