CHAPTER 2

Engineering Geology

QUESTIONS AND PRACTICE PROBLEMS

Section 2.1 The Geologic Cycle

2.1 Describe the inter-relationships in the geologic cycle among magma, different types of rocks, and soil.

Solution

Refer to Figure 2.1. Igneous rocks are formed by the cooling and solidification of magma at depth and lava at the earth's surface. Pyroclastic ejection of magma leads to the formation of soil and sedimentary rocks. Metamorphosis of igneous rocks or sedimentary rocks produces metamorphic rocks. The weathering of igneous, sedimentary and metamorphic rocks produces soils, which can be turned into sedimentary rocks through induration. Finally, magma can be produced through the melting of igneous or metamorphic rocks.

Section 2.2 Rocks

2.2 Which would probably provide better support for a large, heavy building, a diorite or a shale? Why?

Solution

Diorite is a hard igneous rock that is very strong and thus provides excellent support for structures. Shale is a sedimentary rock derived from clay. It has weak bedding planes and may be prone to shear failure along these planes. Thus, in general, diorite would provide much support for the building.

2.3 Would a tunnel excavated in a granite require more or less support than a tunnel excavated in a mudstone? Why?

Solution

Granite generally has excellent engineering properties and would require less support than mudstone. Mudstone would deteriorate after excavation and exposure to the atmosphere.

2.4 Fossils are imprints in rock of ancient plants and animals. What type of rock might contain fossils? What type would never contain fossils? Explain.

Solution

Fossils are formed when plants or animals, or at least evidence of their presence (e.g., footprints) are caught in a rock while it is being formed. Thus, the likelihood of finding fossils depends on the kinds of processes that formed the rock, and the possibility of plants or animals interacting with these processes. The majority of fossils are found in sedimentary rocks because they form by accumulation of sediments on the ground surface. In contrast, fossils are never found in intrusive igneous rocks, because they are formed by the cooling of magna deep within the earth's crust.

2.5 What type of rock is most likely to develop sinkholes? Why?

Solution

Carbonate sedimentary rocks, especially limestone, are most prone to have sinkholes because they can be dissolved by long exposure to water, especially if the water is actually a mild solution of carbonic acid.

2.6 In general, how does the age of a rock affect its engineering characteristics?

Solution

In general, there may be a relationship between the age of a sedimentary rock and its engineering characteristics. An older sedimentary rock has been buried under a higher overburden and therefore should be denser and stronger. There may not be such a straightforward relationship for igneous and metamorphic rocks; the engineering characteristics of these rocks may be more dependent on other factors such as the degree of weathering.

Section 2.3 Rock-Forming Minerals

2.7 Name four common minerals. For each mineral named, state one characteristic or property of the mineral and describe how this characteristic or property may be reflected in the property of a rock that contains the mineral.

Solution

- Feldspar has a moderate hardness, making rocks containing feldspar susceptible to weathering.
- Quartz is harder than most minerals, making rocks containing quartz very resistant to weathering.
- Calcite is soluble in water; therefore, rocks containing calcite may develop solution cavities.
- Gypsum is water soluble, and thus can dissolve in groundwater. Rocks containing gymsum can develop solution caverns and sinkholes.

Section 2.4 Structural Geology

2.8 Define "bedding planes" and explain why it is important to assess their orientations as a part of slope stability analyses.

Solution

Bedding planes are the interfaces between the layers in a sedimentary rock. The shear strength along these planes is often much less than the strength perpendicular to them, so the orientation of the bedding planes is very important. For example, if the bedding planes are inclined outward from a slope, the rock might slide outward along the bedding. However, if the bedding planes are inclined into the slope, such sliding is much less likely.

2.9 The bedding planes in a certain sedimentary rock have an average strike of N43°E and an average dip of 38°SE, as shown by the attitude in Figure 2.28. A 15-m tall, east-west striking cut slope inclined at 34° with the horizontal is to be made in this rock. The ground surface above and below this proposed slope will be nearly level. Compute the apparent dip of the bedding planes as they will appear in cross-section A-A′, then draw this cross-section. Your drawing should show the ground surface and the bedding planes. Do these bedding planes pose a potential slope stability problem? Explain.

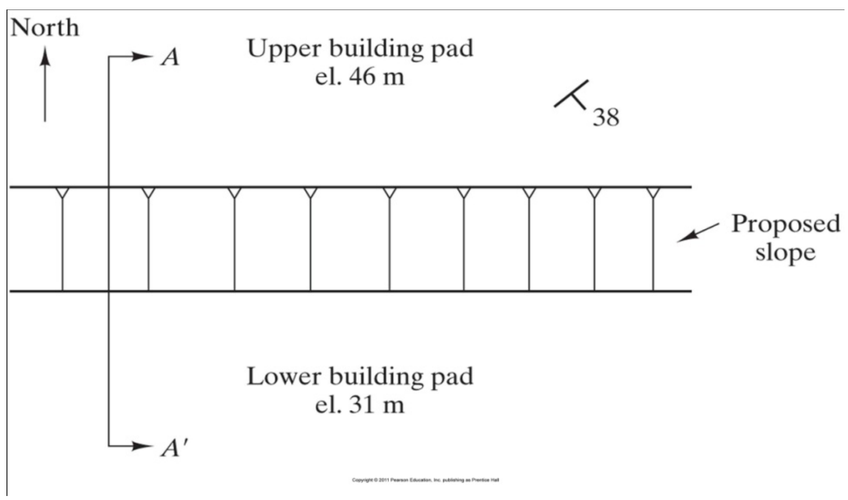


Figure 2.28 Plan view of proposed slope for Problem 2.9. el. = elevation.

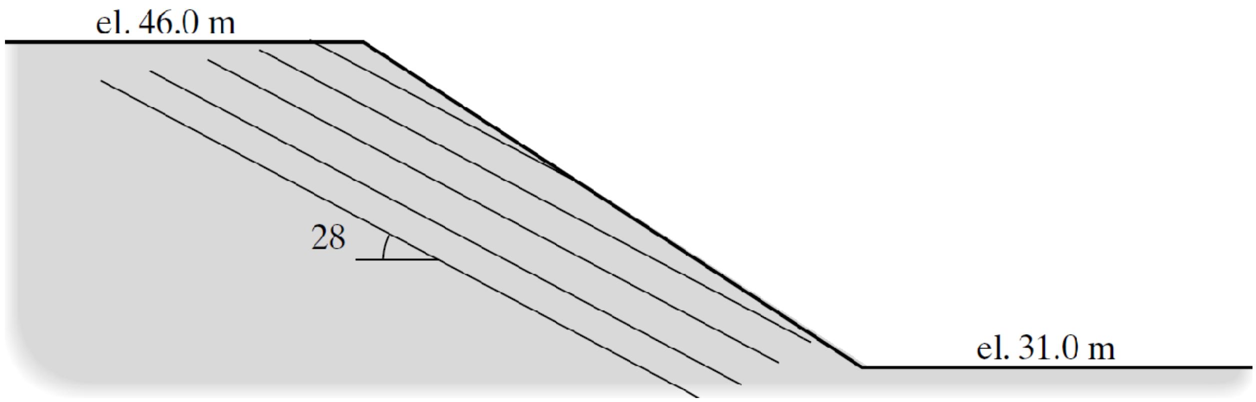
Solution

The apparent dip in cross-section A-A’ is:

$$\begin{aligned}\tan\delta_a &= \tan\delta\sin\alpha \\ &= \tan 38°\sin 43°\end{aligned}$$

$$\delta_a = 28°$$

The bedding planes dip out-of-slope and daylight (intersect with the slope face), as shown in the cross-section. Therefore, this slope may have inadequate stability.



2.10 Draw cross-section A-A′ in Figure 2.11 and compute the apparent dip of the bedding planes as they would appear in this cross-section. There are two nearby attitudes, so compute the apparent dip for each. Then, sketch in the bedding planes on the cross-section. Do these bedding planes pose a potential stability problem? Why or why not?

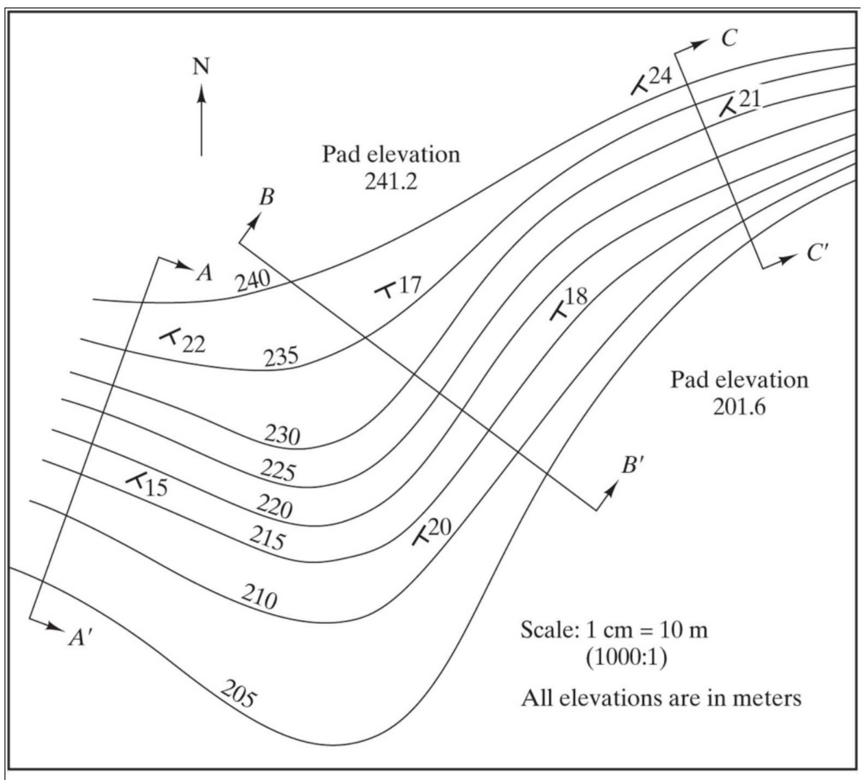


Figure 2.11 Geologic map showing bedrock attitudes. In this case, the attitudes represent the bedding planes in a sedimentary rock.

Solution

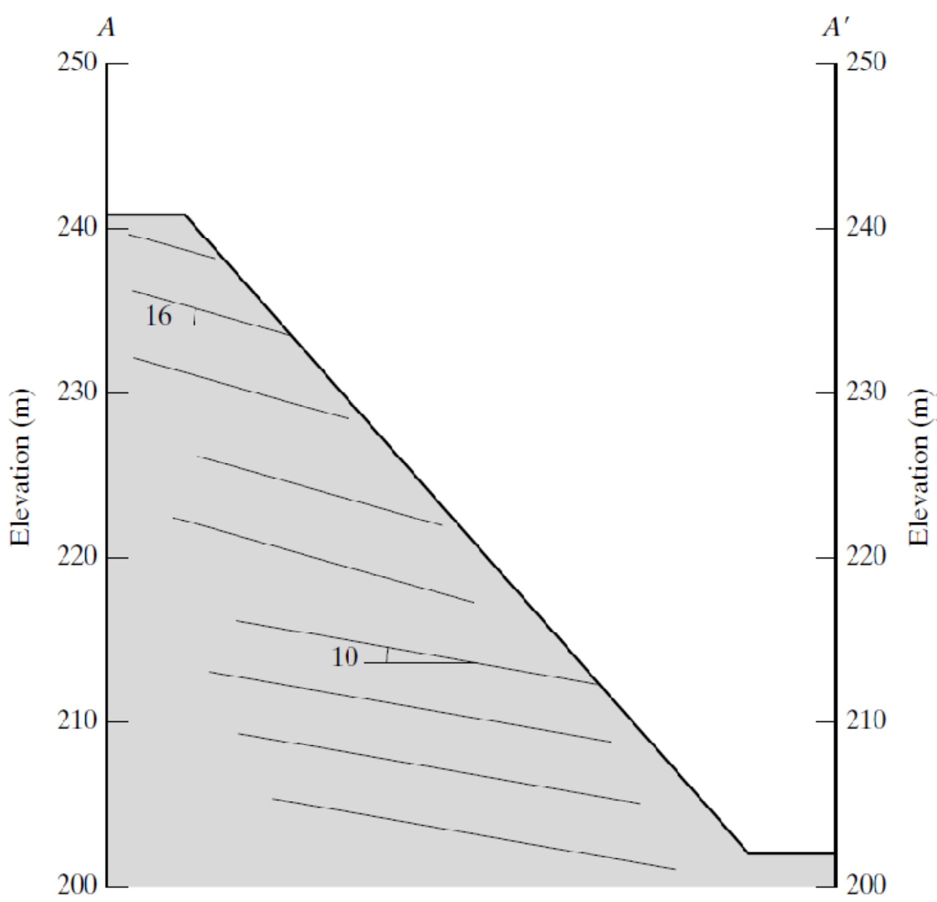
$$\begin{aligned}\tan\delta_a &= \tan\delta\sin\alpha\\ &= \tan 22°\sin 47°\end{aligned}$$

$$\delta_a = 16°$$

$$\begin{aligned}\tan\delta_a &= \tan\delta\sin\alpha\\ &= \tan 15°\sin 45°\end{aligned}$$

$$\delta_a = 10°$$

The apparent dip is 16° in the upper portion of the slope and 10° in the central portion. Both of these produce bedding planes that are inclined out-of-slope, and thus pose a potential instability problem



2.11 Draw cross-section C-C′ in Figure 2.11 and compute the apparent dip of the bedding planes as they would appear in this cross-section. There are two nearby attitudes, so compute the apparent dip for each. Then, sketch in the bedding planes on the cross-section. Do these bedding planes pose a potential stability problem? Why or why not?

Solution

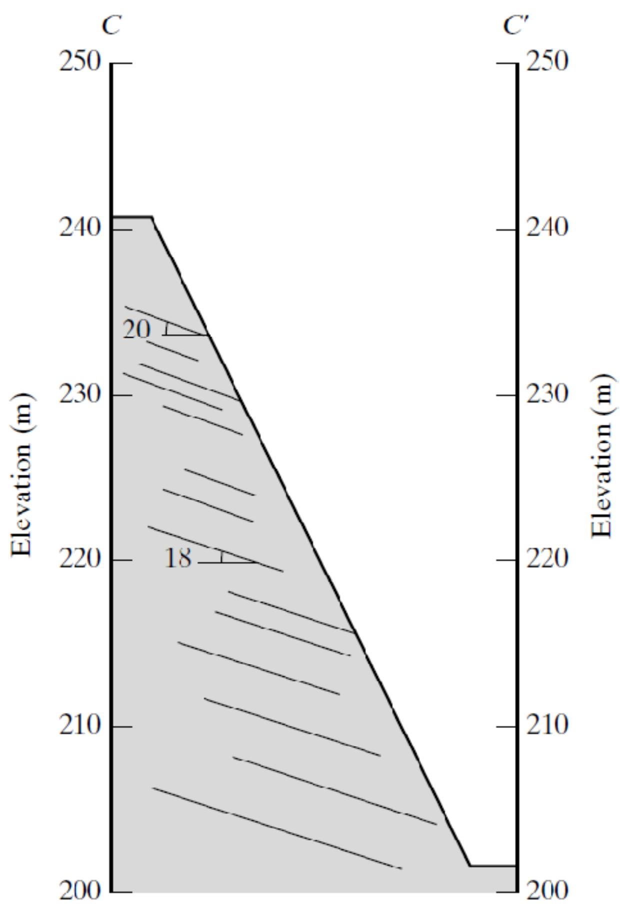
$$\tan\delta_a = \tan\delta\sin\alpha$$
$$= \tan 24^\circ \sin 55^\circ$$

$$\delta_a = 20^\circ$$

$$\tan\delta_a = \tan\delta\sin\alpha$$
$$\tan\delta_a = \tan 21^\circ \sin 56^\circ$$

$$\delta_a = 18^\circ$$

These bedding planes are inclined out-of-slope and daylight, so they pose a potential stability problem.



Section 2.5 Weathering

2.12 Name the three major types of weathering and define each.

Solution

- Physical weathering is the disintegration of rock into smaller particles through physical processes, such as the erosive action of heat, water, ice, wind, and pressure.
- Chemical weathering is the disintegration of rock through chemical reactions between the minerals in the rock, water, and oxygen in the atmosphere.
- Biological weathering is the disintegration of rock into smaller particles caused by biological activities that produce organic acids.

2.13 Discuss how weathering affects the engineering properties, e.g. density and strength, of a rock.

Solution

As a rock weathers, the minerals it contains break down, leading to a decrease in its density and strength and an increase in its porosity.

Section 2.6 Soil Formation, Transport, and Deposition

2.14 Define residual soils. Name one type of residual soil and describe its typical engineering characteristics.

Solution

Residual soils are soils weathered in-place from their parent rocks. A residual soil typically retains many of the characteristics of the parent rock. For example, completely decomposed granite is a sandy residual soil derived from the weathering of granitic rocks. It is commonly used in construction as a high-quality fill material.

2.15 Define transported soils. Name the major types of transported soils and describe how each is formed.

Solution

Transported soils are formed by the deposition of sediments that have been transported from their places of origin by various agents.

- Glacial soils are transported by glaciers over long distances, so the resulting deposits often contain a mixture of materials from many different sources.
- Alluvial soils are transported to their present locations by rivers and streams.
- Lacustrine and marine soils are transported and deposited in lakes and oceans, respectively.
- Aeolian soils are transported and deposited by wind.
- Colluvial soils are transported downslope by gravity.

2.16 Explain the difference between ablation till and lodgement till. Which would provide better support for heavy civil engineering projects? Why?

Solution

Lodgement till is soil that has been covered by a glacier, and thus has been heavily consolidated and is very dense. Ablation till is soil that has been pushed ahead and deposited at the foot or along the sides of a glacier. It has not been covered by a glacier, and thus is generally very loose. Lodgement till provides excellent support for heavy civil engineering projects, but ablation till provides only fair support. Thus, lodgement till is better.

2.17 Which would probably provide better support for a proposed structure, an alluvial sand or an aeolian sand? Why?

Solution

Aeolian sands are those that were deposited by wind. Because of this deposition process, these sands are usually very loose, and thus prone to excessive settlement and shear failures. Alluvial sands are those deposited by water. Their density varies from loose to very dense, but they are usually denser than aeolian sands and thus less prone to problems. Therefore, alluvial sands will usually provide better support for structures.

2.18 A new car dealership has recently been built in an area known for occasional strong winds. Unfortunately, an open field of fine sandy soil exists immediately upwind of the dealership. Soon after construction, a 70 mi/hr wind blew large quantities of this soil onto the new cars, seriously damaging their paint. Could this problem have been anticipated? What mode of aeolian transport brought the sand from the field to the cars? Given the current conditions, how might this problem be avoided in the future?

Solution

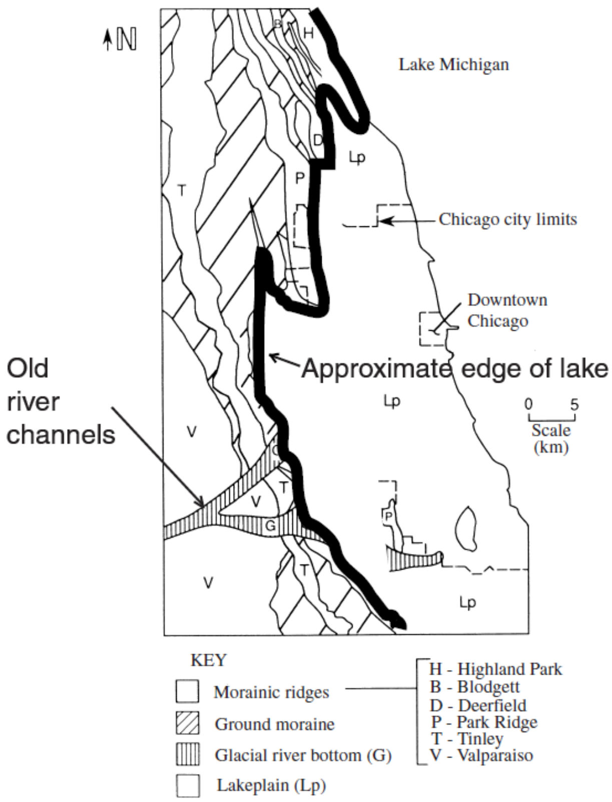
Yes, this problem could have been anticipated because the area known for having strong winds, and the proximity of the sandy soils. These aeolian fine sands were probably transported primarily by saltation, which means they probably reached altitudes of no more than about 1 m.

There are several ways this problem could be avoided in the future, including one or more of the following:

1. Plant and maintain appropriate vegetation in the field with the sand. This will help hold sand together and reduce the wind velocity immediately above the ground surface, thus significantly reducing erosion. In addition, the vegetation will trap soil particles that may enter the field from further upwind via creep or saltation.
2. Install a line of closely-spaced 1-m-tall shrubs between the new cars and the sandy field. Use shrubs with very dense foliage that extends down to the ground surface, thus providing a barrier to creep and saltation.
3. Build a 1-m-tall wall between the new cars and the sandy field. This will will act as a barrier to creep and saltation.
   Note: This is a true case history. Solution #2 was used to avoid future problems.

2.19 Make a copy of Figure 2.18 and indicate the probable lateral limits of Lake Michigan and the probable locations of previous river channels.

Solution



Note: This interpretation is based solely on the information given in the map. Additional information, such as boring logs, would be very helpful.

Section 2.7 Rock and Soil as Geomaterials

2.20 What are the major differences between a rock and a soil?

Solution

- Rocks are generally cemented; soils are rarely cemented.
- Rocks usually have much lower porosity than soils.
- Rocks can be found in states of decay with greatly altered properties and attributes; effects of weathering on soils are more subtle and generally less variable.
- Rock masses are often discontinuous; soil masses usually can be represented as continuous.
- Rocks have more complex, and generally unknowable stress histories. In many rock masses, the least principal stress is vertical; in most soils the greatest principal stress is vertical.

2.21 Geologists and engineers do not always use the same definitions of "rock" and "soil." Thus, there are some materials that are "rock" in the geologic sense, but not in the engineering sense. For example, some mudstones might be classified as rock by a geologist, yet be weaker than some "soils." Give an example of a situation where this difference could cause problems in the design or construction of a civil engineering project.

Solution

- Example 1: Some people think all "rock" is very difficult to excavate, while all "soil" is easy to excavate. However, some rocks, such as mudstone, can easily be excavated by normal earthmoving equipment, while some soils, such as caliche, are very difficult to excavate. A contractor who does not understand this may bring the wrong equipment to a job site.
- Example 2: A contractor has been hired to make an excavation at a site that contains both hard soil and soft rock. The payment for this work will be based on a certain price per cubic meter for soil and another higher price for rock. The contract does not define the terms "rock" and "soil." During construction, the constructor submits an invoice for a certain volume of "rock" excavation, but a dispute arises because the engineer believes the material was "soil." It would have been much better if the contract defined how to differentiate between these two materials (i.e., it is "rock" if it cannot be ripped with a certain type of earthmoving equipment).
- Example 3: A geologist has identified a certain siltstone strata as "bedrock." The engineer has never seen this material, but imagines it to be something akin to granite. Therefore, based on the geologist's description, the engineer decides to specify its use for rip-rap along a river bank. Then, during construction, it becomes evident that this "bedrock" has a very low strength, is highly erodible, and thus is completely unsuitable for use as rip-rap. This misunderstanding results in a frantic last-minute search for a suitable source of rip-rap, unanticipated expense for the owner, and possibly a lawsuit.

Comprehensive

2.22 A proposed construction site is underlain by a sedimentary rock containing rounded gravel-size particles and sand. The gravel-size particles represent about 75 percent of the total mass. What is the name of this rock? Would you expect it to provide good support for the proposed structural foundations? Would it be difficult to excavate?

Solution

According to Table 2.1, this is a conglomerate. It will probably provide excellent support for structural foundations, but may pose some excavation problems, especially if it is cemented with silica or iron oxide.

2.23 As the glaciers in North America melted, the runoff formed a large lake in what is now southern Manitoba, eastern North Dakota, and western Minnesota. Called Lake Agassiz, it was larger than all of the current Great Lakes combined. The present Lake Winnipeg is a remnant of this ancient lake. The City of Winnipeg is located on the ancient lakebed. What kinds of soils would you expect to find beneath the city, and what would be their likely geologic origin? What would be the typical engineering characteristics of these soils?

Solution

The soils deposited along the bottom of the former Lake Agassiz would be lacustrine soils, and are likely to be predominantly clays and silts.

2.24 Would you expect to find till in Houston, Texas? Why or why not?

Solution

No, there would not be any till in Houston because there were never any glaciers there.

2.25 A heavy structure is to be built on a site adjacent to the Hudson River near Albany, NY. This area was once covered with glaciers that left deposits of lodgement till and glaciofluvial soils. Since then, the river has deposited alluvial soils over the glacial deposits. The design engineer wishes to support the structure on pile foundations extending to the lodgement till, and you are planning a series of exploratory borings to determine the depth to these strata. What characteristics would you expect in the lodgement till, i.e. how would you recognize it?

Solution

The lodgement till would be much harder than the overlying glaciofluvial and alluvial soils. This difference in hardness should be very evident in the borings. In addition, lodgement till usually has a wide range of particle sizes, including gravel, sand, and clay.

2.26 New Orleans, Louisiana is located near the mouth of the Mississippi River. What geological process has been the dominant source of the soils beneath this city? What engineering characteristics would you expect from these soils, i.e. overall quality, uniform or erratic, etc.? Explain.

Solution

New Orleans is in the Mississippi River Delta, which is primarily alluvial soils deposited by the river. At one time this area was part of the Gulf of Mexico, so some of these alluvial soils were deposited underwater, and thus could be considered to be marine soils. Since the terrain in this area is very flat and water velocity in the river is low, the underlying soils probably include large quantities of clay, silt, and fine sand. In addition, these deposits are relatively young, and thus have not been heavily consolidated. Therefore, their engineering properties are probably poor to fair.

2.27 A project is to be built on a moderately sloping site immediately below the mouth of a canyon near Phoenix, Arizona. Using the geologic terms described in Section 2.6, what type of soil is most likely to be found? Why? What engineering characteristics would you expect from these soils? Explain.

Solution

Considering its location near the mouth of a canyon in an arid area, and the moderate slope, the site is probably on an alluvial fan. The soils should be coarser near the mouth of the canyon and become finer away from the mouth. The soils may be layered with interbedded sediments including gravels, sands, silts and clays.

2.28 A varved clay deposit has been progressively buried by other deposits and eventually has been lithified into a sedimentary rock. What type of rock is it? Would you expect its bedding planes to be distinct or vague? What engineering characteristics would you expect from these soils? Explain.

Solution

This rock might be a mudstone, siltstone, claystone, or shale, depending on the relative contents of silt and clay and on the degree of induration. Since the original soil was varved, the rock will have distinct bedding planes.