Mid-Atlantic Region
Technician Certification Program

AGGREGATE TECHNICIAN MANUAL

U.S. Department of Transportation
Federal Highway Administration

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FOREWORD

This manual does not propose to be the last authority regarding Aggregate Testing. It is intended to act as a guide and reference to obtaining Certified Status in the field of Aggregate Testing in the Mid-Atlantic Region.

ACKNOWLEDGEMENTS
MARTCP TEAM MEMBERS:

Mr. Robert A. Kochen, Chair	***- Maryland Dept. of Transportation***
Mr. David P. Van Kavelaar	***- Delaware Dept. of Transportation***
Mr. George W. Hall III	***- Maryland Dept. of Transportation***
Mr. Quinton D. Davis	***- New Jersey Dept. of Transportation***
Mr. Paul M. Ingram	***- Pennsylvania Dept. of Transportation***
Mr. Kerry W. Petrasic	***- Pennsylvania Dept. of Transportation***
Mr. Stanley L. Hite	***- Virginia Dept. of Transportation***
Mr. Larry J. Lundy	***- Virginia Dept. of Transportation***
Mr. Ralph I. Adams	***- West Virginia Dept. of Transportation***
Ms. Carolyn S. Baird	***- West Virginia Dept. of Transportation***
Mr. Lawrence Chung	***- Washington D.C. Dept. of Public Works***

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Mr. Robert Dineen - Pennsylvania Dept. of Transportation
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Mr. Woody Hood - Maryland Dept. of Transportation
Team Facilitator/Coordinator MARTCP

National Stone Sand and Gravel Association

Chapters 4 & 5 of this manual are adopted from the National Stone Sand and Gravel Associations Aggregate Handbook, and used with their permission.

CHAPTER 1

TEST DESCRIPTIONS

1.1 OVERVIEW - TEST DESCRIPTIONS

1.1.1 MARTCP METHOD SA-1.1 - MARTCP ROUNDING PROCEDURE

This method addresses rounding-off of numbers from test results and calculations.

1.1.2 AASHTO T 2 – SAMPLING OF AGGREGATES

This test procedure defines a standard method in obtaining quality representative samples of aggregate.

Procedures defined in this test method were developed to minimize adverse impacts on sample quality caused by improper sample collection. Following these procedures assures the state agency, as well as the supplier, that a fair and representative sample has been collected for testing.

1.1.3 AASHTO T 248 – REDUCING SAMPLES OF AGGREGATE TO TESTING SIZE

This test procedure provides a standard method of taking a large representative sample and reducing it to a size suitable for testing. This procedure assures the smaller sample is representative of the total supply. This procedure describes both the uses of a mechanical splitter and the quartering method that may be used to reduce sample size.

1.1.4 AASHTO T 11 – MATERIALS FINER THAN 75μm (No.200) SIEVE IN MINERAL AGGREGATES BY WASHING

This test washes the fine particles through the 75 µm (No. 200) sieve to give an accurate determination of minus 75 µm (No. 200) portion in the sample. The determination of minus 75 µm (No. 200) material is used to compare material performance with gradation specifications, and indirectly to gauge such properties as plasticity, permeability, and soils classifications.

1.1.5 AASHTO T 27 – SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

This procedure defines a standard method to determine by mechanical means the distribution of various particle sizes of an aggregate mixture. The procedure can be adapted to fit the design sieves for aggregate mixtures that are defined by each state's specifications.

1.1.6 AASHTO T 19 – BULK DENSITY ("UNIT WEIGHT") AND VOIDS IN AGGREGATES

This procedure defines the method for determining the Unit Weight and Voids in Aggregates containing particles not exceeding a nominal maximum size of five inches (125 mm). The unit weight is necessary for selecting proper proportions in concrete mix designs. Calculation of voids in fine, coarse, or mixed aggregate is based upon the determination of the unit weight.

1.1.7 MARTCP SA-1.3 - PERCENT MOISTURE CONTENT PROCEDURE

This procedure establishes a uniform test method for pan-drying soils and aggregate samples on the project.

1.1.8 AASHTO T 84 - SPECIFIC GRAVITY OF FINE AGGREGATES

This method determines the Specific Gravity of Fine Aggregates that have been soaked for a period of 15-19 hours. The determinations made from this procedure are identical to those under AASHTO T 85 (Specific Gravity and Absorption of Coarse Aggregate).

1.1.9 AASHTO T 85 - SPECIFIC GRAVITY OF COARSE AGGREGATES

This method determines the Specific Gravity of Coarse Aggregates that have been soaked for a period of 15-19 hours. There are four determinations that may be made from this procedure: Bulk Specific Gravity (G_{sb}) (also known as Bulk Dry Specific Gravity), Bulk SSD Specific Gravity (G_{sb} SSD), Apparent Specific Gravity (G_{sa}), and Absorption (% Abs.).

1.1.10 AASHTO T 89 – DETERMINING THE LIQUID LIMIT OF SOILS

This method determines the Liquid Limit of Soils. The Liquid Limit is the moisture content at which a specific soil moves from a plastic to a liquid state. Generally, soils with high Liquid Limits are clays with poor engineering properties. Soils with a high clay content are cohesive (stick together), plastic (moldable), compressible (able to be consolidated), and nearly impervious (impenetrable by water).

1.1.11 AASHTO T 90 – DETERMINING THE PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

This method determines the Plastic Limit of Soils. The minimum moisture content at which a soil behaves as a plastic is called the Plastic Limit. This method, in conjunction with the Liquid Limit Method, also determines the Plasticity Index of a material. The Plasticity Index is a calculated value derived by subtracting the Plastic Limit from the Liquid Limit;
i.e. PI = LL - PL

1.2 - TEST METHODS

1.2.1 MARTCP METHOD SA-1.1 - MARTCP ROUNDING PROCEDURE

This Method addresses rounding off of numbers from test results and calculations.

If the number following the last number to be retained is less than 5, the last number to be retained is left unchanged and the number(s) following the last number to be retained is/are discarded (e.g. 14.649 = 14.6, 14.749 = 14.7).

If the number following the last number to be retained is greater than 5, increase the last number to be retained by 1 and discard the number(s) following the last number to be retained (e.g. 14.66 = 14.7, 14.76 = 14.8).

If the number following the last number to be retained is 5, and there are no numbers beyond 5, only zeros, the last number to be retained is increased by 1 if odd, or left unchanged if even. The number(s) following the last number to be retained is/are discarded (e.g. 14.750 = 14.8, 14.650 = 14.6).

If the number(s) following the last number to be retained is 5 and there is/are numbers following the 5, the last number to be retained is increased by 1 regardless of being odd or even. The number(s) following the last number to be retained is/are discarded (e.g. 14.751 = 14.8, 14.651 = 14.7).

For questions involving significant figures, refer to AASHTO R 11. In most instances, the individual state specifications and test procedures will define the level of accuracy needed for the test results.

1.2.2 AASHTO T 2 - SAMPLING OF AGGREGATES

Aggregates compose a major portion of most highway construction. They are used in all phases, including base construction, pavement mixes, granular shoulders, granular surfacing, drainage and erosion control. For aggregates to perform as intended, they must meet certain physical requirements such as proper gradation, durability to resist the effects of weathering, and resistance to abrasion loss.

The most important phase of an aggregate technician's duties is securing a representative sample. At this point, all the money and time which will be expended on the remaining activities of testing and evaluation may be lost or rendered useless by an improper sampling technique. In other words, if the samples taken are not representative of the total material, it is impossible to obtain meaningful test results. At the completion of this instruction, the technician must know how to obtain a proper sample. Without this knowledge, it is useless to proceed further into the areas of the test procedures.

Test samples should represent the total amount of the material being produced or used. This is normally accomplished by random sampling. All material should have an equal chance of being tested. Random samples are taken when the plant or operation is processing at the usual rate. During production at the source, care must be taken to assure that the virgin material being processed is normal to the overall consistency of the available material. Clay pockets, boulders or varying seams in a gravel pit, mine, or quarry may create short-term variations in the consistency of the product.

It must be pointed out that not all samples are random samples. At times the technician must choose the time of sampling, especially during the production phase. Control samples may be needed during start-up, equipment changes or changes in the material. These circumstances will directly affect the gradation of the material and must be checked to keep the material within proper limits. During a normal day's operation, all samples taken may be random samples if all operations are running consistently. Random samples may not be taken every day, such as the first days run to establish crusher settings, etc. A combination of random and control check samples may be taken on the same day. The technician should sample based on random sampling techniques and not by judgement.

Keep in mind that, during normal and steady operations, samples should be selected in a random method prescribed by state specifications.

When securing processed aggregate samples, at least three increments of coarse aggregate shall be taken by an appropriate method as described in this instruction. There should be five increments of fine aggregate sampled using the sampling tube or other suitable device. When practical, more increments should be taken to build the field sample. Taking more increments provides a better cross-section of the total material.

The discussion of securing samples would not be complete without mentioning safety. The production and placement of aggregates require the use of heavy equipment and large bins. The conditions are frequently dusty and noisy. The aggregate technicians must use extreme caution to insure that sampling locations are safe.

1.2.2.1 SUMMARY OF AGGREGATE SAMPLING

There are four methods approved by AASHTO for securing aggregate samples. The method the technician uses depends on the type of aggregate to be sampled, the location of the sample, and the sampling equipment available. The four methods are Flowing Aggregate Stream, Conveyor Belt, Stockpiles or Transportation Units, and Roadway (Bases and Sub-bases), as illustrated below in Figures 1 through 4.

Figure 1 - Flowing Aggregate Stream (Bins or Belt Discharge)

Figure 2 - Conveyor Belt

Figure 3 - Stockpiles or Transportation Units

Figure 4 - Roadway (Bases and Subbases)

The most accurate way to insure that processed aggregates meet requirements would be to test the entire stockpile. This would be impractical. Accurate, representative samples must be secured for testing to insure that the required characteristics are measured.

Aggregate samples may be obtained at different stages of production or construction as required by state specifications:

- Preliminary source investigation. These samples are normally obtained by the party responsible for development of the source.
- During aggregate production at the source, samples for quality control of the production are obtained by the manufacturer, contractor or other responsible party.
- Control of the operations at the job site is also the responsibility of the producer, contractor or other qualified party.
- Samples to determine acceptance or rejection by the states are obtained by the purchaser or an authorized representative.

Samples secured for the purpose of quality testing such as soundness, clay content, resistance to abrasion, etc., should be obtained from the finished product when practical. Samples from the finished product to be tested for resistance to abrasion shall not be subjected to further crushing or manual reduction in particle size (unless the size of the finished product is such that it requires further reduction for testing purposes).

COMMON TESTING ERRORS

- Using an improper sampling device.
- Sampling in segregated areas.
- Not obtaining enough increments.
- Improper sampling method for a particular aggregate.
- Allowing overflow in a streamflow device.
- Obtaining a biased or non-representative sample.

1.2.2.2 NUMBER AND MASS OF FIELD SAMPLES

The number of field samples required depends on each state's sampling program. The number of field samples obtained during production must be sufficient to give the desired confidence in the test results. A single field sample should neither be so large as to mask the effects of significant variability within the unit, nor so small as to be affected by the inherent variability between small portions of any bulk material.

Field sample size must be based on the type and number of tests to be run on the aggregate. Standard acceptance and control tests are covered by AASHTO/ASTM Standards and specify the portion of the field sample required for each specific test. Generally speaking, the masses shown in the following table will provide sufficient material for routine grading and quality analysis. Extract test portions from the field sample according to AASHTO T 248.

Nominal Maximum Size Of Aggregates*	Appropriate Minimum Mass of Field Samples, kg (lb.)**
Fine Aggregates	
2.36 mm (No. 8)	10 (25)
4.75 mm (No. 4)	10 (25)
Coarse Aggregates	
9.5 mm (3/8 in.)	10 (25)
12.5 mm (1/2 in.)	15 (35)
19.0 mm (3/4 in.)	25 (55)
25.0 mm (1 in.)	50 (110)
37.5 mm (1 ½ in.)	75 (165)
50.0 mm (2 in.)	110 (220)
63.0 mm (2 ½ in.)	125 (275)
75.0 mm (3 in.)	150 (330)
90.0 mm (3 ½ in.)	175 (385)

* *For processed aggregate the nominal maximum size of particles is the largest sieve size listed in the applicable specification, upon which any material is permitted to be retained.*

** *For combined coarse and fine aggregates, minimum mass shall be equal to the coarse aggregate minimum plus 10 kg (25 lb.).*

1.2.2.3 SHIPPING SAMPLES

Transport the aggregate samples in bags made for that purpose or other suitable containers constructed so as to prevent loss, contamination or damage to the sample during handling and shipping.

The sample containers shall have proper identification that is attached to or enclosed within, to facilitate field reporting, laboratory logging and test reporting.

1.2.2.4 SAMPLING METHODOLOGY - AGGREGATE STREAMFLOW

Before taking a sample, you must first gather all equipment necessary to obtain the sample. To obtain a sample using the aggregate streamflow, you will need the following:

- Sampling device designed for use at each particular plant. This device consists of a pan of sufficient size to intercept the entire cross section of the discharge stream and retain the required quantity of material without overflowing. In some situations, a set of rails may be necessary to support the pan as it is passed through the streamflow.
- Safety equipment such as hard hat, glasses, etc.
- Sample containers, tags, etc.

Sampling Procedure and Guidelines

Pass the sampling device through the streamflow, being sure to cut through the entire cross section of the material as it is being discharged. Care must be taken to pass the device through the stream rapidly enough to prevent any overflow of material during the sampling procedure. Obtain a minimum of three increments for each sample. Be sure to obtain equal increments. Obtain the appropriate size to accommodate all tests to be performed on the sample. Allow an amount of time to elapse between passes to get a representative sample of the material. When sampling aggregate from a loaded bin, increments should not be obtained when the belt first starts or when the bin is nearly empty. This minimizes the natural segregation that may occur as the material exits the bin.

Figure 1 - Streamflow Sampling

1.2.2.5 SAMPLING METHODOLOGY - CONVEYOR BELT

The equipment required for sampling from a conveyor belt is somewhat different than that used for sampling from a streamflow. The following is the equipment needed to secure a proper sample from a conveyor belt:

- A template constructed to conform to the shape of the loaded belt. An adjustable spacer between the two ends of the template is helpful to allow for adjustment of the device to the amount of aggregate on the belt (see Figure 2).
- A scoop or trowel to aid in removing the aggregate from the stopped belt.
- A brush or broom to aid in removing fine particles from the belt surface (see Figure 3).
- Sample containers, tags, etc.
- Safety equipment such as hard hat, gloves, glasses, etc.

Figure 2 - Belt Cut Using Template

Figure 3 - Cleaning fines from belt.

Sampling Procedures and Guidelines

Insert the template into the aggregate on the stopped conveyor belt. Make sure the template passes through the aggregate and rests on the surface of the belt. Do not sample the portions of material first discharged on the belt or material discharged as the bin empties. These areas are normally segregated and the sample will not be representative. Using the small scoop or trowel, remove the aggregate from the belt. Brush the remaining fines into the sample container. A dustpan may be useful in some applications to collect the fines. Obtain at least three increments for each field sample being sure to collect the minimum size needed to perform all required tests. When possible, allow the belt to run awhile between each increment. This will aid in obtaining a sample representative of the lot of material being tested.

Figure 4 - Three belt cuts to make one sample.

1.2.2.6 SAMPLING METHODOLOGY - STOCKPILES OR TRANSPORTATION UNITS

The equipment necessary to obtain a sample from a stockpile or transportation unit is listed below:

- Sampling tube (approximately 1¼ in. (30 mm) minimum by 6-ft. (2 m) in length.
- Square-nosed shovel.
- Flat board.
- Sample containers, tags, etc.
- Safety equipment such as hard hats, gloves, glasses, etc.
- Front-end loader (if available).

Sampling Procedure and Guidelines

To obtain stockpile samples of coarse or combined aggregates, follow the sampling procedures of the respective state agency. General principles for sampling from stockpiles apply to sampling from transportation units such as trucks, rail cars and barges.

When available, have the power equipment operator create a small stockpile for sampling by drawing material from various levels and locations from the main pile. Several increments should then be sampled from this pile using the square-nosed shovel. A flat board shoved vertically into the pile just above the sampling point aids in preventing further segregation. This will hold the material above the location in place.

When power equipment is not available, the same method may be employed at various levels and locations around the main pile. A minimum of three increments must be obtained, one from the top third, one from the midpoint, and one from the bottom third of the pile.

If it is necessary to determine the degree of variability existing within the pile, separate samples should be drawn from separate areas of the pile.

When sampling from transportation units, reference should be made to respective state specifications and procedures. In the absence of such procedures, the following methods may be used.

A common sampling procedure when power equipment is not available requires trenching at three or more locations across the unit in areas that visually represent the characteristics of the load. The trench bottom should be approximately level and at least 0.3 m (1 ft.) in width and depth. A minimum of three increments from approximately equally spaced points along each trench should be taken by pushing the shovel downward into the material.

Sampling of fine aggregates from stockpiles or transportation units could be accomplished with a sampling tube. The technician must be careful to avoid segregated areas located around the base of the stockpile or transportation unit to be sampled. Use a square-nosed shovel or other means to dig into the pile before insertion of the sampling tube. Insert the tube into the pile at several locations to extract a minimum of five increments of material to create the field sample. *This method should not be used for coarse or combined aggregates.*

The technician may choose to sample the fine aggregate by creating a vertical face in the selected sample areas with a square-nosed shovel and then carefully slide the nose of the shovel in an upward motion from the base of the prepared sample area. The shovel should be held at an approximate ninety degree angle to the vertical face and inserted into the fine aggregate approximately 50 mm (2 in.). The aggregate should be in a damp condition to use this method.

When sampling a unit of fine aggregate, select at least three areas to obtain the individual increments that, when combined, will make up the field sample. The mass of the field sample must be large enough to provide sufficient material for each test to be performed on the aggregate.

Figure 1 - Stockpile sampling with a sampling tube

Figure 2 - Stockpile sampling with a square-nosed shovel

1.2.2.7 SAMPLING METHODOLOGY - ROADWAY (BASES AND SUBBASES)

The equipment to sample aggregate from the roadway includes the following:

- Square-nosed shovel.
- Square or rectangular template.
- Sample containers, tags, etc.
- Safety equipment, such as hard hats, gloves, glasses, etc.

Sampling Procedure and Guidelines

Selecting representative samples of aggregate in place creates a special challenge. A method of random sampling must be used in obtaining an unbiased and representative sample.

Obtain at least three increments from the unit being sampled. Combine them to form a field sample with a size that meets or exceeds the minimum amount required for the type of material being sampled. Increments taken from the roadway must be from the full depth of the material. Care must be taken to avoid contaminating the sample with underlying material. A square or rectangular template placed over the area to be sampled aids in securing approximately equal amounts of material. A square-nosed shovel may also be used to aid in defining the sample area.

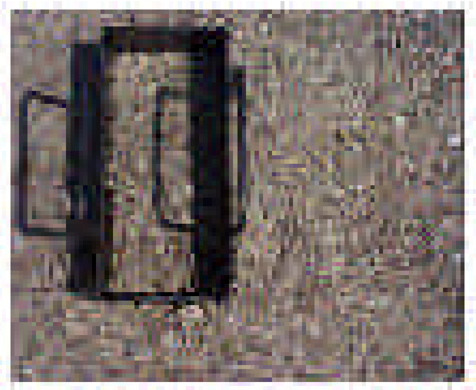

Figure 1 - Template placed in subbase

NOTE:
When sampling in a construction zone, always be aware of the activities around you.

1.2.3 AASHTO T 248 - REDUCING SAMPLES OF AGGREGATE TO TESTING SIZE

1.2.3.1 PROCEDURE

Aggregates compose a major portion of most highway construction. They are used in all phases including base construction, pavement mix, granular shoulders, granular surfacing, drainage and erosion control. In order to assure the aggregate performs as intended for the specified use, a variety of tests must be performed on the aggregate. These samples must be representative of the aggregate selected for use and should be obtained by appropriate methods as described in AASHTO T 2.

The field samples of aggregate must generally be reduced to an appropriate size for testing to determine physical characteristics. The methods described in this text are intended to minimize variations in the aggregate characteristics between the smaller test samples and the larger field samples.

Several methods of sample reduction will be described. The technique to be used by the technician is dependent on such factors as aggregate size and moisture content. The reduction methods include Mechanical Splitters, Quartering and Miniature Stockpiles.

Method A - Mechanical Splitters

Figure 1a

Figure 1b

Method A - Mechanical Splitters (continued)

Figure 1c

Figure 1d

Method B - Quartering

Figure 2a

Figure 2b

Method C - Miniature Stockpile

Figure 3a

Figure 3b

Method C - Miniature Stockpile (continued)

Figure 3c

Figure 3d

In some circumstances, reducing the field sample prior to testing is not recommended. Substantial differences may occur during sample reduction as in the case of an aggregate having relatively few large size particles in the sample. These few particles may be unequally distributed among the reduced size test samples.

Failure to follow the sample reduction procedures may result in providing a non-representative sample.

1.2.3.2 SUMMARY OF SAMPLE REDUCTION

Aggregates sampled in the field need to be reduced to appropriate sample size for testing. It is, therefore, necessary to reduce field samples while minimizing the chance of variability during handling. In some instances, a few particles on a given sieve might affect a gradation significantly enough to alter an interpretation of the field sample and subsequently the entire lot's compliance with specifications.

The appropriate field sample reduction method depends chiefly on the nominal maximum size of the aggregate, the amount of free moisture in the sample, and the equipment available.

The following chart may be used in selecting the appropriate reduction method for the aggregate to be tested.

Mechanical Splitter	Quartering	Miniature Stockpile*
Fine Aggregates - Air Dry	Fine Aggregates - Free Moisture on the Particle Surface	Fine Aggregates - Free Moisture on Particle Surface
Coarse Aggregates	Coarse Aggregates	Not Appropriate for Coarse Aggregates
Combined Aggregates	Combined Aggregates with Free Moisture on the Particle Surface	Not Appropriate for Combined Aggregates

* Note: Obtain a sample for each test by selecting at least five increments of material at random locations from the miniature stockpile.

1.2.3.3 COMMON SAMPLE REDUCTION ERRORS

- Failure to obtain a field sample using the methods and guidelines given in AASHTO T 2.
- Failure to select proper method for sample reduction based on aggregate moisture content.
- When using a mechanical splitter, failure to uniformly distribute the field sample from edge to edge while placing it in the hopper or pan prior to pouring it through the chutes.

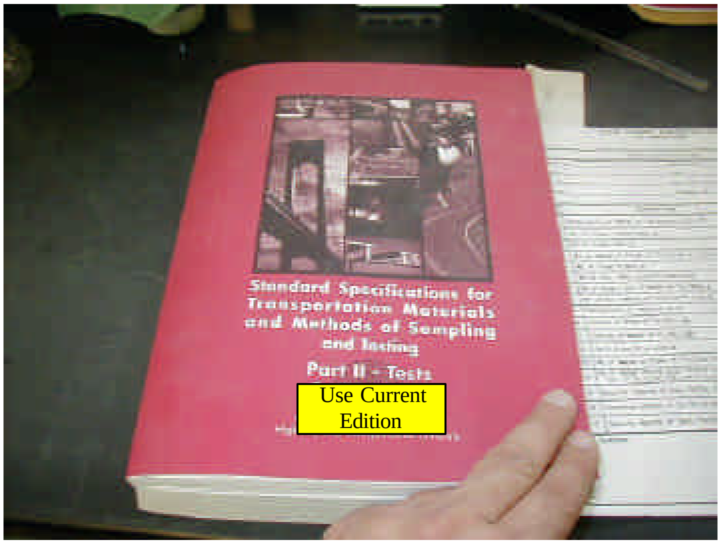

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Figure 4 - AASHTO Standards

Figure 5 - Sample spread uniformly in splitter

Figure 6 - Sample not spread uniformly in splitter

- Failure to control the rate at which the materials are poured through the chutes of a mechanical splitter such that the material is free flowing into the receptacle pans below. This includes using a hopper or straight-edged pan that, per AASHTO T 248, has a width equal to or slightly less than the overall width of the chute assembly.

Figure 7 - Proper sized pan to fit splitter

.

- Failure to use mechanical splitters which meet the applicable requirements for the number of chute openings and chute width.

Figure 8 – Incorrect Openings

- When using the quartering method or miniature stockpile method, failure to mix the sample thoroughly by turning the entire sample over three times.

Figure 9 - Improper mixing of sample for quartering

- When using the quartering method, failure to brush the cleared spaces clean of fines after removing the two diagonally opposite quarters from the flattened field sample.

Figure 10a

Figure 10b

(Remember: Collect all sample fines)

- When using the miniature stockpile method, failure to obtain the five (minimum) increments of material from random locations in the miniature stockpile. Do not take all five samples from the same location.

Figure 11 - Non-representative sampling

1.2.4 AASHTO T 11 - MATERIALS FINER THAN 75mm (No. 200) SIEVE IN MINERAL AGGREGATES BY WASHING

1.2.4.1 SCOPE

Aggregates compose a major portion of most highway construction. They are used in all phases including base construction, pavement mix, granular shoulders, granular surfacing, drainage and erosion control. In order to insure the aggregate performs as intended for the specific use, a variety of tests must be performed on the aggregate. One such test is determining materials finer than 75 µm (No. 200) sieve in mineral aggregates by washing. Fine materials, such as clay particles or water-soluble particles removed by washing, can cling to larger particles and do not dislodge readily. In this test, the fine particles are washed through the 75 µm (No. 200) sieve to give an accurate determination of the minus 75 µm (No. 200) portion in the sample. Determination of the minus 75 µm (No. 200) material is utilized to compare material performance with gradation specifications and indirectly to gauge such properties as plasticity and permeability. This knowledge helps in determining whether a material is potentially frost susceptible and whether permeability (measurement of material capacity to allow water flow through it) will be affected.

1.2.4.2 SUMMARY OF TEST

A measured amount of material is placed in a wash container and covered with water (containing a wetting agent, if required) and agitated to suspend the finer sized particles. The rinse water is then poured through a 75 µm (No. 200) sieve. After thorough washing, transfer the remaining sample to a pan, dry and weigh. The percentage passing through the 75 µm (No. 200) sieve is then calculated.

1.2.4.3 EQUIPMENT

- Balance - general purpose (AASHTO M 231).
- Sieves - a 2.36 mm (No. 8) or 1.18 mm (No. 16) and a 75 µm (No. 200).
- Container - of sufficient size to properly agitate the sample without losing material.
- Oven - capable of maintaining a temperature of 110 ± 5 °C (230 ± 9 °F).
- Wetting agent (if required).

1.2.4.4 SAMPLE PREPARATION

Dry sample to a constant mass in an oven regulated at 110 ± 5 °C (230 ± 9 °F). Determine the proper dried sample mass from the following table (Table 1.1) based on the maximum nominal size of the sample to be tested.

Figure 1 - Placing sample in oven.

Table 1.1 – Sample Mass Requirements

Nominal Maximum Size, mm (in.)	Minimum Mass of Sample, g (lb.)
4.75 (No. 4) or smaller	300 (0.66)
9.50 (3/8)	1,000 (2.2)
19.00 (3/4)	2,500 (5.5)
37.50 (1 ½) or larger	5,000 (11.0)

1.2.4.5 PROCEDURE

1. Dry sample to a constant mass. Record this as the dry mass of the material to the nearest 0.1 % of the mass of the test sample. Allow sample to air cool.

2. Place sample into a wash container large enough to mix the sample with water (Figure 2). Cover the sample with water (with wetting agent if required), and agitate it with sufficient movement so that the particles finer than the 75 mm (No. 200) sieve become suspended in the water. A spoon or other instrument may be used to stir and agitate the sample. Care should be taken not to lose any portion of the sample.

3. Pour the water with the suspended fines through nested sieves. Nested sieves, with openings of 2.36 mm (No. 8) or 1.18 mm (No. 16) above the75 µm (No. 200) sieve are required. Take care to pour only the water with suspended fines and not the sample itself, since samples with larger size

aggregates might damage or clog the fine screen on the 75 µm (No. 200) sieve (Figure 3). *NOTE: Occasionally inspect the 75 mm (No. 200) sieve for cracks along the seam or holes in the screen, as any imperfections will affect the final wash sieve results.*

Figure 2 - Wash sample in a large container. Sample should be stirred or agitated in order to suspend the fines in the water.

Figure 3 - Fines suspended in the water are washed over a 2.36 mm (No. 8) or 1.18 mm (No. 16) and a 75 µm (No. 200) sieve.

Figure 4

4. Continue washing the sample with additional water and agitate. When the washed sample is near completion, the water should be relatively clear (Figure 4).

Figure 5 - Material retained on the 75 µm (No. 200) sieve after washing

5. Give the sample a final rinse, pouring as much of the remaining water as possible out of the sample and into the nest of sieves. Transfer the remaining sample into a pan for oven drying.

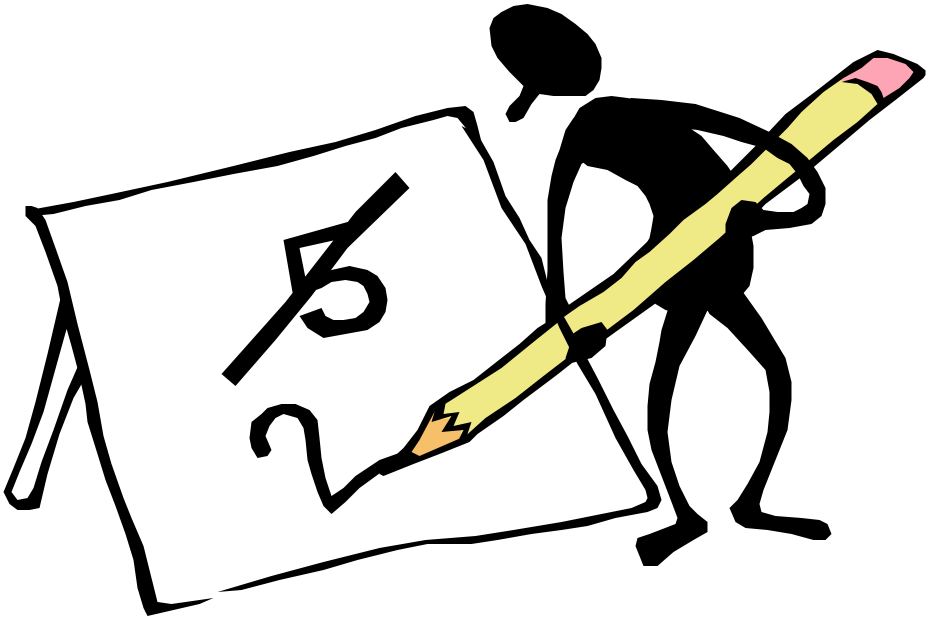
6. Any fines remaining on the 75 mm (No. 200) sieve must be included in the sample for drying (Figures 5 & 6).

Figure 6 - A water bottle may be used to rinse the material from the 75 μm (No. 200) sieve to the drying pan.

Figure 7 - Washed sample ready for drying.

7. Place the container with the washed sample (Figure 7) into an oven (Figure 1) regulated at 110 ± 5°C (230 ± 9°F) and dry to a constant mass. Record the dry mass.

8. Perform calculations in accordance with AASHTO T 11.



1.2.4.6 COMMON ERRORS

- Failure to adequately pre-dry the sample.
- Overloading wash sieve [75 µm (No. 200) sieve].
- Avoid clogging the sieve by dumping the whole sample on it, as it may damage the delicate screen.
- Loss of material during the test.
- Splashing material over the sides of the wash container.
- Using a deficient 75 µm (No. 200) sieve, i.e., holes in the screen material, screen material not sealed to the side of the sieve frame or a blocked sieve.
- Failure to completely dry the washed sample to a constant mass.

1.2.5 AASHTO T 27 - SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

1.2.5.1 Scope

The sieve analysis, commonly known as the gradation test, is a basic and essential test. The sieve analysis determines the gradation (the distribution of aggregate particles, by size, within a given sample) in order to verify compliance with design, production control requirements and specifications. This data can be used to calculate relationships between various aggregates and to predict trends during production by plotting gradation curves graphically. Used in conjunction with other tests, the sieve analysis is a quality control and quality acceptance tool.

NOTE: Accurate determination of material passing the 75 mm (No. 200) sieve cannot be made with this test alone. It is recommended to use this test in conjunction with AASHTO T 11 in order to determine the amount of material finer than the 75 mm (No. 200) sieve.

1.2.5.2 Summary of Test

A measured amount (mass) of material is placed on the top of a set of nested sieves, and shaken by mechanical means for a specified period of time. The amount of material is determined by the nominal maximum size of the aggregate. The top sieve has the largest screen openings and the screen opening size decreases with each successive sieve. After shaking the material through the nested sieves, the material retained on each of the sieves is weighed using one of two methods. The method used will depend on the individual state's requirements.

In the *cumulative method* (percent retained), material from the largest sieve is placed in a tared container and weighed. The contents of the next smaller sieve are then added to the tared container and the accumulated weight is recorded. Repeat this procedure until the material from all the sieves and the pan, if required, has been weighed and recorded.

In the *non-cumulative method* (percent passing), the contents of each sieve and the pan, if required, are individually weighed and recorded. Do not discard material until the entire test is completed. The amount retained on and passing each sieve is then calculated.

1.2.5.3 EQUIPMENT

- Balance - general purpose class (AASHTO M 231).
- Sieves - mounted on suitable frames, shall conform to AASHTO M 92.

- Mechanical sieve shaker - if used, must provide a vertical or lateral and vertical motion to the sieve. Sieve shaker must provide sieving thoroughness within a reasonable time.

- Oven - capable of maintaining 110 ± 5 °C (230 ± 9 °F).

1.2.5.4 SAMPLE PREPARATION

Samples should be obtained in the field and reduced to test size in compliance with the applicable test methods (AASHTO T 2 and AASHTO T 248). Samples should be dried to a constant mass in an oven regulated to 110 ± 5 °C (230 ± 9 °F), except where control situations necessitate rapid test results on coarse aggregate. AASHTO T 27 allows the coarse aggregate test to be performed in a moist condition as long as the nominal maximum size of the aggregate is greater than 12.5 mm (½ in.). Drying is allowed on a hot plate providing the particles do not fracture and/or change chemically due to the heat. Use Table 1.2 to determine the appropriate sample size based on the nominal maximum size of the aggregate in the sample to be tested.

Table 1.2

AASHTO Sample Sizes for Aggregate Gradation

Nominal, Maximum Size Agg. mm (in.)	Minimum Mass of Test Sample kg (lb)
9.5 (3/8)	1 (2)
12.5 (1/2)	2 (4)
19.0 (3/4)	5 (11)
25.0 (1)	10 (22)
37.5 (1 1/2)	15 (33)
50.0 (2)	20 (44)
63.0 (2 1/2)	35 (77)
75.0 (3)	60 (130)
90.0 (3 1/2)	100 (220)

NOTE:
Aggregate with at least 95% passing a 2.36 mm (No. 8) sieve.................................100 g
Aggregate with at least 85% passing a 4.75 mm (No. 4)
and more than 55 retained on a 2.36 mm (No. 8) ....300 g

For materials containing a mixture of fine and coarse aggregate, always use the mass from the coarse aggregate table.

NOTE ON SAMPLE SIZES: these sample sizes are standard for aggregate testing but, due to equipment restraints, samples may need to be split *into several "sub-samples" that will comprise the final test. For example, a gradation test on a material with a nominal maximum size of 75 mm (3 in.), which requires 60 kg (130 lb.) sample size, would not fit into a large tray shaker in one increment.*

1.2.5.5 PROCEDURE

1. Weigh the sample to the nearest 0.1% by total mass of sample (e.g. 130 lb ± sample recorded to nearest 0.1 lb, 1 kg ± sample recorded to nearest 0.001 kg or 1 g). This mass will be used to check for any loss of material after the sample has been graded. Select suitable sieve sizes in accordance with agency specifications. Standard sieve sizes recognized by AASHTO may differ from region to region. Always consult agency specifications in order to determine the proper sieve sizes.

Figure 1 - Large Tray Shaker

Figure 1a - Large Tray Shaker

2. Nest the sieves in order of decreasing size from top to bottom and begin shaking the sample for a sufficient amount of time. For coarse aggregate, the large tray shaker is most commonly used (Figure 1 & 1a). This device provides a clamping mechanism, which holds the sieve in place during shaking. Shakers of this make usually need to be run a minimum of 7 minutes to adequately grade the sample.

   For fine aggregate, round 203.2 mm (8 in.) sieves are commonly used (Figure 2). These sieves are self-nesting and supported in a shaking mechanism at the top and bottom by a variety of clamping and/or holding mechanisms. Small shakers of this type usually require shaking times of 10 minutes to adequately grade the fine aggregate sample.

   NOTE: Every effort should be made to avoid overloading the sieves. AASHTO defines overloading large sieves as mass retained in excess of 2.5 times the sieve opening in mm, as expressed in kg/m^2. For a 19.0 mm (3/4 in.) sieve, this means an excess of 47.5 kg/m^2 (9.7 lb/ft^2) is considered an overloaded sieve. For fine aggregate, no mass shall be in excess of 7 kg/m^2. This amounts to 200 g on any small round 203.2 mm (8 in.) sieve below the 4.75 mm (No. 4) sieve.

Figure 2 - Small Sieve Shaker

3. For coarse aggregates, after the material has been sieved, remove each tray, weigh and record the mass to the nearest 0.1% of total mass. Be sure to remove any aggregate trapped within the sieve openings by gently working from either or both sides with your hands until the aggregate is freed. Banging the sieve on the floor or hitting it with hammer will damage the sieve. The final total of the masses retained on each sieve should be within 0.3% of

the original mass of the sample prior to grading. Particles larger than 75 mm (3 in.) should be hand-sieved. When passing large stones through sieves, do not force the aggregate through the sieve openings.

4. For fine aggregates, weigh the material retained on each sieve size to the nearest 0.1% by total mass (e.g. 300 g ± sample recorded to nearest 0.1 g). Insure that all material entrapped within the openings of the sieve is cleaned out and included in the mass retained. This can be done using brushes to gently dislodge entrapped materials. The 203.2 mm (8 in.) round sieves need to be handled with special care due to the delicate nature of their screen mesh. As a rule, use coarse wire brushes to clean the 203.2-mm (8-in.) sieves down through the 600 μm (No. 30) sieve (Figure 3). Any sieve with an opening size smaller then the 600 μm (No. 30) should be cleaned with a soft cloth hairbrush (Figure 4). The final total of the masses retained on each sieve should be within 0.3% of the original mass of the sample prior to grading.

Figure 3 - Use Wire Brush on Coarse Sieves

Figure 4 - Use Hair Brush on Fine Sieves

Periodically check sieves for signs of wear and tear to avoid possible biasing of test results. In particular, inspect the sieve screens for holes, tears and cracks along the outer rim (Figure 5). Sieves with bowed screens that are not taut need to be discarded or re-screened.

Figure 5 - Cracked Outer Seam

5. Check the sieving thoroughness periodically in the following manner (Figure 6). Hold the individual sieve, provided with a snug fitting cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and, with an upward motion against the heel of the other hand at a rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes.

   Weigh the material that has passed through the sieve and into the pan. If the mass exceeds more than 0.5% of the total mass of the sample, the sieving thoroughness for that sieve (and shaker) is inadequate, and it is possible that increased shaking times are required. For example, a 300 g sample should lose no more than 1.5 g on any sieve.

Figure 6 - Checking thoroughness of sieving

1.2.5.6 CALCULATION

Two methods, cumulative or non-cumulative, are typically used to calculate a gradation in order to determine the percentage of material either retained on or passing each sieve. Both are shown here to illustrate the calculation. The method used will depend on the individual agency's requirements.

Cumulative Method

1. In the cumulative method (percent retained), material from the largest sieve is placed in a tared pan and weighed. The contents of the next smaller sieve are then added to the pan and the accumulated weight is recorded. This is repeated until the weights of the material from all the sieves and the bottom pan if required, have been recorded. Do not tare the scale until the entire cumulative mass has been recorded. The final mass on the scale is the total mass of the sample. In this example, the total mass of the sample is 414.9 g (Figure 7).

Initial Dry Mass of Sample 414.9 g

Sieve Size	Cumulative Mass (g)	Cumulative Percent Retained	Percent Passing
4.75 mm (No. 4)	48.4		
2.00 mm (No. 10)	191.7		
850 µm (No. 20)	354.6		
600 µm (No. 30)	387.2		
425 µm (No. 40)	400.8		
180 µm (No. 80)	410.2		
75 µm (No. 200)	413.3		
Total	414.9		

Figure 7 - Record the cumulative mass of materials retained on the sieves

2. Cumulative Percent Retained is calculated by dividing the Cumulative Mass retained on each sieve by the total mass of the sample and multiplying by 100 (Figure 8). In this example the 4.75 mm (No. 4) sieve had 96.8 g retained. This mass divided by the total mass (829.8) and multiplied by 100 is 11.7 %. This process is repeated for the remainder of the sieves.

Sieve Size	Cumulative Mass (g)	Cumulative Percent Retained	Percent Passing
4.75 mm (No. 4)	48.4	11.7	
2.00 mm (No. 10)	191.7		
850 µm (No. 20)	354.6		
600 µm (No. 30)	387.2		
425 µm (No. 40)	400.8		
180 µm (No. 80)	410.2		
75 µm (No. 200)	413.3		
Total	414.9		

Figure 8 48.4 grams retained on the 4.75 mm sieve, divided by the total mass (414.9g) and multiplied by 100, is 11.7%

3. Percentage passing is determined for each sieve by taking the cumulative percent retained on that sieve and subtracting it from 100%. In this example, 100 - 11.7 = 88.3 % passing the 4.75 mm (No. 4) sieve (Figure 9). This process is repeated for the remainder of the sieves.

Sieve Size	Cumulative Mass (g)	Cumulative Percent Retained	Percent Passing
4.75 mm (No. 4)	48.4	11.7	88.3
2.00 mm (No. 10)	191.7	46.2	
850 mm (No. 20)	354.6	85.5	
600 mm (No. 30)	387.2	93.3	
425 mm (No. 40)	400.8	96.6	
180 mm (No. 80)	410.2	98.9	
75 mm (No. 200)	413.3	99.6	
Total	414.9	100.0	

Figure 9: 100 – 11.7 = 88.3% Passing

4. The advantage to the cumulative method (Figure 10) is that the technician does not have to empty out or tare the pan on the scale, saving time. Some technicians find the cumulative calculation easier to use as well. However, if a sieve is overloaded, the sample must be discarded and the test repeated.

Sieve Size	Cumulative Mass (g)	Cumulative Percent Retained	Percent Passing
4.75 mm (No. 4)	48.4	11.7	88.3
2.00 mm (No. 10)	191.7	46.2	53.8
850 µm (No. 20)	354.6	85.5	14.5
600 µm (No. 30)	387.2	93.3	6.7
425 µm (No. 40)	400.8	96.6	3.4
180 µm (No. 80)	410.2	98.9	1.1
75 µm (No. 200)	413.3	99.6	0.4
Total	414.9	100.0	0.0

Figure 10 - Cumulative method completed

Non - Cumulative Method:

1. Tare the pan on the scale. Weigh the material retained on each sieve (from top to bottom). After the material from each sieve is weighed, empty the tared pan and go to the next sieve. Once all the sieves have been weighed, total the mass (Figure 11).

Initial Dry Mass of Sample: 414.9 g

Sieve Size	Mass (g)	Percent Retained	Percent Passing
4.75 mm (No. 4)	48.4		
2.00 mm (No. 10)	191.7		
850 µm (No. 20)	354.6		
600 µm (No. 30)	387.2		
425 µm (No. 40)	400.8		
180 µm (No. 80)	410.2		
75 µm (No. 200)	413.3		
Pan	414.9		
Total	48.4		

Figure 11 - Record mass of material on each sieve individually, and record the total the mass.

2. Calculate the percent retained by dividing the mass retained on each sieve by the total and multiply by 100 (Figure 12). Example: for the 4.75 mm (No. 4) sieve, (48.4 ÷ 414.9) x 100 = 11.7 %. Calculate the percentage retained for each sieve using the above method.

Sieve Size	Mass (g)	Percent Retained	Percent Passing
4.75 mm (No. 4)	48.4	11.7	
2.00 mm (No. 10)	143.3	34.5	
850 µm (No. 20)	162.9	39.3	
600 µm (No. 30)	32.7		
425 µm (No. 40)	13.6		
180 µm (No. 80)	9.4		
75 µm (No. 200)	3.0		
Pan	1.6		
Total	414.9		

Figure 12 - Calculate percent of material retained on each sieve individually by dividing the mass of material retained on that sieve by the initial dry mass of the material and multiply by 100.

3. Once you have calculated the "percent retained" column, add the percentages to make sure they equal 100. In this example, they total 100.1 %. In cases where odd percentages occur (either 99.9 or 100.1), increase or decrease the largest percentage in the gradation by 0.1%. In this example, 39.3 was decreased to 39.2 in order to sum up to an even 100. (Figure 13).

Sieve Size	Mass (g)	Percent Retained	Percent Passing
4.75 mm (No. 4)	48.4	11.7	
2.00 mm (No. 10)	143.3	34.5	
850 µm (No. 20)	162.9	39.3	← change to 39.2
600 µm (No. 30)	32.7	7.9	
425 µm (No. 40)	13.6	3.3	
180 µm (No. 80)	9.4	2.3	
75 µm (No. 200)	3.0	0.7	
Pan	1.6	0.4	
Total	414.9	100.1	← change to 100.0

Figure 13 - When the percent retained does not add up to 100, change the percentage by 0.1 on the sieve which retained the most material.

4. Calculate the percent passing a sieve by subtracting the percent retained on that sieve from the percent passing the sieve above. The top sieve shall have zero mass retained, i.e., zero percent retained and 100 percent passing (Figure 14).

Sieve Size	Mass (g)	Percent Retained	Percent Passing
9.5 mm (3/8")	0.0	0.0	100.0
4.75 mm (No. 4)	48.4	11.7	88.3
2.00 mm (No. 10)	143.3	34.5	53.8
850 mm (No. 20)	162.9	39.2	14.6
600 mm (No. 30)	32.7	7.9	6.7
425 mm (No. 40)	13.6	3.3	3.4
180 mm (No. 80)	9.4	2.3	1.1
75 mm (No. 200)	3.0	0.7	0.4
Pan	1.6	0.4	
Total	414.9	100.0	

Figure 14 - A cumulative subtraction of the percentages retained from 100 determines the percentage passing for each sieve.

5. Continue the cumulative subtraction down through the last sieve (Figure 15). The percent passing the last sieve should be almost equal to the percent retained in the pan.

Sieve Size	Mass (g)	Percent Retained	Percent Passing
9.5 mm (3/8")	0.0	0.0	100.0
4.75 mm (No. 4)	48.4	11.7	88.3
2.00 mm (No. 10)	143.3	34.5	53.8
850 µm (No. 20)	162.9	39.2	14.6
600 µm (No. 30)	32.7	7.9	6.7
425 µm (No. 40)	13.6	3.3	3.4
180 µm (No. 80)	9.4	2.3	1.1
75 µm (No. 200)	3.0	0.7	0.4
Pan	1.6	0.4	
Total	414.9	100.0	

Figure 15 - Non-cumulative method completed. Compare these results with Figure 10.

If you compare the results obtained between Figure 10 (Cumulative Method) and Figure 15 (Non-Cumulative Method) you will see that they are the same.

The calculation for the sieve analysis applies to both coarse and fine aggregate samples.

TABLE 1
Maximum Allowable Quantity of Material Retained on a Sieve, (kg)

Sieve Opening Size, mm	Nominal Dimensions of Sieve[A]				
	203.2-mm dia[B] (8 in)	254-mm dia[B] (10 in)	304.8-mm dia[B] (12 in)	350 by 350 mm (14 x 14 in)	372 by 580 mm (16 x 24 in)
	Sieving Area, m^2				
	0.0285	0.0457	0.0670	0.1225	0.2158
125	[C]	[C]	[C]	[C]	67.4
100	[C]	[C]	[C]	30.6	53.9
90	[C]	[C]	15.1	27.6	48.5
75	[C]	8.6	12.6	23.0	40.5
63	[C]	7.2	10.6	19.3	34.0
50	3.6	5.7	8.4	15.3	27.0
37.5	2.7	4.3	6.3	11.5	20.2
25.0	1.8	2.9	4.2	7.7	13.5
19.0	1.4	2.2	3.2	5.8	10.2
12.5	0.89	1.4	2.1	3.8	6.7
9.5	0.67	1.1	1.6	2.9	5.1
4.75	0.33	0.54	0.80	1.5	2.6

Notes:

[A] Sieve frame dimensions in inch units: 8.0-in. diameter; 10.0-in. diameter; 12.0-in. diameter; 13.8 by 13.8 in. (14 by 14 in. nominal); 14.6 by 22.8 in. (16 by 24 in nominal).

[B] The sieve area for round sieve frames is based on an effective diameter 12.7 mm (1/2 in.) less than the nominal frame diameter, because Specification M92 permits the sealer between the sieve cloth and the frame to extend 6.35 mm (1/4 in.) over the sieve cloth. Thus the effective sieving diameter for a 203.2-mm (8.0-in.) diameter sieve frame is 190.5 mm (7.5 in.). Some manufactures of sieves may not infringe on the sieve cloth by the full 6.35 mm (1/4 in.).

[C] Sieves indicated have less than five full openings and should not be used for sieve testing except as provided in 8.6.

1.2.5.7 Fineness Modulus

Fineness Modulus (FM) is defined as an index to the particle size, not to the gradation. Fineness Modulus is calculated from the sieve analysis. It is defined mathematically as the sum of the cumulative percentages retained on the standard sieves divided by 100. The standard size sieves are 6" (150 mm), 3" (75 mm), 1 1/2" (37.5 mm), 3/4" (19.0 mm), 3/8" (9.5 mm), No. 4 (4.75 mm), No. 8 (2.36 mm), No. 16 (1.18 mm), No. 30 (600 µm), No. 50 (300µm), and No. 100 (150 µm).

In fineness modulus, the finer the material the more the water demand is. It is used for the purpose of estimating the quantity of coarse aggregate to be used in the concrete mix design. Generally, the FM of fine aggregates should not be less than 2.3 or more than 3.1, or vary by more than 0.2 between batches of concrete.

Procedure for Determining the Fineness Modulus

Add the Cumulative % Retained on all of the sieves except the No. 200 (75 µm) and the Pan. Then divide by 100.

Example:

Sieve	Cumulative	Cumulative	
Size	Grams Retained	%Retained	%Passing
3/8 in	0.0	0.0	100.0
No. 4	14.8	2.9	97.1
No. 8	47.6	9.4	90.6
No. 16	117.3	23.2	76.8
No. 30	274.2	54.1	45.9
No. 50	418.8	82.7	17.3
No. 100	467.4	92.3	7.7
No. 200	494.2	97.6	2.4
PAN	506.4	100.0	0.0

$$\frac{0.0 + 2.9 + 9.4 + 23.2 + 54.1 + 82.7 + 92.3}{100.0} = \frac{264.6}{100.0} = \mathbf{2.65}$$

1.2.5.8 COMMON TEST ERRORS

- Insufficient sample size
- Overloading the sieves
- Loss of material during the test
- Insufficient cleaning of the sieves
- Using defective (e.g., worn, cracked, etc.) sieves
- Lack of thorough sieving
- Not pre-drying the sample

1.2.6 - AASHTO T 19 - BULK DENSITY (“UNIT WEIGHT”) AND VOIDS IN AGGREGATE

1.2.6.1 - SCOPE

This test procedure is used to determine the unit weight of oven dried aggregates in a compacted or loose condition using a calibrated measure. After the unit weight has been determined, the void content (the space between the aggregate particles) can be calculated. The main reason for determining the void content is to establish accurate material proportions for designing concrete mixes.

1.2.6.2 - SUMMARY OF TESTING

This test method is often used to determine unit weight values, which are necessary for many methods of selecting proportions for concrete mixtures.

1.2.6.3 - EQUIPMENT

- Balance (Scale) - the balance will have sufficient capacity to determine the mass of the sample and measure to the nearest 50 grams (0.1 lb).

- Tamping Rod - a round, straight steel rod 16 mm (5/8 in.) in diameter and a minimum 600 mm (24 in.) in length, having one end rounded to a hemispherical tip of the same diameter as the rod.

- Measure - a cylindrical metal measure with handles on the sides. The capacity of the measure is determined by the nominal size of the aggregate to be tested. See Table 1.4. The top rim will be smooth and true. See Section 1.2.6.4 for calibration of measure.

- Glass Plate - a piece of plate glass that is a minimum of 6 mm (1/4 in.) thick and at least 25 mm (1 in.) larger than the diameter of the calibrated measure.

- Miscellaneous - square-nosed shovel, flat metal dustpan or scoop, rake, counter brush and broom.

Figure 1 - 1/3 cubic foot measure.

Table 1.4 - CAPACITY OF MEASURES

Nominal Maximum Size of Aggregate		Capacity of the Measure	
Mm	in.	L (m^3)	ft^3
12.5	½	2.8 (0.0028)	1/10
25.0	1	9.3 (0.0093)	1/3
37.5	1 ½	14 (0.014)	½
75	3	28 (0.028)	1
112	4 ½	70 (0.070)	2 ½
125	6	100 (0.100)	3 ½

Figure 2 - 1/10 cubic foot measure.

1.2.6.4 CALIBRATION OF MEASURE

1. Determine the mass of the measure to the nearest 50 grams (0.1 lb).
2. Determine the mass of the measure with plate glass to the nearest 50 grams (0.1 lb).
3. Fill the measure with water that is preferably at room temperature, so that the meniscus is above the rim of the measure. Slide the plate glass across the rim of the measure in a way to eliminate (remove) any air bubbles and excess water. Dry the overflow water off the outside of the measure and plate glass with an absorbent towel. Determine the mass of the measure, water, and plate glass.
4. Determine the temperature of the water.
5. Use Table 1.5 to determine density of water based on the temperature.

Table 1.5
DENSITY OF WATER CORRECTED FOR TEMPERATURE

TEMPERATURE		kg/m^3	lb/ft^3
ºC	ºF		
15.6	60	999.01	62.366
18.3	65	998.54	62.336
21.1	70	997.97	62.301
(23.0)	(73.4)	(997.54)	(62.274)
23.9	75	997.32	62.261
26.7	80	996.59	62.216
29.4	85	995.83	62.166

6. Calculate the volume of the measure by dividing the mass of the water required to fill the measure, by the density of water.

$$\text{Volume} = \frac{M_1 - M_2}{D_w}$$

Where: M_1 = Mass of measure, water and glass plate
M_2 = Mass of measure and glass plate
D_w = Density of the water taken from the above table

Measure Factor = $D_w \div M_3$

Where: $M_3 = M_1 - M_2$ = Mass of water to fill measure

EXAMPLE CALIBRATION CALCULATION:

Given: Measure = 0.014 m^3 (1/2 ft^3)
Temperature = 29.4°C (85°F)

Mass of measure, water, and plate glass	= M_1	= 23800 grams
Mass of measure and plate glass	= M_2	= 9350 grams
Water Mass	= M_3	= 14450 grams

Volume = ((14450 g ÷ 1000 g/kg) ÷ 995.83 kg/m^3) = 0.015 m^3
Measure Factor = (995.83 kg/m^3 ÷ 14.45 kg) = 68.916/ m^3

1.2.6.5 TEST SAMPLE:

- Representative materials should be sampled and reduced to the appropriate sample size by AASHTO T 2 & T 248 test methods.
- Sample size should be 125 – 200% more than the capacity of your calibrated measure.
- The test sample shall be dried to a constant mass in an oven at 110º ± 5ºC (230° ± 9°F).

1.2.6.6 TESTING PROCEDURE – RODDING/JIGGING:

- Test procedure and size of the measure are normally determined by the largest nominal size of aggregate to be tested.

  Rodding – Nominal 37.5 mm (1½ in.) or less.
  Jigging – Nominal greater than 37.5 mm (1½ in.) up to 125 mm (5 in.).

- Thoroughly mix the sample before filling the measure.
- Fill the calibrated measure in thirds. After each third, rod or jig as explained below.

Rodding – rod each layer with the tamping rod 25 strokes distributed equally over the entire layer surface. On the first layer do not allow the rod to forcibly strike the bottom of the measure. On the second and third layers use only enough force for the rod to reach but not penetrate the previous layer.

Jigging – jig each layer 50 times, 25 times each side by raising the opposite sides alternately about 50 mm (2 in.) and letting the measure drop in such a manner to sharply hit the base.

The final layer should overflow the top of the measure before and after the rodding/jigging procedure. Level the surface of the aggregate with a straight edge, by hand or rolling a rod in a manner such that slight projections of aggregate above the rim are balanced with the voids below the rim.

- Determine the mass of the aggregate and measure.
- Follow this procedure a minimum of two times on a given sample as long as the results are within tolerances. The tolerance between two consecutive tests for one operator is 40 kg/m^3 (2.5 lb/ft^3.).

1.2.6.7 TESTING PROCEDURE – SHOVELING (Loose Method):

- The size of the measure is normally determined by the largest nominal size of aggregate to be tested.
- Place the prepared sample into a miniature stockpile on a level, clean, smooth, dry surface. Thoroughly mix the material by re-shoveling.
- Fill your calibrated measure to overflowing by discharging the aggregate from a height not to exceed 50 mm (2 in.) above the rim of the measure.
- Level the surface of the aggregate with a straight edge, by hand, or rolling a rod in a manner such that slight projections of aggregate above the rim are balanced with the voids below the rim.
- Determine the mass of the aggregate and measure.
- Follow this procedure a minimum of two times on a given sample as long as the results are within tolerances. The tolerance between two consecutive tests for one operator is 40 kg/m^3 (2.5 lb/ft^3.).

1.2.6.8 COMMON TESTING ERRORS:

- Failure to thoroughly mix sample
- Inconsistent leveling of top layer
- Sample not oven dried
- Rodding too hard or penetrating underlying layers
- Not placing material in equal layers

1.2.7 MARTCP SA 1.3 - PERCENT MOISTURE CONTENT PROCEDURE

1.2.7.1 SCOPE

The moisture content of a material influences its ability or inability to be excavated, consolidated, moved, screened, weighed, dried out or reabsorbed. Moisture content calculations used for soils and aggregates are by convention defined as the mass of water lost through drying divided by the dry mass of the material. The moisture content is used to calculate a variety of properties such as dry density, plasticity, permeability etc.

1.2.7.2 MATERIALS AND EQUIPMENT

- Electric hot plate or gas burner.
- Scale or balance as required by state specifications.
- Metal container, such as a large frying pan or equivalent.
- Pointing trowel or large spoon.

1.2.7.3 TEST PROCEDURE

1. Select a representative quantity of material based on the following table, or state specifications:

TABLE 1.6
Aggregate Moisture Content Test Sample Sizes

Nominal Maximum Size, mm (in.)	Minimum Sample Mass, kg (lbs.)
4.75 (No. 4)	0.5 (1.1)
9.5 (3/8)	1.5 (3.3)
12.5 (1/2)	2.0 (4.4)
19.0 (3/4)	3.0 (6.6)
25.0 (1)	4.0 (8.8)
37.5 (1 ½)	6.0 (13.2)
50.0 (2)	8.0 (17.6)
All Soil Moisture Content Sample Sizes must be a minimum of 500 grams	

2. Weigh a clean, dry container.
3. Place the sample in the container and weigh.

4. Place the container on the stove or hot plate and, while drying, mix the sample continuously to expedite drying and prevent burning of the aggregate. Always use a low flame or heat setting.

5. When the sample looks dry, remove it from the stove, cool, and weigh. Put sample back on the stove, continue drying for another two to three minutes, cool, and re-weigh. When a constant mass has been achieved, the sample is dry. Record the mass of the sample and container.

   Note: *Care must be taken to avoid losing any portion of the sample.*

1.2.7.4 COMMON TESTING ERRORS

- Spillage or loss of sample – loss of sample voids test results
- Insufficient sample quantity (size) to yield accurate results
- Overheating sample during drying process causing a loss of organic material or partial oxidation of other sample constituents.

1.2.7.5 CALCULATIONS

Moisture content of aggregate:

$$w,\% = \frac{(W_{wet} - W_{dry})}{(W_{dry} - W_{con})} \times 100$$

Where:

$w, \%$ = percent moisture
W_{wet} = mass of wet aggregate and container
W_{dry} = mass of dry aggregate and container
W_{con} = mass of container

1.2.7.6 REPORT

Report the moisture content according to required state specifications.

1.2.8 AASHTO T 84 - SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE

1.2.8.1 - SCOPE

Specific Gravity is the ratio of the mass of a given volume of aggregate to the mass of an equal volume of water. Specific Gravity is important for several reasons.

Specific gravity is critical information for the Hot Mix Asphalt Design Engineer. It is used in calculating air voids, voids in mineral aggregate (VMA), and voids filled by asphalt. In Superpave mixes, it is used to determine the fine aggregate angularity. All are critical to a well performing and durable asphalt mix. Water absorption can also be an indicator of asphalt absorption. A highly absorptive aggregate could lead to a low durability asphalt mix.

In Portland Cement Concrete, the specific gravity of the aggregate is employed in calculating the percentage of voids and the solid volume of aggregates in computations of yield. The absorption is important in determining the net water-cement ratio in the concrete mix.

Knowing the specific gravity of aggregates is also critical to the construction of water filtration systems, slope stabilization projects, railway bedding and many other applications.

1.2.8.2 – SUMMARY OF PROCEDURES

This method determines the specific gravity of fine aggregates soaked for a period of 15 -19 hours. The determinations made from this procedure are identical to those made using AASHTO T 85 (Specific Gravity and Absorption of Coarse Aggregate).

1.2.8.3 – EQUIPMENT

- Balance - conforming to the requirements of M 231, Class G2

- Pycnometer - a flask or other suitable container into which the fine aggregates can be readily introduced (Figure 1). Volume content for the container needs to be reproduced within ± 100 mm^3. The volume of the container filled to the mark shall be at least 50 percent greater than the space required to accommodate the test sample.

- Mold - a metal mold in the form of a frustum of a cone with acceptable dimensions.

- Tamper - a metal tamper having a mass of 340 ±15 g and having a flat circular tamping face of 25 ± 3 mm in diameter.

Figure 1 - Pycnometers, mold & tamper

1.2.8.4 - Testing Procedure

1. Thoroughly mix the material and reduce it to a sample size in accordance with AASHTO T 248. The sample size for this procedure is approximately 1 kg of material passing the 4.75 mm (No. 4) sieve.

2. Dry the test sample to a constant mass in an oven regulated at 110 ± 5°C (230 ± 9°F). Cool the sample to a comfortable handling temperature. After the cooling period, immerse the sample in water at room temperature for a period of 15 to 19 hours.

   NOTE: In lieu of completely immersing the sample in water, AASHTO considers the sample to be "soaked" if it is maintained at a moisture content of at least 6% for the prescribed period. The sample will be much closer to the Saturated Surface Dry (SSD) condition which expedites the drying procedure. This eliminates the need to decant excess water from the sample prior to testing. Decanting is time consuming and difficult. Great care must be taken to avoid losing some of the sample along with the water.

3. Decant water from sample, avoiding loss of fines. Spread sample on a flat, non-absorbent surface. Stir sample frequently to assist in uniform drying. A current of warm air may be used to assist in the drying process (Figure 2).

Figure 2

4. Determine the SSD condition of the sample using the Cone Test.

   4.1 Cone Test Procedure - Throughout the process of drying in Step 3, test the sample for SSD condition using the cone method. Place the cone with the large diameter down on a smooth, non-absorbent surface. Fill cone to overflowing with the sample. Lightly tamp the sample into the mold with 25 light drops of the tamper (Figure 3). Each drop should start about 5 mm above the top surface of the sample. Remove loose material from the base and carefully lift the mold vertically. If surface moisture is still present, the sample will retain its molded shape. When the sample achieves an SSD condition, it will slump slightly (Figure 4). If the sample slumps on the first trial, moisture must be re-added and the sample allowed to sit in a covered container for thirty minutes, and the drying process repeated.

Figure 3 - Tamping sample using the Cone Method to determine SSD

Figure 4 - Sand at SSD condition will slump once the cone is removed

5. Place 500 ± 10 g of the SSD sand into the pycnometer partially filled with distilled water (Figure 5). Fill with water to 90% of pycnometer capacity.

Figure 5 - Pouring sand into the pycnometer once SSD is achieved

Figure 6 - Rolling of pycnometer

6. Roll, invert, and agitate the pycnometer to eliminate all air bubbles (Figure 6). This process usually takes 15 to 20 minutes.

7. Adjust temperature of sample and water to 23 ± 1.7°C in a water bath.

8. Bring the pycnometer to its calibrated capacity with additional water (Figure 7) If bubbles prevent the proper filling of the pycnometer, adding a few drops of isopropyl alcohol is recommended to disperse the foam.

9. Determine the total mass of pycnometer, specimen, and water. Record the mass to the nearest 0.1g.

10. Calibrate a specific gravity flask pycnometer by filling with water at 23±1.7°C (73.4±3°F) to calibration line. Record this value as the mass of the pycnometer filled with water to the nearest 0.1g.

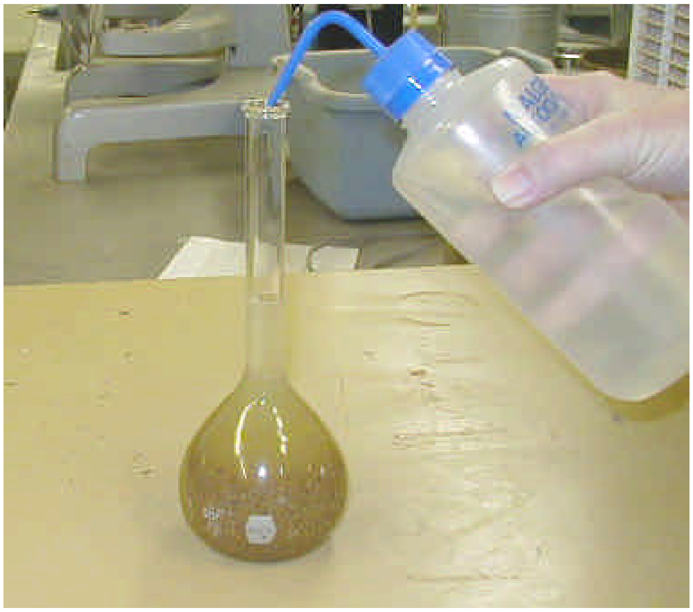


Figure 7 - Filling pycnometer

1.2.8.5 – CALCULATIONS

Determine calculations based on appropriate formula for desired result - those formulas are again:

A. Bulk Specific Gravity (G_{sb}): The ratio of the mass (in air) of a unit volume of aggregate to the mass (in air) of an equal volume of gas-free distilled water at a stated temperature.

$G_{sb} = A / (B - C)$

Where: A = Oven dry mass B = SSD mass C = mass in water

B. Bulk SSD Specific Gravity (G_{sb} SSD): The ratio of the mass (in air) of a unit volume of aggregate* to the mass (in air) of an equal volume of gas-free distilled water at a stated temperature.

* This includes the mass of water within the voids achieved by immersing the aggregate in water for approximately 15 hours.

$G_{sb}\ SSD = B / (B - C)$

C. Apparent Specific Gravity (G_{sa}): The ratio of the mass, in air, of a unit volume of the “impermeable” portion of aggregate (does not include the permeable pores in aggregate) to the mass, in air, of an equal volume of gas-free distilled water at a stated temperature.

$$G_{sa} = A / (A - C)$$

D. Absorption (%Abs): The increase in mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles.

$$\%Abs = [(B - A) / A] \times 100$$

1.2.8.6 – COMMON TESTING ERRORS

- Improper Pycnometer calibration.
- Air entrapped in sand leading to false weight measurement.
- Improper surface moisture test due to one or more of the following:
    - Improper drop of tamper (too high or low during compaction into the cone).
    - Insufficient timing of test. Testing should be completed more frequently as the sample approaches SSD condition.
    - Vibration of the testing surface leading to a false slump.
    - Excess airflow near the test sample resulting in uneven drying of the sample.
- Loss of material during transfer to the drying pans resulting in an inaccurate calculation.

1.2.9 - AASHTO T 85 - Specific Gravity of Coarse Aggregates

1.2.9.1 - Summary of Procedure

Specific Gravity is the ratio of the mass of a given volume of aggregate to the mass of an equal volume of water. Specific Gravity is important for several reasons. Some deleterious particles are lighter than acceptable quality aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity can be used during production to separate the poor quality particles from the acceptable quality particles, using a heavy liquid media.

Specific gravity is critical information for the asphalt mix design Engineer. It is used in calculating air voids, voids in mineral aggregate (VMA) and voids filled by asphalt (VFA). All are critical in the performance of an asphalt mix. Water absorption can also be an indicator of asphalt absorption. A highly absorptive aggregate could affect the durability of an asphalt mix.

In Portland Cement Concrete, the specific gravity of the aggregate is used in calculating the percentage of voids and the solid volume of aggregates in determining the yield. The absorption is important in determining the net water-cement ratio in the concrete mix. Knowing the specific gravity of aggregates is also critical to the construction of water filtration systems, slope stabilization projects, railway bedding and many other applications.

This method determines the specific gravity of coarse aggregates that have been soaked for a period of 15-19 hours.

1.2.9.2 – EQUIPMENT

Figure 1 - Balance: conforming to class G5 (AASHTO M 231).

Figure 2 - Coarse Aggregate Gravity Apparatus.

Figure 3 - Sample container: wire basket of 3.35 mm (No. 6) or less mesh wire cloth, with a capacity to contain aggregate with a nominal maximum size of 37.5 mm (1½ in.) or smaller.

Figure 4 - Water tank: large enough to completely immerse basket containing aggregate and equipped with an overflow valve to keep water at a constant level.

Figure 5 - Suspension apparatus: wire used shall be of smallest practical diameter.

- Sieves: 4.75 mm (No. 4) or other sizes as needed, conforming to AASHTO M 92.

- Oven: capable of maintaining 110 ± 5° C (230 ± 9° F).

1.2.9.3 - Procedure

1. Thoroughly mix the sample and reduce to test size (Figures 6a & 6b) in accordance with AASHTO T 248 (Reducing Field Samples of Aggregate to Test Size). Use sample sizes as indicated in Table 1.

Figure 6a - Quartering method.

Figure 6b - Mechanical splitter method.

2. Dry sieve the sample through a 4.75 mm (No. 4) sieve and discard any material that passes the sieve. NOTE: if a substantial amount of material passes the 4.75 mm (No. 4) sieve, you may need to use a 1.18 mm (No. 8) sieve instead of the 4.75 mm (No. 4) ***or*** you may need to perform a specific gravity on minus 4.75 mm (No. 4) material. Wash the aggregate retained on the 4.75 mm (No. 4) sieve.

TABLE 1.

Nominal Maximum Size	Minimum Sample Mass
12.5 mm (1/2 in.)	2 kg (4.4 lbs.)
19 mm (3/4 in.)	3 kg (6.6 lbs.)
25 mm (1 in.)	4 kg (8.8 lbs.)
37.5 mm (1 ½ in.)	5 kg (11 lbs.)
50 mm (2 in.)	8 kg (18 lbs.)
63 mm (2 ½ in.)	12 kg (26 lbs.)
75 mm (3 in.)	18 kg (40 lbs.)

3. Dry test sample to constant mass in an oven regulated at 110 ± 5°C (230 ± 9°F). Cool the sample at room temperature for 1 to 3 hours. After the cooling period, immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

4. Remove the sample from soaking and drain any excess water from the aggregate. Place the aggregate on an absorbent towel and then shake and roll the aggregate from side to side. This procedure is usually effective in reducing the sample to the SSD (saturated, surface-dry) condition (Figure 7).

Figure 7

The sample may be contained in the rolled towel and shaken until it achieves SSD condition. The SSD condition is one in which the aggregate has no “free” water on its surface (Figures 8 & 9).

Figure 8

Figure 9

5. Weigh the SSD sample to the nearest gram.

6. After weighing, place the entire sample in a container and immerse in water. Shake container to release any entrapped air, hook onto scale and weigh. Insure that the overflow is working properly to compensate for the water displaced by the sample (Figure 10 & 10A). Record the mass of the sample and container in water to the nearest gram.

Figure 10a - Sample in water tank

Figure 10b - Fill to overflowing

7. Remove the sample and container from the water. Remove sample from the container and dry in a pan to a constant mass in an oven. Cool in air at room temperature for 1 to 3 hours (until the aggregate can be comfortably handled). Record mass to the nearest 1.0 g as oven dry mass.

There are four determinations that may be made from this procedure. They are as follows:

I. Bulk specific Gravity (G_{sb}) (also known as Bulk Dry Specific Gravity)

The ratio of the mass (in air) of a unit volume of aggregate to the mass (in air) of an equal volume of gas-free distilled water at a stated temperature (Figure 11). This unit volume of aggregates is composed of the solid particle, permeable voids and impermeable voids.

The formula for G_{sb} is as follows:

$G_{sb} = A / (B - C)$

Where: A = Mass (grams) of Oven Dry Specimen in Air
B = Mass (grams) of SSD Specimen in Air
C = Mass (grams) of SSD Specimen in Water

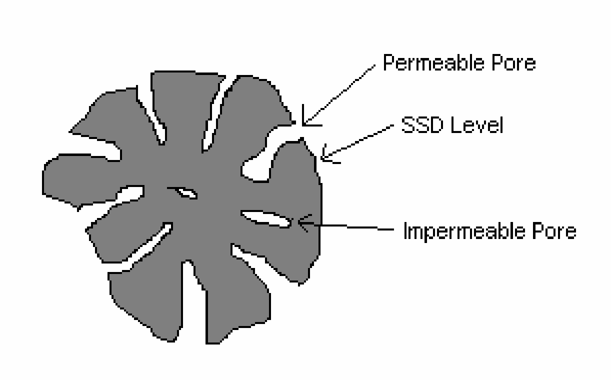


Figure 11 - Diagram of Bulk Specific Gravity

II. Bulk SSD Specific Gravity (G_{sb} SSD)

The ratio of the mass (in air) of a unit volume of aggregate***** to the mass (in air) of an equal volume of gas-free distilled water at a stated temperature (Figure 12).

***** This includes the mass of water within the voids achieved by immersing the aggregate in water for approximately 15 hours.

The formula for G_{sb} SSD = B / (B – C)

Where: B = Mass (grams) of SSD Specimen in Air
C = Mass (grams) of SSD Specimen in Water

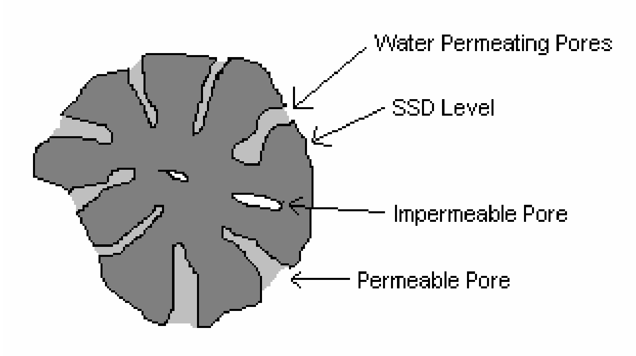


Figure 12 - Diagram of Bulk SSD Specific Gravity SSD mass is the Saturated Surface Dry Condition and includes the mass of the water in the permeable pore space.

III. Apparent Specific Gravity (G_{sa})

This ratio of the mass (in air) of a unit volume of the “impermeable” portion of aggregate (does not include the permeable pores in aggregate) to the mass (in air) of an equal volume of gas-free distilled water at a stated temperature (Figure 13).

The formula for $G_{sa} = A / (A - C)$

Where: A = Mass (grams) of Oven Dry Specimen in Air
C = Mass (grams) of SS Specimen in Water

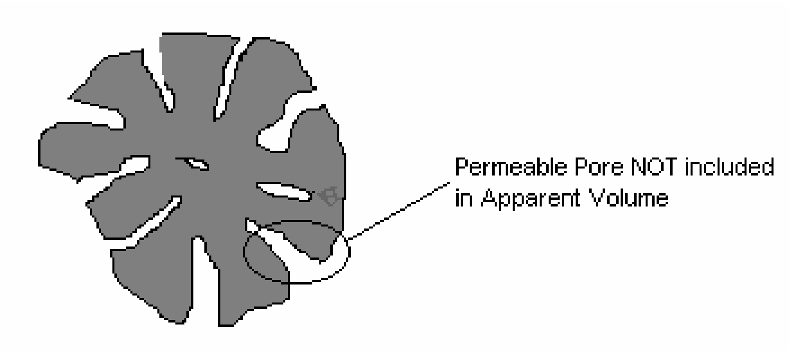


Figure 13 - Diagram of Apparent Specific Gravity
Apparent Volume = volume of aggregate particle **not including** permeable voids.

IV. Percent Absorption (% Abs.)

The increase in mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles (Figure 14.)

$$\%Abs. = \left[(B - A) / A\right] \times 100$$

Where: A = Mass (grams) of Oven Dry Specimen in Air
B = Mass (grams) of SSD Specimen in Air

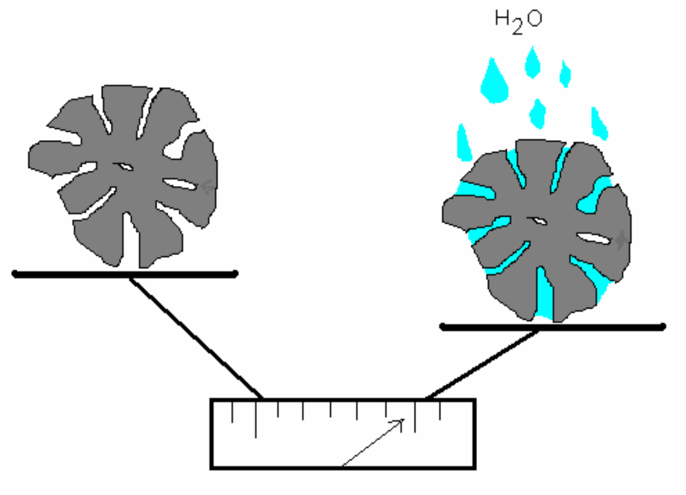


Figure 14. Increase in mass due to absorption of water

1.2.9.4 - Calculations:

Perform calculations based on appropriate formula for desired result.

1. **Bulk Specific Gravity (G_{sb})**

$$G_{sb} = A / (B-C)$$

2. **Bulk SSD Specific Gravity (G_{sb} SSD)**

$$G_{sb}\ SSD = B / (B-C)$$

3. **Apparent Specific Gravity (G_{sa})**

$$G_{sa} = A / (A-C)$$

4. **Absorption (%Abs.)**

$$\%Abs. = [(B - A) / A] \times 100$$

Where:
A = Mass (grams) of Oven Dry Specimen in Air
B = Mass (grams) of SSD Specimen in Air
C = Mass (grams) of SSD Specimen in Water

Example Calculations for Coarse Aggregate

Sample	A	B	C	B-C	A-C	B-A
1	2031	2045	1304	741	727	14
2	1820	1833	1168	665	652	13
3	2035	2049	1304	745	731	14

Sample	Bulk SSD B/B-C	Bulk A/B-C	Apparent A/A-C	% Absorption [(B-A)/A]X100
1	2.76	2.74	2.79	0.7
2	2.76	2.74	2.79	0.7
3	2.75	2.73	2.78	0.7

These calculations demonstrate the relationship between G_{sb}, G_{sb} SSD, and G_{sa}; in that the G_{sb} (bulk specific gravity) will always be the lowest value since the volume calculated includes voids permeable to water. The G_{sb} SSD (bulk specific gravity at SSD) will always be the intermediate value and the

G_{sa} (apparent specific gravity) will always be the highest, since the volume calculated concerns only the "solid" aggregate particle (i.e., does not include those voids permeable to water). When running this test, check to make sure the values calculated are realistic.

1.2.9.6 - Common Testing Errors

- Improper identification of SSD (i.e. over or under-drying).
- Air entrapped in suspended sample or sample immersion container.
- Suspension apparatus in contact with another object, resulting in false readings.
- Loss of material during transfer to the drying pans.
- Weighing errors (i.e. improper tare weights or loss of material).

1.2.10 AASHTO T 89 DETERMINING THE LIQUID LIMIT OF SOILS

1.2.10.1 SCOPE

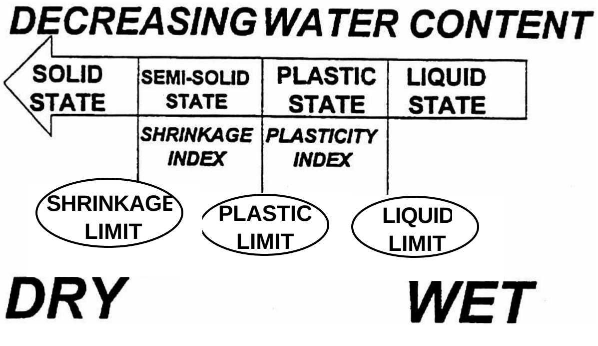
ATTERBERG LIMITS

Earth materials form the foundation of all transportation facilities. The final structure will be no more durable than the foundation upon which it rests. In order to ensure that these materials function as intended, it is necessary for all designers to have basic information about them. Designers use this information to decide if naturally occurring materials can support the anticipated traffic load or if they will require modification (e.g., stabilization, lime treatment or treatment with fly ash) to enable it to perform as a highway foundation.

Several laboratory tests are performed that provide information to the designer about materials which may be used as the foundation for a roadway. The Atterberg Limits are among these tests. In 1911, a Swedish scientist, A. Atterberg, developed some simple tests for determining the moisture contents of a soil at which the soil moves from a solid to a semisolid, to a plastic and to a liquid state. The moisture contents generated by these tests are used to quantitatively describe the effect of varying water contents on the fines of a material. As the moisture content of a material increases, the properties of the fine fraction (passing No. 40 sieve) material will eventually change from a solid to a liquid state.

The Atterberg Limits are:

- Shrinkage Limit - The water content at which material changes from a solid to a semisolid state.
- Plastic Limit - The water content at which material changes from a semisolid to a plastic state.
- Liquid Limit - The water content at which material changes from a plastic to a liquid state.



After exceeding the optimum moisture necessary to achieve compaction, material becomes less stable as moisture increases (moving from left to right on the diagram). A material whose moisture content is greater than the Liquid Limit is soft and unstable.

The Liquid Limit and Plastic Limit are used to determine the Plasticity Index. The Plasticity Index is not an Atterberg Limit. It is a number that is derived by subtracting the Plastic Limit of a soil from its Liquid Limit.

$$\mathbf{PI = LL - PL}$$

The Plasticity Index of a material is a measure of the cohesive properties of the material. It is the numerical range of moisture contents in which a cohesive material is plastic. Many state highway departments specify Plasticity Index values for materials to be used in construction.

The Shrinkage Limit is not used in determining the Plasticity Index and is not used as widely in highway construction specifications. The point at which a material moves from a solid to a semisolid state is not as significant as the Liquid Limit in determining the material’s suitability for highway construction.

When samples are received by the laboratory, they may be identified by a field classification (e.g., plastic, non-plastic, hard, friable, etc.) based on moisture content and consistency at the time of sampling. This field classification provides an indication of a material’s suitability for use in construction. However, a more accurate determination of the material’s behavior at varying moisture contents is needed to ensure that materials will perform as necessary in a pavement structure. It is critical that the tests for Atterberg Limits be properly performed. These values are used to classify a soil in terms of its suitability for a specific use.

LIQUID LIMIT

The Liquid Limit is the moisture content at which a specific material moves from a plastic to a liquid state. Generally, soils with high Liquid Limits are clays with poor engineering properties. Soils with a high clay content are cohesive (stick together), plastic (moldable), compressible (able to be consolidated), and nearly impervious (impenetrable by water). Their compressibility leads to rutting under load and can even cause the soil structure to shear under its own weight, causing embankment failure.

Clay soils may become unstable when they absorb water. Materials with high clay content also are subject to swelling and shrinking during normal changes in moisture content. The swell/shrinkage cycle may also lead to foundation failure. Swelling and shrinkage are directly related to shear failure. When clay soils are disturbed by construction, they lose their shear strength and are subject to failure.

The Liquid Limit is used in conjunction with the Plasticity Index to identify materials with a clay content high enough to keep them from performing well in construction.

1.2.10.2 SUMMARY OF TEST

There are two methods (A and B) approved by AASHTO to determine the Liquid Limit of a material. The basic test steps are the same for both methods. The differences are in the initial quantity of water added to the test specimen, the number of specimens which are tested, the mandatory blow count range and the calculations involved.

If using Method B or using tap water results in questionable test values, Method A with special parameters must be used to establish the validity of the values.

The Liquid Limit test is performed on material passing the 0.425 mm (No. 40) sieve. First mix the test specimen with water, alternately stirring and chopping the sample. Continue adding water until it is at a uniform stiff consistency. You will need some experience to recognize when you have reached the correct consistency for each material. Place some of the test specimen in the cup of the Liquid Limit device. Use the spatula to press and spread the material to the correct thickness. Be careful not to trap air bubbles in the test specimen when spreading it in the cup.

Use the grooving tool to divide the test specimen in the cup through its center. Move the tool from back to front only one time for each stroke. Be sure to form a clean, sharp groove. Use no more than six strokes of the grooving tool to divide the specimen. Only the last stroke of the grooving tool is to scrape the bottom of the cup.

If you are using a manual device, turn the crank approximately 2 revolutions per second. If you are using an automatic device, turn on the machine. Count the number of blows of the machine or use the automatic counter if the device is equipped with one. When the groove closes to 13 mm (0.5 inch), stop the device. Record the number of blows required to close the groove.

For Method A, repeat these steps two more times until you have blow counts within the following ranges:

Trial	No. of Blows
1	25 to 35
2	20 to 30
3	15 to 25

There must be a difference of at least ten blows between the high and low blow count for the test result to be valid.

For Method B, the blow count must be within the range of 22-28, and only one specimen is used for testing. A second specimen is run to verify the blow count.

From each test specimen, remove a slice of material approximately the width of the spatula, extending from edge to edge of the specimen at right angles to the groove. Be sure to take that portion of the groove in which the material flowed together. Determine the moisture content of each specimen in accordance with AASHTO T 265. The Liquid Limit is a mathematical calculation based on the moisture content and number of blows at closure.

TYPICAL TEST RESULTS

Liquid Limits vary widely. It is possible to obtain values as high as 80 - 100. Values between 40 - 60 are typical of clay soils. For silty soils, typical values are between 25 - 50. The Liquid Limit test will not produce a result for granular and non-plastic materials.

1.2.10.3 EQUIPMENT

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. To determine the Liquid Limit of the fines portion of a material, you will need the following.

- Dish - An unglazed porcelain container (or similar mixing container) approximately 115 mm (4½ in.) in diameter.

- Spatula - A flat blade or pill knife approximately 75 - 100 mm (3 - 4 in.) long and approximately 20 mm (3/4 in.) wide

- Liquid Limit Device - Manual or mechanically operated conforming to AASHTO T 89

- Grooving Tool - Conforming to AASHTO T 89

- Gage - Conforming to AASHTO T 89 or a metal bar 10.0 ±0.2 mm (0.394 ±0.008 inches) thick and approximately 50 mm (2 inches) long

- Containers - Enough containers with close-fitting lids to provide one container for each moisture content determination. Containers must be resistant to corrosion and not subject to change in mass with repeated heating and cooling.

- Balance - Conforming to AASHTO M 231, Class C

- Oven - A thermostatically controlled oven capable of maintaining a temperature of 110 ± 5º C (230 ± 9º F)

- Distilled or Demineralized Water (or tap water, if approved)

- Semi-logarithmic Graph Paper

- Stable, flat surface - Support for testing apparatus to ensure uniform impact and base stability of device

Figure 1 - Testing Equipment

1.2.10.4 EQUIPMENT CALIBRATION

1. Inspect the Liquid Limit device and grooving tool.

   - Check that the pin connecting the cup is not worn to the point of allowing side play.

   - Check that the screws connecting the cup to the hanger arm are tight. Loose screws allow excessive cup movement and cause erratic blow counts.

   - Check that the points of contact on the cup and base are not excessively worn. Excessive wear is defined as exceeding approximately 13 mm (0.5 inches) in diameter.

   - Check the lip of the cup for excessive wear. Excessive wear is defined as any point on the cup rim which is worn to approximately one half the original thickness.

   - Check the center of the cup to ensure that use has not worn a groove into the cup. (Replace any cup in which there is a pronounced groove.)

   - Check the cam follower. It should not be worn beyond the tolerance allowed nor allow any rocking on the height gage when checking height of drop.

   - Check the adjusting screws. All screws in the adjusting assembly must be tight with no noticeable movement.

   - Check the dimensions of the grooving tool to ensure that the tool conforms to the tolerances of AASHTO T 89.

Figure 2 - Placing Masking Tape on Cup Bottom

2. Adjust the height of drop so that the point on the cup that contacts the base rises to a height of 10.0 ± 0.2 mm (0.394 ± 0.008 in.)

   - Mark the point of contact of the cup with the base. Facing the front of the cup, raise the cup by hand. Place a piece of masking tape across the outside bottom of the cup. Place the tape parallel to the pivot pin with the top edge of the tape bisecting the wear mark on the cup where it contacts the base.

   NOTE: When a cup is new, place a piece of carbon paper on the base, carbon side up, then allow the cup to drop several times to mark the contact spot.

   - Lower cup into position.

   - Turn the crank and raise the cup to its maximum height.

   - Slide the height gage under the cup from the front until the gage contacts the edge of the tape on the cup. If the gage contacts the cup at the edge of the tape, the adjustment is approximately correct.

   NOTE: You may remove the cup from the device to apply the tape. If this was done, place cup on device and install pivot pin.

Figure 3 - Checking Contacts with Height Gage

- If the gage does not contact the cup at the edge of the tape, use the adjusting screw device to adjust the height until the cup is in proper position. Lock the adjustment assembly into proper position.

- Leave the gage in position. Check the adjustment by turning the handle at two revolutions per second. If the cup does not move and a ringing or clicking sound is heard, the adjustment is correct. If no sound is heard or if the cup rises from the gage, re-adjust the height of the drop.

- Remove the tape as soon as the check procedure is completed.

1.2.10.5 SAMPLE PREPARATION

Test Specimen

Prepare a material sample in accordance with AASHTO T 87, Standard Method of Preparing Disturbed Soil Samples, or in accordance with AASHTO T 146, Standard Method of Wet Preparation of Disturbed Soil Samples. Separate the material passing the 0.425-mm (No. 40) sieve. Obtain a representative portion of approximately 100 grams from this material.

Figure 4 - Weighing Test Specimen

1.2.10.6 PROCEDURE METHOD A

1) Place the test specimen in the mixing dish. Add 15 - 20 mL of water. Mix thoroughly by alternately stirring, kneading, and chopping with the spatula. Add enough water to form a material mass with a stiff consistency. After the initial addition of 15 - 20 mL of water, add subsequent water in increments of 1 - 3 mL. Mix each increment of water thoroughly into the soil mass before adding the next increment.

NOTES: 1) It is permissible to use tap water for routine testing, if comparative tests indicate no difference in test results.

2) Do not use the cup of the Liquid Limit device to mix the material and water.

Figure 5a - Adding water

Figure 5b - Blending water and soil

2) If too much water is added, either discard the test specimen or continue to mix and knead the material until natural evaporation lowers the moisture content to the proper consistency.

3) Do not add additional dry material to the test specimen.

   NOTE: Some soils (fine silts and clays) are slow to absorb water. When testing these soils, allow additional mixing time to ensure water absorption. If water is added too quickly to these soils, it is possible to obtain a false value for the liquid limit.

4) Use the spatula to scoop a representative specimen of the mixed material about the size of a golf ball. Immediately cover mixing dish to eliminate moisture loss.

5) Place this specimen in the cup of the liquid limit device directly above the point where the cup rests on the base.

6) Use the spatula to press, spread, and level the specimen so that the material is no more than 10 mm (0.4 in.) thick at its maximum depth and is centered as close as possible over the contact point of the cup and the base. Use as few spatula strokes as possible. Do not trap air bubbles within the mass.

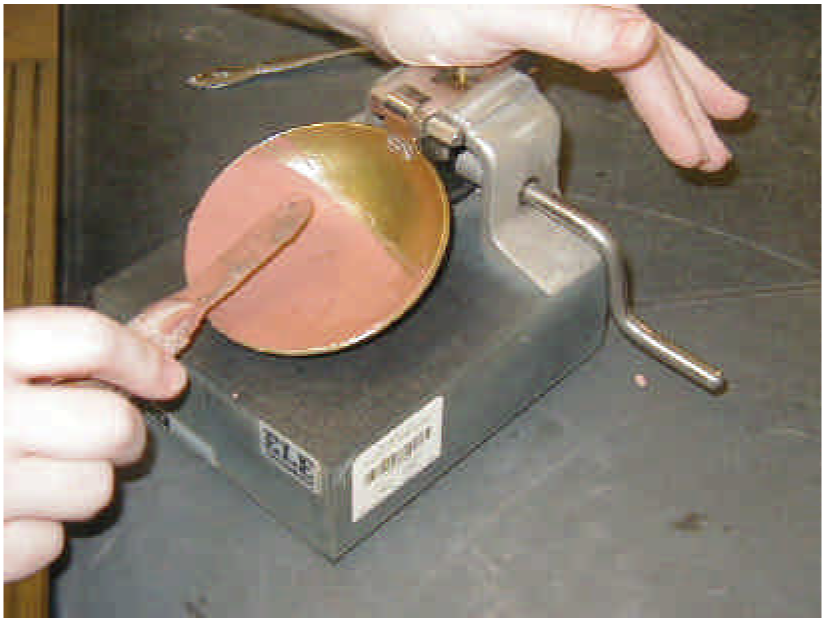


Figure 6 - Spreading Specimen in Liquid Limit Cup

7) Trim excess soil from the specimen during Step 6. Return the excess to the mixing dish and immediately cover to prevent moisture loss.

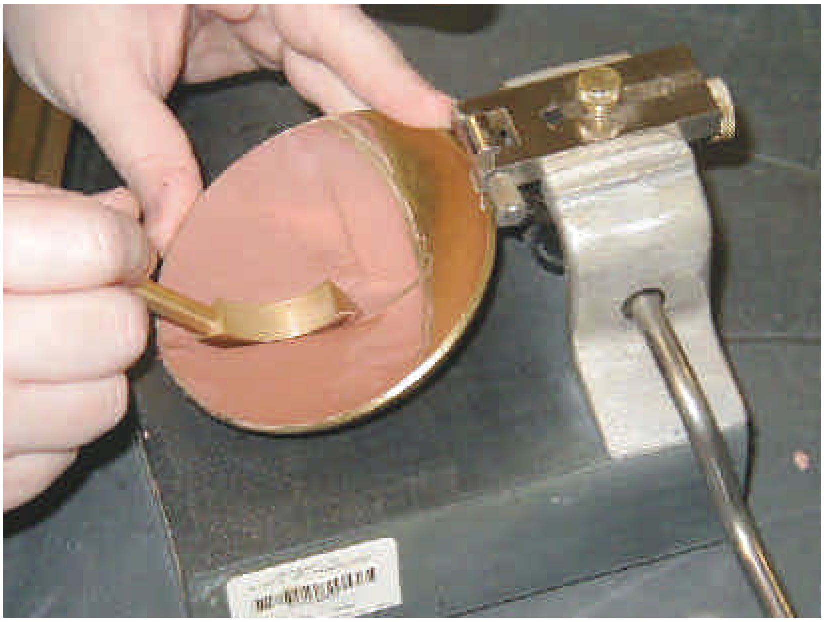


Figure 7 - Grooving the Soil Specimen

8) Use the grooving tool to make a smooth firm stroke through the soil pat. Move the grooving tool from back to front though the center of the soil pat.

   Note: Do not allow the soil pat to tear or slide in the cup while making the groove. If the soil pat tears or slides, the soil is too dry or may be non-plastic. Add more water and try again.

   Increase the depth of the groove with each stroke, but do not allow the tool to touch the bottom of the cup, except on the last stroke. Use no more than six strokes to complete the division. While grooving the material, you can use the curved end of the grooving tool to determine if the pat is the proper thickness. When the grooving tool touches the cup, the top of the soil cake should be level with the top of the curved portion of the grooving tool. The curved portion of the grooving tool is 10 mm (0.4 in.) high.

9) Apply blows. If the device is automatic, turn on the device. If the device is manual, turn the crank at approximately two revolutions per second. Continue applying blows until the two sides of the material come in contact at the bottom of the groove along a distance of about 13 mm (0.5 in.).

   NOTE: Do not hold the base of the device with the free hand while turning the crank.

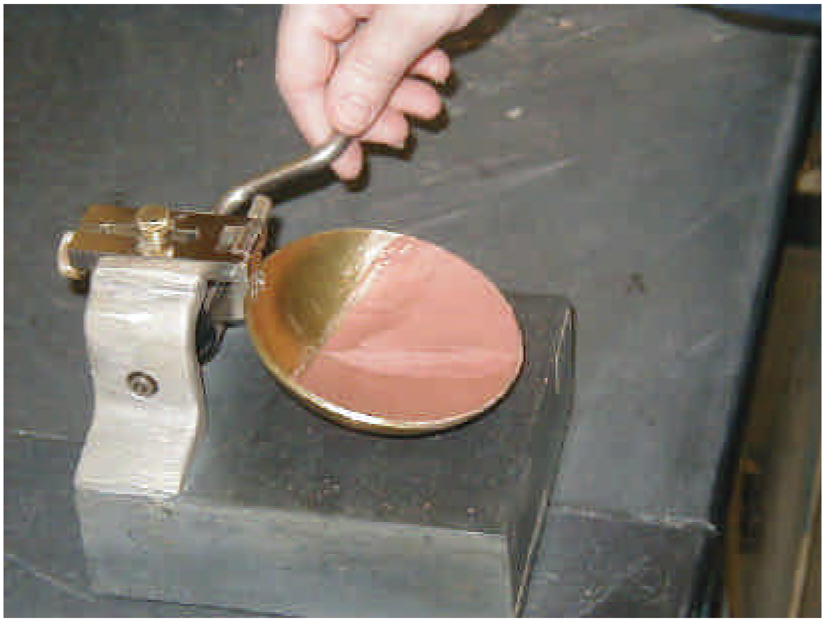


Figure 8 - Applying Blows by Turning the Handle

NOTE: Some soils tend to slide on the surface of the cup instead of flowing together. If this occurs, remix the material with additional water and repeat the procedure. If the soil continues to slide at fewer than 25 blows, the Liquid Limit test is not applicable. Record that the Liquid Limit could not be determined.

10) Record the number of blows needed to close the groove to 13 mm (0.5 in.)

11) Use the spatula to take a slice of soil from the specimen in the cup. Remove the slice from edge to edge of the soil cake at right angles to the groove. Include that portion of the groove where the soil has flowed together. Place the slice in a drying container.

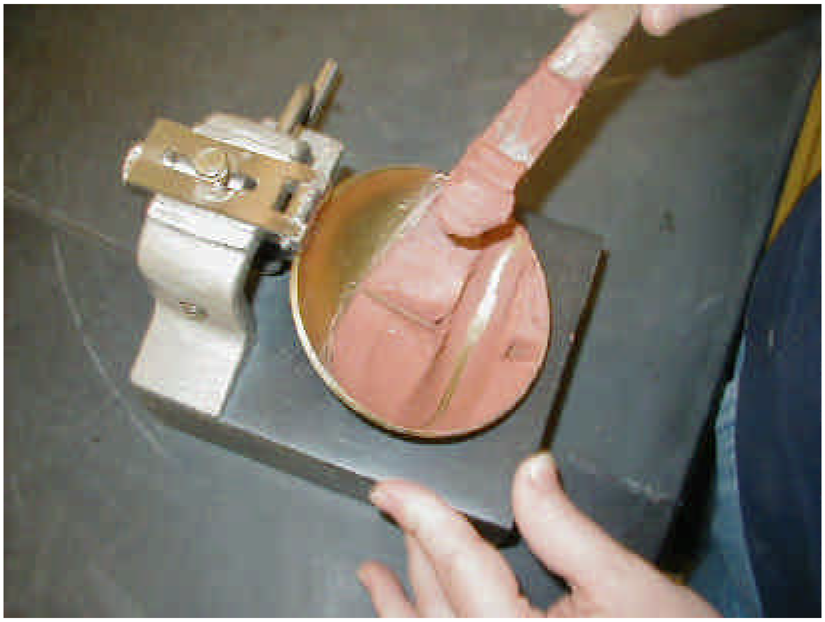


Figure 9 - Removing the Moisture Content Specimen

12) Determine the moisture content of the slice in accordance with AASHTO T 265.

13) Put the remaining part of the soil cake back into the mixing dish and cover it. Wash and dry the cup and grooving tool.

14) Add more water to the material in the mixing dish and remix, making the material more fluid. The intent is to increase the fluidity of the soil by 5 shocks (blows).

15) Repeat Steps 2 through 14 at least twice, until at least one determination is made in each of the following ranges. The range of the three determinations must be at least 10 blows.

Trial	No. of Blows
1	25 to 35
2	20 to 30
3	15 to 25

Figure 10 Weighing test sample

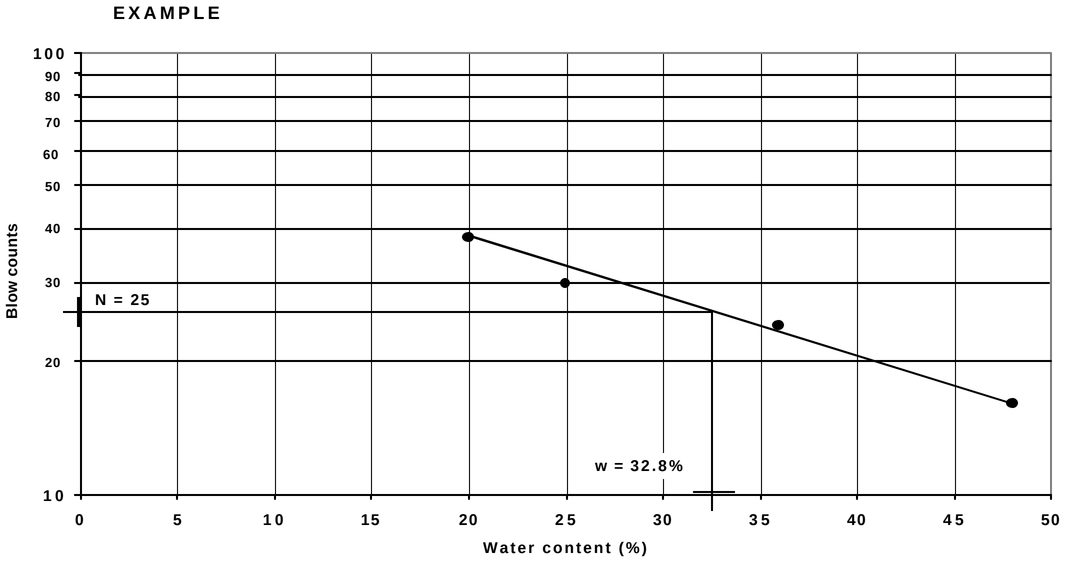
1.2.10.7 CALCULATIONS METHOD A

1) Prepare semi-logarithmic graph paper by labeling the x and y axes for moisture content and number of shocks respectively.

2) For each test specimen, plot the point corresponding to the blow count and moisture content.

3) Draw a flow curve (a straight line drawn as nearly as possible to all plotted points)

EXAMPLE



4) Determine the Liquid Limit**:** The moisture content at the intersection of the flow curve and the 25-blow line is the Liquid Limit. Record the Liquid Limit to the nearest whole number.

NOTE: The lower point, although recorded, was outside the 25 - 35 range. The course developers, unlike AASHTO directions, prefer that all points be recorded.

1.2.10.8 REFERENCE TEST

When performing Method A as a reference test, use the following time schedule:

- Mixing of soil with water: **5 - 10 minutes**
  The more plastic the soil, the longer the mixing time should be.
- Seasoning in the humidifier: **30 minutes**
- Remixing the material before placing it in the brass cup:
  Add 1 mL of water and mix: **1 minute**
- Placing the material in the brass cup and testing: **3 minutes maximum**
- Adding water and remixing: **3 minutes**

1.2.10.9 PROCEDURE METHOD B

Method B is a quicker determination of Liquid Limit, because it is only necessary to run one complete point. If results from Method B are questionable, use Method A as a referee test with the special parameters listed under reference test. You will need the same equipment as for Method A except semi-logarithmic graph paper. In addition to the equipment listed for Method A, you will need one of the following:

- Liquid Limit Slide Rule
- Calculator
- Liquid Limit Nomograph
- Other Approved Charts or Graphs

Obtain a test specimen of approximately 50g and perform in accordance with Method A except as noted.

1) Prepare the test specimen and perform the test exactly like Method A, with the following exception. Use approximately 8 - 10 mL of water for initial specimen preparation.

2) The blow count must be between 22 and 28.

3) After the blow count is in the correct range, return the material from the cup to the mixing dish. Remix quickly, being sure to avoid moisture loss. Repeat the blow count procedure without adding additional water to reaffirm the blow count.

4) When blow count is acceptable, obtain the slice of soil from the specimen in the cup and determine moisture content in accordance with AASHTO T 265.

> NOTE: The discussion in this training package for Method B will be limited to the Corps of Engineers Nomograph and the determination of Liquid Limit by formula.

1.2.10.10 CALCULATIONS: METHOD B

Use one of the methods shown in AASHTO T 89 to determine the Liquid Limit. In this training package only the formula and nomograph are shown as examples.

1) Use the following formula to determine the Liquid Limit.

Example:

$$LL = W_N\left(\frac{N}{25}\right)^{0.121}$$

Where: LL = Liquid Limit
N = Blow Count
W_N = Moisture Content at Blow Count, %
25 = Constant, Midrange of Acceptable Blow Count
0.121 = Empirical Constant

Example

N = 23
W_N = 48.5

$$LL = W_N\left(\frac{N}{25}\right)^{0.121}$$
$$LL = 48.5\left(\frac{23}{25}\right)^{0.121}$$
$$LL = 48.5(0.99)$$
$$LL = 48.01 = 48$$

2) Use the Nomograph to determine the Liquid Limit.
(Refer to the Nomograph in AASHTO T 89.)

- Plot the moisture content (WN) on the left vertical column.
- Plot the blow count (N) on the right vertical column.
- Using a straightedge, connect the two points.
- Read the Liquid Limit from the middle column.

Developed by the Waterways Experiment Station, Corps of Engineers
U. S. Army, to determine Liquid Limit Using Mean Slope Method

1.2.10.11 COMMON TESTING ERRORS

- Improperly adjusted Liquid Limit device.
- Loose adjusting screws.
- Excessively worn pin.
- Excessively worn base or cup.
- Worn grooving tool.
- Automatic counter not zeroed.
- Miscounting blows on manual device.
- Restraining the base of the Liquid Limit device during testing.
- Trapping air bubbles in the test specimen.
- Soil cake of improper thickness.
- Moisture content test specimen not representative of Liquid Limit test specimen.
- Plotting or calculation errors.
- Non-uniform moisture content in sample.
- Performing test before moisture content in soil specimen is equalized.
- Contaminated water used for testing.
- Adding water too quickly for the soil to absorb it during the mixing process.

1.2.11 AASHTO T 90 – DETERMINING THE PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

1.2.11.1 SCOPE: PLASTIC LIMIT AND PLASTICITY INDEX

PLASTIC LIMIT

As the moisture content of a material moves below the Liquid Limit, the material can be considered plastic. External force is needed to make the soil deform. Its bearing capacity begins to increase. Material is considered to be in a plastic state when it can be molded or worked into a new shape without crumbling. The minimum moisture content at which a material is in the plastic state is called the Plastic Limit. The Plastic Limit is determined by a simple test where the material is repeatedly rolled into threads approximately 3 mm in diameter. During the repeated rolling, the material gradually loses moisture until it reaches the point where it will no longer hold together and breaks into short pieces. The moisture content at which the material begins to break up is identified as the Plastic Limit.

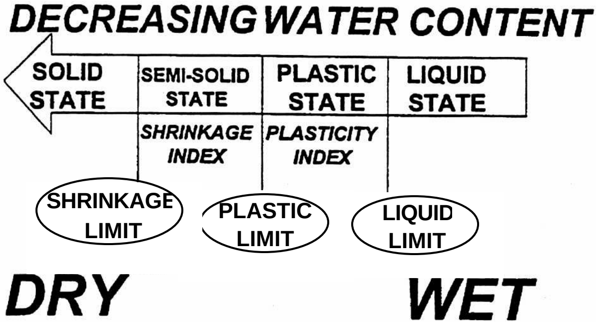
PLASTICITY INDEX

The range of moisture contents at which a material is considered to be plastic are those which fall between the Liquid Limit and the Plastic Limit. This range is identified as the Plasticity Index (PI). The Plasticity Index is a calculated value derived by subtracting the Plastic Limit from the Liquid Limit.

$$\mathbf{PI = LL - PL}$$

The Plasticity Index is an indicator of the suitability of the clay or silt fraction of a material for use in highway construction. The Plasticity Index is used in classifying soils, the quality control of aggregates and in specifications by many highway departments. When the Plasticity Index of the binder fraction of a material is too high, the material will tend to soften under wet conditions. Pavement structures constructed with material having a high PI tend to have problems with rutting, shifting and shoving. They may develop a washboard surface or other failures that are caused by foundation failures. When such materials are used, they tend to become slippery in wet weather. When the Plasticity Index is too low or the soil fraction is non-plastic, the material will tend to become friable in dry weather. It may ravel at the edges and abrade under traffic. Surfaces constructed with low PI material tend to be dusty and may lose much of their binder during dry periods.

The Plasticity Index is the numerical range of moisture contents through which a material behaves plastic. Materials become less stable as the moisture content increases through this range (moves left to right on the graph).



It is possible for a material to have a PI of zero, if the Plastic Limit and Liquid Limit are the same. Such a material is considered non-plastic, since the range of moisture contents at which the material behaves as a plastic is so severely limited that the range cannot be determined by standard laboratory tests. Non-plastic materials are almost totally free of clay particles. Non-plastic materials never reach a cohesive state, but change abruptly from a viscous liquid state to a dry granular state. A non-plastic material will not solidify. It will not form clods or other solid masses. It cannot be rolled into a thread as small as 3 mm (1/8 inch), ergo; the material cannot be tested for a Plastic Limit.

1.2.11.2 SUMMARY OF TESTING

To determine the Plastic Limit of a material, you will first add water to a dried sample and mix it thoroughly. When the moisture content is uniform, place the test specimen on a flat smooth impermeable surface and with the heel of the hand roll it into a thin thread. Remold the test specimen without adding additional water. Repeat the procedure until the specimen crumbles. The moisture content of the test specimen is determined in accordance with AASHTO T 265. The moisture content obtained is the Plastic Limit. Finally, determine the Plasticity Index by subtracting the Plastic Limit from the Liquid Limit.

TYPICAL TEST RESULTS

The Plastic Limit test was designed to be performed on silts and clays. Normally, silty soils have lower Plastic Limits than clay soils. The Plastic Limit usually falls in the range of 5 - 30. Non-plastic materials (e.g., sand) cannot be tested by this procedure. Non-plastic materials lack the cohesiveness to be rolled into a thread. The Plasticity Index can range as high as 70 or 80 for very plastic clays. However, most clays have a PI of 20 - 40 and silts have a PI of 10 - 20.

CRUMBLING

Different types of materials exhibit different modes of breaking up during rolling. Some materials fall apart in many small aggregations; others form a tubular layer on the outside that splits at both ends. When this occurs, the splitting tends to progress toward the middle until the thread falls apart in many small platy particles. Heavy clay requires a lot of pressure to deform, especially as it approaches the Plastic Limit. With clay, the thread often breaks into a series of barrel-shaped segments about 6 – 9 mm (1/4 - 3/8 in.) in length. The technician is never to attempt to produce failure at exactly 3 mm (1/8 in.) by reducing the rate of rolling or modifying hand pressure. It is acceptable to reduce the amount of rolling required for materials with low plasticity by making the initial diameter of the ellipsoidal test specimen near the 3 mm (1/8 in.) final diameter.

1.2.11.3 EQUIPMENT

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. To determine the Plastic Limit of a specimen, you will need the following.

- Dish - An unglazed porcelain container (or similar mixing container) approximately 115 mm (4½ in.) in diameter.

- Spatula - A flat blade or pill knife approximately 75 - 100 mm (3 - 4 in.) long and approximately 20 mm (3/4 in.) wide

- Surface for Rolling – Ground glass plate or smooth, unglazed paper

- Containers - Enough containers with close-fitting lids to provide one container per moisture content determination. Containers must be resistant to corrosion and not subject to change in mass with repeated heating and cooling.

- Balance - Conforming to AASHTO M 231, Class C

- Oven - A thermostatically controlled oven capable of maintaining a temperature of 110 ± 5º C (230 ± 9º F)

Figure 1 - Equipment for Plastic Limit

1.2.11.4 SAMPLE PREPARATION

Test Specimen

Prepare a sample in accordance with AASHTO T 87, Standard Method of Preparing Disturbed Soil Samples. Separate the material passing the 0.425 mm (No. 40) sieve. Obtain a representative portion of approximately 20 g from this material if you are only going to perform the test to determine the Plastic Limit. Place the air-dried material in a mixing dish and thoroughly mix with water until it can be easily shaped into a ball. Knead the material into plastic mass until the moisture content and texture are uniform. Take a ball of approximately 8 g to perform the test.

Figure 2 - Weighing Material for Test Specimen

1.2.11.5 PROCEDURE

1) Squeeze the 8 g test specimen into an ellipsoidal mass.

Figure 3 - Ellipsoidal mass

2) Select a 1.5 – 2.0 g portion and place on the rolling surface. Applying just enough pressure to cause the specimen to move, roll it back and forth with your hand until it forms a thread of uniform diameter throughout its length. Roll it back and forth at a speed of approximately 80 – 90 strokes per minute being sure to apply pressure uniformly during the procedure. A stroke equals one complete motion back and forward to the starting point.

Figure 4 - Rolling sample

2) When the diameter of the thread becomes 3 mm (1/8 inch), stop rolling. Break the thread into six or eight reasonably equal-sized pieces.

Figure 5 - Individual Pieces

3) Squeeze the pieces between the thumbs and fingers to create a uniform ellipsoidal mass.

5) Repeat Steps 2 - 4, until the thread crumbles under the pressure required for rolling and the specimen can no longer be rolled into a thread.

6) Gather the pieces of the crumbled thread together. Place them in a tared container to determine the moisture content.

7) Repeat this process until all the portions are tested.

8) Determine the moisture content in accordance with AASHTO T 265 and record the results.

NOTE: The test specimen may crumble when the thread has a diameter greater than 3 mm (1/8 inch). It is acceptable to end the rolling procedure at this point if the specimen has previously been rolled to the 3 mm diameter.

1.2.11.6 CALCULATIONS

1. Determine the Plastic Limit using the following formula and report the result to the nearest whole number.

$$PL = \frac{\text{Mass of Water}}{\text{Mass of Oven - Dry Soil}} \times 100$$

Example:

Mass of Water = 5.34 g
Mass of Oven Dry Soil = 22.01 g

$$PL = \frac{5.34}{22.01} \times 100$$

$$PL = 0.2426 \times 100$$

$$PL = 24.26 = 24$$

2. Determine the Plasticity Index using the following formula and report the result to the nearest whole number.

$$PI = LL - PL$$

Example:

LL = 70
PL = 24

PI = 70 – 24
PI = 46

1.2.11.7 COMMON TESTING ERRORS

- Non-uniform mixing of material and water
- Contaminated water
- Improperly blended sample
- Too thin or too thick material threads
- Errors in determining mass
- Applying too much pressure or non-uniform pressure in rolling
- Rolling on the wrong type surface

CHAPTER 2

GEOLOGY

2.1 INTRODUCTION

This chapter introduces the use of geology for the exploration and evaluation of naturally occurring construction materials for use as concrete aggregate, rip-rap, quarry stone, fill, and filter materials in the Mid-Atlantic Region. The Mid-Atlantic Region includes Pennsylvania (PA), New Jersey (NJ), West Virginia (WV), Maryland (MD), Delaware (DE), and Virginia (VA)

2.2 Geological Principles

2.2.1 Geologic Time

Geologists are used to thinking of millions of years in the same way normal people think in terms of days. Geologic time encompasses the interval from the formation of the Earth and Solar System (approximately 4.5 billion years ago) to now. It is measured by using radioactive isotopes (that decay at constant rates) and by fossils. The consolidated rocks in the Mid-Atlantic Region range in age from 1 billion to 200 million years old, and unconsolidated sediment ranges in age from 70 million years old to the present.

The geologic time scale is divided into the Precambrian Era (4.9 billion to 590 million years ago), Paleozoic Era (590 to 250 million years ago), Mesozoic Era (250 to 67 million years ago), and Cenozoic Era (67 million years ago to the present). The Mid-Atlantic Region has rocks or unconsolidated sediment representing portions of all the Eras (see Figure 1). The Eras are subdivided into Periods. Periods are generally named after the place where their rocks were first described. Thus, the Devonian Period is named after Devonshire in the UK, the Permian Period is named after the Perm region in Russia, the Jurassic Period is named after the Jura Mountains in Europe, and the Pennsylvanian Period is named after Pennsylvania.

The rock record is not continuous in any one place. The geologic story is put together from bits and pieces of rocks preserved across the globe. The gaps in the local rock record occur because of non-deposition or erosion. The rocks in the Mid-Atlantic Region record a fairly large portion of the Paleozoic Era (Figure 2.1), but the earth’s story is incomplete even in this stack of rocks. The rocks have been mapped, described, and analyzed by geologists, paleontologists, and geochemists from the state geological surveys, the state transportation departments, universities, the United States Geological Survey, and industry

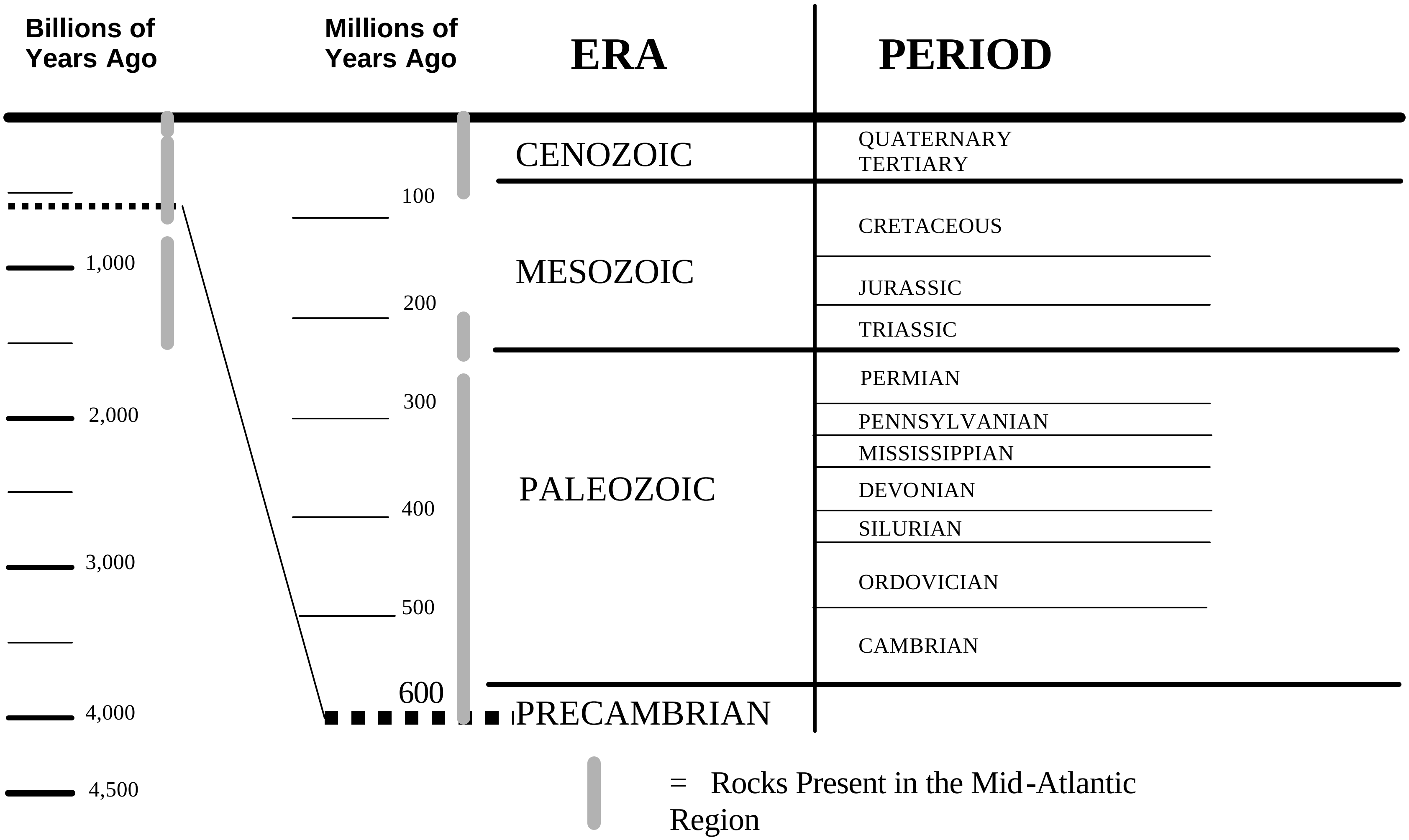


FIGURE 2.1: GEOLOGIC TIME

2.2.2 Law of Superposition

One of the primary tools of the geologist is the Law of Superposition, which simply states that rocks or sediment on the bottom of a pile are older than rocks or sediment at the top of the pile (assuming that the pile has not been intruded, tipped, folded, or faulted).

2.2.3 Paleoenvironments

Paleoenvironments are environmental conditions (climate, latitude, topographic relief, depth of marine or fresh water, absence of water, and/or vegetation) that existed during a specified portion of geologic time in a particular place. For instance, the latitude of the continents have changed, sea level rose and fell, and mountain ranges rose and were eroded away many times during geologic time.

The latitude, configuration, and size of the continents and oceans have changed over geologic time because of *Plate Tectonics*. Plate Tectonics is the mechanism that has driven the migration of the continents across the Earth's surface. Plate Tectonics is the theory that the Earth's surface consists of a group of solid lithologic (rocky) plates that slide on more ductile or molten material at depth. These plates underlie the oceans and continents. Their motion gives Earth the most dynamic planetary surface in the Solar System.

The plates are created at spreading centers, usually marked by mid-ocean ridges, where molten magma comes to the surface along a narrow, long fracture zone, and are consumed at deep trenches overlying subduction zones, where the plates plunge into the depths of the Earth. Plates that are composed of 'continental rocks' (mostly granite) are less dense than plates comprised of 'oceanic rocks' (mostly basalt). At the subduction zones, the continental plates float on the hot ductile and molten rocks that lie below, while the oceanic plates sink or are dragged into the deeper rocks. Thus, oceanic plates tend to be consumed at subduction zones, and continental plates survive and accumulate new material along their edges. The new material is scrapped off the colliding plate. High mountains and plateau are forced up where two continental plates collide. The Indian and Asian plates are colliding today, and the Himalayas are being pushed up along their suture zone. The Great Lakes of Africa and the Red Sea and Dead Sea in the Middle East lie along new spreading centers. Collisions and splits of continents have controlled the rising and sinking of the land, size and shape of the continents, and the extent of the oceans.

The Mid-Atlantic Region is on the North American Plate. It was on the eastern edge of the plate for much of the Early Paleozoic Era. The North American Plate presently extends from the center of the Atlantic Ocean to the San Andreas Fault in California. The North American Plate only extended east to the cities of Newark, NJ- Philadelphia- Baltimore- Richmond during the early Paleozoic. Islands, small continents, and the African and European plates were welded to the North American Plate at various times during the Middle and Late Paleozoic. The welding occurred when the continental plates collided. Each collision resulted in compression or squeezing at the suture, and the pushing up of lofty mountain ranges. Portions of the adjacent continents were left behind on the North American Plate when the continents subsequently split apart during the Triassic Period. Thus, the region contains pieces of islands, micro-continents, Africa, and Europe because of earlier collisions and fissioning.

The changing latitude of the continents has controlled climatic changes. During the Early Paleozoic, the Mid-Atlantic Region was near the Equator and the mountain ranges plowed up by the plate collisions were eroded by tropical rains and rivers.

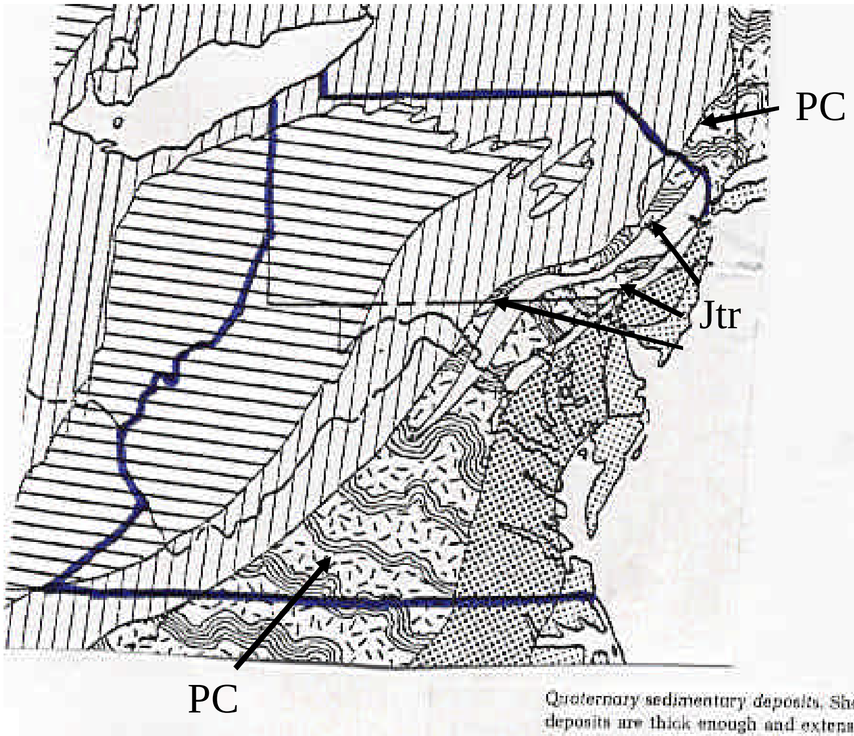
2.2.4 ROCKS AND MINERALS

The rocks of the region can be divided into three basic types: igneous, sedimentary, and metamorphic. The distribution of the basic rock types in the region is depicted on Figure 2.2. The rocks are composed of one or more *minerals*- naturally occurring elements or compounds formed by inorganic chemical reactions. Minerals have relatively consistent chemical compositions and physical properties.

There are over 4,000 described minerals, but only nine rock-forming minerals or mineral groups are common:

Quartz
Feldspar Group
Clay Group
Mica Group
Pyroxene Group
Amphibole Group
Carbonates (calcite and dolomite)
Iron Oxides (limonite, hematite, and magnetite)
Pyrite

Igneous rocks are derived from molten rock or lava. They are composed of minerals such as feldspars, pyroxenes, amphiboles, mica, quartz, and/or metal oxides. Igneous rocks that solidify slowly at depth are coarsely crystalline, while igneous rocks that crystallize rapidly at shallow depths or at the Earth's surface are finely crystalline. *Granite*, *granodiorite*, and *gabbo* are typical coarsely crystalline rocks. *Basalt* and *diabase* are generally finely crystalline rocks.



Quaternary sedimentary deposits. Shown only where deposits are thick enough to cover the bedrock. Marine and fluvial sediments are present along the coast.

Tertiary formations. Sedimentary deposits of fluvial and marine origin along the coast.

*Early Mesozoic formations.*Triassic and Jurassic fluvial and lake sediments plus igneous rocks in basins.

Upper Paleozoic formations. Mississipian, Pennsylvanian, and Permian marine and continental deposits.

*Lower Paleozoic formations.*Cambrian, Ordovician, Silurian, and Devonian marine and continental deposits.

Metamorphic rocks. Mostly Mostly precambrian with considerable infolded Paleozoic metamorphic rocks. PC

Modified from Hunt, 1974

FIGURE 2.2: BEDROCK GEOLOGY OF THE MID-ATLANTIC REGION

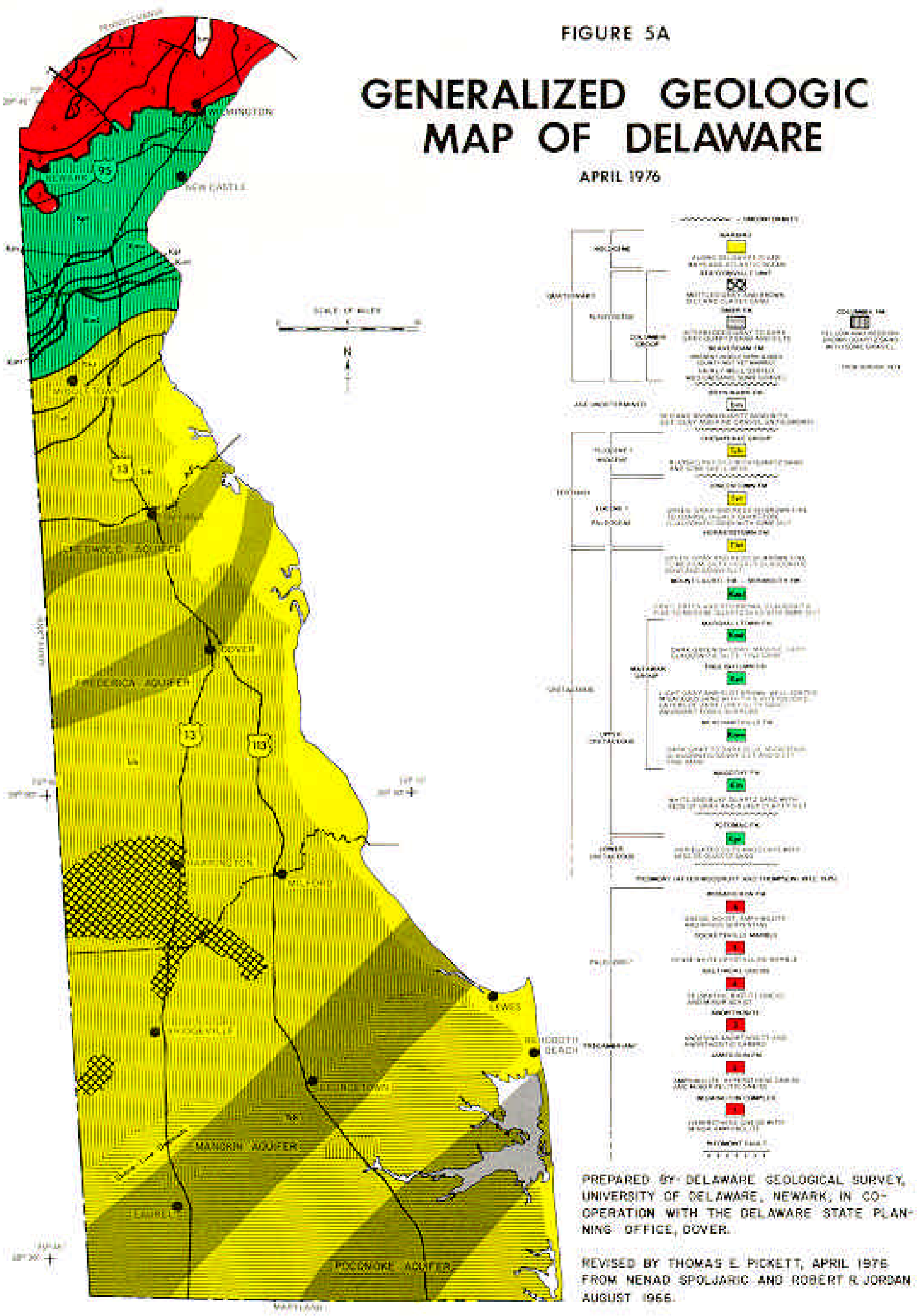


FIGURE 5A
GENERALIZED GEOLOGIC MAP OF DELAWARE
APRIL 1976
WILMINGTON
NEWARK
NEW CASTLE
95
MIDDLETOWN
SMYRNA
13
CHESWOLD AQUIFER
DOVER
FREDERICA AQUIFER
HARRINGTON
MILFORD
LEWES
REHOBOTH BEACH
BRIDGEVILLE
GEORGETOWN
MANOKIN AQUIFER
LAUREL
POCOMOKE AQUIFER
MARYLAND
PREPARED BY DELAWARE GEOLOGICAL SURVEY, UNIVERSITY OF DELAWARE, NEWARK, IN CO-OPERATION WITH THE DELAWARE STATE PLANNING OFFICE, DOVER.
REVISED BY THOMAS E. PICKETT, APRIL 1976 FROM NENAD SPOLJARIC AND ROBERT R. JORDAN AUGUST 1966.

Figure 2.3

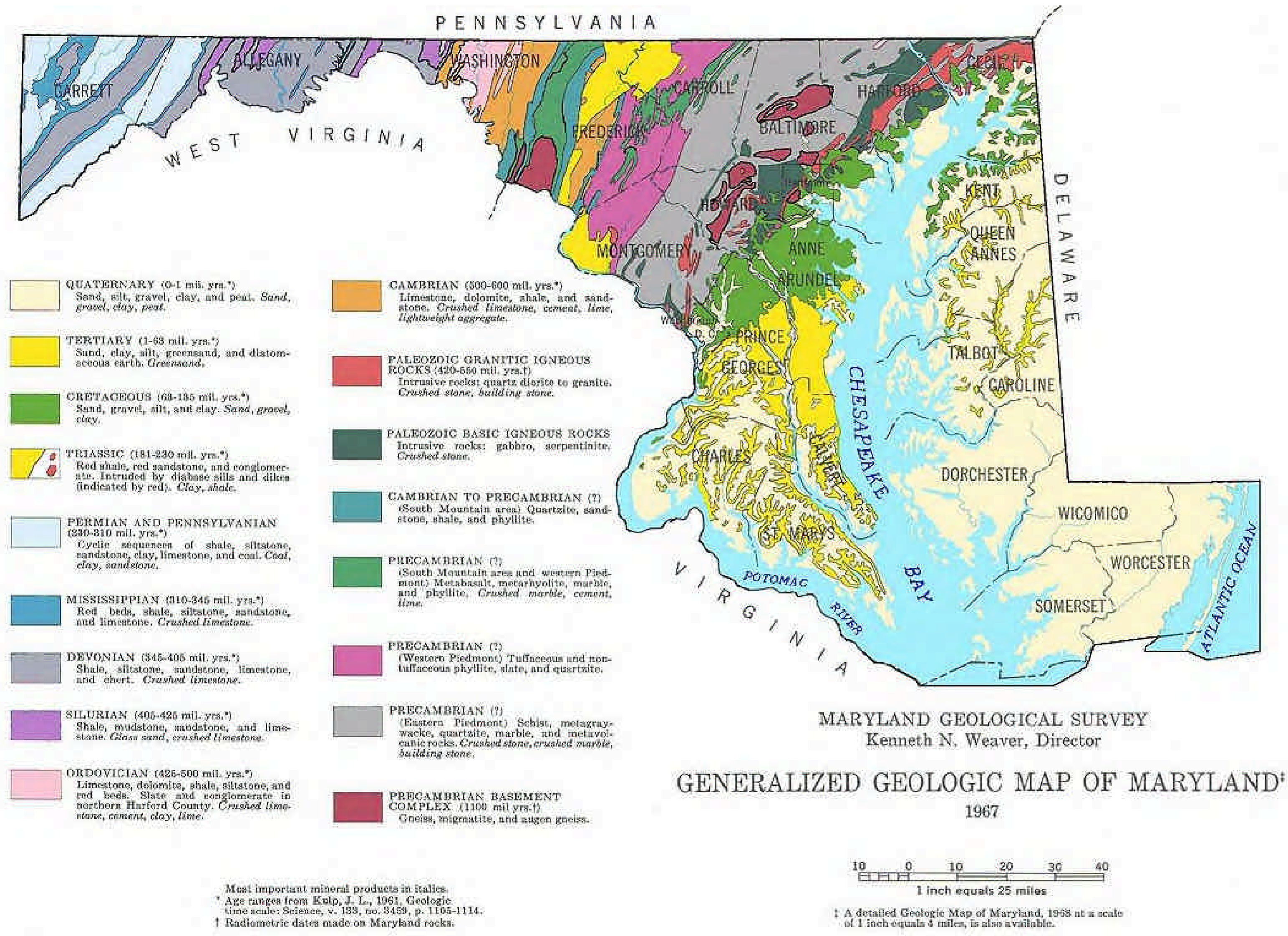
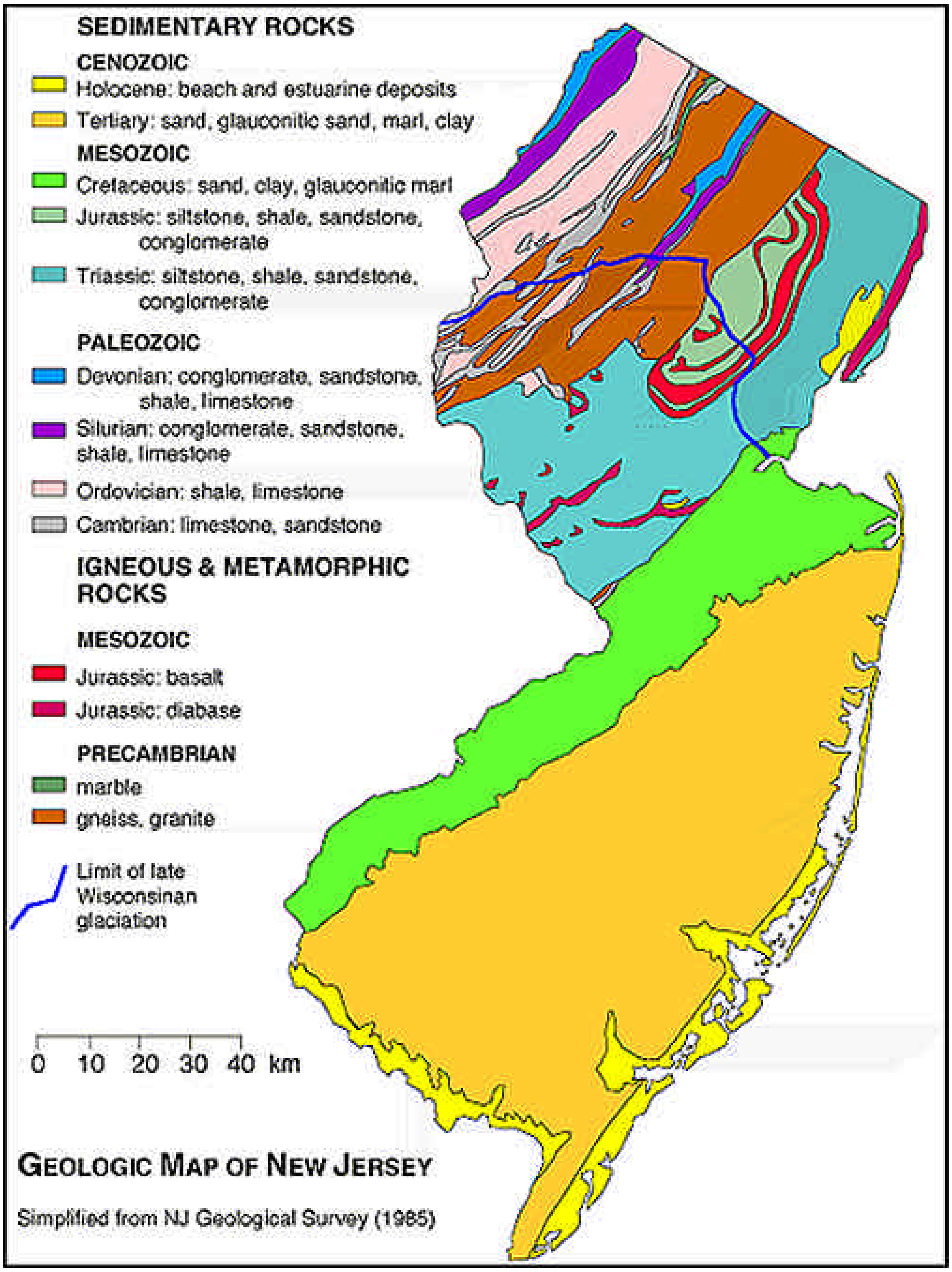

PENNSYLVANIA
WEST VIRGINIA
VIRGINIA
DELAWARE
ATLANTIC OCEAN
CHESAPEAKE BAY
POTOMAC RIVER
GARRETT
ALLEGANY
WASHINGTON
FREDERICK
CARROLL
BALTIMORE
HARFORD
CECIL
HOWARD
MONTGOMERY
ANNE ARUNDEL
PRINCE GEORGES
CHARLES
CALVERT
ST. MARYS
KENT
QUEEN ANNES
TALBOT
CAROLINE
DORCHESTER
WICOMICO
WORCESTER
SOMERSET
D.C.
QUATERNARY (0-1 mil. yrs.*) Sand, silt, gravel, clay, and peat. Sand, gravel, clay, peat.
TERTIARY (1-63 mil. yrs.*) Sand, clay, silt, greensand, and diatomaceous earth. Greensand.
CRETACEOUS (63-135 mil. yrs.*) Sand, gravel, silt, and clay. Sand, gravel, clay.
TRIASSIC (181-230 mil. yrs.*) Red shale, red sandstone, and conglomerate. Intruded by diabase sills and dikes (indicated by red). Clay, shale.
PERMIAN AND PENNSYLVANIAN (230-310 mil. yrs.*) Cyclic sequences of shale, siltstone, sandstone, clay, limestone, and coal. Coal, clay, sandstone.
MISSISSIPPIAN (310-345 mil. yrs.*) Red beds, shale, siltstone, sandstone, and limestone. Crushed limestone.
DEVONIAN (345-405 mil. yrs.*) Shale, siltstone, sandstone, limestone, and chert. Crushed limestone.
SILURIAN (405-425 mil. yrs.*) Shale, mudstone, sandstone, and limestone. Glass sand, crushed limestone.
ORDOVICIAN (425-500 mil. yrs.*) Limestone, dolomite, shale, siltstone, and red beds. Slate and conglomerate in northern Harford County. Crushed limestone, cement, clay, lime.
CAMBRIAN (500-600 mil. yrs.*) Limestone, dolomite, shale, and sandstone. Crushed limestone, cement, lime, lightweight aggregate.
PALEOZOIC GRANITIC IGNEOUS ROCKS (420-550 mil. yrs.†) Intrusive rocks: quartz diorite to granite. Crushed stone, building stone.
PALEOZOIC BASIC IGNEOUS ROCKS Intrusive rocks: gabbro, serpentinite. Crushed stone.
CAMBRIAN TO PRECAMBRIAN (?) (South Mountain area) Quartzite, sandstone, shale, and phyllite.
PRECAMBRIAN (?) (South Mountain area and western Piedmont) Metabasalt, metarhyolite, marble, and phyllite. Crushed marble, cement, lime.
PRECAMBRIAN (?) (Western Piedmont) Tuffaceous and nontuffaceous phyllite, slate, and quartzite.
PRECAMBRIAN (?) (Eastern Piedmont) Schist, metagraywacke, quartzite, marble, and metavolcanic rocks. Crushed stone, crushed marble, building stone.
PRECAMBRIAN BASEMENT COMPLEX (1100 mil yrs.†) Gneiss, migmatite, and augen gneiss.
Most important mineral products in italics.
* Age ranges from Kulp, J. L., 1961, Geologic time scale: Science, v. 133, no. 3459, p. 1105-1114.
† Radiometric dates made on Maryland rocks.
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director
GENERALIZED GEOLOGIC MAP OF MARYLAND‡
1967
10
0
10
20
30
40
1 inch equals 25 miles
‡ A detailed Geologic Map of Maryland, 1968 at a scale of 1 inch equals 4 miles, is also available.

Figure 2.4



GEOLOGIC MAP OF NEW JERSEY

Simplified from NJ Geological Survey (1985)

Figure 2.5

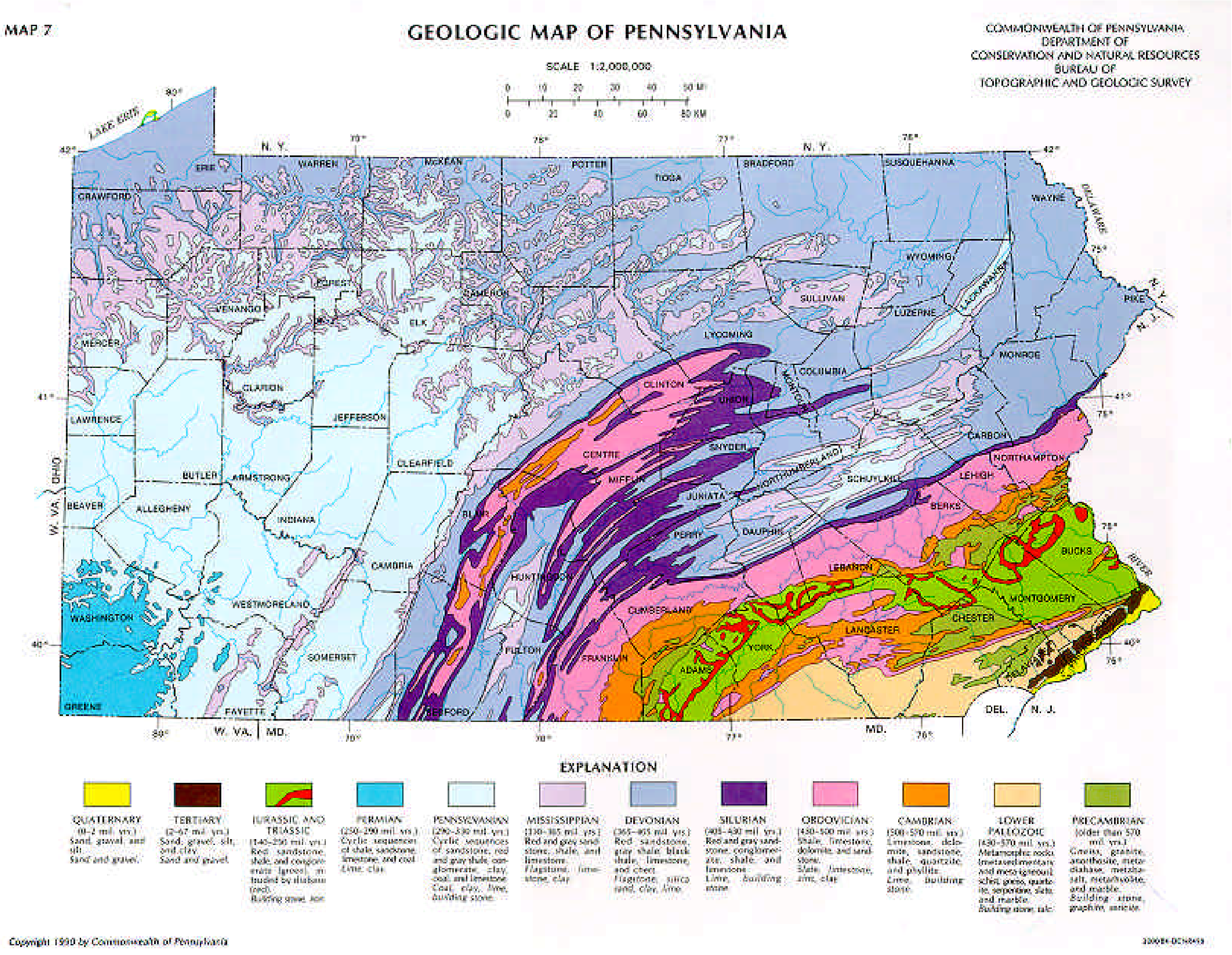

MAP 7
GEOLOGIC MAP OF PENNSYLVANIA
SCALE 1:2,000,000
0 10 20 30 40 50 MI
0 20 40 60 80 KM
COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF
CONSERVATION AND NATURAL RESOURCES
BUREAU OF
TOPOGRAPHIC AND GEOLOGIC SURVEY
LAKE ERIE
N. Y.
N. J.
DEL.
MD.
W. VA.
OHIO
DELAWARE
RIVER
42°
41°
40°
80°
79°
78°
77°
76°
75°
ERIE
CRAWFORD
WARREN
McKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
PIKE
MERCER
VENANGO
FOREST
ELK
CAMERON
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
LUZERNE
MONROE
LAWRENCE
BUTLER
CLARION
JEFFERSON
CLEARFIELD
CENTRE
CLINTON
UNION
MONTOUR
COLUMBIA
CARBON
NORTHAMPTON
LEHIGH
BEAVER
ALLEGHENY
ARMSTRONG
INDIANA
CAMBRIA
BLAIR
HUNTINGDON
MIFFLIN
JUNIATA
SNYDER
NORTHUMBERLAND
SCHUYLKILL
BERKS
BUCKS
WASHINGTON
WESTMORELAND
SOMERSET
BEDFORD
FULTON
FRANKLIN
CUMBERLAND
PERRY
DAUPHIN
LEBANON
LANCASTER
CHESTER
MONTGOMERY
YORK
ADAMS
DELAWARE
PHILADELPHIA
GREENE
FAYETTE
EXPLANATION
QUATERNARY (0–2 mil. yrs.) Sand, gravel, and silt. Sand and gravel.
TERTIARY (2–67 mil. yrs.) Sand, gravel, silt, and clay. Sand and gravel.
JURASSIC AND TRIASSIC (140–250 mil. yrs.) Red sandstone, shale, and conglomerate (green), intruded by diabase (red). Building stone, iron
PERMIAN (250–290 mil. yrs.) Cyclic sequences of shale, sandstone, limestone, and coal. Lime, clay
PENNSYLVANIAN (290–330 mil. yrs.) Cyclic sequences of sandstone, red and gray shale, conglomerate, clay, coal, and limestone. Coal, clay, lime, building stone.
MISSISSIPPIAN (330–365 mil. yrs.) Red and gray sandstone, shale, and limestone. Flagstone, limestone, clay
DEVONIAN (365–405 mil. yrs.) Red sandstone, gray shale, black shale, limestone, and chert. Flagstone, silica sand, clay, lime
SILURIAN (405–430 mil. yrs.) Red and gray sandstone, conglomerate, shale, and limestone. Lime, building stone
ORDOVICIAN (430–500 mil. yrs.) Shale, limestone, dolomite, and sandstone. Slate, limestone, zinc, clay
CAMBRIAN (500–570 mil. yrs.) Limestone, dolomite, sandstone, shale, quartzite, and phyllite. Lime, building stone.
LOWER PALEOZOIC (430–570 mil. yrs.) Metamorphic rocks (metasedimentary and meta-igneous): schist, gneiss, quartzite, serpentine, slate, and marble. Building stone, talc
PRECAMBRIAN (older than 570 mil. yrs.) Gneiss, granite, anorthosite, metadiabase, metabasalt, metarhyolite, and marble. Building stone, graphite, sericite.
Copyright 1990 by Commonwealth of Pennsylvania

Figure 2.6

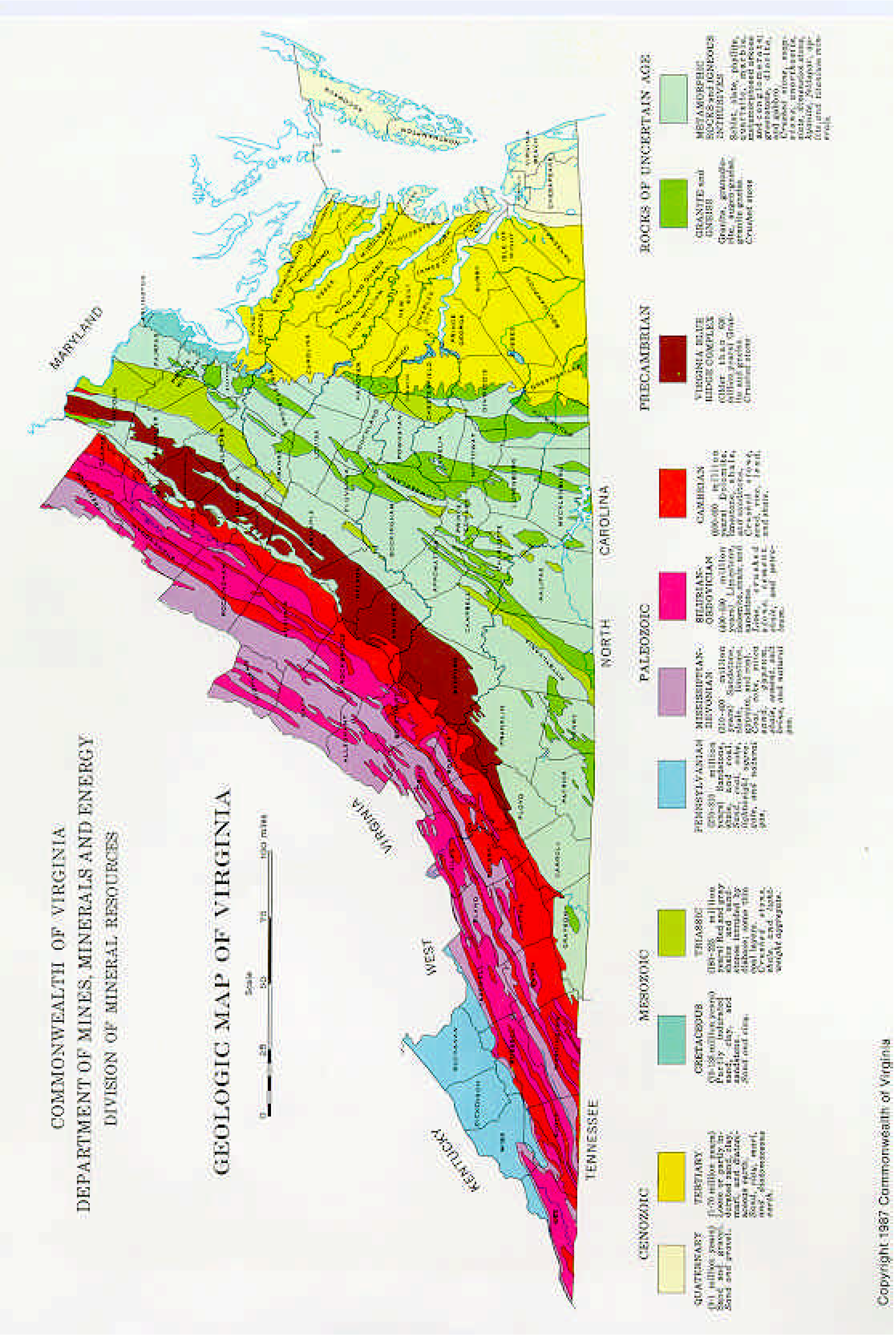

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINERAL RESOURCES
GEOLOGIC MAP OF VIRGINIA
Scale
0
25
50
75
100 miles
MARYLAND
WEST
VIRGINIA
KENTUCKY
TENNESSEE
NORTH
CAROLINA
CENOZOIC
QUATERNARY
TERTIARY
MESOZOIC
CRETACEOUS
TRIASSIC
PALEOZOIC
PENNSYLVANIAN
MISSISSIPPIAN-DEVONIAN
SILURIAN-ORDOVICIAN
CAMBRIAN
PRECAMBRIAN
VIRGINIA BLUE RIDGE COMPLEX
ROCKS OF UNCERTAIN AGE
GRANITE and GNEISS
METAMORPHIC ROCKS and IGNEOUS INTRUSIVES
Copyright 1987 Commonwealth of Virginia

Figure 2.7

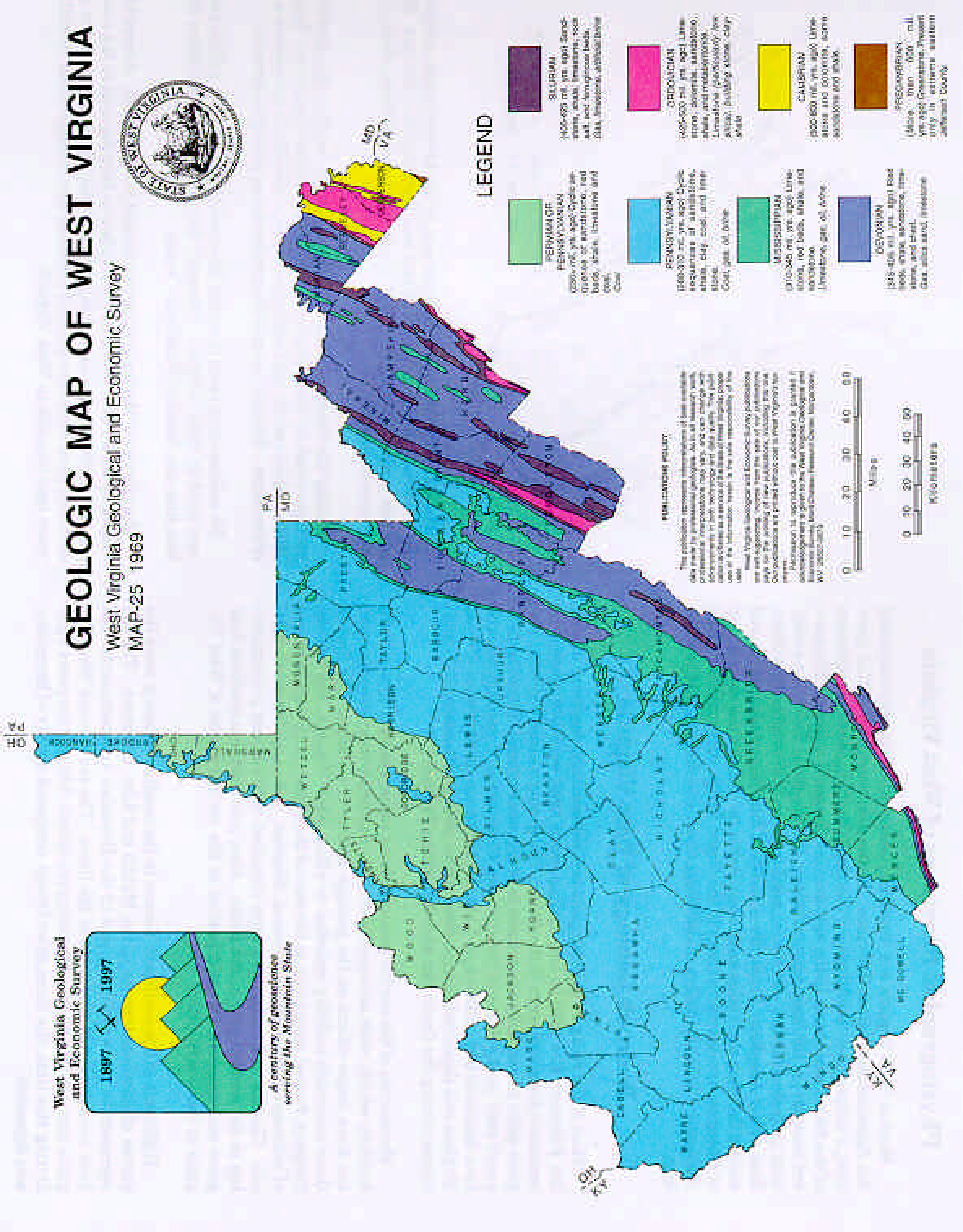

GEOLOGIC MAP OF WEST VIRGINIA
West Virginia Geological and Economic Survey
MAP-25 1969
LEGEND
PERMIAN OR PENNSYLVANIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PRECAMBRIAN
PUBLICATIONS POLICY
Miles
Kilometers
West Virginia Geological and Economic Survey
1897
1997
A century of geoscience serving the Mountain State
OH
PA
PA
MD
MD
VA
OH
KY
KY
VA

Figure 2.8

Sedimentary rocks are either derived from older rocks (clastic sedimentary rocks) or from biochemical or chemical precipitates in aqueous solutions (chemical sedimentary rocks). Clastic rocks include *conglomerate*, *sandstone*, *siltstone*, and *shale*, based on decreasing grain size. They were derived from gravel, sand, silt, and clay, respectively. The clastic sedimentary rocks are cemented with various materials, such as quartz or silica, clay, carbonate, or iron oxides. Clay-cemented sandstones or siltstones are *graywackes*. Carbonate-cemented sandstones are *calcareous*. Quartz-cemented sandstones are *quartzose* sandstone or *quartzite*.

The chemically precipitated rocks include *gypsum* and *salt*, the silicate *chert*, and the carbonates *limestone* and *dolomite*. Gypsum and salt are highly soluble and soft, and rarely are exposed at the Earth's surface. They are not used in road construction (although gypsum is used in wallboard). The carbonates are the primary chemically derived rocks used in aggregates because they are harder and less soluble. Chert is generally a minor constituent in rocks, although it can cause deleterious chemical reactions in concrete if it is too plentiful.

Metamorphic rocks are pre-existing igneous or sedimentary rocks that have been chemically or texturally altered by heat and pressure. Metamorphic rocks are composed of many of the same minerals that occur in igneous rocks. Metamorphic sedimentary rocks include *quartzite*, which was originally conglomerate or sandstone; *gneiss*, which was originally clay-rich sandstones and siltstones; *argillite*, *phyllite*, *schist*, or *slate*, which were derived from siltstone and shale; and *marble*, derived from limestone or dolomite. Gneiss can also be derived from diabase, granite, and granodiorite. *Serpentine* is a serpentine, chlorite, and mica-rich rock that was derived from oceanic sediment that has been squeezed and injected by water-rich magmas in the suture between colliding continents or between colliding oceanic and continental plates. Serpentine rich areas form *greenstone* belts. Greenstone Belts are common in central VA and eastern MD and PA.

2.2.5 WEATHERING AND SOILS

Soil is defined by engineers as unconsolidated accumulations of solid particles produced by the chemical or physical weathering of bedrock. The organic matter content of soil can vary from nil to 100%. Weathering can involve simple mechanical of the bedrock into smaller particles or can cause complete chemical alteration of the original mineral assemblage. Engineering soils are further divided into fine-grained soil and coarse- grained soil. Fine-grained soil passes through the 200 sieve (0.0029 inch, 75 micrometer). Fine-grained soil is classified as silt or clay, depending on the grain size, plasticity, and compressibility of the material. Generally, the smaller the grain size, the higher the plasticity and compressibility. Coarse-grained soil is retained on the 200 sieve, and is noncohesive and nonplastic. It is classified into sand, gravel, cobble, and boulders, based on increasing grain size. Organic matter tends to behave somewhat like clay, it increases the compressibility and plasticity of the soil. Organic soils are not suitable for highway construction or most other engineering purposes.

Igneous, sedimentary, and metamorphic rocks are weathered at the Earth's surface and converted into unconsolidated soils. Weathering includes physical and chemical processes. Physical weathering includes disaggregation by crystals (ice or salts); stress release; heat stress; abrasion and fracturing by glacial ice, water, or air; and swelling of clays or iron oxides due to absorption of water. Physical weathering reduces the size and increases the surface area of particles, making them more susceptible to movement and chemical weathering.

Chemical weathering processes include oxidation, solution and leaching, hydration, cation exchange, carbonation, and chelation. Carbonation is caused by the reaction of carbonic acid (derived from carbon dioxide gas in the atmosphere reacting with water vapor) with carbonates and feldspar. Chemical and physical weathering are accelerated by the presence of water, by fracturing (faults or joints), and by higher temperatures.

The common rock forming minerals break down into the following soil forming minerals:

Table 2.1 Common Rock and Soil Forming Minerals

Rock Forming Mineral	**Soil Forming Mineral**
Quartz	Quartz
Feldspar Group	Clay Minerals and Quartz
Mica Group	Clay Minerals, Quartz, and Iron Oxides
Pyroxene Group	Clay Minerals, Quartz, and Iron Oxides
Amphibole Group	Clay Minerals, Quartz, and Iron Oxides
Carbonates	None (dissolved)
Iron Oxides	Iron Oxides and Hydroxides
Pyrite	Iron Oxides and Hydroxides

Mass movements, water, ice, and air, transport the soils created by physical and chemical weathering.

The common soils in the Mid-Atlantic Region are:

Residual soil: derived from bedrock that has weathered and remained in place. Residual soils occur in most of the region, particularly the south of the limit of the glacial soils.

Alluvial soil: derived from soil particles that have been transported and redeposited by running water. Alluvial soils are found along most of the streams and rivers of the region.

Colluvial soil: derived from materials transported downslope by gravity and water (mass movement). The colluvial soils are deposited along the base of steep slopes. They are found throughout the mountainous regions of the region.

Glacial soils: were transported and redeposited by glacial ice. They range from non-stratified, unsorted glacial till to well-washed and sorted kame, esker, and outwash sand and gravel. Glacial soils are common in PA and NJ.

Aeolian soils: are formed by material transported and redeposited by the wind. Aeolian soils tend to be sand (dune) and silt (loess) sized. Aeolian soils are locally abundant along the Lake Erie and Atlantic coasts and along the valleys of large rivers or shorelines of extinct glacial lakes.

Organic soils: are soils rich in organic matter.

2.2.6 SEDIMENTARY FACIES

Sedimentary facies is the total appearance of a sedimentary rock or deposit. It includes grain size, sorting (or grading), degree of compaction, color, bedding, and shape of the overall deposit. The environment of deposition controls the facies. High energy environments, such as river channels or wave washed beaches, winnow away fine grained particles, leaving coarse sand, gravel, and/or boulders behind that become conglomerate or sandstone when they *lithify* (turn to stone). Sand is deposited in moderately energetic environments, such as deltas and coastal plains. Relatively quiet or low energy environments, such as portions of floodplains, deep oceans, or lake basins, receive fine-grained materials, such as clay or silt that become siltstone or shale. The sedimentary facies control the engineering characteristics of rocks. Beach sandstones have large mineable volumes and consistent sorting. River sandstones have smaller volumes and more variable sorting, but are generally more durable.

The paleoenvironments of the Mid-Atlantic Region have changed through time, sometimes the change was abrupt and at other times it was gradual. During the Paleozoic Era, sea level rose and fell many times in response to Plate Tectonic events and to the melting and formation of glaciers. As the sea rose onto the North American Plate, waves eroded the older land surface, and sheets of winnowed gravel and sand were deposited. Mud (silt and clay) then was deposited as the sea deepened. At the same time, mountains rose in the eastern part of the region as the African or European plates collided with North America, and rivers delivered large quantities of sediment to the sea, forming broad coastal plains and deltas as the sea filled up. The episodic rise and fall of the sea, and rising and disintegration of the mountains resulted in the migration or shifting of shorelines and deltas, and in repeating sequences of coarse- to fine-grained sedimentary rock. The changing sea level resulted in sequences of shale and siltstone alternating or interfingering with sandstone and conglomerate.

The rocks are metamorphosed when they are subjected to heating by deep burial, by intrusions of molten rock, and by intense pressure during plate collisions. Argillites and slates were shales and siltstones that were metamorphosed by diabase intrusions during the Paleozoic and Mesozoic Eras.

2.3 PHYSIOGRAPHIC PROVINCES

A *Physiographic Province* is a natural region having characteristics peculiar to itself- a distinctive geologic structural framework giving rise to distinctive landforms and, for the most part, distinctive climate, soil, water, and other resources (modified from Hunt, 1974, pg. 3). Knowledge of a locality's Physiographic Province allows one to make predictions of the landscapes, topography, geologic resources, soils, and drainage in the locality's vicinity.

One of the most important geomorphological concepts is "*hard rocks erode slower than soft rocks*." Generally, hard rocks, such as granite, gneiss, quartzite, or sandstone, form ridges, while soft rocks, such as shale or limestone, form valleys. Limestones are especially susceptible to chemical erosion because they are soluble in weak acid. Carbon dioxide in the air forms a natural acid rain (carbonic acid) that easily dissolves the limestone.

The Physiographic Provinces of the region are the Atlantic Coastal Plain, Piedmont, Blue Ridge, New England Uplands, Ridge and Valley, Appalachian Plateau, and Central Lowlands (Figure 2.10). The provinces form southwest to northeast trending bands across the region.

The *Atlantic Coastal Plain Province* forms a belt of unconsolidated, eastward dipping, Late Mesozoic and Cenozoic marine and continental sediments in eastern NJ, PA, DE, MD, and VA (Figures 2.9 and 2.10). It is bordered by the Atlantic Ocean on the east, and by the Piedmont Province on the west. The boundary between the Coastal Plain and Piedmont is marked by rapids flowing across lithified rocks, and is called the *Fall Line*. The topography of the Coastal Plain is low, with small hills underlain by the unconsolidated sediments. Rivers on the Coastal Plain are relatively wide and meandering. Tidal waters flood their lower reaches, frequently as far west as the Fall Line. The Coastal Plain has grown eastward through time by incremental additions of river-borne and coastal

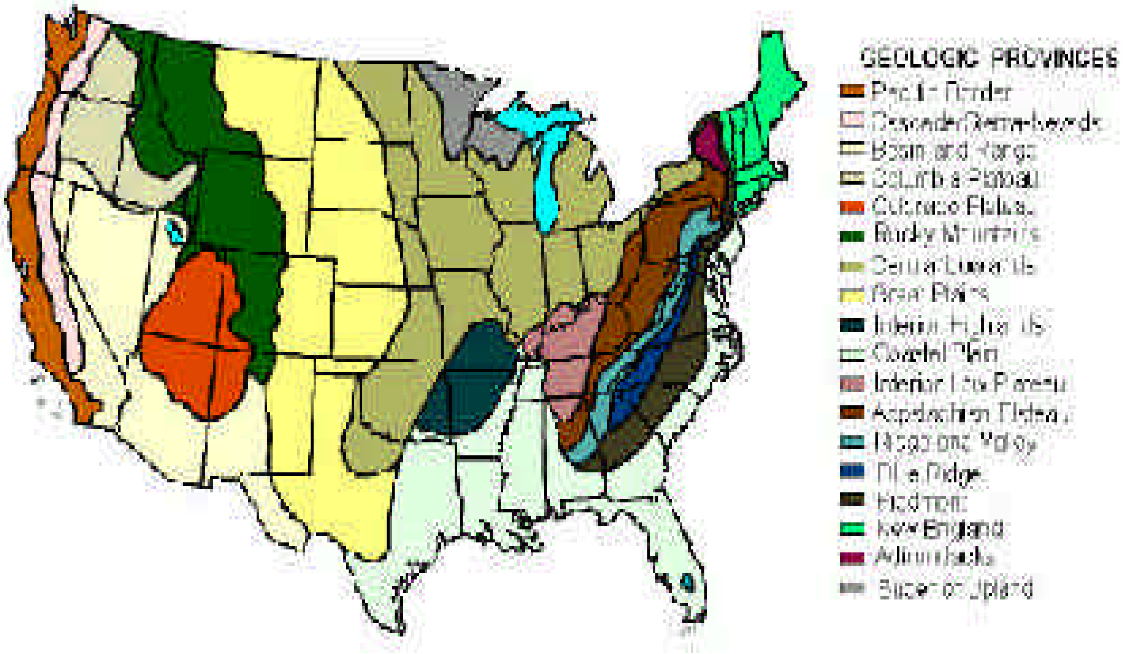
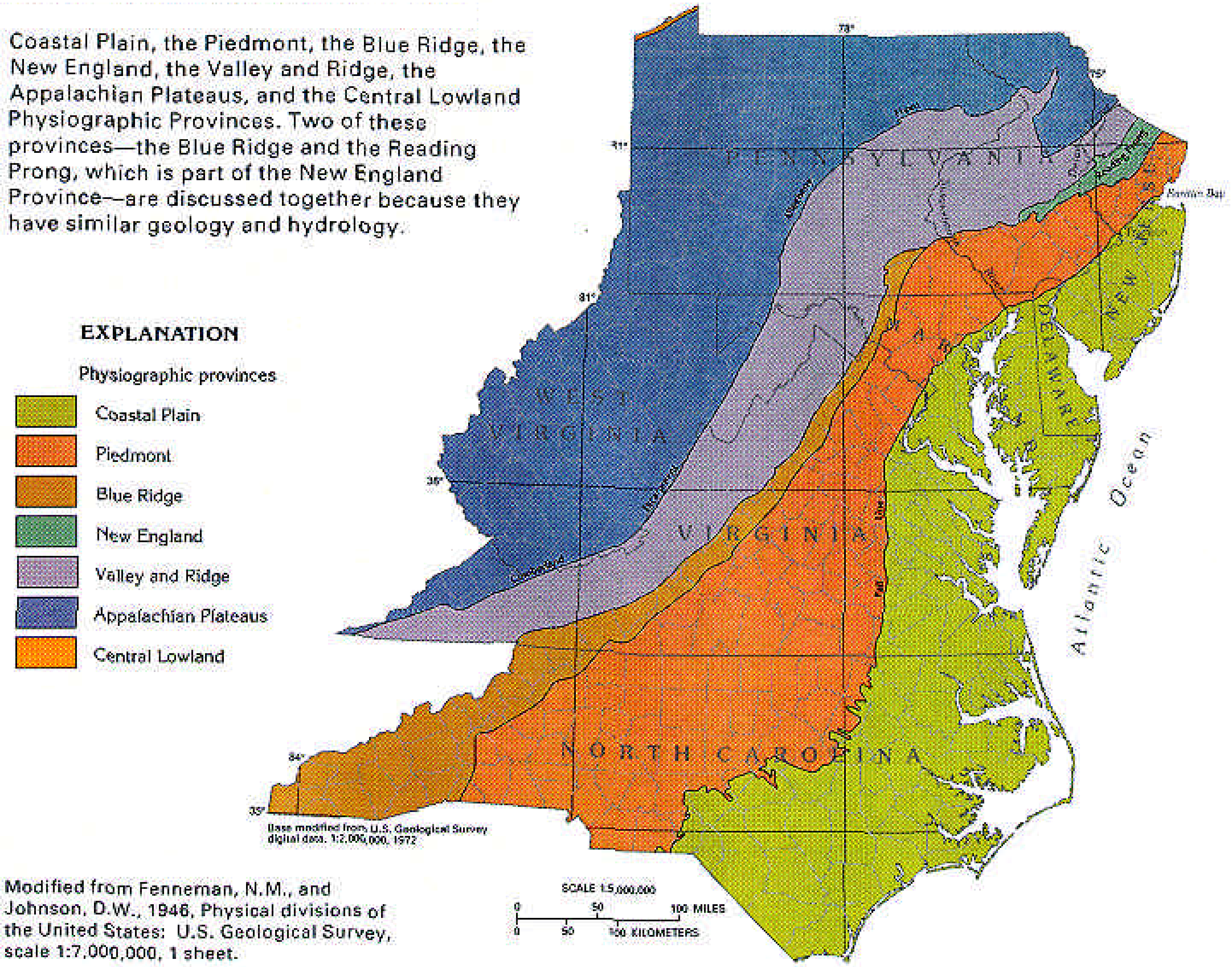

GEOLOGIC PROVINCES
Pacific Border
Cascade/Sierra-Nevada
Basin and Range
Columbia Plateau
Colorado Plateau
Rocky Mountains
Central Lowlands
Great Plains
Interior Highlands
Coastal Plain
Interior Low Plateau
Appalachian Plateau
Ridge and Valley
Blue Ridge
Piedmont
New England
Adirondacks
Superior Upland

Figure 2.9

Coastal Plain, the Piedmont, the Blue Ridge, the New England, the Valley and Ridge, the Appalachian Plateaus, and the Central Lowland Physiographic Provinces. Two of these provinces—the Blue Ridge and the Reading Prong, which is part of the New England Province—are discussed together because they have similar geology and hydrology.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Fenneman, N.M., and Johnson, D.W., 1946, Physical divisions of the United States: U.S. Geological Survey, scale 1:7,000,000, 1 sheet.

Figure 2.10 Mid-Atlantic Region Physiographic Provinces

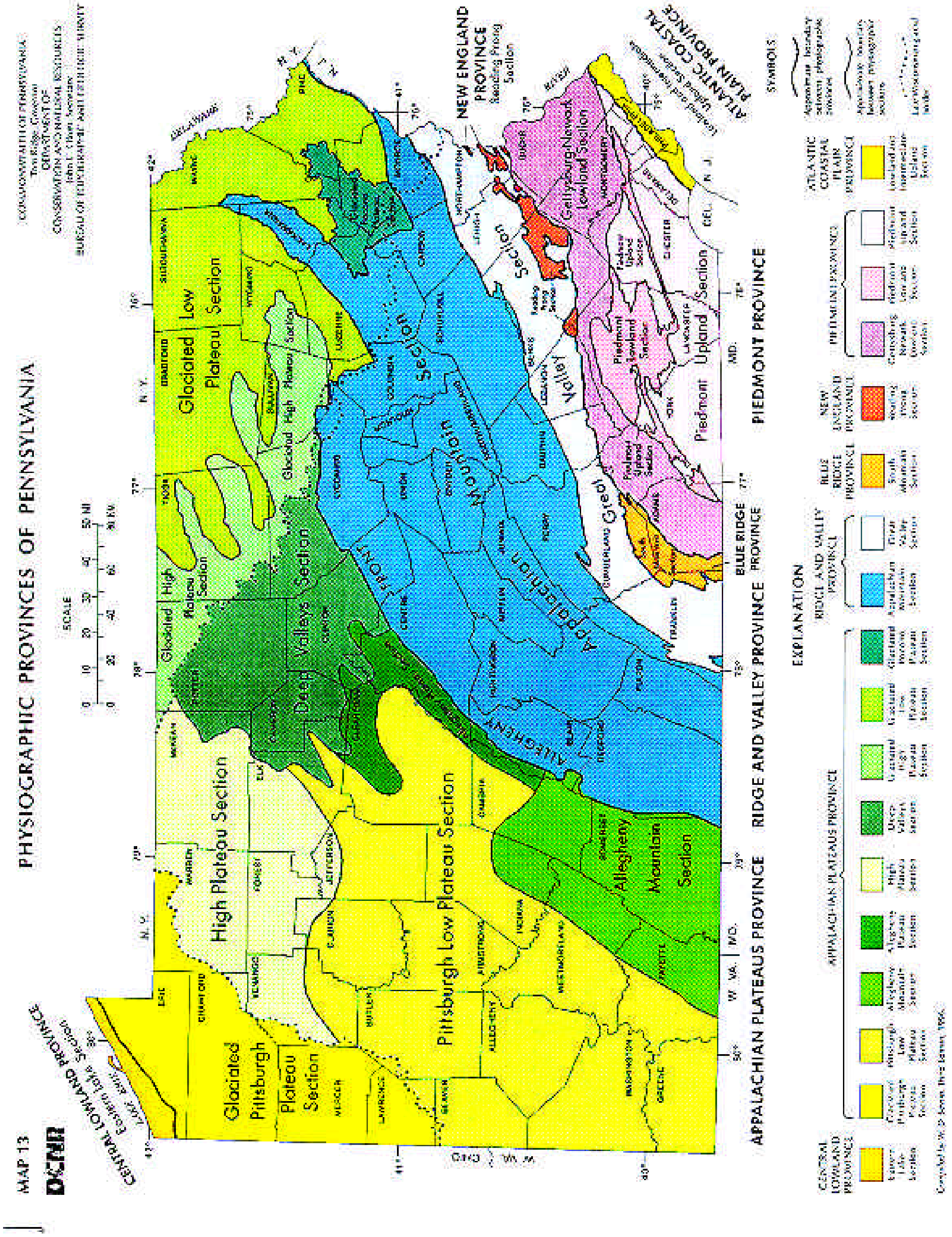

MAP 13
DCNR
PHYSIOGRAPHIC PROVINCES OF PENNSYLVANIA
SCALE
CENTRAL LOWLAND PROVINCE
Eastern Lake Section
Glaciated Pittsburgh Plateau Section
High Plateau Section
Pittsburgh Low Plateau Section
Deep Valleys Section
Glaciated High Plateau Section
Glaciated Low Plateau Section
Allegheny Mountain Section
ALLEGHENY FRONT
Appalachian Mountain Section
Great Valley Section
Gettysburg-Newark Lowland Section
NEW ENGLAND PROVINCE
Reading Prong Section
ATLANTIC COASTAL PLAIN PROVINCE
Piedmont Upland Section
Piedmont Lowland Section
APPALACHIAN PLATEAUS PROVINCE
RIDGE AND VALLEY PROVINCE
BLUE RIDGE PROVINCE
PIEDMONT PROVINCE
N. Y.
N. J.
MD.
W. VA.
OHIO
DEL.
EXPLANATION
SYMBOLS

Figure 2.11

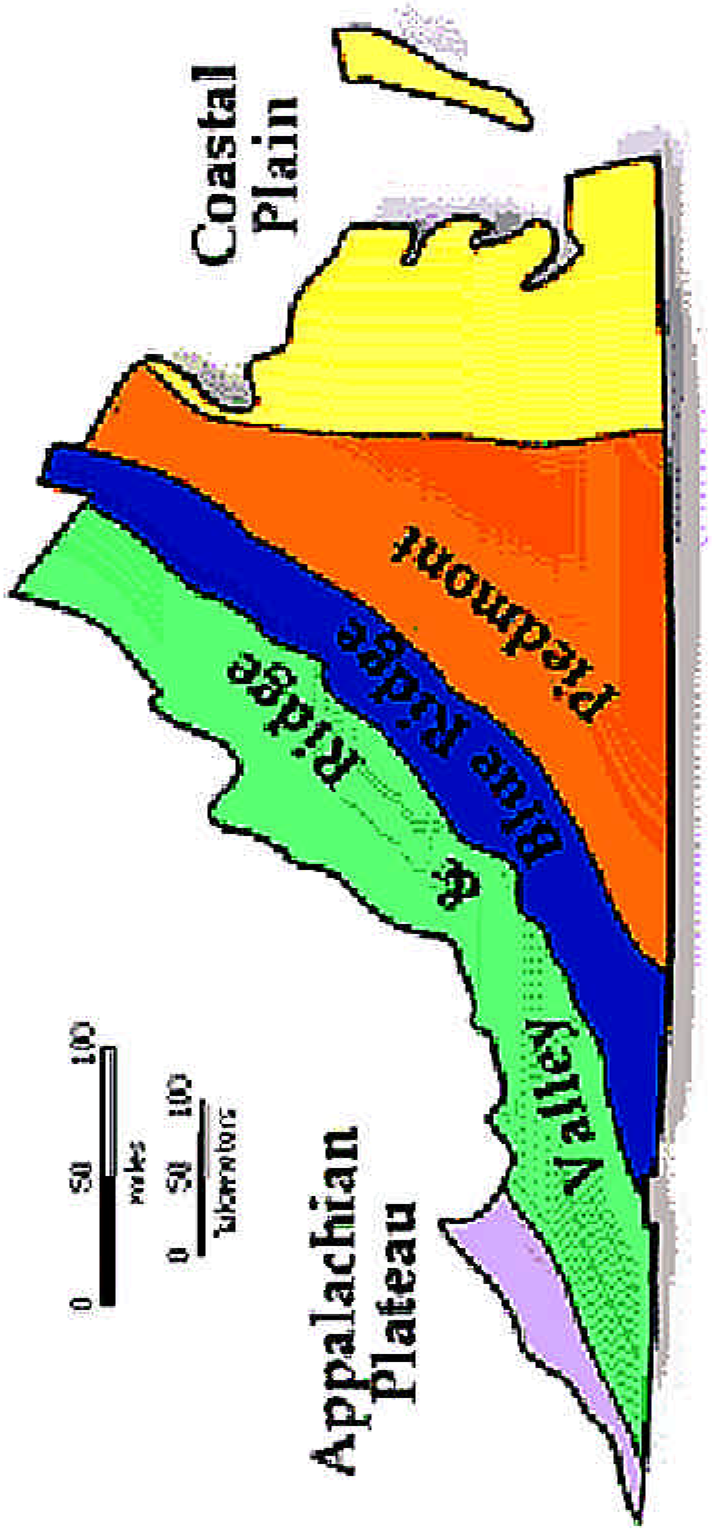


Figure 2.12 Physiographic Provinces of Virginia

sediment. The present coastline is quite dynamic, and is presently subject to radical alteration by storms and slow sea level rise.

Engineering soils in the Coastal Plain include residual soils, aeolian soils, alluvial soils, and beach and tidal soils. Glacial soils occur in northernmost PA and NJ.

The *Piedmont Province* underlies portions of NJ, PA, DE, MD, and VA (Figures 2.9 and 2.10). It bordered on the east by the Fall Line and on the west by the rugged topography of the Blue Ridge Province. The Piedmont Province is characterized by gently rolling topography that is developed on folded Precambrian and Early Paleozoic igneous and metamorphic rock and interior basins of relatively undeformed Early Mesozoic sedimentary and igneous rock (Triassic Lowlands).

A complex of metamorphic rocks, such as schist and gneiss or igneous rocks and gneiss underlies the Piedmont. Schist floored valleys tend to lie several hundred feet below adjacent gneiss cored hills. The hills trend northeast to southwest. Precambrian and Lower Cambrian quartzites, Cambrian and Ordovician carbonates, and Ordovician shales underlie much of the Piedmont. The shales and carbonates underlie valleys and the quartzites underlie low, northeast-southwest ridges.

The *Triassic Lowlands* are underlain by Triassic conglomerates, sandstones, and shales, with intrusions of Jurassic diabase. The tilted sandstones, lava flows, and diabase form low, parallel ridges and the interlayered shales form valleys. The conglomerates form high ridges that tower above the adjacent landscape.

The soils of the Piedmont Province are mainly residual, except for alluvial soils along the streams and rivers and extensive glacial soils in northern NJ, northwestern PA, and northeastern PA.

The *Blue Ridge* and *New England Uplands provinces* are both rugged areas underlain by metamorphosed Precambrian and Early Paleozoic igneous and sedimentary rock (Figures 2.2 and 2.10). The Blue Ridge Province underlies portions of VA, MD, and southern PA, the New England Uplands Province underlies northeastern PA and NJ.

The soils of the Blue Ridge are predominantly colluvium, with thin ribbons of alluvium along rivers. The soils of the New England Uplands are colluvium, limited alluvium, and thin glacial soils. The colluvium has accumulated at the base of the Blue Ridge and southern New England Uplands. They are unstable and susceptible to sudden mass movements caused by earthquakes, precipitation events, and construction. The lower slopes of the northern New England Uplands are mantled by thick glacial soils; many of these soils contain sources of gravel.

The *Ridge and Valley Province* underlies portions of eastern WV, VA, MD, PA, and NJ (Figure 2.10). The Ridge and Valley Province includes the Great Valley of VA, MD, and PA. It is underlain by highly folded and faulted Early to Middle Paleozoic sedimentary rock (Figure 2.2).

The Great Valley is developed over Ordovician shale, slate, and Cambrian and Ordovician carbonates. The shale and slate stand higher in elevation than the carbonates. Minor variations in lithology control the locations of low ridges in this province. Sandy beds form linear ridges in the shales, and cherty or silicified zones form ridges in the carbonates. The carbonate area contains many sinkholes, springs, caves, and disappearing streams because of solution by acidic rain water.

The province contains long, narrow, even-crested mountains underlain by tightly folded and faulted Silurian and Ordovician quartzites and sandstones in the south, and Mississipian and Pennsylvanian conglomerates and sandstones in the north. Cambrian and Ordovician carbonates, Silurian siltstones and limestones, and Devonian siltstones underlie the narrow, elongate valleys. Resistant beds, such as interbedded sandstones or cherty zones, form lower ridges in the valleys. The high cuesta of the Allegheny Front forms the western border of the province.

The northern portion of the Ridge and Valley has been glaciated, and is blanketed by glacial soils, especially lacustrine clay and silt and glacial till. The Great Valley contains abundant alluvium, and the ridges are mantled with residual soils. Colluvium occurs along the bases of slopes.

The *Appalachian Plateau Province* underlies portions of WV, VA, MD, and PA (Figure 2.10). The Appalachian Plateau Province includes the Cumberland Plateau in VA. It is underlain by relatively flat-lying Middle through Late Paleozoic sedimentary rocks (Figure 2.2). Most of the coal deposits of the region occur in this province, and strip mines are common. The province is deeply dissected by rivers and streams, and contains deep valleys with moderate to steep sideslopes and flat-bottomed valleys. The intervening uplands are gently rolling.

The northernmost portion of this province has been glaciated. A 25 to 100-foot mantle of glacial deposits cover the bedrock. The rivers in the glaciated section have been diverted to the southwest. Residual soils coat the uplands, colluvium mantles lower portions of the valley sides, and alluvium is found along the rivers.

The *Central Lowland Province* occupies a small portion of PA along the Lake Erie shoreline (Figure 2.10). It is developed on nearly flat-lying Devonian rocks, which are covered by 25 to 100 feet of glacial deposits (Figure 2.2). Beach and aeolian soils are developed along the Lake Erie shoreline

2.4 Controls on Aggregate Quality

2.4.1 Durability, Erosion Resistance, and Skid Resistance

The Mohs Hardness Scale is a measure of the relative hardness of minerals (and rocks) based on the ability of selected common minerals and objects to scratch each other. The hardness scale ranges from 1 to 10, with 10 the hardest, and is as follows:

Table 2.2 Moh's Scale of Hardness

Hardness	Mineral
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Your fingernail has a hardness of 2+ (it will scratch talc, serpentine, or gypsum, and be scratched by calcite), a copper penny of 3, a steel knife blade has a hardness of 5, glass of 5 ½, and a steel file of 6 ½. Thus, you can amuse yourself by scratching a window with a quartz crystal or a diamond ring. Your Significant Other might not be amused, however, if you try this experiment at home or in the car.

The Mohs Hardness Scale can be used to make general predictions on the relative resistance to erosion and the durability of common rocks in the region. The minerals comprising igneous rocks tend to have a narrow range of hardness, from 6 for feldspars, pyroxenes, and amphiboles to 7 for quartz. Secondary minerals, such as the micas, are significantly softer (hardness of 2 to 3). The igneous rocks tend to be erosion resistant, particularly if they have low iron and magnesium contents. The iron and magnesium rich minerals are somewhat less resistant to chemical erosion than quartz or iron-poor minerals. The igneous rocks usually hold up hills and mountains. They make durable aggregates in roads, but have low skid resistance because their minerals wear evenly due to the similar hardness. They contain variable amounts of micas. The mica group is composed of platy minerals that easily split apart, and can weaken igneous (and metamorphic) rocks if they are too plentiful.

Skid resistance tends to parallel hardness. There is not a simple relationship between hardness, erosion resistance, and skid resistance, however. The higher skid resistance corresponds to rocks that are composed of minerals of dissimilar hardness. The harder materials erode slower than the softer, and stick above the general road surface, forming irregularities that the tires can grip. Variable crystal size can impart skid resistance, as smaller crystals tend to erode faster than larger crystals

Sedimentary rocks range widely in relative hardness, resistance to erosion, and skid resistance. Most of the sand-size particles in sandstones are quartz, with lesser amounts of feldspars and rock fragments. Conglomerates and sandstones tend to be erosion-resistant, and hold up plateau and ridges. Rocks that are susceptible to chemical weathering, such as dolomite and limestone, and soft rocks, such as shale, underlie valleys. Unconsolidated material, such as gravel and sand, erode easily. Rocks with dissimilar matrix and grains, such as Calcareous Sandstone (calcite matrix and quartz grains, hardness of 3 and 7) or Graywacke Sandstone and Graywacke Siltstone (clay matrix and quartz or feldspar grains, hardness of 4 and 6 1/2), have high skid resistance.

Metamorphic rocks also vary widely in resistance to erosion, skid resistance, and hardness. Fine-grained rocks are usually rich in micas and chlorite (hardness from 2 to 3), while coarser rocks contain quartz and feldspars (hardness from 6 to 7). Gneiss and hornfels have similar composition, but the crystals in gneiss are distinctly banded or layered, while the quartz and feldspar crystals in hornfels are randomly oriented. Both rock types are resistant to erosion and hold up ridges. The micas and chlorite in schist and serpentine are easily eroded, resulting in valleys developing over these rocks. Marble is both soft (hardness of 3 to 4) and easily chemical weathered, so it usually underlies valleys.

CHAPTER 2
GEOLOGY STUDY QUESTIONS

1. __________________________ are naturally occurring elements or compounds with a definite structure and are the building blocks of both soils and rocks.

2. The ____________________________ describes the ways that rocks are formed and
changed by weathering and other natural processes.

3. What are the different types of rock listed on the Rock Cycle?

4. Silt is formed by ______________________________.

5. Aeolian, residual, alluvial and glacial are different types of _____________
______.

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CHAPTER 3

TERMINOLOGY AND DEFINITIONS

Absorbed Water: Water that fills the voids of a soil.

Adsorbed Water: Water that is held in a film on the surface of soil particles.

Aeolian Soil: The deposition of soil transported by wind.

Aggregate: A granular material of mineral composition such as sand, gravel, slag or crushed stone used for mixing in graduated amounts.

- **Coarse Aggregate** - Aggregate retained on the 4.75 mm (No. 4) sieve.
- **Coarse-Graded Aggregate** - One having a continuous grading in sizes of particles from coarse through fine with a predominance of coarse sizes.
- **Dense-Graded Aggregate** - An aggregate that has a particle size distribution such than when it is compacted, the resulting voids between the aggregate particles, expressed as a percentage of the total space occupied by the material, are relatively small.
- **Fine Aggregate** - That passing the 4.75 mm (No. 4) sieve.
- **Fine-Graded Aggregate** - One having continuous grading in sizes of particles form coarse through fine with a predominance of fine sizes.
- **Mineral Filler** - A finely divided mineral product of which at least 70 percent will pass a 0.075 mm (No. 200) sieve. Pulverized limestone is the most commonly manufactured filler, although other stone dust, hydrated lime, Portland cement, and certain natural deposits of finely divided mineral matter are also used.
- **Open-Graded Aggregate** - One containing little or no mineral filler in which the void spaces in the compacted aggregate are relatively large.
- **Well-Graded Aggregate -** Aggregate graded from the maximum size down to filler with the object of obtaining an asphalt mix with a controlled void content and high stability.

Air Dry:	When the material appears to be dry, but still has some absorbed moisture in its pore structure.
Alluvial Soil:	The deposition of soil transported by water.
Angular Aggregate:	Aggregate, the particles of which possess well-defined edges formed at the intersection of roughly planar faces.
Arid:	Dry.
Atterberg Limits:	Test designed by A. Atterberg. Used to identify the limits at which a soil passes from solid, semisolid, plastic, and liquid states of consistency. Atterberg Limits are the Plastic Limit, Liquid Limit and Shrinkage Limit. The Plastic Limit and Liquid Limit are used to determine the Plastic Index, and is one of the criteria for AASHTO and Unified Soil Classification Systems.
Background Count:	The naturally occurring radiation from lights, the sun and many other sources.
Basalt:	Igneous rock that has been ejected by volcanic activity to the surface of the earth's crust.
Base Course:	A layer of specified or selected material of planned thickness constructed on the subgrade or subbase for the purpose of serving one or more functions such as distributing load, providing drainage, minimizing frost action, etc.
Batholith:	Large (greater than 40 square miles), intrusive, igneous mass of crystallized granitic rock, which usually forms mountain cores.
Bell Jar:	Glass container used for vacuum testing, which is strong enough to resist collapsing.
Borrow:	Material that has been excavated from one area to be used as fill in another.
Boulder:	A rock fragment, usually rounded by weathering or abrasion, with an average dimension of 305 mm (12 in.) or more.

Brittle:	A material, such as shell, which will break easily during preparation, resulting in reduced particle size.
Calcium Carbonate:	A compound found in nature as calcite and aragonite and in combination in soil or rocks, such as limestone and caliche.
Capillary Action:	The attraction of water to a surface that causes it to rise against the force of gravity through surface tension.
Carbonation:	The dissolving of carbon dioxide in water to form carbonic acid, which reacts with calcium or other elements to form carbonates (e.g., limestone).
Chemical Weathering:	Deterioration of parent rock into soil through chemical changes (e.g., carbonation, leaching, and oxidation).
Clastic:	Material consisting of fragments of pre-existing rock.
Clay:	Fine-graded soil or the fine-grained portion of soil that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dried. An earth material with a particle size smaller than 0.002 mm.
Cobble (Cobblestone):	A rock fragment usually rounded or semi-rounded, with an average dimension between 75 and 305 mm (3 and 12 in.).
Cohesionless Soil:	A soil that when unconfined has little or no strength when air-dried and that has little or no cohesion when submerged.
Cohesive:	Tending to stick together through water surface tension and electrochemical charges.
Cohesive Soil:	A soil that when unconfined has considerable strength when air-dried and that has significant cohesion when submerged.
Colloids:	Earth material with very small particles, being anything smaller than 0.001 mm.
Colluvial Soil:	Rock detritus and soil accumulated at the foot of a slope.
Compaction:	The reduction of voids in a soil mass. It is the densification of a soil mass through an applied dynamic force such as that delivered by a falling rammer or compaction equipment (e.g. rollers)

Compaction Curve:	The curve showing the relationship between the dry unit weight (density) and the water content of a soil for a given compactive effort.
Compaction Test:	The process of determining the degree of densification.
Compactive Effort:	The force applied to achieve compaction of a soil mass.
Constant Mass:	The point at which a specimen no longer loses mass between two successive weighings.
Continental Drift:	The movement of continents around the earth through geologic time due to plate tectonics.
Crust:	The outer layer of the earth’s structure directly in contact with the atmosphere.
Dehydration:	Removal of moisture**.**
Degradation:	Breakdown of soil or rock material through mechanical or chemical means.
Density:	The mass of the soil or aggregate divided by the volume.
Deposition:	The process carried out by wind, ice, and water moving material from one location to another.
Detritus:	Loose material (e.g. rock fragments) that results directly from degradation.
Dry Density:	The density of a soil or aggregate corrected for moisture content.
Effective Diameter:	D10, particle diameter corresponding to 10% fine on the grain size curve.
Entrapped Air:	Air that occupies some of the voids within the soil.
Erosion:	Wearing away.
Extrusion:	Molten material (magma) from deep within the earth, which has been ejected onto the surface through volcanic activity.
Fast Neutron	

Source:	Each atom has a nucleus comprised of varying numbers of Protons and Neutrons. When a high-energy electron strikes a nuclei, one or more Protons or Neutrons are released. These Neutrons are used to measure moisture content by a nuclear gauge.
Fines:	That material which passes a 0.075 mm (No. 200) sieve.
Fraction:	A term applied to a portion of a sample usually resulting from a sieving process.
Friable:	A non-cohesive material that crumbles readily.
Gamma Detector:	An electronic devise that converts electronic pulses into a numerical count. The electronic pulse is caused by high energy photons passing through a special gas enclosed in a tube.
Gamma Source:	A radioactive material that emits high energy photon radiation. The radiation is invisible and capable of passing through many millimeters of wood, soil, or other material.
Geology:	The science that deals with the history of the earth, especially the study of rock forms.
Geotechnical:	Having to do with the properties of soil and rock materials.
Glacial:	Referring to the parts of geologic time from Precambrian onward, when a much larger portion of the earth was covered with sheets of ice.
Glacial soils:	Soils transported and redeposited by glacial ice.
Gradation:	The particle size distribution of soil and aggregates determined by using sieves with square openings.
Granite:	A light colored predominately siliceous rock normally found in igneous intrusions.
Granular:	Grainy, coarse, rough texture.
Gypsum:	A widely distributed mineral consisting of calcium sulfate that forms on the stony soil of arid regions as a result of evaporation.
Heterogeneous:	Consisting of dissimilar components; non-uniform blend.

Homogeneous:	Of uniform structure and composition throughout.
Horizon Soil:	A layer of soil produced by soil forming processes, lying approximately parallel to the surface, having distinct characteristics.
Humus:	A brown or black complex variable material resulting from partial decomposition of plant or animal matter and forming the more stable organic portion of a soil.
Hydration:	A reaction of other chemicals with water.
Hydrometer:	A testing device used to measure the specific gravity of a liquid in which particles are either suspended or dissolved.
Hygroscopic Moisture:	Moisture still remaining in soil after it has been air-dried.
Igneous:	Resulting from the intrusion or extrusion of magma or the activity of volcanoes: rocks formed from molten magma.
In situ:	In its natural or original position.
Intrusion:	Molten crustal material that is injected into other rock through fissures and bedding planes.
Leach:	To dissolve and remove soluble compounds from a substance by the action of water percolating through soils.
Liquid Limit:	An Atterberg Limit. It is the moisture content corresponding to an arbitrary limit at which a soil moves from a liquid state to a plastic state of consistency.
Loam:	A mixture of sand, silt, or clay, or a combination of any of these, with organic matter.
Lot:	A given quantity of material that needs to be sampled.
Magma:	Molten rock.
Mantle:	The layer of the earth’s structure lying immediately below the earth’s crust.
Mass Wasting:	The movement of rock debris downslope under the direct influence of gravity.

Maximum Dry Density:	The dry unit mass of a soil when it is compacted with standard compactive effort and at optimum moisture content.
Mesh:	The square opening of a sieve.
Meniscus:	The curved concave upper surface of a column of liquid in a tube. This concave surface is caused by surface tension.
Metamorphic:	The types of rocks produced by a pronounced change of pressure, heat, and water, resulting in a more compact and more highly crystalline condition.
Mica:	A mineral comprised of very thin friable plates.
Moisture Content:	The ratio, expressed as a percentage, of the mass of the water in a given soil mass to the mass of the solid particles. The mass of the soil remaining after oven drying is used as the mass of the solid particles.
Moisture-Density Curve:	A smooth line connecting the points obtained from this test procedure when plotted on a graph with moisture on the x-axis and density on the y-axis.
Moisture-Density Relationships:	The interrelationship between density and changing moisture contents in a soil.
Nomenclature:	A system of terms used in a particular discipline.
Nominal Maximum Size:	The largest sieve size listed in the applicable specification upon which any material may be retained.
Non-plastic:	Not capable of being molded into a sustainable shape.
Non-Representative:	A sample that does not exhibit the same characteristics as the in-situ material from which it was taken.
Optimum Moisture Content:	The percent of moisture at which a soil or aggregate can reach its maximum density with standard compactive effort.

Organic:	Plant and animal residue in the soil in various stages of decomposition.
Organic Clay:	Clay with sufficient organic content to influence the soil property.
Organic Silt:	Silt with sufficient organic content to influence the soil property.
Oxidation:	The process of chemically changing a compound through exposure to oxygen.
Parent Rock:	The original rock formation: either the original rock mass or the Clastic material in which soil or aggregate forms.
Particle Size:	A soil or aggregate is composed of many fragments of varying dimensions. When sorted by a sieving process, the soil or aggregate can be defined by sizes of the fragments related to the sieve size.
Passing:	Material fragments that fall through a sieve during sieving operations.
Peat:	A soil comprised primarily of vegetable tissue in various stages of decomposition, usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous (completely decomposed).
Percent Compaction:	The ratio, expressed as a percentage, of the dry density of a soil or aggregate to its maximum dry density.
Permeability:	The property of a soil or aggregate that enables water to move through the material.
Phreatic Surface:	Ground water elevation.
Physical Weathering:	Degradation caused by agents such as wind, water, and ice.
Plastic:	Capable of being molded into a sustainable shape.
Plasticity Index:	A measure of the cohesive properties of a soil. The numerical difference between the Liquid Limit and the Plastic Limit.

Plastic Limit:	An Atterberg Limit. It is the moisture content corresponding to an arbitrary limit at which a soil moves from a plastic state to a semisolid state of consistency.
Plate Tectonics:	The movement of the earth's crust, divided into large pieces, which float on a viscous material in the mantle.
Protocol:	Standardized methods and sequences of testing developed to ensure reliable results.
Pulverize:	The process to reduce soil or aggregate mass into individual particles.
Pycnometer:	A small hand blown glass bottle of known volume, usually 100 ml or less, with a vent in its stopper to allow excess water to leave the bottle when the stopper is inserted.
Quality Assurance:	The independent monitoring, testing and documenting process verifying that materials meet appropriate specifications.
Quality Control:	The process of monitoring the handling, testing and documentation used to maintain conformance to appropriate material specifications.
Radioisotope:	Radioactive isotope of an element, such as Cesium 137 and Americium 241.
Random:	An equal probability that any one of a group will be selected.
Random Sampling:	Procedure for obtaining non-biased representative samples.
Relative Compaction:	The ratio, expressed as a percentage, of the dry density of a soil or aggregate to its maximum dry density.
Relief:	The relative elevations of the land surface; topography.
Representative:	A sample that exhibits the same characteristics as the in situ material from which it was taken.
Residual Soil:	Soil formed in place by weathering of parent rock.

Retained:	Material fragments that do not fall through a sieve during sieving operations.
Riffle Splitter:	A device containing chutes on each side that effectively divide a sample into two equal portions.
Sand:	Material that will pass a 4.75 mm (No. 4) sieve and be retained on a 0.075 mm (No. 200) sieve with the following subdivisions: • **Coarse** - Passes a 4.75 mm (No.4) and is retained on a 2.00 mm (No.10) sieve. • **Medium** – Passes a 2.00 mm (No.10) sieve and is retained on a 0.425 mm (No.40) sieve. • **Fine**- Passes a 0.425 mm (No. 40) sieve and is retained on a 0.075 mm (No. 200) sieve.
Saturated Surface Dry (SSD):	An aggregate is considered to be in a saturated surface dry condition when there is no free moisture present, but the aggregate is in a nonabsorbent state. In other words, the aggregate has all the moisture it can absorb and the surface of the aggregate is dry.
Scaler:	Part of a nuclear gauge that converts electronic pulses into numerical counts and displays the results.
Sedimentary Rock:	Formed from materials transported by moving water, air, ice, or chemically precipitated.
Segregation	The tendency of any graded material to separate into individual particle size groupings.
Shear Strength:	Resistance of a material to forces acting along a defined plane.
Shrinkage Limit:	An Atterberg Limit. It is the point at which a soil changes from a solid to a semisolid state.
Sieve:	A frame enclosing a wire, cloth, or perforated plate used to separate materials by particle size.

Silt:	Soil passing a 0.075 mm (No. 200) sieve that is non-plastic or very slightly plastic and that exhibits little or no strength when air-dried.
Soil:	Sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter.
Soil Mechanics:	The study of engineering properties and behavior of soils.
Specific Gravity:	The ratio of a mass of a given volume of material, to the mass of an equal volume of water.
Statistical Analysis:	The systematic collection, analysis and interpretation of numerical data.
Subbase:	A layer used in a pavement system between the subgrade and base coarse.
Subgrade:	The soil prepared and compacted to support a structure or a pavement system.
Sublots:	A portion of a lot that represents a certain quantity of the material from a lot.
Surface Tension:	The lifting of water against gravity in a narrow (capillary) tube.
Talus:	A slope formed by an accumulation of rock debris; rock debris at the base of a cliff.
Thermal Neutron Detector:	An electronic device that counts Neutrons as they pass through a special gas.
Topography:	The configuration of a surface including its relief and the position of its natural and man-made features.
Topsoil:	Surface soil, usually containing organic matter.
Traction:	The pushing, dragging, or rolling of particles too large to be lifted by the transporting force.
Unit Weight:	A ratio of weight to volume

Volumetric Flask:	A large glass bottle of known volume, with an etched calibration line on its stem.
Weathering:	The action of the elements in altering the texture, composition or form of exposed objects; the physical degradation and chemical decomposition of earth materials.
Zero Air Voids Curve:	The curve showing the zero air voids unit weight as a function of water content. Also known as the Saturation Curve.

CHAPTER 4

AGGREGATES EXTRACTION SYSTEMS

4.1 Introduction

The primary function of this chapter is to describe the extraction system in terms of how its various components interrelate and how the system as a whole interacts with the remainder of the aggregate production operation. The term ***extraction*** includes the planning and design for removal of rock, sand, and gravel from the ground. The term extraction also includes the actual removal or mining process, and then reclamation of the land after mining is complete. A simplified description of the extraction process consists of the removal of rock, sand or gravel from its natural state and delivery of this material to the primary crushing or sizing facility in the optimum physical dimensions for continued processing.

4.2 Quarry Operations

4.2.1 Planning

Before any extraction system can be implemented, significant short and long range planning must be performed. This planning may range from a simple statement of, “I think the quarry should be about here,” to a complex, computer-aided analysis of numerous alternatives. The final result is a design, optimizing all pertinent factors influencing the economics of the proposed project, including post-mining land use or reclamation. Computer-aided planning and design methods can aid in application of data collected for purposes of mine planning, but do not replace the necessity for adequate exploration and analysis of geological data.

When a pit or quarry design is complete and the necessary permits have been obtained, the operator begins the detailed equipment selection and procurement process, as specified in the "*long and short term plans*." The *long-term plan* covers approximately five or more years. The *short-term* plan normally addresses the specific decisions to be made within a one-year time frame.

4.2.2 Surface Mining

In the aggregate industry, a wide variety of methods are used to extract the raw material from its natural state. These methods are broadly categorized into those used in the production of: sand and gravel; and crushed stone. This categorization is due to the geological environment in which the two resources are found. Crushed stone is produced from solid rock formations and must normally be drilled and blasted prior to extraction. The area in which the drilling and blasting operations take place is referred to as a ***quarry***. The broken rock generated from the blast is referred to as *muck* or *shot rock.*

Sand and gravel products are extracted from unconsolidated deposits, which do not require drilling and blasting. These deposits occur at or immediately beneath ground level or on the bottoms of streams, lakes or oceans. When sand and gravel products are extracted from deposits at or near ground level, the mining area is called a ***pit****.* A quarry is also sometimes referred to as a pit. Other types of sand and gravel extraction areas are not given a name such as pit or quarry, but are referred to by the type of deposit, such as a stream deposit, lake deposit, or marine deposit.

4.2.3 Quarry Development

Once the overall quarry design is complete, the development sequence is formulated. This sequence normally includes stripping a sufficient amount of *overburden* to access the deposit and establish a working face from which the production sequence can begin. In the event the deposit outcrops or protrudes above the surrounding surface, the stripping of overburden for the most part is not required. However, the establishment of a *production face*, which is an area of exposed rock where production blasting can take place, remains the essential first element.

4.2.4 Stripping Methods

The method used for overburden stripping is determined by the type and thickness of material to be removed. Overburden ranges from loose soil to solid rock or combinations of the two. Soil and partially weathered rock can be removed by pushing it into piles using a bulldozer and removing it with conventional loaders and trucks. Harder or more consolidated material requires drilling and blasting. Very often the surface topography of the deposit is irregular, causing the removal of the overburden at the immediate contact with the deposit to be very costly and difficult. Whatever method is chosen, care should be taken to separate the organic topsoil from the remainder of the overburden.

4.2.4.1 Stripping Sequence

The initial area to be stripped is usually minimized to keep the pre-production development cost low and allow production to begin quickly. After production starts, stripping continues as a normal part of the production sequence. Stripping is scheduled at a convenient time to minimize interference with peak production periods.

4.2.4.2 Haul Road Development

When pre-production stripping is complete, development continues with the excavation of the primary haul road down into the deposit or up onto the outcrop. The haul road provides access to the production face, which is where the extraction sequence begins. The location of the primary haul road is based on the orientation of the deposit in relation to the processing facility, and the optimum location in the deposit to begin production (considering overburden thickness and quality of the material). Additional geologic factors are the bench or the face height selected as optimum for production blasting.

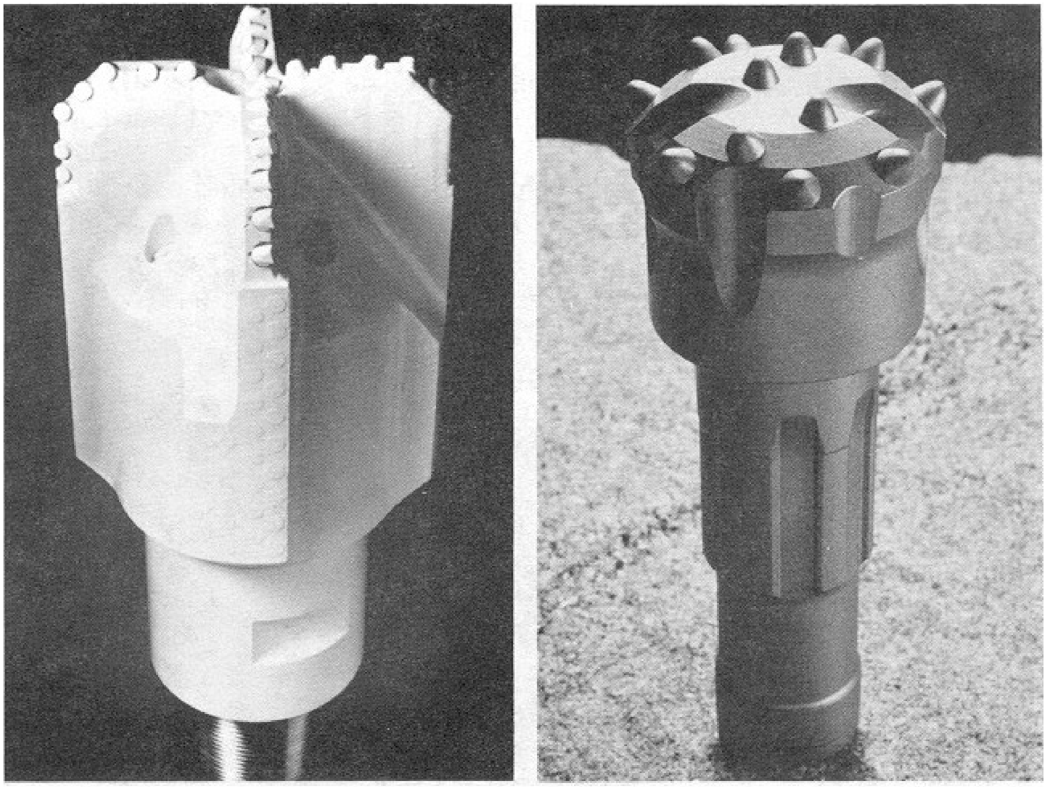
The haul road logically follows the shortest route from the processing plant to the point where production begins. The haul road should be located so that it should not have to be moved later as the pit or quarry expands.

4.2.5 Drilling and Blasting

A wide variety of drills and explosives are used in the surface quarrying industry because of the diversity of rock types and the formations mined for aggregates. Factors affecting the type of drill used include deposit geology and thickness, rock hardness, chemical composition, climatic conditions, and geographical/environmental restrictions. The type of drill bit used varies dramatically as the different areas within the same deposit are mined. The bit configuration and composition are optimized to match prevailing geological conditions.

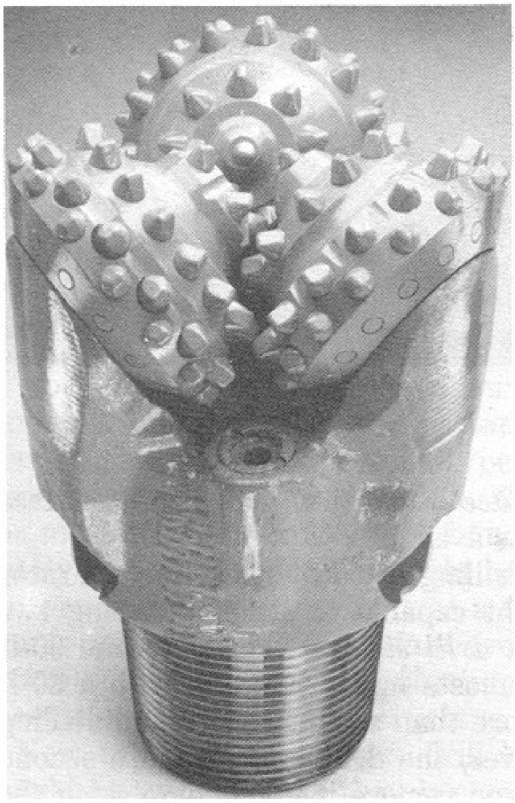
4.2.5.1 Type of Drills

Rock hardness and composition determine the basic type of drill used. In softer type rocks such as soft limestone, a rotary drill is commonly used (Fig. 4.1 a). When the rock is highly abrasive, a drill bit containing tungsten carbide inserts is required (Fig. 4.1 b). When in medium hard formations, a rotary drill using a *tri-cone* bit is used (Fig. 4.1 c). If very hard rock is mined, a *down the hole* or *in the hole,* hammer drill is normally used
(Fig 4.2).



(a) DTH Drill Bit

(b) Rotary Drill Bit



(c) Drag Drill Bit

Figure 4-1 Common quarry blast hole drill bits.

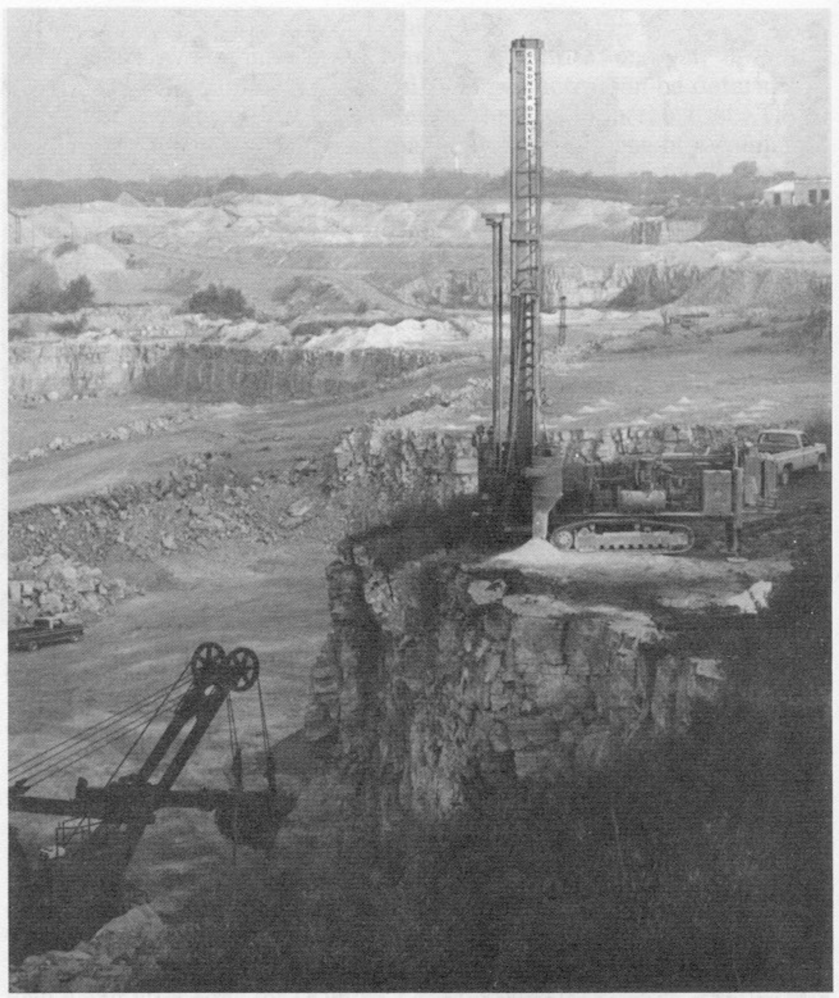


Fig 4.2 Down The Hole Hammer Drill.

4.2.5.2 Blasting

The goal is to achieve the desired level of rock fragmentation using the least amount of explosives while minimizing vibration. The blast hole drill pattern can be held constant for several blasts using different types of explosives. The rock fragmentation results and vibration levels are monitored until the most efficient explosive is found for the existing condition. The important concept to remember is that fragmentation of rock by primary blasting is more cost effective than fragmentation by mechanical crushing or secondary breaking. The aggregate industry includes plants that vary in production capacity from 100,000 tons to 10 million tons or more per year. The typical aggregate operation normally produces approximately 450,000 tons each year.

4.2.6 Equipment

Figures 4.3 through 4.6 show typical equipment used in quarry operations

Fig 4.3 Front end loader loading off road vehicle from muck pile.

Fig. 4.4 Off road haul truck

Fig. 4.5 Front end loader.

Fig. 4.6 Hydraulic power shovel.

4.2.7 Secondary Breaking

Secondary breaking is the reduction in size of rock in the quarry following primary blasting. Secondary breakage is required when portions of the shot rock produced from primary production blasting are too large for loading, hauling or processing. These pieces of rock, commonly referred to as over-size, setbacks or drop ball rock, are undesirable when additional cost must be incurred to reduce them to a manageable size.

Secondary breaking by the impact from dropping a heavy weight on the rock is a commonly used method in very hard deposits. A drop ball or drop cross is used for this purpose (Fig. 4.7). This is similar in concept to a wrecking ball employed in building demolition.

In secondary breaking by blasting, small holes 1 to 2 inches in diameter are drilled in the oversized rock and charged with small quantities of high strength explosives. The desired result from secondary blasting is the reduction of the rock to a manageable size for loading and hauling with a minimum amount of additional drilling and blasting. Due to its high cost, secondary blasting is normally employed as a last resort.

Figures 4.8 and 4.9 show additional impact equipment that may also be used in secondary breaking operations.

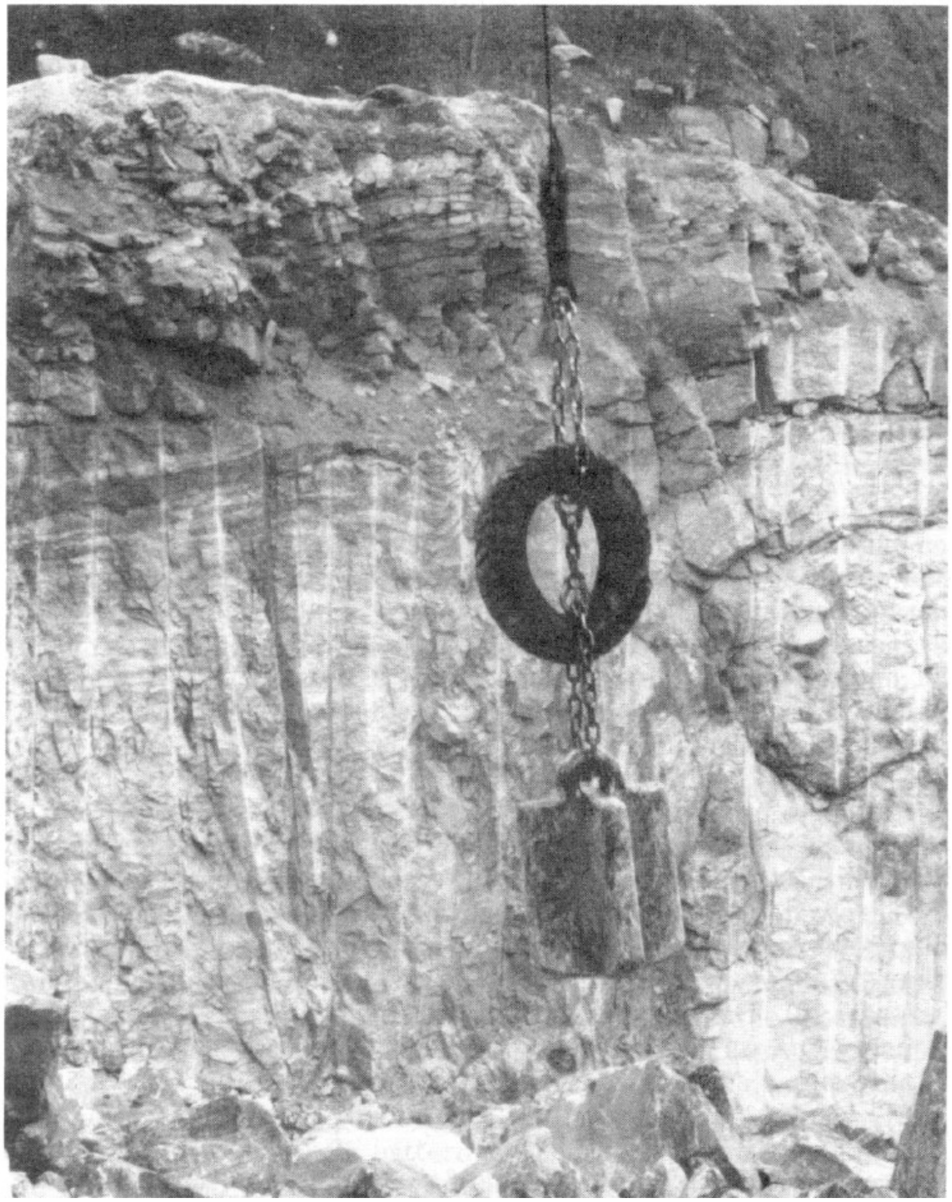


Fig. 4.7 Drop cross (drop ball).

Fig 4.8 Backhoe mounted hydraulic impact hammer.

Fig 4.9 Concentrated impact device.

4.2.8 Sand and Gravel Extraction

In contrast to the solid deposits of rock which are sources of raw material for the crushed stone industry, sand and gravel deposits are in a loose state. These loose deposits are mined without the necessity of drilling and blasting. Many of the types of equipment used in quarrying, such as front end loaders, power shovels, and haul trucks are also employed in extracting sand and gravel from either dry deposits or those which can be dewatered. In dry deposits, the extraction process is very similar to quarrying. When the sand and gravel deposit is consolidated to the point where digging with a front-end loader or power shovel is too difficult, a bulldozer equipped with a ripper is used to loosen the material. A ripper consists of a large tooth (or a series of teeth) which is attached to the rear of the bulldozer and pulled through the material as the bulldozer moves forward.

Wet sand and gravel deposits include those that occur beneath bodies of water such as rivers, estuaries, lakes and oceans. Since these deposits cannot be dewatered, materials must be removed with specialized equipment such as dredges, draglines and floating cranes. Dredging equipment is typically mounted on floating platforms that move freely above the underwater deposits. Removal of the sand and gravel is accomplished either with large suction pumps, which pull the material to the platform level, or by one or more bucket excavators, which carry the material up to the same level. At locations where dredging is performed near shorelines, it is not uncommon to utilize pumps and pipelines to transport material to on shore storage locations.

A floating crane uses a grab type bucket suspended on a cable from a boom to raise the sand and gravel from the deposit. A dragline is a land-based crane, which casts its bucket into the water above the area to be mined. The bucket is allowed to sink to the bottom and is then dragged back to the crane. As the bucket is dragged along the deposit, it becomes filled with material. The bucket is then raised out of the water and dumped at a designated area.

4.3 Underground Mining

Underground mining is normally more expensive than surface mining and is not as common. As the value of the deposit becomes greater or as the ratio of depth of overburden to the thickness of the deposit becomes greater, underground mining becomes more economically feasible.

To be suitable for underground mining, the material overlying the deposit must have the ability to support its own weight when undercut by development of the area to be mined. If the overburden is sufficiently competent to sustain undercutting, it is probably too thick and/or too hard to allow economical stripping for quarrying methods.

4.3.1 Basic Considerations

Many unique factors exist when considering development of an underground quarry. The most important is probably the stability of the ground overlaying the deposit to be mined. Studies must be conducted to determine both the type of development sequence and mining method to be used. From examination of the geologic structure and determination of the rock's strength, rock mechanics is used as an aid in evaluating whether the ground is sufficiently competent to remain open without artificial ground support.

4.3.2 Access

Once the decision is made to use the underground mining method, the means must be determined for accessing the deposit. In the majority of underground quarries, the bedding of the deposit is nearly horizontal or lies at a shallow dip angle.

If the deposit is exposed at the surface, a tunnel excavated horizontally into the deposit provides access. If the deposit lies at some depth below the surface, access can be achieved by sinking a shaft to the deposit. This may require mechanical hoisting of extracted material. Use of a ramp excavated from the surface to the deposit is another possibility. If a ramp is used, off road trucks or conveyors can be employed to haul the material to the surface.

4.3.3 Room and Pillar Mining

Some form of *room and pillar mining is* employed for all or part of most underground quarries. The basic sequence in room and pillar mining consists of excavating several wide, straight, parallel openings with regularly spaced, perpendicular interconnections. The unmined areas between openings form vertical columns of rock called pillars that are left in place to provide support for the overlying material. The required minimum pillar dimensions and openings are determined by using principles of rock mechanics. A single lift quarry operation consists of mining at one elevation. In a multiple-lift quarry, which is performed in thick deposits, the top bench is usually excavated for a short distance, as illustrated in Figure 4.10. Subsequent benches are then started at lower levels and the sequence continues in this fashion. Each of the upper benches is kept far enough ahead of the lower benches to provide adequate working space on each lift. The rock excavated to form the openings between pillars becomes the quarry's production. The dimensions and spacing of the pillars are determined by the amount of support required for the overlying material and the strength of the rock, which composes the pillars. The pillar sizes vary as required. They are normally about 8 ft in length and width and spaced at intervals of 25 to 35 ft from center to center in a checkerboard pattern. Other dimensions might be required to satisfy particular structural or geological conditions. This method of mining requires that 20 to 50% of the rock be left in place.

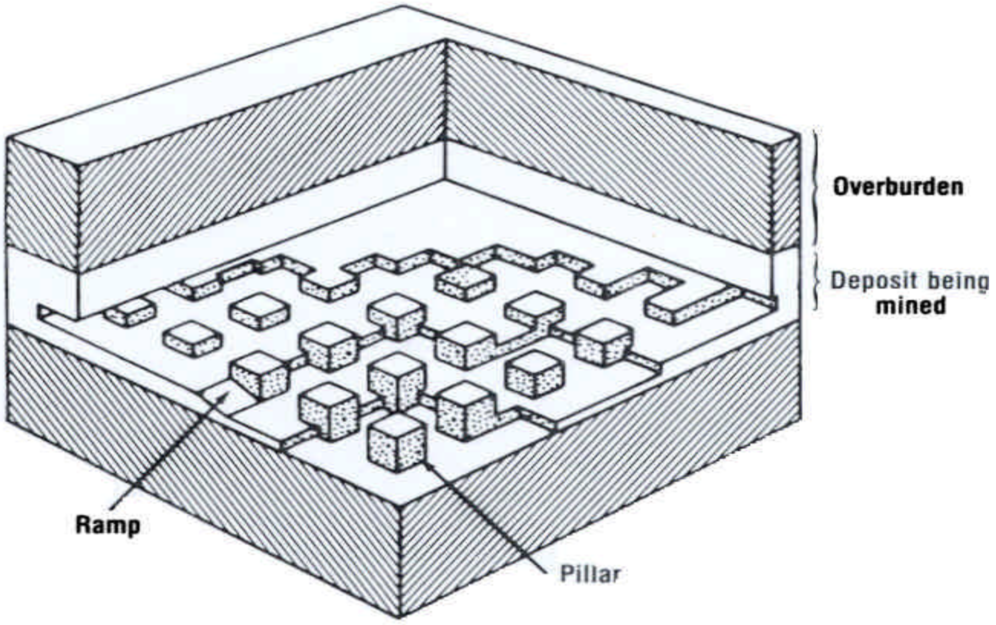


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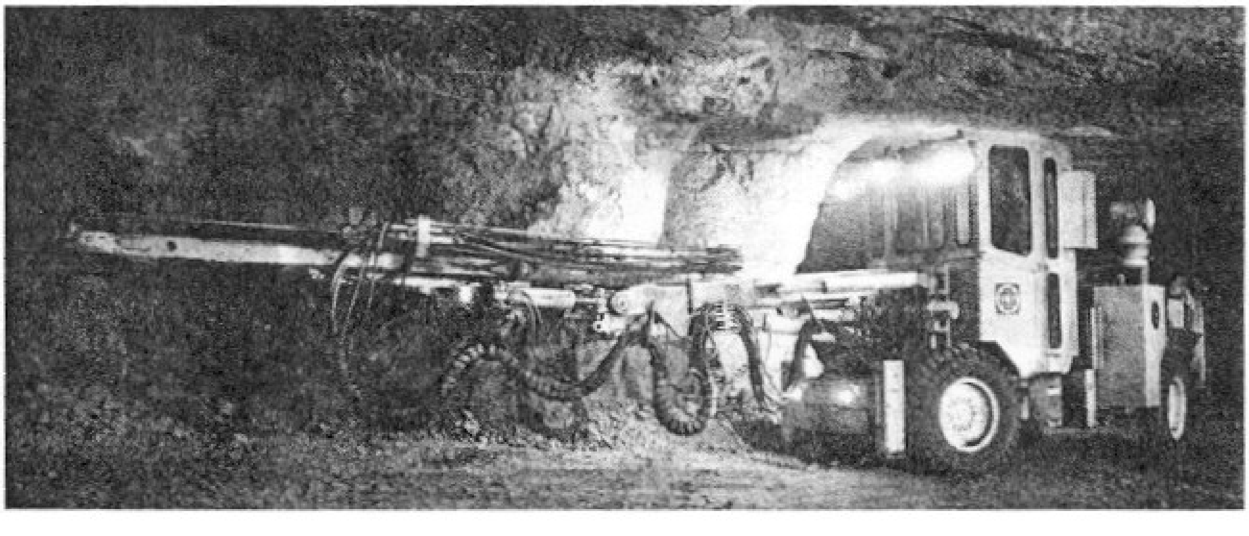
Fig 4.10 Room and pillar mining sequence.

4.3.4 Drilling and blasting:

The type of extraction method used in underground quarries determines the method of drilling and blasting as well as the required equipment. In the majority of underground quarries, a conventional room and pillar approach is employed as described in the previous section. If the deposit is thin (up to 25 ft), it is normally drilled horizontally from the floor using a standard *drill jumbo* (Figs.4.11 & 4.11a.). In a thin deposit, extraction is accomplished in one pass, which is referred to as a lift. If the deposit is thick (greater than 25 ft), the initial pass is drilled with a jumbo, and bench drilling, similar to surface mining operations, is used to extract subsequent layers as illustrated in Fig.4.12.

The procedure for choosing drilling equipment and blasting agents is similar to that described for surface quarrying. When very thick seams are mined in underground quarries, surface-drilling equipment can be used with minor modifications to accommodate restricted opening sizes. The amount of *overbreak,* which is the fracturing of rock beyond the desired area, must be minimized in underground quarries, since fracturing decreases the ability of the pillars to support the overlying material.



(Courtesy of Gardner–Denver/Cooper Ind., Inc.)

Fig. 4.11 Drill jumbo.

Fig. 4.11a Drill jumbo.

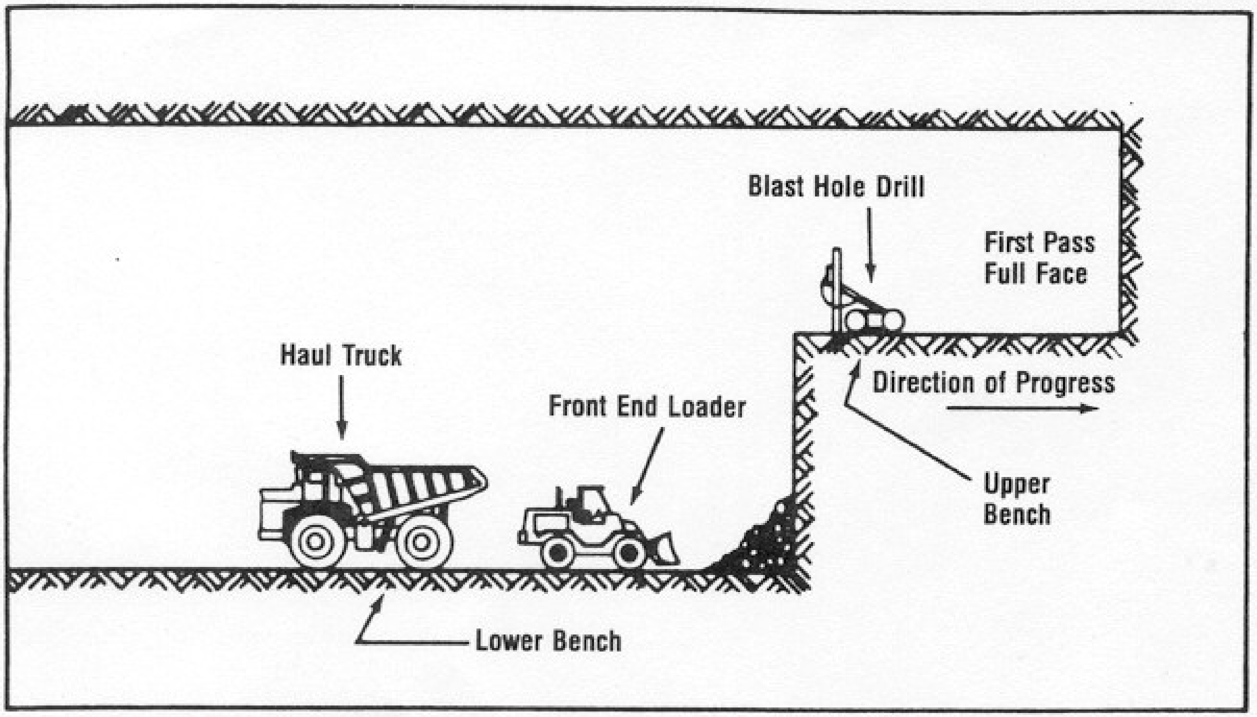


Fig 4.12 Underground bench mining (cross section)

CHAPTER 5

QUALITY CONTROL/ QUALITY ASSURANCE

5.1 Definition

Quality Control (QC) is the process of controlling the quality of the aggregate. This process includes plant design, processing techniques, materials handling, testing, documentation, stockpiling, and loadout. *Quality Assurance (QA)* is the independent monitoring, testing and documentation process to assure that the products shipped meet appropriate aggregate specifications. The scope of QC and QA in this section is limited to the processing plant. The gradations, cleanliness, and particle shape of the products are controlled in the processing plant. Segregation and degradation of the products are factors to consider in the stockpiling and handling of materials prior to shipping.

Sampling and testing the finished product stockpiles and the loadout station are necessary to meet state and other agencies' QA requirements and to protect the producer. Many companies have implemented a computerized statistical analysis program to monitor and document their QC program.

5.2 In-Plant Testing (Quality Control)

The reason for in-plant testing is to monitor and control the variables in the processing plant. Production surges within the crushers and screens can result in wide variations of finished product gradations and must be minimized. Only plants designed with adequate surge piles and surge bins can maintain conditions to achieve optimum production output and desired quality for the various products required.

5.2.1 Gradation Variation

In-plant testing provides information for QC and productivity. A variation in gradations of the finished product is a result of a plant operating at less than optimum capacity. In many plants, the last crushing and screening stages are loaded while the crushers and screens upstream are not loaded. Balancing the loading on all the crushers and screens in the circuit to achieve optimum production rates is a major factor in QC and contributes to the goal of the lowest possible operating cost.

A partial listing of plant checks include the following:

- Setting of crusher(s)
- Power draw on crusher(s)
- Gradation of feed to crusher(s)
- Gradation of product from crusher(s)
- Throughput rate in tons per hour of crusher(s)
- Production rate in tons per hour through the plant
- Gradations of the products from the screens
- Operating speed of the crusher(s) and screens
- Amplitude and direction of the operation of the screens.

5.2.2 Marginal Materials

Special attention should be given to in-plant testing to address problems associated with processing marginal deposits, such as one resulting in soft particles or a deposit producing undesirable particle shapes (i.e., flat and elongated particles).

Variations in the quality of the products being produced are minimized once the plant is operating at the optimum production rate. A continuous feed must exist and the proper close-side crusher settings be maintained for the desired product mix. Variations in the aggregate product can result from segregation or degradation in the stockpile or in the loadout bins.

5.3 Segregation

Segregation is defined as the tendency of a graded aggregate to separate into individual particle size groupings. Segregation is caused by the methods used to mix, transport, handle or store the aggregate under conditions favoring non-random distribution of the aggregate sizes.

5.3.1 Occurrence of Segregation

Segregation starts with the blasting process in the quarry as a result of blasting energy and size distribution of the shot rock in the formation of the muck pile. A wide variation of gradation exists in the quarry run material to be dumped in the primary crusher.

Cone Stockpile: Many aggregate plants stockpile by dumping from a truck and pushing aggregate piles with track-type dozers, rubber tire dozers, or front-end loaders. The trend in aggregate plants today is to stockpile with conveyors to minimize the cost of handling aggregate. Tests clearly show that a single cone stockpile results in the highest variation of gradation due to segregation.

Segregation occurs with movement, vibration and possibly wind. For example, when transporting material on the primary conveyor belt, the finer material has a tendency to migrate downward to the belt surface. Figure 5-1 shows that the primary conveyor trajectory generates a segregating effect as the coarser particles are thrust farther away from the head pulley, while the finer particles drop out closer to the head pulley. As the height of the cone of the surge pile increases, the coarser particles tend to roll and slide to the perimeter of the pile. Segregation becomes more pronounced as the height of the stockpile approaches its peak. Degradation of aggregate particles occurs when the aggregate falls a great distance from the conveyor to the stockpile. This can be minimized by keeping the stockpile at a high level or by the use of boom stackers that can be adjusted vertically to control the height of fall.

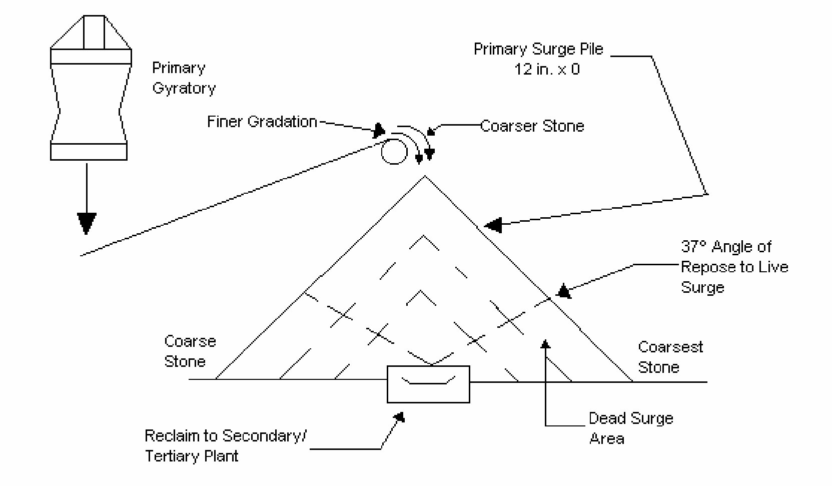


Figure 5-1 Ascending Surge Pile

Material Removal: In Figures 5-2 through 5-5, the primary plant is not operating, but removal of material from the pile continues. The reclaimed feed to the secondary plant goes from a relatively fine feed to the coarsest feed.

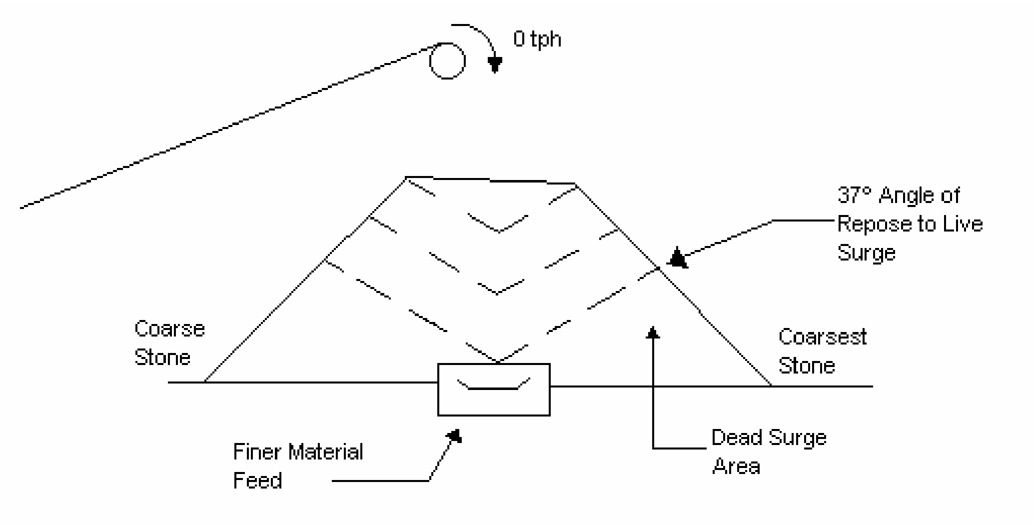


Figure 5-2 Ascending Surge Pile

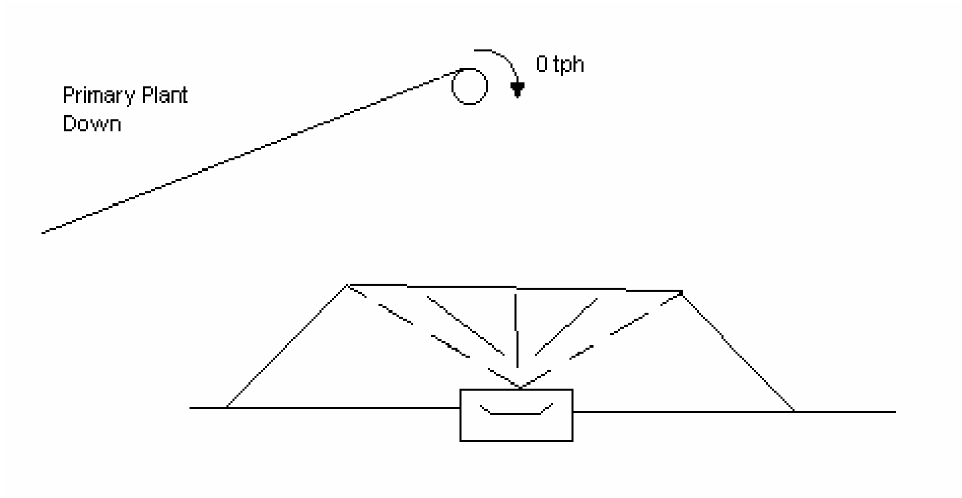


Figure 5-3 Feed from Live Surge

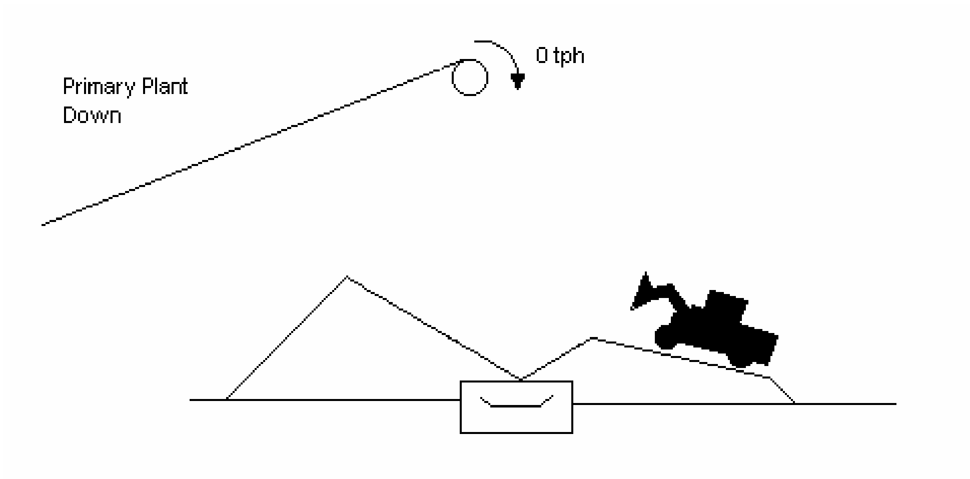


Figure 5-4 Reclaiming Plant Feed From Dead Surge Pile Area

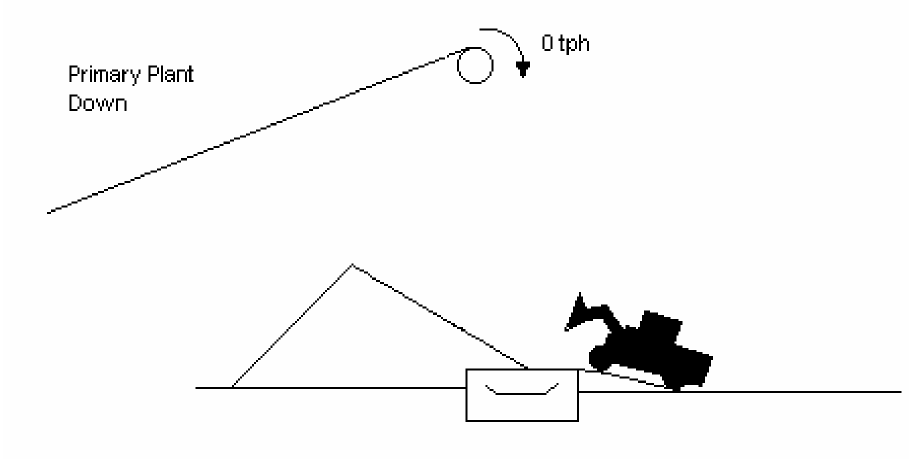


Figure 5-5 Reclaiming Plant Feed From Coarsest Dead Surge Pile Area

Segregation is best controlled using the arrangement shown in Figures 5-6 and 5-7. Figure 5-6 has a multi-feeder arrangement of the reclaiming tunnel that is at right angles to the conveyor. Figure 5-7 has a single feeder arrangement of the reclaiming tunnel that is in line with the primary conveyor.

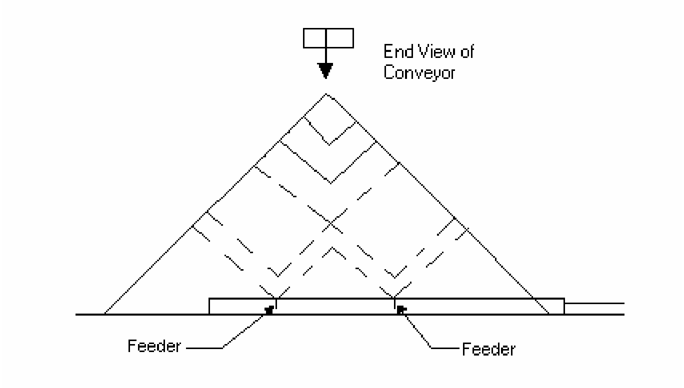


Figure 5-6 Multi Feeders Reclaiming From Surge Pile

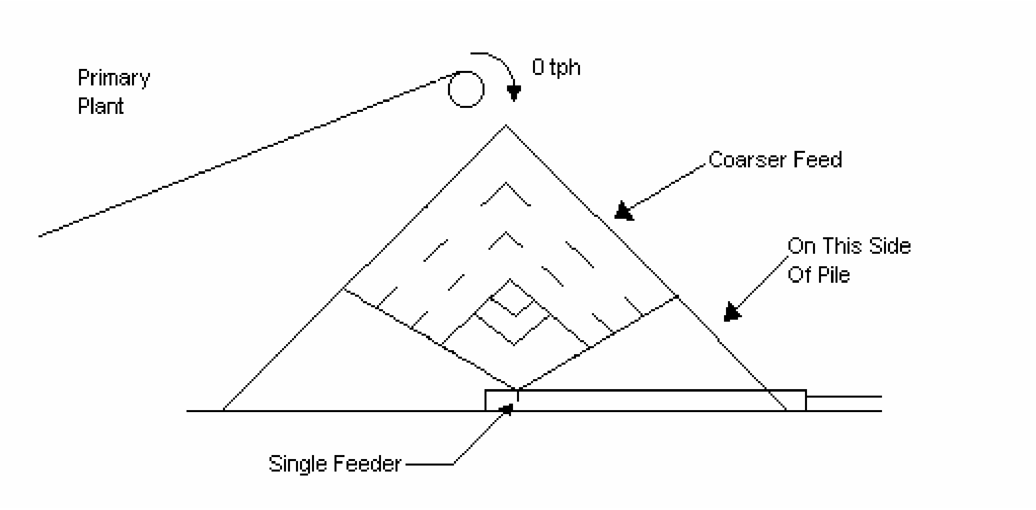


Figure 5-7 Note Alignment of Primary Conveyor and Tunnel

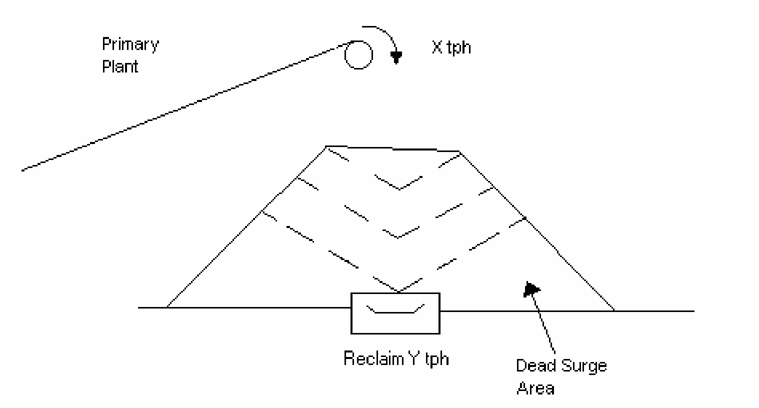


Figure 5-8 Inverted Cone

An inverted cone results when the production from the primary plant is slightly less than or approximately equal to the reclaim rate to the secondary plant, as shown in Figure 5-8. This condition results in a more uniform feed to the secondary plant.

The segregation occurring in the intermediate surge pile and finished product stockpile is less than in the primary surge pile. This occurs because the maximum size has been reduced and the ratio of larger to smaller sizes has also been decreased.

5.3.2 Minimizing Segregation

A fractionating plant is designed to provide separate aggregate piles with a given pile having nearly equal aggregate sizes. A fractionating plant is one of the better processing alternatives for controlling segregation. Blending the various size aggregates together at the loadout point, in the asphalt plant, or at the ready mix plant minimizes the effect of segregation and helps to achieve the desired product specification.

5.4 Degradation

Degradation is the breakdown of an aggregate into smaller particles. Degradation can also result in dust formation. Dozers operating on coarse aggregate stockpiles and multiple handling of the aggregate both cause degradation. Although hard rock quarries have limited problems, degradation is a concern in quarries having softer and more friable aggregate. Some aggregate producers compensate for degradation by producing the aggregate slightly on the coarse side of the specifications. Experience and documentation from the in-plant testing (QC) program can guide producers in controlling their products.