CHAPTER 3

Surficial Geology

An integral part of the military engineer’s mission is the location and processing of materials for construction use. Most construction materials are derived from rocks and soils that occur naturally on or near the surface of the earth. These materials may be obtained by developing a quarry or a borrow pit.

Quarries are sites where open excavations are made into rock masses by drilling, cutting, or blasting for the purpose of producing construction aggregate. These operations require extensive time, manpower, and machinery. Borrow pits are sites where unconsolidated material has been deposited and can be removed easily by common earth-moving machinery, generally without blasting.

This chapter covers the processes that form surficial features which are suitable for potential borrow pit operations and the types of construction materials found in these features.

FLUVIAL PROCESS

The main process responsible for the erosion and subsequent deposition of weathered material suitable for the development of borrow pits is that of moving water. When water moves very quickly, as over a steep gradient, it picks up weathered material and carries it away. When the stream slows down (for example, when the gradient is reduced), the capacity of the stream to carry the weathered material decreases; then it deposits the material in a variety of possible surficial features.

Stream deposits are characteristically stratified (layered) and composed of particles within a limited size range. Fluvial deposits are sorted by size based on the velocity of the water. When the velocity of the stream falls below the minimum necessary to carry the load, deposition occurs beginning with the heaviest material. In this way, rivers build gravel and sandbars on the inside of meander loops and dump fine silts and muds outside their levees during floods. This creates deposits of reasonably well-sorted, natural construction materials.

Drainage Patterns

Without the benefit of geologic maps, it is difficult to determine the type and structure of the underlying rocks. However, by studying the drainage patterns as they appear on a topographic map, both the rock structure and composition may be inferred.

Many drainage patterns exist; however, the more common patterns are—

- Rectangular.
- Parallel.
- Dendritic.
- Trellis.
- Radial.
- Annular.
- Braided.
**Rectangular.** This pattern is characterized by abrupt, nearly 90-degree changes in stream directions. It is caused by faulting or jointing of the underlying bedrock. Rectangular drainage patterns are generally associated with massive igneous and metamorphic rocks, although they may be found in any rock type. Rectangular drainage is a specific type of angular drainage and is usually a minor pattern associated with a major type, such as dendritic (see Figure 3-1a). Angular drainage is characterized by distinct angles of stream juncture.

**Parallel.** This drainage is characterized by major streams trending in the same direction. Parallel streams are indicative of gently dipping beds or uniformly sloping topography. Extensive, uniformly sloping basalt flows and young coastal plains exhibit this type of drainage pattern. On a smaller scale, the slopes of linear ridges may also reflect this pattern (see Figure 3-1b).

**Dendritic.** This is a treelike pattern, composed of branching tributaries to a main stream. It is characteristic of essentially flat-lying and/or relatively homogeneous rocks (see Figure 3-1c).

**Trellis.** This is a modified version of the dendritic pattern. Tributaries generally flow perpendicular to the main streams and join them at right angles. This pattern is found in areas where sedimentary or metamorphic rocks have been folded and the main streams now follow the strike of the rock (see Figure 3-1d).

**Radial.** This pattern, in which streams flow outward from a high central area, is found on domes, volcanic cones, or round hills (see Figure 3-1e).

**Annular.** This pattern is usually associated with radial drainage where sedimentary rocks are upturned by a dome structure. In this case, streams circle around a high central area (see Figure 3-1f).

**Braided.** A braided stream pattern commonly forms in arid areas during flash flooding or from the meltwater of a glacier. The stream attempts to carry more material than it is capable of handling. Much of the gravels and sands are deposited as bars and islands in the stream bed (see Figure 3-1g and Figure 3-2, page 3-4). Figure 3-2 shows the vicinity of Valdez, Alaska. Both the Copper and Tonsina Rivers are braided streams.

**Density**

The nature and density of the drainage pattern in an area provides a strong indicator as to the particle size of the soils that have developed. Sands and gravels are usually both porous and permeable. This means that during periods of precipitation, water percolates down through the sediment. The density of the drainage and the surface runoff are minimal due to this good internal drainage.

Clays and silts are normally porous but not permeable. Most precipitated water is forced to run off, creating a fine network of stream erosion.

Sandstone and shale may exhibit the same type of drainage pattern. Sandstone, due to its porosity and permeability, has good internal drainage while shale does not. Therefore, the texture or density of the drainage pattern which develops on the sandstone is coarse while that on shale is fine.

**Stream Evolution**

The likelihood of finding construction materials in a particular stream valley can be characterized by the evolution of that valley. The evolutionary stages are described as—

- **Youth.**
- **Maturity.**
- **Old age.**

**Youth.** Youthful stream valleys, which are located in highland areas, are typified by steep gradients, high water velocities with rapids and waterfalls present, downcutting in stream bottoms resulting in the creation of V-shaped valleys, and the filling of the entire
Figure 3-1. Typical drainage patterns.
Figure 3-2. Topographic expression of a braided stream.
valley floor by the stream (see Figure 3-3a). Although there is considerable erosion taking place, there is very little deposition.

Maturity. A mature system has a developed floodplain and, while the stream no longer fills the entire valley floor, it meanders to both edges of the valley. The stream gradient is medium to low, deposition of materials can be found, and (when compared with the youthful stream) there is less downcutting and more lateral erosion that contributes to widening the valley (see Figure 3-3b).

Old Age. In an old-age system, the stream gradient is very gentle, and the water velocity is low. The river exhibits little downcutting, and lateral meandering produces an extensive floodplain. Because of the low water velocity, there is a great amount of deposition. The river only occupies a small portion of the floodplain (see Figure 3-3c).

Recognition of the stream evolution stage of a particular river system is required to develop sources of construction aggregate. Rivers in maturity or old age provide the greatest quantities of aggregate. In youthful rivers, sources of aggregate are often scarce or unobtainable due to the steep gradients and high velocity. Table 3-1, page 3-6, summarizes the characteristics of each stage of stream evolution. Figure 3-4, page 3-7, shows an example of the topographic expression of a youthful stream valley in the vicinity of Portage, Montana. Figure 3-5, page 3-8, shows a mature stream valley in the vicinity of Fort Leavenworth, Kansas. Figure 3-6, page 3-9, shows an old age stream valley in the vicinity of Philipp, Mississippi.

Figure 3-3. Stream evolution and valley development.
Stream Deposits

Coarse-grained (gravels and sands) and fine-grained (silts and clays) deposits can be found by map reconnaissance. Certain surficial features are comprised of coarse-grained materials, others are made up of medium-sized particles, and still others of fine-grained sediments. However, if the source area for a stream is composed only of fine-grained materials, then the resulting depositional features will also contain fine-grained sediments, regardless of their usual composition.

The following surficial features can be identified by their topographic expressions on military maps and are likely sources of construction materials.

- Point bars.
- Channel bars.
- Oxbow lakes.
- Natural levees.
- Backswamps/floodplains.
- Alluvial terraces.
- Deltas.
- Alluvial fans.

**Point Bars.** Meandering is the process by which a stream is gradually deflected from a straight-line course by slight irregularities. Most streams that flow in wide, flat-floored valleys tend to meander (bend). These streams are alternately cutting and filling their channels, and as the deflection progresses, the force of the flowing water concentrates against the channel wall on the

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### Table 3-1. Stream evolution process.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Youth</th>
<th>Maturity</th>
<th>Old Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient</td>
<td>Steep, irregular</td>
<td>Moderate, smooth</td>
<td>Low, smooth</td>
</tr>
<tr>
<td>Valley profile</td>
<td>Narrow, V-shaped</td>
<td>Broad, moderately U-shaped</td>
<td>Very broad</td>
</tr>
<tr>
<td>Valley depth</td>
<td>Deep</td>
<td>Deep, moderate, shallow</td>
<td>Shallow</td>
</tr>
<tr>
<td>Meanders</td>
<td>Absent</td>
<td>Common</td>
<td>Extremely common</td>
</tr>
<tr>
<td>Floodplain</td>
<td>Absent or small</td>
<td>Equals width of meander</td>
<td>Wider than width of meander</td>
</tr>
<tr>
<td>Natural levees</td>
<td>Absent</td>
<td>May be present</td>
<td>Abundant</td>
</tr>
<tr>
<td>Tributaries</td>
<td>Few, small</td>
<td>Many</td>
<td>Few, large</td>
</tr>
<tr>
<td>Velocity</td>
<td>High</td>
<td>Moderate</td>
<td>Sluggish</td>
</tr>
<tr>
<td>Waterfalls</td>
<td>Many</td>
<td>Few</td>
<td>None</td>
</tr>
<tr>
<td>Erosion</td>
<td>Downward cutting</td>
<td>Downward and lateral</td>
<td>Lateral cutting</td>
</tr>
<tr>
<td>Deposition</td>
<td>Absent or transitory</td>
<td>Present, but partly</td>
<td>Much and fairly permanent</td>
</tr>
<tr>
<td>Culture</td>
<td>Steep-walled valleys</td>
<td>Flat valley floors are</td>
<td>Large rivers and nearby</td>
</tr>
<tr>
<td></td>
<td>are barriers to roads</td>
<td>good transportation routes</td>
<td>swamps are barriers</td>
</tr>
<tr>
<td></td>
<td>and railroads</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Summary of Regional Erosion Cycle**

<table>
<thead>
<tr>
<th></th>
<th>Dissection</th>
<th>Complete</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Divides</td>
<td>Partial</td>
<td>Complete</td>
<td>None</td>
</tr>
<tr>
<td>Valley development</td>
<td>Broad, flat, high</td>
<td>Knife-edged</td>
<td>Low, broad, rounded</td>
</tr>
<tr>
<td>Number of streams</td>
<td>Youthful to mature</td>
<td>Mostly mature</td>
<td>Old age</td>
</tr>
<tr>
<td>Relief</td>
<td>Few</td>
<td>Maximum</td>
<td>Few</td>
</tr>
<tr>
<td></td>
<td>Great</td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
</tbody>
</table>
Legend—
A = Rapids
B = Tributaries
C = Steep-sided valley

Figure 3-4. A youthful stream valley.
Figure 3-5. A mature stream valley.
Figure 3-6. An old age stream valley.
outside of the curve. This causes erosion on that wall (a body in motion tends to remain in motion in the same direction and with the same velocity until acted on by an external force) (see Figure 3-7). Consequently, there is a decrease in velocity and carrying power of the water on the inside of the curve, and the gravels and sands are deposited, forming point bar deposits (see Figure 3-3). Point bar deposits on many maps will not be apparent but can be inferred to be at the inside of each meander loop.

**Channel Bars.** When a stream passes through a meander loop, its speed increases on the outer bank due to the greater volume of water that is forced to flow on the outside of the loop. When the stream leaves the meander and the channel straightens out, the forces that caused the stream to move faster are no longer in control and the stream slows down and deposits materials. These materials are coarse-grained (gravels and sands) and are on the opposite bank and downstream of the point bar. If there is a series of meander loops, these deposits may not be present between point bars, depending on the spacing of the meanders. However, a channel bar can be expected after the last meander loop. Figure 3-9, page 3-12, shows channel bar deposits, oxbow lakes, and backswamp/floodplain deposits in the vicinity of Fort Leavenworth, Kansas. A prominent channel bar is located north of Stigers Island.

Mud Lake, Burns Lake, and Horseshoe Lake are oxbow lakes. Backswamps on the floodplain are represented by swampy ground symbols.

**Oxbow Lakes.** During high-water stages, a stream that normally flows through a meander loop may cut through the neck of a point, thus separating the loop. When this happens, the stream has taken the path of least resistance and has isolated the bend. The cutoff meander bend is eventually sealed from the main stream by fine deposits. The bend itself then forms an oxbow lake (see Figure 3-10, page 3-13). These deserted loops may become stagnant lakes or bogs, or the water may evaporate completely leaving a U-shaped depression in the ground. Fine-grained deposits (silts and clays) are normally located in oxbow lakes. An old point bar deposit can be found on the inside of the U (see Figure 3-11, page 3-13). In Figure 3-9, page 3-12. Horseshoe Lake is an example of the topographic expression of an oxbow lake.

**Natural Levees.** Stream velocity increases during flooding as the stream swells within the confines of its bank to move a greater volume of water. As the stream moves faster, it has the ability to carry more material. If the volume of water becomes so great that the water cannot stay in the channel, the stream spills over its banks onto the surrounding
Figure 3-8. Point bar deposits designated by gravel symbols.
Figure 3-9. Channel bar deposits, oxbow lakes, and backswamp/floodplain deposits.

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Figure 3-10. Meander development and cutoff.

Figure 3-11. Oxbow lake deposits, natural levees, and backswamp deposits.
floodplain, which is a flat expanse of land adjacent to a stream or river. Once the stream spills over its banks, the water velocity decreases as the water spreads out to occupy a larger area. As the velocity decreases, sediment carried by the floodwater is deposited. The size of this material depends primarily on the character of the material in the source area upstream and the velocity of the water in the stream channel. Generally, gravels and sands can be found in a natural levee, with the larger material deposited near the stream bank and a gradual gradation to smaller sand particles away from the stream.

**Backswamps/Floodplains.** After a flood ends and the stream regresses into its channel, much of the water that spilled over the banks onto the floodplain is trapped on the outside of the natural levees. The fine materials (silts and clays) that are suspended in this water settle onto the floodplain. Consequently, these areas are often used for agricultural production. In the lower-lying areas of the floodplain, a large amount of fines may accumulate, inhibit drainage, and form swamplike conditions called a backswamp (see Figure 3-9, page 3-12).

**Alluvial Terraces.** A depositing stream tends to fill its valley with a fair amount of granular alluvial material. If a change in the geological situation results in the uplift of a large area or rejuvenation of the stream, an increase in the stream velocity by other means, or a change in the sedimentation and erosion process, the stream may begin to erode away the material it had deposited previously. As the eroding stream meanders about in its new valley, it may leave benchlike remnants of the preexisting valley fill material perched against the valley walls as terraces. This action of renewed downcutting may occur several times, leaving several terrace levels (see Figure 3-12). These are easily recognized on a topographic map because they show up as flat areas with no contour lines, alternating with steeply sloping regions with many contour lines. Alluvial terraces usually occur on one side of the stream but can be found on both sides. They are a normal feature of the history of any fluvial valley. They are usually a good source of sands and gravels. Figure 3-13 shows alluvial terraces in the vicinity of Souris River, North Dakota.

**Deltas.** When streams carrying sediments in suspension flow into a body of standing water, the velocity of the stream is immediately and drastically reduced. As a result, the sedimentary load begins to settle out of
Legend:
A = Paired terraces
B = Unpaired terraces
M = Meander loop
X = Meander bluff (separating the terrace trends)
Y = Linear swampy depression

Figure 3-13. Topographic expression of alluvial terraces.
suspension, with the heavier particles settling first. If the conditions in the body of water (sea or lake) are such that these particles are not spread out over a large area by wave action, or if they are not carried away by currents, they continue to accumulate at the mouth of the stream. Large deposits of these sediments gradually build up to just above the water level to form deltas (see Figure 3-14). These assume three general forms, depending mainly on the relative influence of waves, fluvial processes, and tides. These forms are—

- Arcuate (see Figure 3-15a and b).
- Bird’s-foot (see Figure 3-15c).
- Elongate (see Figure 3-15d).

Arcuate deltas are arc- or fan-shaped and are formed when waves are the primary force acting on the deposited material. Arcuate
deltas usually result from deposition by streams carrying relatively coarse material (sands and gravels) with some occasional fine material. Arcuate deltas consisting primarily of coarse material have very good internal drainage; therefore, they have few minor channels. On the other hand, an arcuate delta having a considerable amount of fine material (silts and clays) mixed with the coarse material does not have good internal drainage. In this case, a larger number of minor channels develop. Generally, arcuate deltas are considered good sources of sands and gravels. An example of an arcuate delta is the Nile Delta in Egypt.

Bird's-foot deltas are formed in situations where fluvial processes have a major influence on deposited sediments. Bird's-foot deltas resemble a bird's foot from the air, hence the name. They are generally composed of fine-grained material and have very poor internal drainage. These deltas are flat with vegetation, have many small outlets, and are a good source of fine materials. The Mississippi Delta is a classic example of this delta type.

Elongate deltas form where tidal currents have a major impact on sediment deposition. They contain only a few distributaries, but the distributaries that occur are large.

**Alluvial Fans.** These are the dry land counterpart of deltas. They are formed by streams flowing from rough terrain, such as mountains or steep faults, onto a flat plain. This type of deposit is found in regions that have an arid to semiarid type of climate, such as the western interior, the Basin and Range Province of the United States, and the desert mountain areas worldwide. The valleys in these areas are normally dry much of the year, with streams resulting only after torrential rainstorms or following the spring snow melt. The mountains themselves are devoid of vegetation, and erosion by the streams is not impeded. These streams rush down a steep gradient, and when they meet the valley floor, there is a sudden reduction in velocity. The sediment load is deposited at the foot of the rough terrain. This deposit is in the form of a broad "semitone" with the apex pointing upstream. Coalescing alluvial fans consist of a series of fans that have joined to form one large feature. This is typical in arid areas. Figure 3-16 depicts alluvial and coalescing alluvial fans. Alluvial fans may be readily identified by their topographic

![Figure 3-16. Alluvial fan and coalescing alluvial fans.](image)
expressions of concentric half-circular contour lines. Figure 3-17 is a topographic map showing the Cedar Creek alluvial fan in the vicinity of Ennis Lake, Montana. This alluvial fan is approximately four miles in radius. Figure 3-18, page 3-20, shows coalescing alluvial fans in the vicinity of Las Vegas, Nevada.

The types of materials found in alluvial fans are gravels, sands, and fines based on a 1/3 rule. The first 1/3, the area adjacent to the highland, is primarily composed of gravels; the middle 1/3 is composed of sands; and the final 1/3, the area farthest from the highland, is composed of fines.

Fluvial features are found throughout the world and are the primary source of borrow pit materials for military engineers. Table 3-2, page 3-21, and Figure 3-19, page 3-21, present a summary of fluvial features. Figure 3-20, page 3-22, shows a generalized distribution of fluvial surficial features throughout the world.

GLACIAL PROCESS

Between ten and twenty-five thousand years ago, much of North America, Europe, and Northern Asia was covered by glaciers. Significant ice sheets still cover Greenland and Antarctica, and lesser ice sheets can be found at high elevations and latitudes (see Figure 3-21, page 3-23).

Glaciation produces great changes in the existing topography by reshaping the land surface and depositing new surficial features that may serve as a source of construction aggregate for military engineers.

Types of Glaciation

The glaciation process may be described as either continental or alpine glaciation.

Continental. Continental glaciation occurs on a large, regional scale affecting vast areas. It may be characterized by the occurrence of more depositional features than erosional features. Continental glaciers can be of tremendous thickness and extent. They move slowly in a plastic state with the ice churning the soil and rocks beneath it as well as crushing and plucking rocks from the ground and incorporating large amounts of material within the glacier itself. The overall range of particle size of these materials is from clays through cobbles and boulders (see Figure 3-22, page 3-24).

Alpine. Alpine or mountain glaciation takes place in mountainous areas and generally results in the creation of mainly erosional forms. Alpine glacial features are very distinctive and easy to recognize. In the past, glaciers scooped out and widened the valleys through which they moved, producing valleys with a U-shaped profile in contrast to the V-shaped profile produced by fluvial erosion (see Figure 3-23, page 3-25).

Glacial Deposits

Materials deposited by glaciers are frequently differentiated into two types. They are—

- Stratified.
- Unstratified.

Stratified. The features composed of stratified deposits are actually the result of deposition of sediment by glacial streams (glaciofluvial) and not by the movement of the ice itself. These features are—

- Outwash plains.
- Eskers.
- Kames.
- Kame terraces.
- Glacial lake deposits.

They result when the material in the glacier has been carried and deposited by meltwater from the glacier. The water selectively deposits the coarsest materials, carrying the fines away from the area. The end result is essentially deposits of sands and gravels.

Outwash plains result when melting ice at the edge of the glacier creates a great volume of water that flows through the end moraine as a number of streams rather than as a continuous sheet of water. Each of the streams
Figure 3-17. Cedar Creek alluvial fan.
builds an alluvial fan and each of the fans joins together and forms a plain that slopes gently away from the end moraine area. The coarsest material is deposited nearest the end moraine, and the fines are deposited at greater distances. Much of the prairie land in the United States consists of outwash plains. Drainage and trafficability in the outwash plains are much better than in a ground moraine; however, kettles can be formed in outwash plains due to large masses of ice left during the recession of the ice front. If the kettles are numerous, the outwash area is called a pitted plain (see Figure 3-22, page 3-24).

Eskers are winding ridges of irregularly stratified sands and gravels that are found within the area of the ground moraine. The ridges are usually several miles long but are
### Table 3-2. Fluvial surficial features.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Bar</td>
<td>A low, crescent-shaped mound located at the inside of many bends in rivers or streams.</td>
</tr>
<tr>
<td>Channel Bar</td>
<td>A low, streamlined mound in braided streams or just downstream from point bars and on the opposite bank.</td>
</tr>
<tr>
<td>Floodplain</td>
<td>A flat valley floor, leveled by back and forth erosion of the river or stream between the valley walls.</td>
</tr>
<tr>
<td>Alluvial Terrace</td>
<td>A platform or flat surface higher than the floodplain and generally close to the valley walls. It is all that remains of what was a floodplain many years before.</td>
</tr>
<tr>
<td>Oxbow Lake</td>
<td>A horseshoe-shaped, abandoned section of a stream or river channel still containing water.</td>
</tr>
<tr>
<td>Clay Plug</td>
<td>A clay-filled, abandoned section of a stream or river at the ends of horseshoe-shaped oxbow lakes.</td>
</tr>
<tr>
<td>Natural Levee</td>
<td>Wide, low mounds (5 to 15 feet high), paralleling the river along both banks with sloping sides away from the river.</td>
</tr>
<tr>
<td>Backswamp</td>
<td>A swampy, level portion of a floodplain with very poor drainage and a high water table.</td>
</tr>
<tr>
<td>Delta</td>
<td>Natural land extension into a body of water, visible as a low, almost level, land mass protruding into the body of water.</td>
</tr>
<tr>
<td>Alluvial Fan</td>
<td>A cone-shaped mound formed against a valley wall, appearing fan-shaped from above.</td>
</tr>
<tr>
<td>Lake Bed Deposit</td>
<td>A layer formed from the settling of sediments to the bottom of lakes. The layers are thick at the center of the lake bed and thin near the lake margins.</td>
</tr>
</tbody>
</table>

**Figure 3-19.** Major floodplain features.
Figure 3-20. World distribution of fluvial landforms.
rarely more than 45 to 60 feet wide or more than 150 feet high. They are formed by water that flowed in tunnels or ice-walled gorges in or beneath the ice. They branch and wind like stream valleys but are not like ordinary valleys in that they may cross normal drainage patterns at an angle, and they may also pass over hills (see Figures 3-22, page 3-24, and Figure 3-24, page 3-26). Figure 3-24, page 3-26, shows kettle lakes, swamps, and eskers.

A similar feature that resembles an esker, but is rarely more than a mile in length, is a ridge known as a crevasse filling. A crevasse is a large, deep crevice or fissure on the surface of a glacier. Unsorted debris washes into the crevasse, and when the surrounding ice melts, a ridge containing a considerable amount of fines is left standing.

Kames are conical hills of sands and gravels deposited by heavily laden glacial streams that flowed on top of or off of the glacier. They are usually isolated hills that are associated with the end or recessional moraine; kettle lakes are commonly found in the same area. The formation of kames normally occurred when meltwater streams deposited relatively coarse materials in the form of a glacioalluvial fan at the edge of the ice; the fine particles were washed away. This material accumulated along the side of the ice, and when the ice receded, the material slumped back on the side formerly in contact with the glacier.

Delta kames are another type of kame that may be formed when the meltwater flows into a marginal lake and forms a delta. After the lake and the ice disappear, deltas are left as flat-topped, steep-sided hills of well-sorted sands and gravels (see Figure 3-22, page 3-24).

Kame terraces are features associated with alpine glaciation. When the ice moves down a valley, it is in contact with the sides of the valley. As the glacier melts away from the valley wall, glacial water flows into the space created between the side of the glacier and the valley wall. The void is filled with gravels and...
Figure 3-22. Continental glaciation.
Area of alpine glaciation showing erosional features and placement of ice.

Same area of alpine glaciation with ice removed.

Figure 3-23. Alpine glaciation.
Figure 3-24. Moraine topographic expression with kettle lakes, swamps, and eskers.
sands, while the fines are carried away by the stream water. A terrace is left where the ice was in contact with the valley; gravels and sands can be found at the base of the terrace (see Figure 3-25).

Glacial lake deposits occur during the melting of the glacier when many lakes and ponds are created by the meltwater in the outwash areas. The streams that fed these waters were laden with glacial material. Most of the gravels and sands that were not deposited before reaching the lake accumulated as a delta (later to be called a delta kame) after melting of the ice. The fines that remained suspended in the water were, on the other hand, deposited throughout the lake. During the summer, a band consisting of light-colored, coarse silt was deposited, whereas a thinner band of darker, finer-grained material was deposited in the winter. The two bands together represent a time span of one year and are referred to as a varve.

Unstratified. Unstratified glacial deposits (sediments deposited by the ice itself) are the most common of the glacial deposits. They comprise the following surficial features:
- Ground moraines.
- End moraines.
- Recessional moraines.
- Drumlins.

Unstratified deposits make up landforms that may be readily identified in the field, on aerial photographs, and from topographic and other maps. Unstratified deposits are composed of a heterogeneous mixture of particle types and sizes ranging from clays to boulders. Till is the name given to this mixture of materials. It is the most widespread of all the forms of glacial debris. In general, features comprised of till are undesirable as sources of military construction aggregate since the material must be washed and screened to provide proper gradation.

Ground moraines, sometimes called till plains, are deposits that are laid down as the glacier recedes. Melting ice drops material that blankets the area over which the glacier traveled. A deposit of this kind forms gently rolling plains. The deposit itself may be a thin veneer of material lying on the bedrock, or it may be hundreds of feet thick. Moraine soil composition is complex and often indeterminate. This variation in sediment makeup is due to the large variety of rocks and soil picked up by the moving glacier (see Figure 3-22 page 3-24).
Morainic areas have a highly irregular drainage pattern because of the haphazard arrangement of ridges and hills, although older till plains tend to develop dendritic patterns. Frequent features associated with ground moraines are kettle holes and swamps. Kettles are usually formed by the melting of ice that had been surrounded by or embedded in the moraine material. Large amounts of fines in the till prevent water from percolating down through the soil. This may allow for the accumulation of water in the kettle holes forming kettle lakes or, in low-lying areas, swamps. [Figure 3-22, page 3-24, and Figure 3-24, page 3-26, show ground moraine with an esker.]

End moraines, sometimes called terminal moraines, are ridges of till material that were pushed to their locations at the limit of the glacier’s advance by the forceful action of the ice sheet. Generally, there is no one linear element, such as a continuous ridge, evident in either the field or on aerial photos. Normally, this deposit appears as a discontinuous chain of elongated to oval hills. These hills vary in height from tens to hundreds of feet. The till material is, at times, quite clayey. Kettle lakes are sometimes associated with terminal moraine deposits also (see Figure 3-22, page 3-24).

Recessional moraines, which are similar to end moraines, are produced when a receding glacier halts its retreat for a considerable period of time. The stationary action allows for the accumulation of till material along the glacier’s edge. A series of these moraines may result during the retreat of a glacier (see Figure 3-22, page 3-24).

Drumlins are asymmetrical, streamlined hills of gravel till deposited at the base of a glacier and oriented in a direction parallel to ice flow. The stoss side (the side from which the ice flowed) of the drumlin is steeper and blunter than the lee side. The overall appearance of a drumlin resembles an inverted spoon if viewed from above. Drumlins commonly occur in groups of two or more. Individual drumlins are seldom more than ½ mile long, and they can rise to heights of 75 to 100 feet (see Figure 3-26 and Figure 3-27).

It is important to understand that features formed from the glacial process only occur in certain areas of the world. [Figure 3-28, page 3-30, and Figure 3-29, page 3-31, illustrate the regions of the United States and the world where glacial landforms occur. Table 3-3, page 3-32, is a summary of glacial surficial features.]

**EOLIAN PROCESS**

In arid areas where water is scarce, wind takes over as the main erosional agent. When a strong wind passes over a soil, it carries many particles of soil with it. The height and distance the materials are transported is a function of the particle size and the wind velocity. The subsequent decrease in the wind velocity gives rise to a set of wind-borne deposits called eolian features.

![Figure 3-26. Idealized cross section of a drumlin.](image-url)
Figure 3-27. Topographic expression of a drumlin field.
Types of Eolian Erosion

There are two types of wind erosion. They are—

- Deflation.
- Abrasion.

Deflation. Deflation occurs when loose particles are lifted and removed by the wind. This results in a lowering of the land surface as materials are carried away. Unlike stream erosion, in which downcutting is limited by a "base level" (usually sea level), deflation can continue lowering a land surface as long as it has loose material to carry away. Deflation may be terminated if the land surface is cut down to the water table (moist soil is not carried away as easily) or if vegetation is sufficient to hold the soil in place. In addition, deflation may be halted when the supply of fine material has been depleted. This makes a surface of gravel in the area where deflation has taken place. This gravel surface is known as desert pavement (see Figure 3-30, page 3-32).

Abrasion. Abrasion occurs when hard particles are blown against a rock face causing the rocks to break down. As fragments are broken off, they are carried away by the wind. This process can grind down and polish rock surfaces. A rock fragment with facets that have been cut in this way is called a ventifact (see Figure 3-31, page 3-33).

Modes of Transportation

Soil particles can be carried by the wind in the following ways:

Bed Load. Material that is too heavy to be carried by the wind for great distances at a time (mainly sand-sized particles) bounces along the ground, rarely higher than two feet.

Suspended Load. These are fines (mostly silts) that are easily carried by the wind. Suspended loads extend to high altitudes (sometimes thousands of feet) and can be transported for thousands of miles. During a particularly bad dust storm in the midwestern "dust bowl" on 20 March 1935, the

Figure 3-28 Distribution of major groups of glacial landforms across the United States.
Figure 3-29. World distribution of glacial landforms.
suspended load extended to altitudes of over 12,000 feet. The lowermost mile of the atmosphere was estimated to contain over 166,000 tons of suspended particles per cubic mile. Enough material was transported to bring temporary twilight to New York and New England (over 2,000 miles away) on 21 March.

**Eolian Features**

Eolian surficial features may consist of gravels, sands, or fines. The three main types of eolian features are:
- Lag deposits or desert pavement.
- Sand dunes.
- Loess deposits.

**Figure 3-32** illustrates the origin of these deposits.

**Lag Deposits or Desert Pavement.** As the wind billows across the ground, sands and fines are continually removed. Eventually, gravels and pebbles that are too large to be carried by the wind cover the surface. These remnants accumulate into a sheet that ultimately covers the finer-grained material beneath and protects it from further deflation. Desert pavement usually develops rapidly on alluvial fan and alluvial terrace surfaces. The exposed surface of the gravels may become coated with a black, glittry substance termed desert varnish. In some

<table>
<thead>
<tr>
<th>Features</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground Moraine</strong></td>
<td>A blanket of till covering the bedrock or an old soil layer extending for miles in all directions.</td>
</tr>
<tr>
<td><strong>End Moraine</strong></td>
<td>A long, irregularly rounded, narrow ridge or parallel ridges of till formed at the edges of a glacier.</td>
</tr>
<tr>
<td><strong>Drumlin</strong></td>
<td>A streamlined hill of till (teardrop-shaped when viewed from above), generally from 20 to 200 feet tall, 50 to 400 feet wide, and 500 to 3,000 feet long. Drumlins are commonly found in groups but may exist alone.</td>
</tr>
<tr>
<td><strong>Esker</strong></td>
<td>A winding, rounded ridge that is generally 100 to 200 feet wide, with a fairly constant height of 50 to 100 feet, trending for distances of several thousand feet to several miles.</td>
</tr>
<tr>
<td><strong>Kame</strong></td>
<td>An irregularly shaped mound of sand and gravel found near or in ridge moraines. Distinguished from mounds of till by slightly greater relief, slightly steeper sides, and better drainage (drier).</td>
</tr>
<tr>
<td><strong>Kame Terrace</strong></td>
<td>A platform or flat surface (in U-shaped, glaciated valleys) higher than the valley floor and butting against the valley wall.</td>
</tr>
<tr>
<td><strong>Outwash Plain</strong></td>
<td>A fairly flat, well-drained plain, formed by large quantities of meltwater running away from the edge of the glacier. Outwash plains are commonly found in front of end moraines.</td>
</tr>
</tbody>
</table>

Note: Till is not a feature. It is the material picked up, moved, and deposited by glaciers. It is largely boulders and silt but also contains gravels, sands, and clays.

**Figure 3-30.** Three stages illustrating the development of desert armor.
locations, the evaporation of water, brought to the surface by the capillary action of the soil, may leave behind a deposit of calcium carbonate (caliche) or gypsum. It acts as a cement, hardening the pavement into a conglomeratelike slab.

Although desert pavement contains good gravel material, the layers are normally too thin to supply the quantity required for construction. However, it does provide a rough but very trafficable surface for all types of vehicles and also provides excellent airfields.

Sand Dunes. Dunes may take several forms, depending on the supply of sand, the lay of the land, vegetation restrictions, and the steady direction of the wind. Their general expressions are as follows:

- Transverse.
- Longitudinal.
- Barchan.
- Parabolic.
- Complex.

Transverse dunes are wavelike ridges that are separated by troughs; they resemble sea waves during a storm. These dunes, which are oriented perpendicular to the prevailing wind direction, occur in desert locations where a great supply of sand is present over the entire surface. A collection of transverse dunes is known as a sand sea (see Figure 3-33a, page 3-34).

Longitudinal dunes have been elongated in the direction of the prevailing winds. They usually occur where strong winds blow across areas of meager amounts of sand or where the winds compete with the stabilizing effect of grass or small shrubs (see Figure 3-33b, page 3-34).

Barchan dunes are the simplest and most common of the dunes. A barchan is usually crescent-shaped, and the windward side has a gentle slope rising to a broad dome that cuts off abruptly to the leeward side. Barchans form in open areas where the direction of the wind is fairly constant and the ground is flat and unrestricted by vegetation and topography (see Figure 3-33c, page 3-34).

Parabolic, or U-shaped, dunes have tips that point upwind. They typically form along coastlines where the vegetation partially covers the sand or behind a gap in an obstructing ridge. Later, a parabolic dune may detach itself from the site of formation and migrate independently (see Figure 3-33d, page 3-34).
Figure 3-33. Sand dune types.
Complex dunes lack a distinct form and develop where wind directions vary, sand is abundant, and vegetation may interfere. These can occur locally when other dune types become overcrowded and overlap, thereby losing their characteristic shapes in a disorder of varying slopes (see Figure 3-33e).

**Loess Deposits.** In a number of regions of the world, thick accumulations of yellowish-brown material composed primarily of windblown silts make up a substantial amount of surface area. These deposits are known as loess. The material that makes up these deposits originated mainly from dried glacial outwash, floodplains, or desert area fines. Loess is composed of physically ground rock rather than of chemically weathered material. The source and deposition point for the material may be many miles apart, and the deposits may range in thickness from a few feet to hundreds of feet. Thickness tends to decrease with distance from the source. In the United States, most of Kansas, Nebraska, Iowa, and Illinois are covered by loess. After a loess has been laid down, it is rarely picked up again. This is due to a very thin layer of fines that interlock after wetting. While dry loess is trafficable, it loses all strength with a slight amount of water (see Figure 3-34).

Eolian features occur worldwide and may consist of areas of sand dunes and desert pavement or loess; however, their topographic expressions vary. In general, dune areas are specified on maps by special topographic symbols since they are continually changing unless stabilized by vegetation. Figure 3-35, page 3-36, is a topographic expression, using special symbols, of sand

![Figure 3-34. Loess landforms.](image-url)
dunes and desert pavement (Summan). Figure 3-36 shows the generalized distribution of eolian landforms throughout the world.

**SOURCES OF CONSTRUCTION AGGREGATE**

Military engineers use their knowledge of surficial features to develop borrow pits and provide construction aggregate to meet mission requirements. Generally, engineer units attempt to develop borrow pit operations in fluvial features since they are easy to identify and are normally accessible. In arid and semiarid regions, eolian deposits and alluvial fans provide large amounts of aggregate. In mountainous regions and continentally...
Figure 3-36. Worldwide distribution of eolian landforms.
glaciated regions, fluvial-glacial deposits can provide large quantities of quality aggregate. Therefore, their presence should not necessarily be discounted in preference to fluvial materials. Table 3-4 summarizes the types of aggregates found in common fluvial, glacial, and eolian surficial features.

Table 3-4. Aggregate types by feature.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Cobbles</th>
<th>Gravels</th>
<th>Sands</th>
<th>Silts</th>
<th>Clays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Bar</td>
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<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel Bar</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Alluvial Terrace</td>
<td>X</td>
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<tr>
<td>Oxbow Lake, Clay Plug</td>
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<td></td>
<td></td>
<td>X</td>
<td>X</td>
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<tr>
<td>Natural Levee</td>
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<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Backswamp</td>
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<td></td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Delta, Bird's-Foot</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Delta, Arcuate</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Alluvial Fan</td>
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<td></td>
<td>X</td>
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<td>Lake Bed Deposits</td>
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<td>X</td>
<td>X</td>
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<td>Esker</td>
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<td>X</td>
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<td>Kame</td>
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<td>Outwash Plains</td>
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<td>X</td>
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<td>Desert Pavement</td>
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<td>Sand Dunes</td>
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</tr>
<tr>
<td>Loess</td>
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